Stanford Public Seminar / EE 402A, EASTASN 402A
Thursday, 26 September 2019
Series Overview

The Present and Future of Edge Computing From an International Perspective

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Director, US-Asia Technology Management Center
Adjuct Professor, Stanford University

Outline

- **About this series**
  - Casual attendance, credit requirements, video recordings
- **Edge computing**
  - Definition, history, basics of tech stack
  - Adoption
- **Drivers of edge computing adoption**
- **Upcoming sessions in the series**
  - And, what we could not include

Welcome to Everyone!
(Visitors & Registered Students)

- **Weekly public lecture / panel discussion series** presented by the **US-Asia Technology Management Center**
  - This year: 27th year of this series
  - Every Thursday (but Thanksgiving) from today through December 5, 2019
- **About the US-Asia Technology Management Center**
  - Industry affiliates program (supported by membership and other fees paid by companies)
  - For 25 years in EE, now under Stanford Global Studies; see http://asia.stanford.edu
- **Continuing mission:** Introduce trends and current developments at the intersection of a particular area of business and technology
  - With special reference to U.S. – Asia: comparisons, cooperation, and competition
  - Speaker slides and videos available for previous years at https://asia.stanford.edu/courses-events/public-lecture-series/

Registering for university credit for this series

- **Available to Stanford students**
- **EASTASN-402A "Topics in International Technology Management"**
  - Cross-listed as **EE-402A, EALC-402A**
  - No pre-requisites, open to undergrads and graduate students
  - May be repeated in future years for credit
- **One unit, pass / no credit (S / NC)**
  - "Seminar" course
  - Beware: some departments limit how many credits from "seminar courses" can apply toward graduation requirements

Seminars 402A – Requirements for Credit

See Syllabus for official statement of credit requirements

REQUIREMENTS MAY BE DIFFERENT THAN FOR OTHER SEMINARS

A. In-person attendance at all but two sessions (e.g. 8 of 10 sessions)

- This Requirement (A) is waived for students registered through SCPD
- Evidence of attendance is required: today fill out survey, from next week sign weekly pass-around sheet at auditorium – no signature, no credit!

B. Submit one written comment / summary per session each week for nine (9) of the ten (10) sessions

- To me (Prof. Dasher) <rdasher at stanford dot edu>
- cc to course assistant
  Sijia Mao <sijiamao at stanford dot edu>>

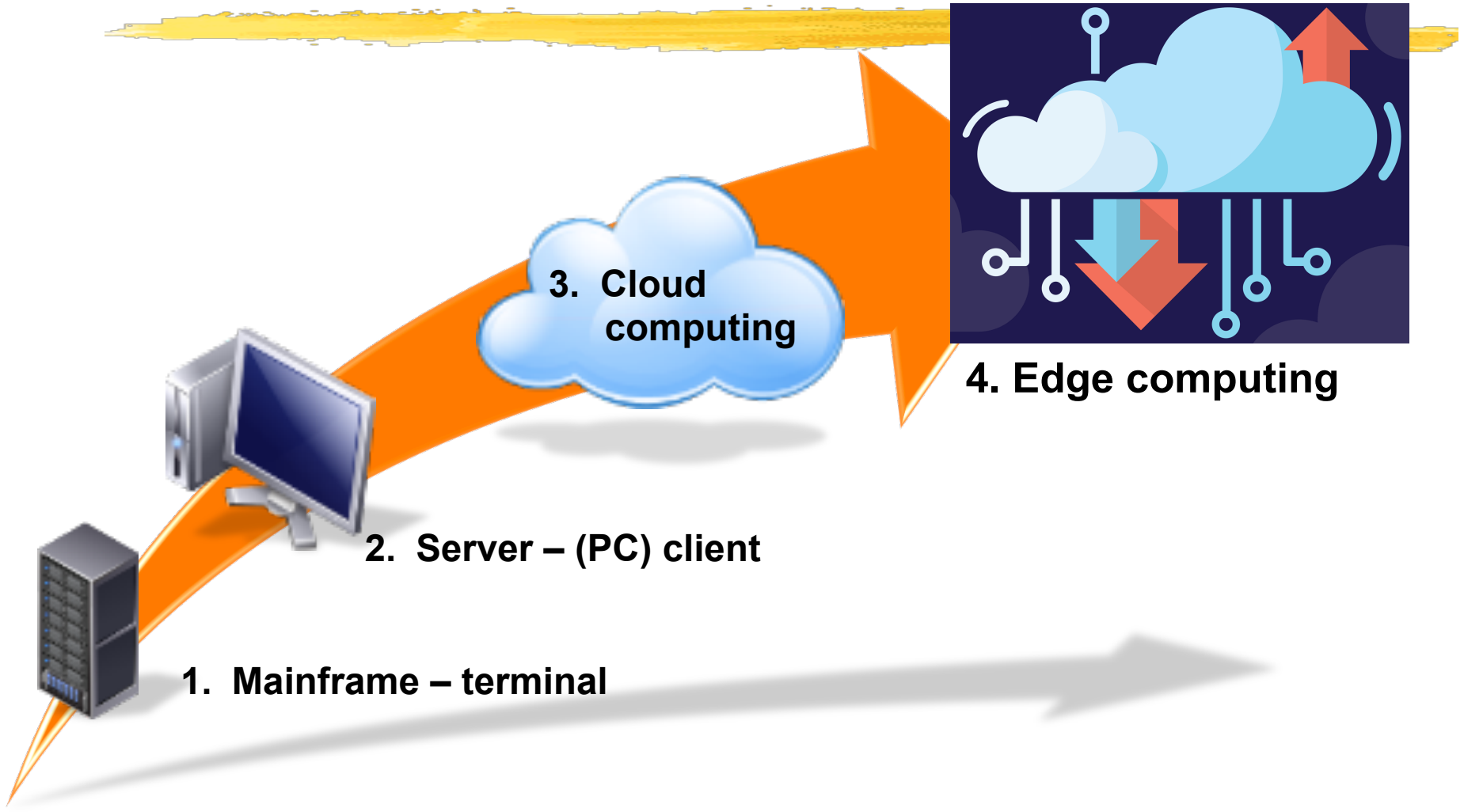
- Comment must provide evidence that you watched the session
- Each comment is due within two weeks of the date of the session
- See Syllabus for details on formatting, etc. (**no attached files**)
- Comments for today are due by October 10, 2019

Video recordings

- **Video cameras located in the back of the room will capture the presentations in this course**
  - Videos will be posted to Canvas and ultimately to Stanford's YouTube channel – freely available to the public
  - US-ATMC provides links to videos and speaker slides of this series (and previous series) on our website http://asia.stanford.edu
- **Video recording is an important aspect of this series**
  - Resource for students in fulfilling the credit requirements
  - Part of the core mission of the US-ATMC: improve knowledge-sharing between technical business communities in Asia and Silicon Valley
- **Cameras are primarily recording the lecturers & instructor**
  - Occasionally images of people in audience are incidentally captured.
  - Before video is made public, editors review the recordings and blur student images.
  - Voices are captured during Q&A
- **Concerned? See Dasher or course assistant**

Edge computing: The next major architecture of networked information processing

Major Stages of networked information processing



Mainframe – terminal (1940's – c. 1980)

Clients: (dumb) terminals – text only display

Connectivity: clients link to mainframe via private custom networks;
time-share access

Application programs:
custom-built for each system

Client – server (c. 1980 – c. 2005)

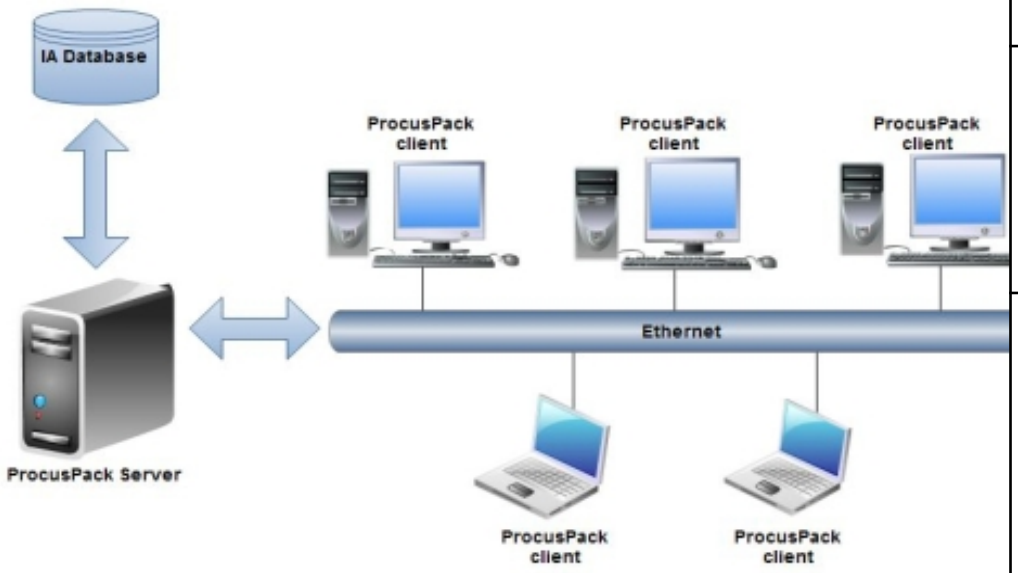


Diagram from Procus (company) website

Early Stage	Late Stage
Clients: Mostly workstations	**Clients:** PCs, workstations, peripherals
Ethernet LANs, spread of TCP/IP (Internet links)	**Internet everywhere** (LAN and open)
Standardized applications run on the client, processing-intensive programs run on server	**Standardized "office" applications on the client;** other apps on server; may use central dbase

Cloud computing (c. 2005 – present)

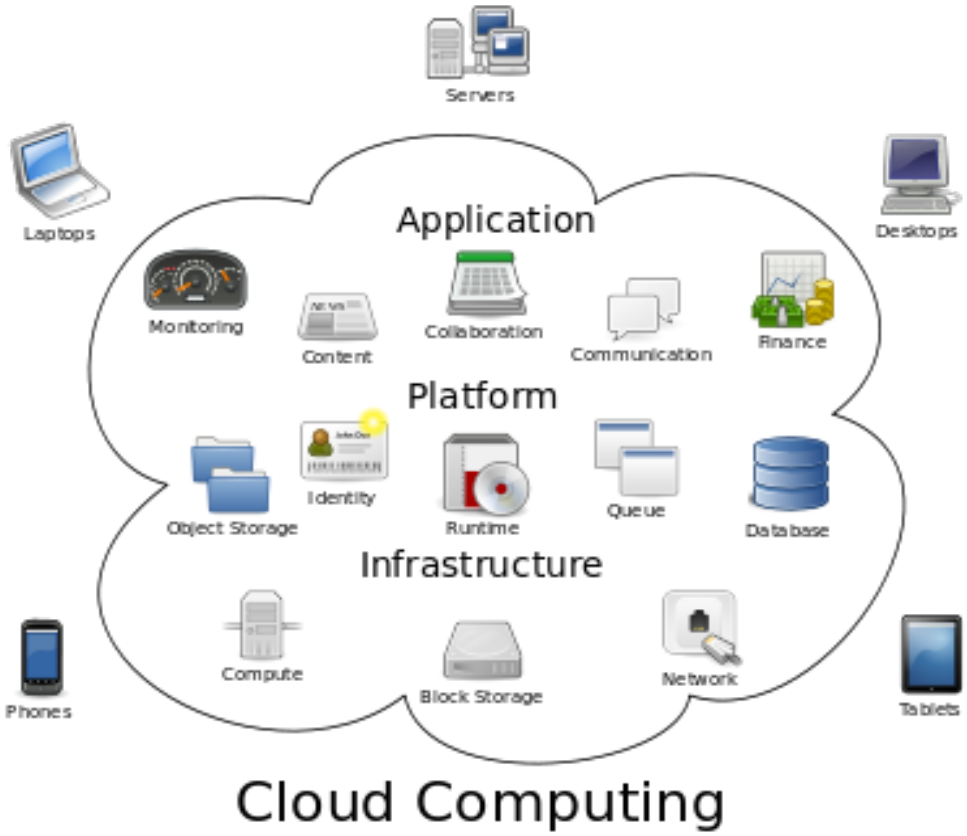


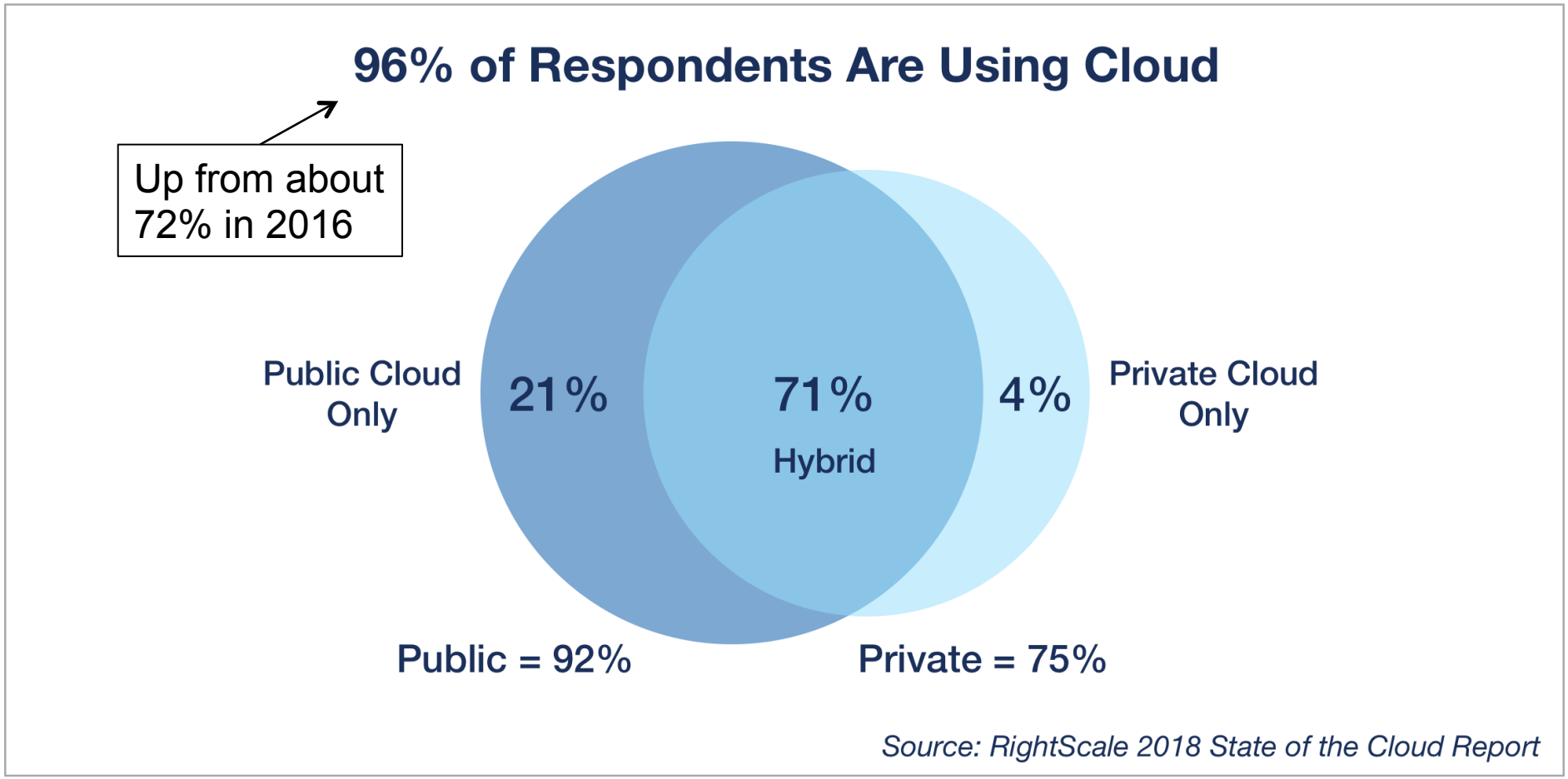
Diagram from Wikipedia

Many client types: smartphones, PCs, tablets, MP3 players, sensors, smart appliances, autos …

Clients network to data centers & other clients via Internet; many LANs are just secure channels over public Internet

(Most) applications run on "virtual machines" in data center(s). Clients access via browsers; physical location of data may be distributed (even unknown)

By 2018: Cloud Computing is Ubiquitous



(January 2018 survey of 997 IT professionals, of whom 53% represented organizations of 1,000 or more employees)

2018 Cloud apps

Small company = < 100 employees, medium = 100 – 499, large = 500+

Cloud Application Usage	Small	Medium	Large
Email	72%	75%	73%
Web presence	72%	73%	72%
Business productivity	67%	75%	77%
Collaboration	62%	77%	76%
Virtual desktop	65%	75%	68%
Financial management	61%	75%	66%
Analytics	62%	72%	74%
CRM	54%	73%	68%
VoIP	61%	67%	62%
HR management	56%	70%	65%
Help desk	62%	66%	56%
Expense management	56%	71%	60%
ERP	52%	69%	62%
Call center	50%	55%	57%

Survey results from 502 businesses in U.S.A. CompTIA, May 2018, *Research report: 2018 trends in cloud computing* https://www.comptia.org/resources/cloud-computing-trends-research

Edge computing

Image from
https://searchdatacenter.techtarget.com/definition/edge-computing

Intelligent clients "at edge, e.g. new smartphones, connected cars, airplanes (UAVs & drones), robots, etc. **plus edge gateway servers (for less intelligent clients)**, e.g. sensors in a smart building, factory …

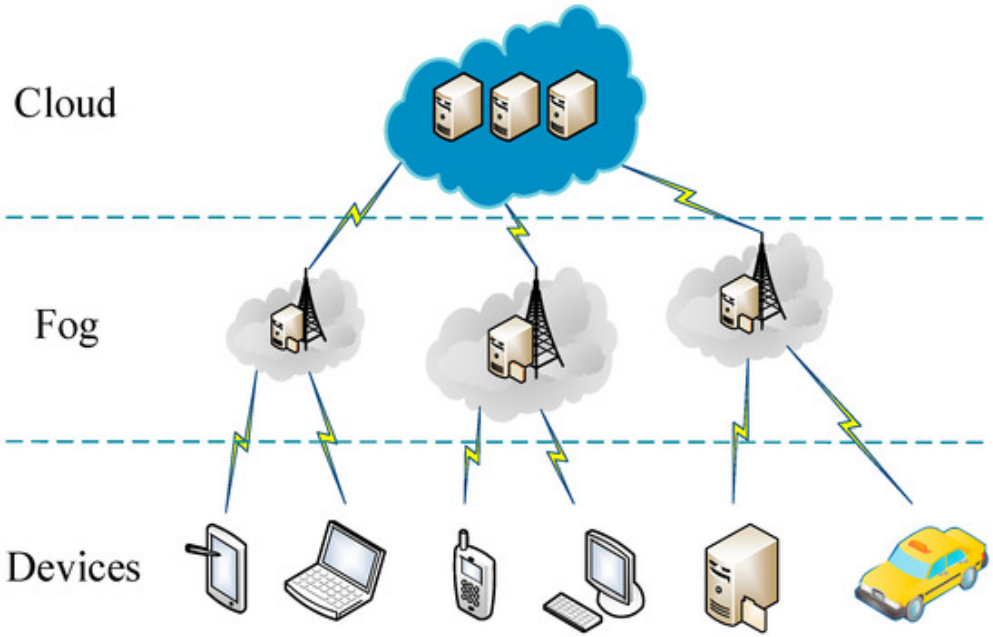
Integration of very high speed mobile and wired connectivity, e.g. 5G networks

Optimization of information processing between cloud (data centers) and edge, e.g. self-driving car operations at edge, biz analytics in cloud

Some important points about edge computing

- **Edge computing does not replace cloud computing**
  - Much information processing will continue to be done in "cloud" data centers
  - Processing at edge will focus on functions in which it's important to avoid latency (delays) or to avoid data transfer for other reasons
  - Processing (e.g. business analytics) that require large amounts or heterogeneous data will stay in the cloud

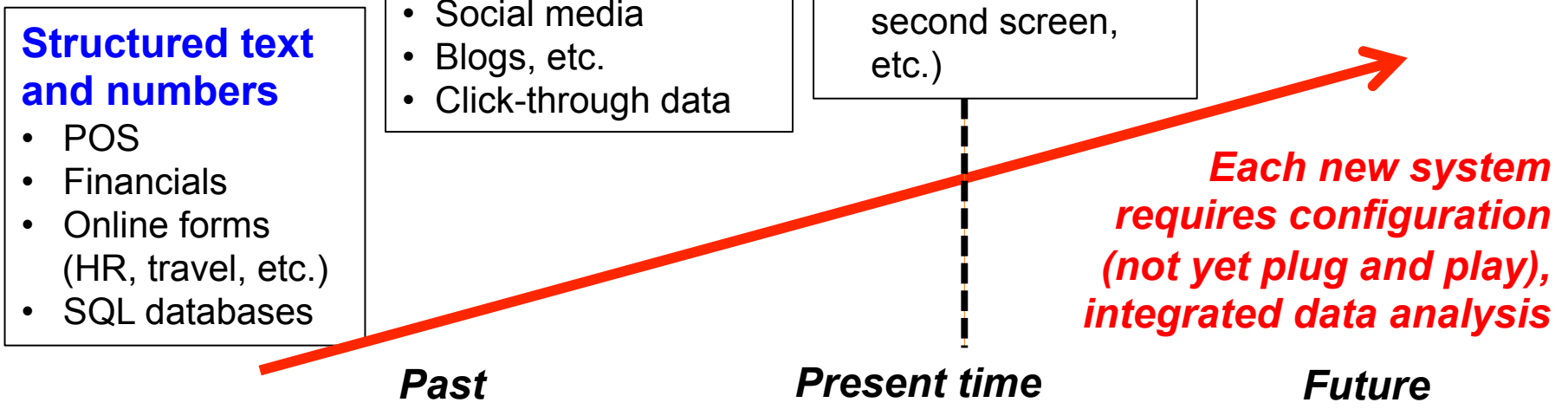
- **You will also hear the term "fog computing"**
  - a decentralized architecture in which data, compute, storage and applications are located somewhere between the data source and the cloud"



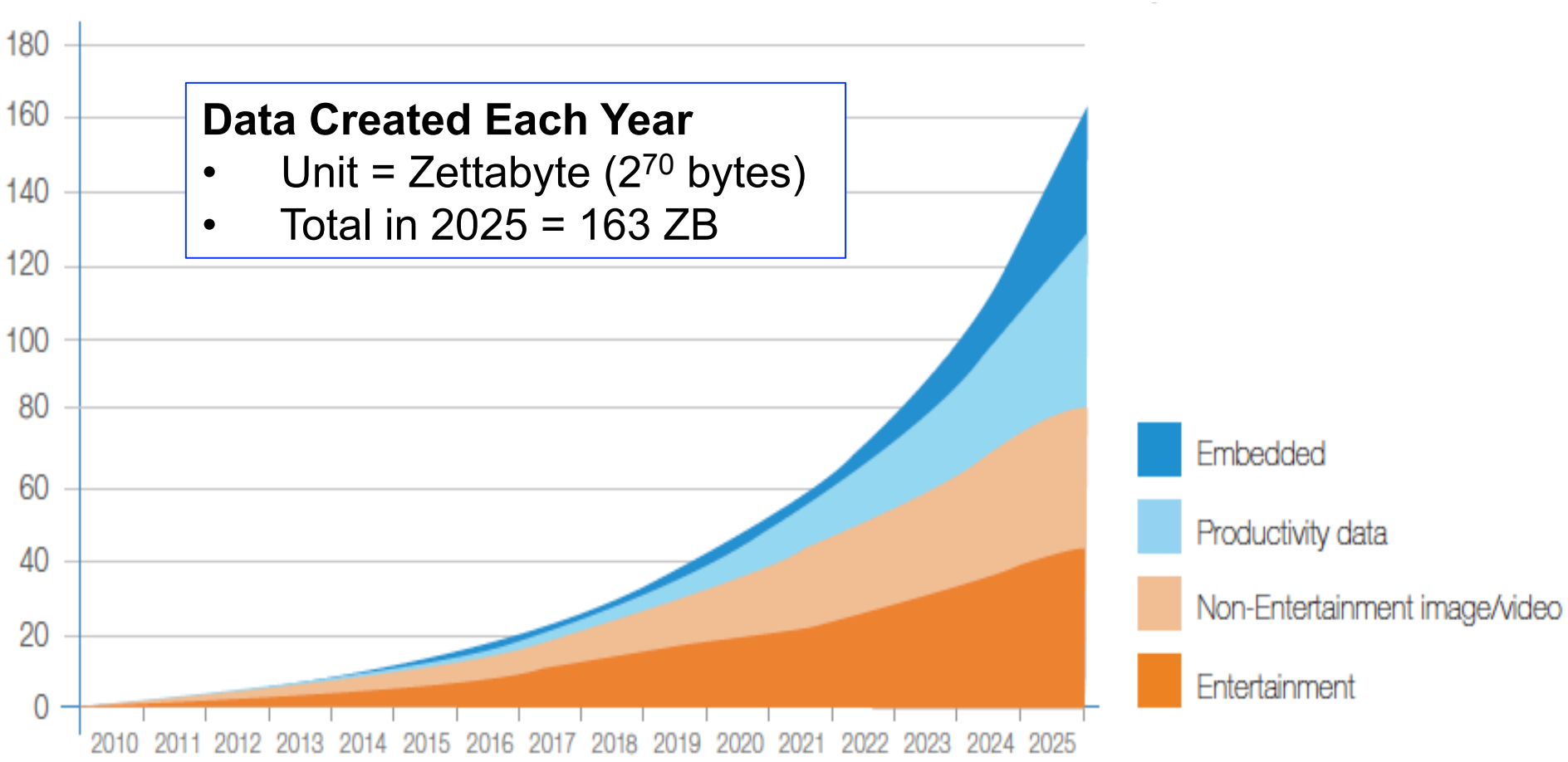
What is driving the advent of edge computing?

- **Huge increase in total data generated**
  - Especially related to advent of “Internet of Things” (IOT)
  - Much of the data that will be created is transient – why bother to clutter up the “cloud” data centers?
- **Huge increase in demand for real-time data processing**
  - No one wants a self-driving car to have to send data to the cloud and back in order to avoid an obstacle
- **Concerns about data security and privacy**
  - Data processing usually involves copying data from where it is stored to a “database” in order to perform search and other functions on it
  - E.g. analyze medical data in the hospital data center, and do not copy it into the cloud
  - Note: IOT security (at the edge devices or local servers) an issue
- **Accelerated computer chips for AI processing**
  - Application-specific chips (ASICs) can be much, much faster than multifunction processing chips (in data centers) and take less energy

New types of data coming into the cloud ...

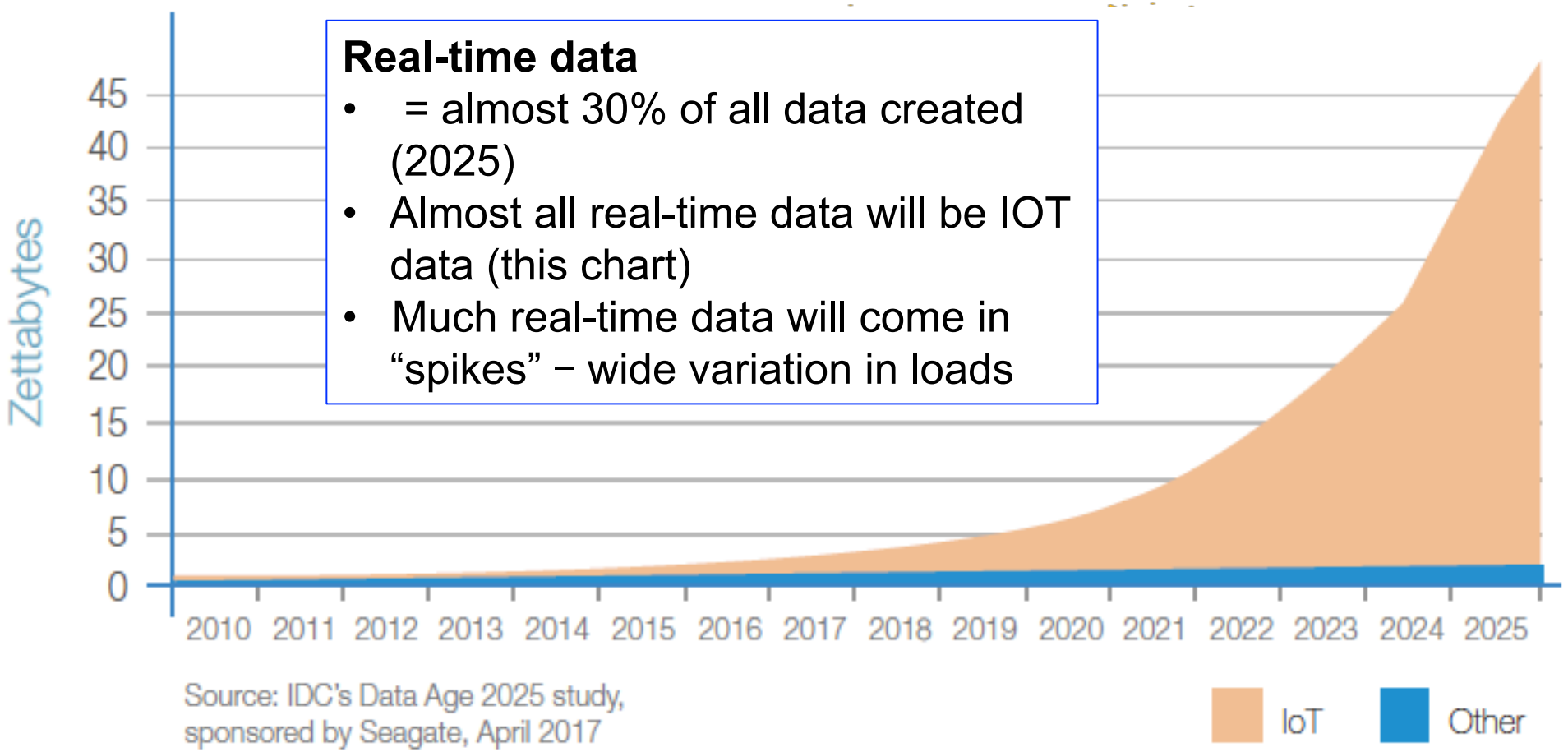


... cause drastic increases in amount of data created



IDC Survey. April 2017. *Data Age 2025 (Figure 6)*, sponsored by Seagate <https://www.seagate.com/files/www-content/our-story/trends/files/Seagate-WP-DataAge2025-March-2017.pdf>

Real-time data (logs, locations, sensor output, etc...) is becoming a bigger share of all data



Market predictions for edge computing
(market research reports published during 2019)

$ billions

Edge computing	2017 - 2018	2019		2024	2025	CAGR (%)
Firm A	$1.47				$28.84	54.0
Firm B	1.73				16.56	32.8
Firm C		2.8		9.0		26.5
Firm D	1.2			6.96		34.0
Firm E	2.17			9.22		27.3
Cloud computing						
Firm X					712.83	18.5
Firm Y	36.7				285.30	29.2
Firm Z		319.8			696.25	10.2

On the market impact of edge computing (comments on previous slide)

- **Cloud computing markets predicted to stay much bigger than edge computing markets**
- **Edge computing markets predicted to have CAGR than are higher than cloud computing in general**
- **Disagreements in calculating market size and growth probably result mostly from differences in definition**
  - Narrow definition: only edge computing services
  - Broader definition would include larger ecosystem for edge computing
    - Some portion of the growth of related technology businesses (e.g. 5G networks)
    - Some portion of use-case spending on applications that utilize edge computing architecture (connected cars, energy systems, etc.)

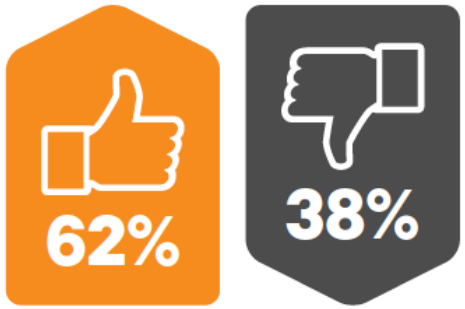
Some use cases for edge computing

- **Smart buildings** (including homes, factories, warehouses, ...)
- **Smart manufacturing** (process control, Industry 4.0)
- **Self-driving cars, drones, airplane systems, etc.**
- **Connected car services**
- **Mobile augmented reality (AR), networked gaming**
- **Mobile ecommerce** (register-less stores, mobile banking, etc.)
- **Healthcare monitoring** (wearable devices, robot assisted surgery, medical data analysis in the hospital)
- **Physical security** and surveillance systems
- **Energy systems** (smart grids, etc.)
- **Some tele-medicine, agricultural systems control**, etc.
- **Virtual assistants** (Alexa) – maybe

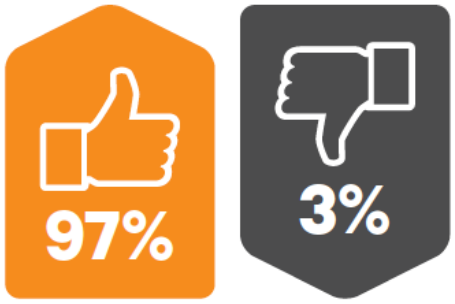
Edge computing: regional perspectives

Edge computing is major topic of interest in Asia

- **Asia predicted to have the highest CAGR for edge computing markets (one firm predicts 40.5% APAC vs. 32.6% global)**
- **High rate of people in Asia say edge will be important**
  - Jan 2017 online survey by VertivCo of 8,500 executives, IT professionals, other business people in SE Asia, N. Asia, Australia, New Zealand
  - Question: Do you have plans to deploy edge initiatives in next 1 – 3 years?



  - Question: Do you think that the edge will be a relevant part of your business and IT strategy over the medium to long run (beyond 3 years)



Will Asia move ahead of the U.S. in edge computing?

- **Asia has been deploying many projects related to edge computing – relatively independently of U.S.**
  - China Unicom: virtual edge-cloud testbed in Tianjin City for video optimization and security monitoring
  - China Telecom: "China Mobile Smart Parking" project in Yunnan and SE Guizhou (similar project by Chunghwa Telecom in Taipei)
  - Baidu has software platform "Apollo" for autonomous vehicles
  - Taiwan: smart streetlight system in Taoyuan City
  - South Korea: world's first 5G enabled self-driving car test zone in Seoul (announced 3/2019)
  - S. Korea to build nationwide 5G network in 2020
  - Japanese companies NTT DoCoMo, KDDI, SoftBank, and Rakuten to invest $14.4 billion in 5G networks
  - NTT Docomo (Japan): proof-of-concept project enables video analytics to be processed on surveillance cameras using MEC ("multi-access" or "mobile" edge computing)

Different technology directions for Asia and U.S.?

- **"Decoupling" of U.S. and China**
  - Restrictions on U.S. firms from buying equipment from or selling hardware or software & services to Huawei, ZTE (currently under "temporary" easing
    - Huawei developed own operating system (since cannot rely on access to Google Android)
    - Huawei, Alibaba have announced their own AI processing computer chips
  - Pressure by administration on U.S. firms to move manufacturing (especially final assembly) to U.S.
    - But some are moving to SE Asian countries instead
  - Tighter monitoring, control of foreign investors in U.S.
    - Sinovation (Kai Fu Lee VC firm) has pulled back from U.S., focuses on China
    - Chinese acquisition of AppLovin (AdTech) blocked; Chinese investor(s) ordered to divest from PatientsLikeMe (HealthTech)
    - China FDI to U.S.: $46 billion (2016) – $27 bn (2017) – $4.8 bn (2018)
  - China: new cybersecurity policies (coming online this autumn) appear to target foreign firms there

China regional influence increasing

- **China – IndoPac region trade (2018) = $2.5 T**
  US – IndoPac trade = $1.4 T
  - China accounts for 24% of IndoPac exports
  - U.S. accounts for 12% of IndoPac exports
- **RCEP trade area negotiations moving forward**
  - China-led alternative to TPP, includes 16 countries
- **Investments in SE Asia**
  - Some prominent: $2 billion by DiDi Chuxing and Softbank in Grab (2017)
  - Chinese VC investments in ASEAN startups increased 4x in 2019H1 to US$667M
  - Recent upswing in Belt and Road investments in SEA
    - $11 billion in 2019H1, $5.6 billion in 2018H2
  - Overall, Japan probably still has much bigger influence in SEA economies

How will regional divergence play out with regard to edge computing?

Topic of this series

Upcoming sessions in this series

- **October 3 "The Promise of 5G"**
  Prof. Arogyaswami Paulraj
  - Critical enabling technology that will have very close relationship to continued growth of edge computing
  - One of the key technologies in U.S. – China competition
  - Prof. Paulraj won the Marconi Prize, his work has been critically important to WiFi and 4G networks
  - World expert on 5G; frequent consultant & advisor
- **October 10 "New chip technologies for AI and for Asia"**

Gary Brown, Director of AI Marketing, Intel
  - New types of chips for faster AI processing with lower power consumption enable more edge computing
  - AI chips causing a resurgence of chip industry growth
  - Gary was with startup Movidius (acquired by Intel); former US-ATMC research assistant with extensive Japan & Asia experience

Upcoming sessions, p. 2

- **October 17 "Edge computing in autonomous vehicles" Dr. Sven Beiker, Dr. Maarten Sierhuis**

  - One of the most-often cited use cases for edge computing
  - Panel discussion with former exec. director of Stanford CARS Lab and CTO of Alliance Innovation Lab SV (Nissan research group)

- **October 24 "Federated learning in medicine" Dr. Thomas Clozel, Founder / CEO, OWKIN**
  - "Federated learning" allows analysis of edge data without copying them to a data center
  - An application of edge computing for security, privacy

Upcoming sessions, p. 3

- **October 31 "tinyML – enormous opportunities ahead"**
  Dr. Evgeni Gousev, Senior Director, Qualcomm
  Mr. Pete Warden, Research Engineer, Google
  - A new industry-led consortium with a solution for AI processing on edge devices
  - Evgeni has mentored much Ph.D. research at Stanford; Pete is a well-known blogger
- **Nov. 7 "Edge computing and the evolution of AR / VR"**
  Mr. Dijam Panigrahi, COO & Co-Founder, GridRaster, Inc.
  - Edge computing is important to improving user experience with augmented reality or virtual reality (latency may make users may feel ill)
  - GridRaster provides a collaborative mobile device – edge cloud platform for mixed-reality experiences with mobile devices
- **Nov. 14 "Japanese startup use cases of edge computing"**
  Dr. Atsunori Kanemaru, Chief Scientist, LeapMind
  - LeapMind has delivered edge computing POCs to major firms (e.g. subway train door management)

Upcoming sessions, p. 4

- **Nov. 21** **Speaker still TBD**
- **Nov. 28** **Thanksgiving – no class**
- **Dec. 05** **“Possibilities for edge computing in U.S. and Asia” (title tentative)**
  Dr. Yoky Matsuoka, Vice President, Google

- Robotics expert
- Former professor at CMU
- Former CTO of NEST
- “Fireside chat” will include discussion of challenges posed by edge computing, international trends in development

Introduction to automated driving

General technology and business considerations

Panel Discussion at Center for East Asian Studies
Stanford University, CA | October 17, 2019

Dr. Sven Beiker
Founder and Managing Director of Silicon Valley Mobility
Lecturer at the Stanford Graduate School of Business

SILICON VALLEY MOBILITY STANFORD BUSINESS GRADUATE SCHOOL OF

1

Sven Beiker – automotive bio, 20+ years in research, industry, consulting

- Mechanical Engineering Education at Technische Universität Braunschweig
- 13 Years with BMW R&D Groups in Germany, Silicon Valley, Michigan
- 6 Years with Stanford University, Center for Automotive Research
- 2.5 Years with McKinsey & Company, Center for Future Mobility
- 2017 – Silicon Valley Mobility and Stanford Business School

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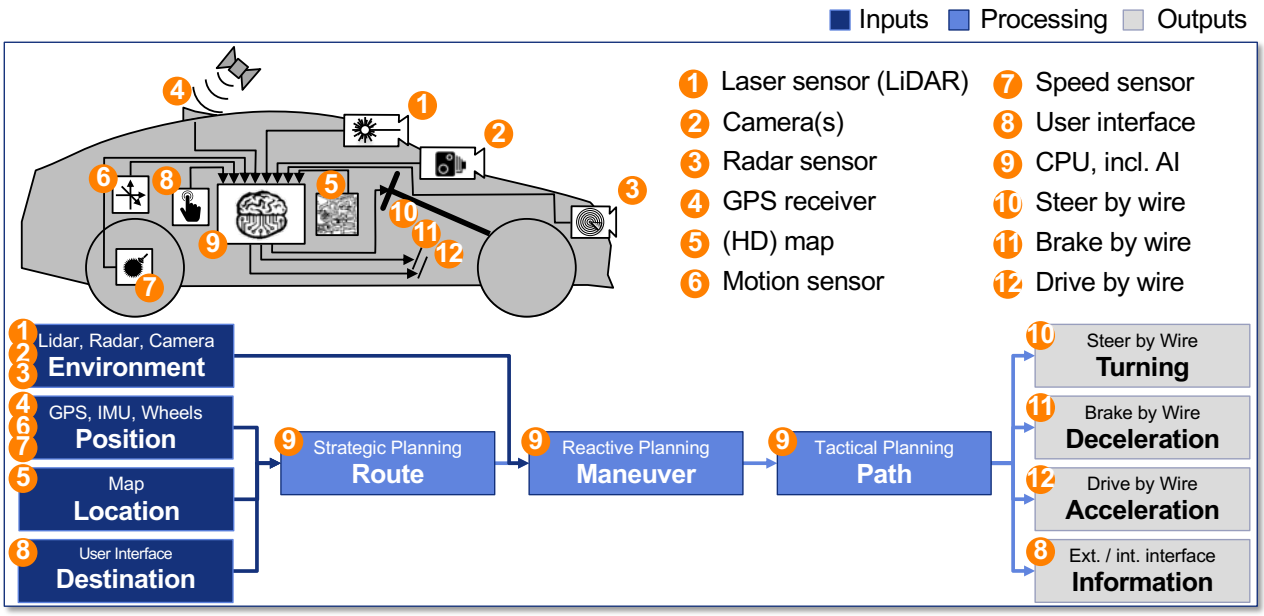
AUTOMATION

Inside the automated vehicle – sensors, software, and by-wire drive systems



Source: self

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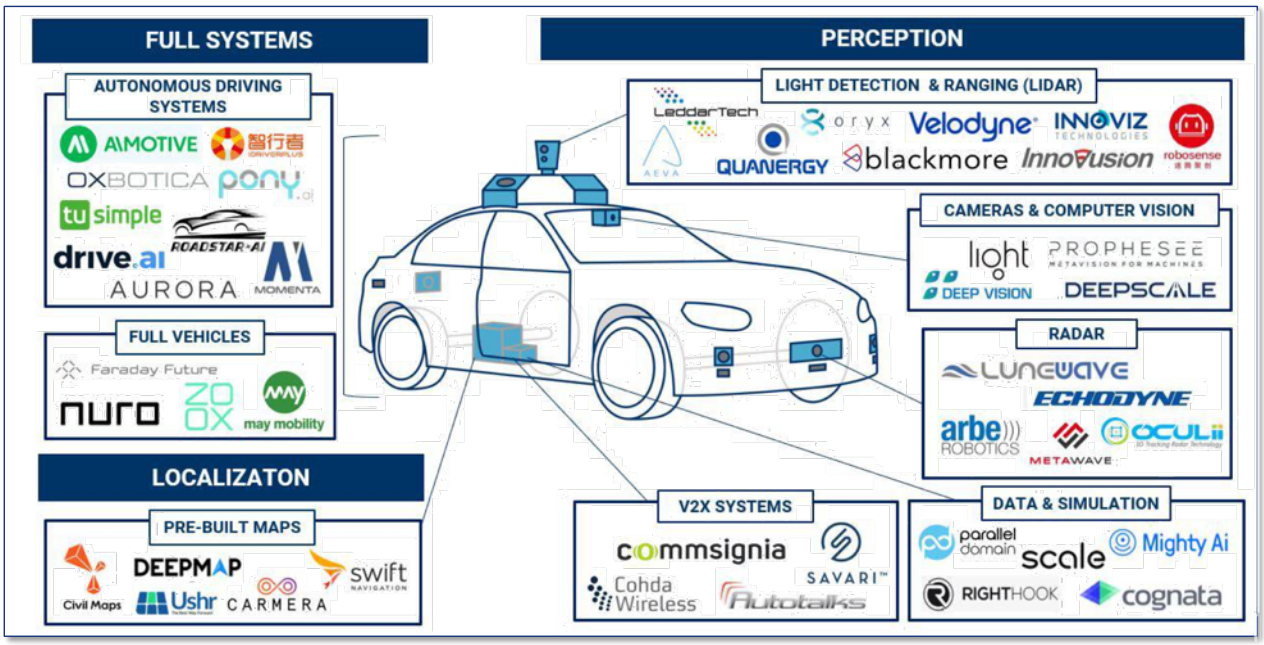
The different players in automated driving can be clustered in three main groups



Source: CB Insights

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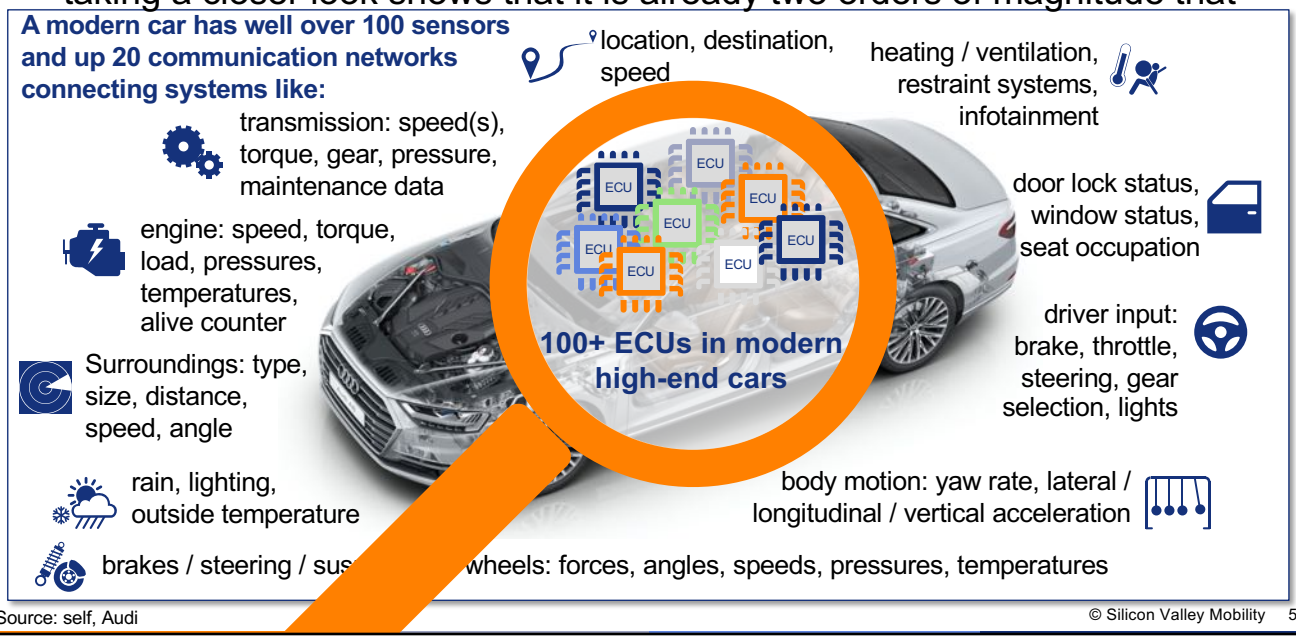
Some people say (a bit teasingly) that a car becomes “a computer on wheels” – taking a closer look shows that it is already two orders of magnitude that



Source: self, Audi

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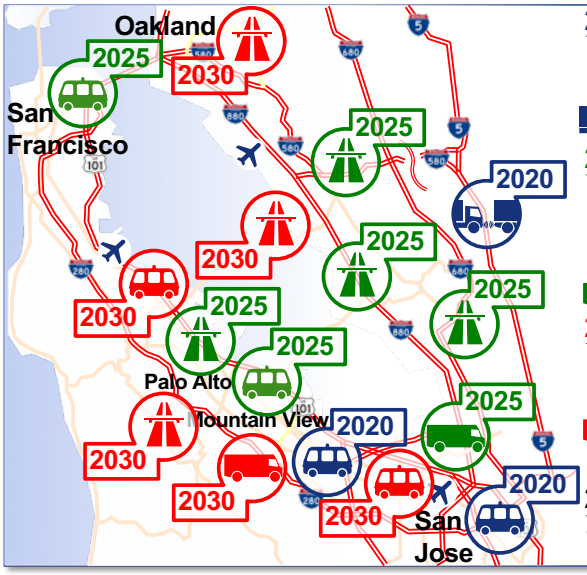
Silicon Valley not only attracts the pioneers in autonomous driving, the broader area is also a good example to show the path to deployment



2020 Early Phase
- L4 mobility services for public use in dedicated downtown areas of Mountain View, San Jose;
- Truck platoons on major freight corridor (I5)

2025 Growth Phase
- L4 mobility services for public use in downtown Palo Alto, San Francisco, and other cities;
- L4 lanes on major commute highways;
- L4 delivery vans in San Jose business areas

2030 Mainstream Phase
- L4 lanes on all major highways
- L4 SFO / SJC airport shuttles in Silicon Valley
- L4 delivery vans in residential and business areas of Silicon Valley, integrated with drones

2035+ Unlimited autonomous driving
- ∞ L5 vehicles capable of navigating all roads

Source: expert interviews, self

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It seems like AV and AI are holding the key to the future of mobility and investments are flowing to solve the problems human-driven mobility has created – really?

$14bn
has been invested in 183 AV companies over last 3 years

30%
of AV investment goes to AI and control software

64
companies have a permit for AV testing in California

Source: Woodside Capital Partners, California Department of Motor Vehicles

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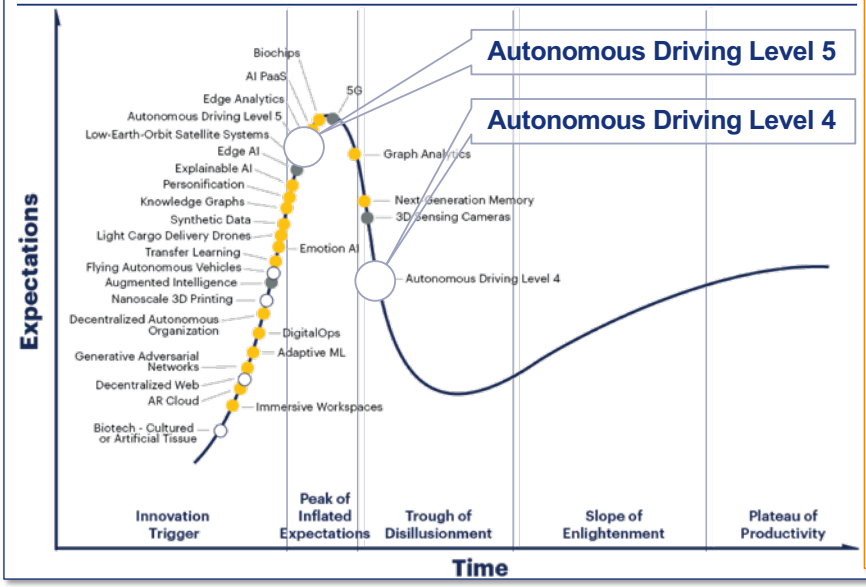
The Gartner Hype Cycle sees Level 4 automation more than 10 years out

Plateau will be reached in: ○ less than 2 years ● 2 to 5 years ● 5 to 10 years ○ more than 10 years ● obsolete before plateau

Gartner Hype Cycle for Emerging Technologies, 2019



The Gartner Hype Cycle for Emerging Technologies **distills insights from more than 2,000 technologies** profiled into a succinct set of must-know emerging technologies & trends.

The **2019 Hype Cycle features technologies with increasingly enabled mobility and the ability to manipulate objects around them, including** 3D sensing cameras and **more advanced autonomous driving**. As **sensors and AI evolve, autonomous robots will gain better awareness of the world around them**.

Source: Gartner

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Before AVs go public, several challenges need to be overcome

○ General challenge, solutions anticipated ◎ Severe challenge, solutions unclear

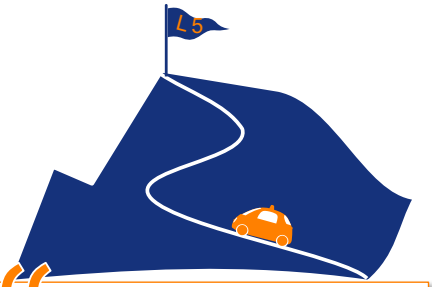
REGULATION
Many U.S. states passed laws, guidelines have been issued on the federal level – **not an insurmountable hurdle**

TECHNOLOGY
Sensors, artificial intelligence, HD maps, connectivity are to be further developed – **ready for limited deployment**

CONSUMERS
Concerns regarding safety and security persist, but increasingly positive mood – **a societal learning process**

REPERCUSSIONS
Ultimately more traffic could be generated, cities and land use get affected – **expected to be solved case-by-case**

REALITY
Traffic has evolved over decades w/ human-driven vehicles, AVs might not mix well – **staged deployment will be key**



"Getting to 90 percent is fairly easy. Getting to 95 percent starts to get interesting. And then you still need to go way beyond that. Nine point nine nine nine nine... Adding each nine is ten times harder. When you're at 95 percent, you've just scratched the surface.

Alexandre Haag, CTO Audi AID

Source: self, The Verge

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SILICON VALLEY MOBILITY

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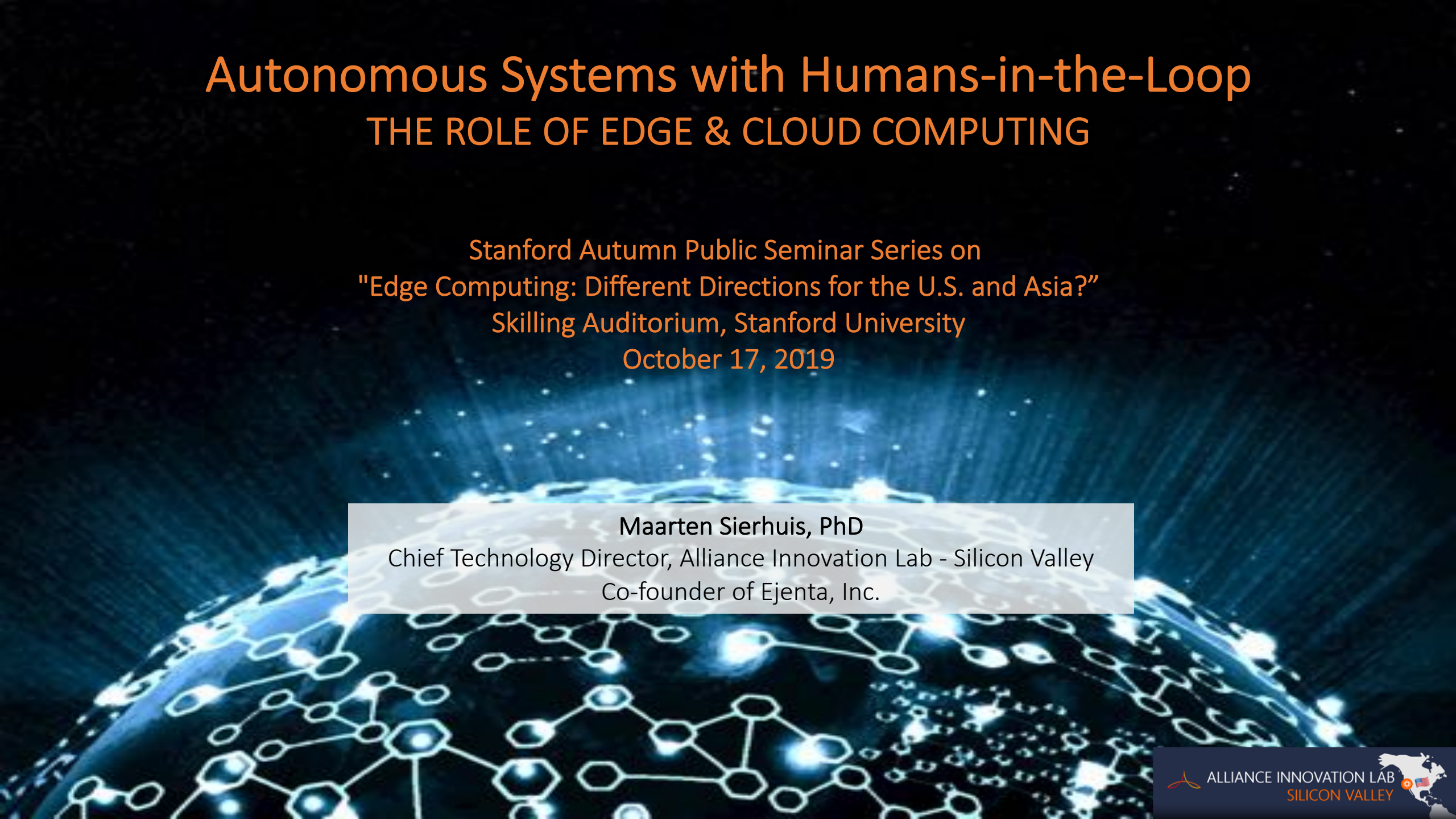
Autonomous Systems with Humans-in-the-Loop

THE ROLE OF EDGE & CLOUD COMPUTING

Stanford Autumn Public Seminar Series on
"Edge Computing: Different Directions for the U.S. and Asia?"
Skilling Auditorium, Stanford University
October 17, 2019

Maarten Sierhuis, PhD
Chief Technology Director, Alliance Innovation Lab - Silicon Valley
Co-founder of Ejenta, Inc.



OUR VISION

ALLIANCE INNOVATION LAB
SILICON VALLEY

Socially Acceptable Autonomy

HUMAN & ROBOT TEAMWORK

=

EXPLAINABLE A.I.

+

SOCIAL SCIENCE

FULL L4/5 AUTONOMY IS HARD

ALLIANCE INNOVATION LAB
SILICON VALLEY

THE FUTURE OF CONNECTED & AUTONOMOUS VEHICLES

ALLIANCE INNOVATION LAB
SILICON VALLEY

Design a World Connecting On-board and Off-board Intelligences

Seamless Autonomous Mobility Platform

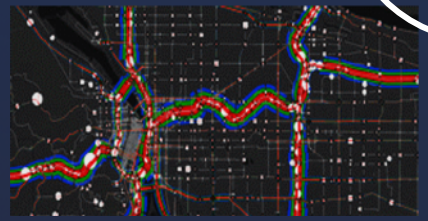
Mobility Information Layer

Human Intelligence

Edge / Cloud-based AI

Traffic Management Platform

Infrastructure Information Layer



Cloud-based AI

Human Intelligence

Share Intelligences

On-board Information Layer

Vehicle Intelligence

UX/UI

to connect intelligences

Vehicle On-board Systems

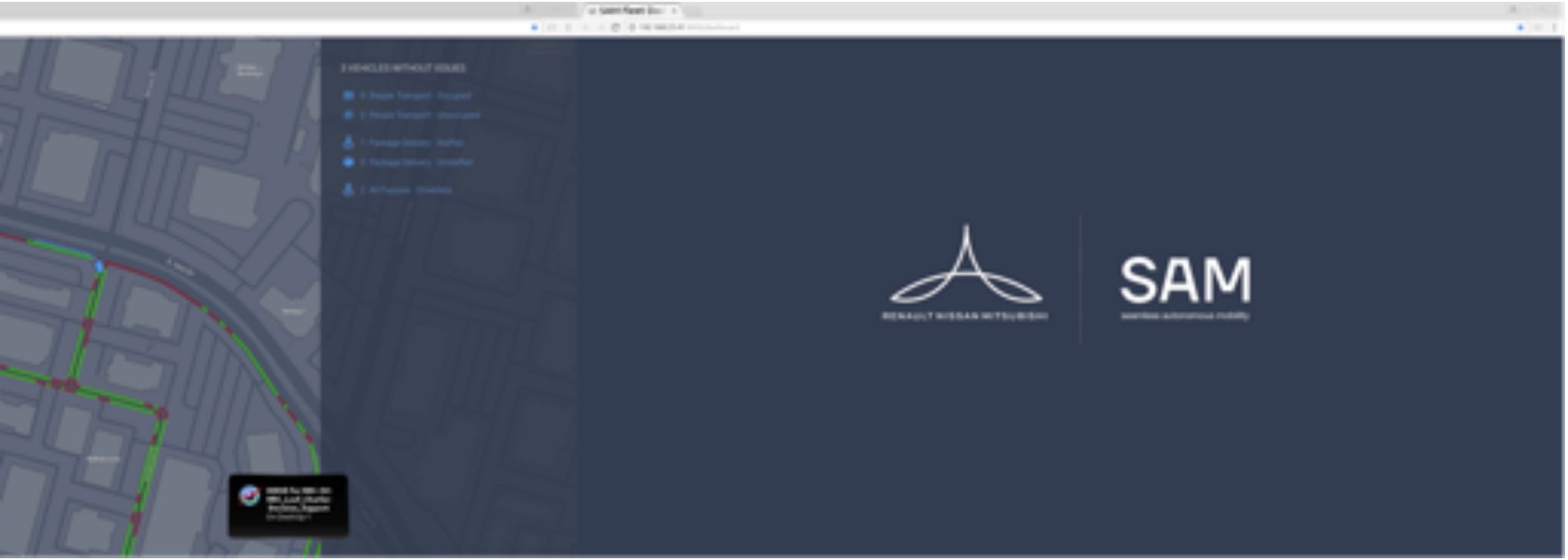
Security & privacy
Energy & environment
People's move

Smart City

STREAMING DATA TO THE EDGE

ALLIANCE INNOVATION LAB
SILICON VALLEY

VIDEO



MOBILITY CONTROL CENTER

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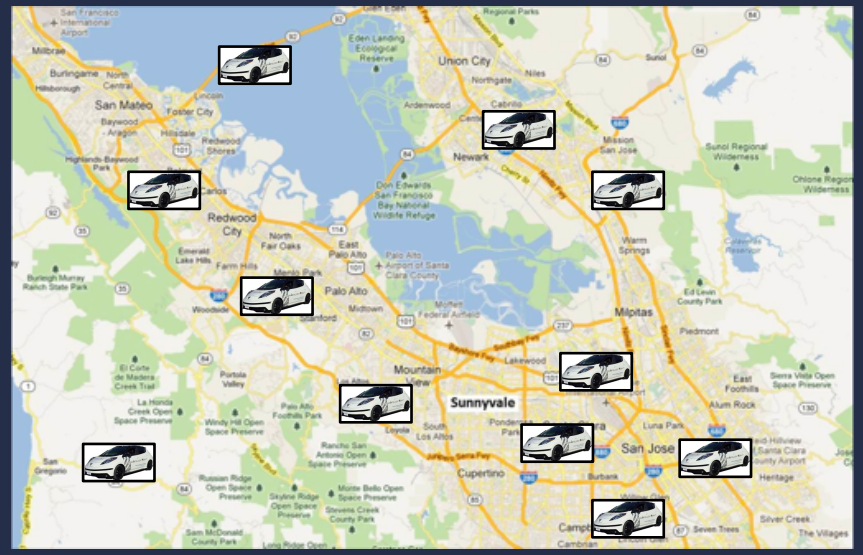
The Human-in-the-Loop



Mobility Managers are personnel responsible for the **safe, orderly, and expeditious flow** of **Robo-Fleets** in the global traffic system.

SEAMLESS AUTONOMOUS MOBILITY

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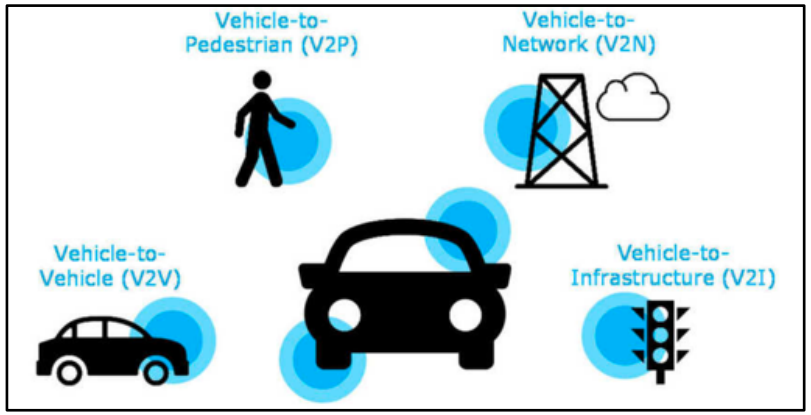
B2B & B2C
Data Sharing

Mobility Center

APIs

APIs

Vehicle-2-Infrastructure



AI &
Analytics

Vehicle
Data

EDGE / CLOUD

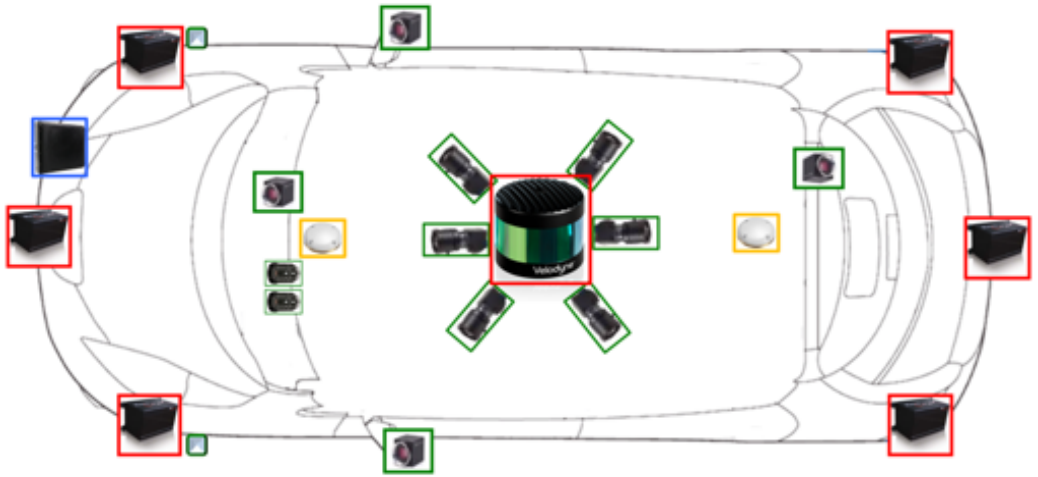
4G/5G Mobile Com

Autonomous
Vehicle

Connected
Vehicle

AV ARCHITECTURE AND TIME-SERIES DATA COLLECTION

ALLIANCE INNOVATION LAB SILICON VALLEY



Sensing

Perception

HMI

A Priori Information

World Model

Ego State

Decision Making

Control

IO

CAN Data

Sensor Data

In Vehicle

VPN

In Cloud

CAN Data

Sensor Data

Shared AV Data

Shared Map Data

LiDAR

Camera

Radar

GPS

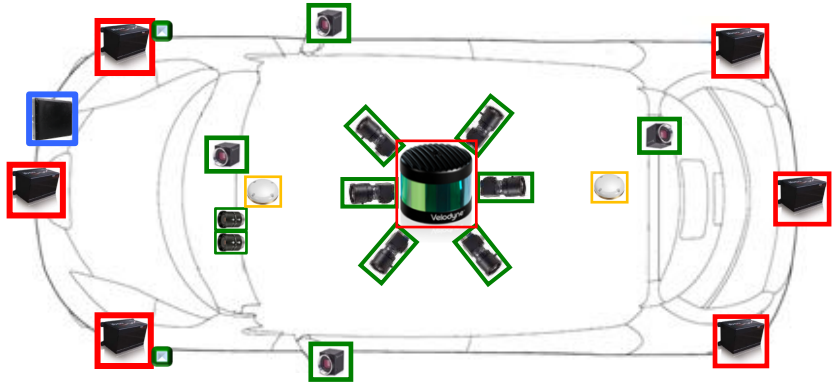
External System Sensors

CAN

Internal System Sensors

L4/L5 AUTONOMOUS VEHICLE SENSOR DATA

ALLIANCE INNOVATION LAB SILICON VALLEY



1 min drive generates ~10 GB of raw data
10 mins drive generates ~100 GB of raw data
1 hour drive generates ~500 GB of raw data
24 hours drive generates ~12 TB of raw data

G A M F have **1.2 Million Terabytes**
=>
100,000 AVs generate this in 24 Hours!!!!

Sensor	Purpose	#	Data Rate
Camera	• Object, road marking, and traffic light state detection. • Teleoperation situational awareness.	15	8 MB/s
LiDAR	• Object and drivable area detection. • Teleoperation situational awareness.	2	10 MB/s
Radar	• Object pose and speed detection	1	0.1 MB/s
GPS	• Coarse pose estimation	1	0.01 MB/s
CAN	• Vehicle & Engine data	1	0.125 MB/s
TOTAL			**140.235 MB/s**

There were 264 Million vehicles in the US in 2015 => 3168 G A M F's worth of data every 24 hours

PRIVACY & SECURITY ISSUES

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SILICON VALLEY

Ubiquitous data collection

- Collection of location and movement data about residents of an entire city/country

- Four aspects of privacy-invasive technologies:
  1. The ubiquitous capture of data in public
  2. Physical surveillance by a privately owned company
  3. The ability to scale without additional infrastructure
  4. Difficulty of notice and choice about data practices for physical sensors that capture data about non-users

- Comparison: CCTVs, Dash Cams, Google Street View

Privacy standards and regulations

- New technologies outpace the creation of reasonable privacy standards
- Habituation to lack of privacy
- Fair Information Privacy Practices

[1] Bloom, et al, Self-Driving Cars and Data Collection: Privacy Perceptions of Networked Autonomous Vehicles, Usenix, 2017 https://www.usenix.org/conference/soups2017/technical-sessions/presentation/bloom

GRIDRASTER

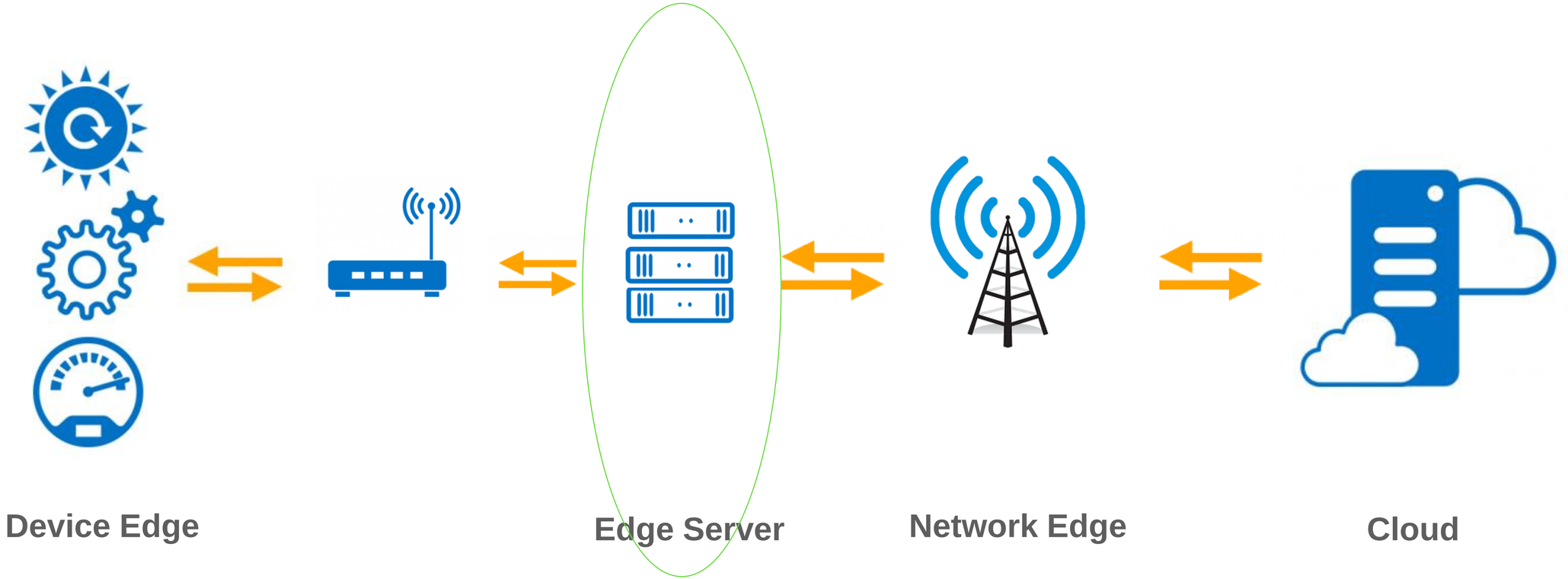
EDGE COMPUTING AND EVOLUTION OF AR/VR

Dijam Panigrahi,
Co-founder/COO, GridRaster Inc.

What is Edge Computing?

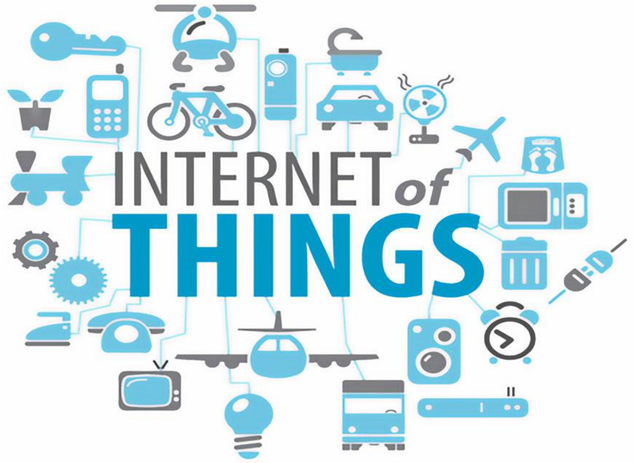
Moving the compute function closer to the user

Edge computing is defined as any compute functions that occurs between the endpoint and the cloud



Emergence of Edge Computing

Factors that’s driving the move towards edge compute

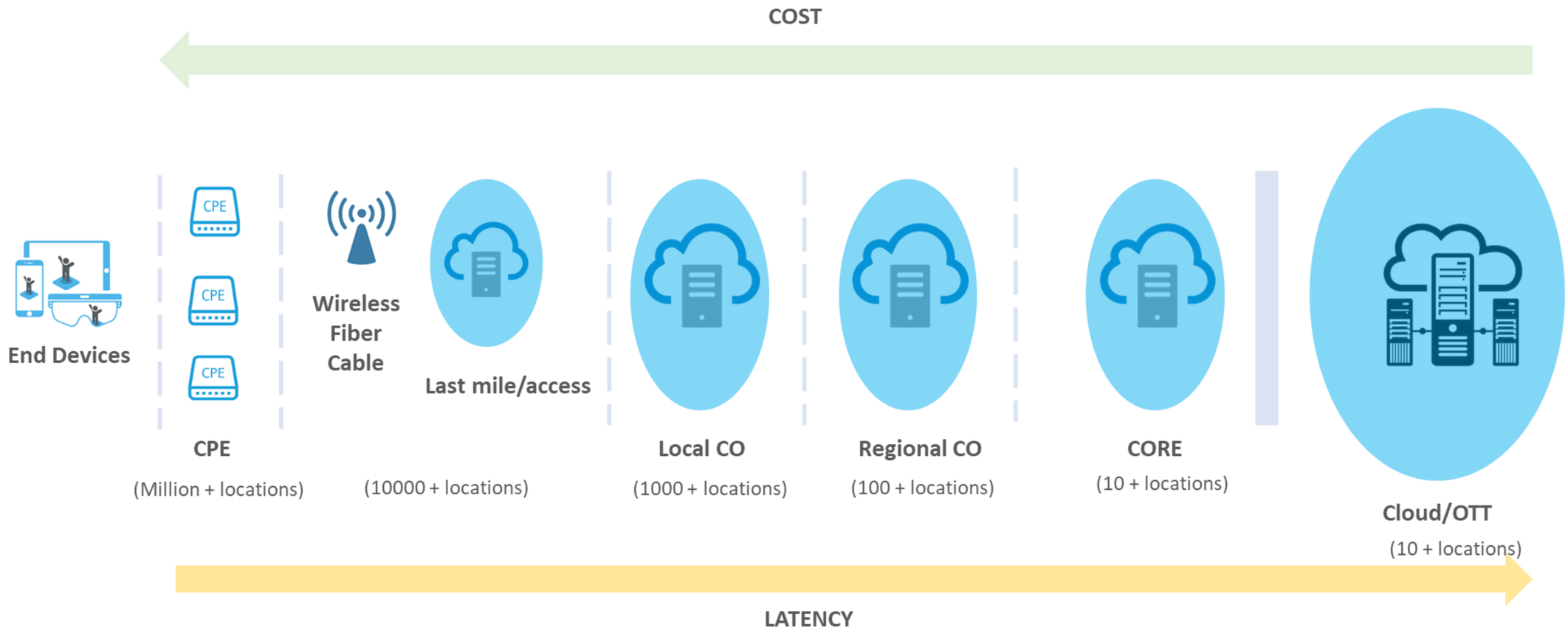


Massive amount of real-world data

Real-time processing of the data

Evolving Cloud and Network Architecture

Hierarchy of computing over a network



Key Benefits of Edge Computing

Better, faster and cheaper for real-time processing of data

- Faster response time
- Reduced data haul over the core network
- Reduced transport cost
- Improved Data Security & Compliance
- Better quality of service

GRIDRASTER

GRIDRASTER - A CLOUD PLATFORM FOR IMMERSIVE AR/VR

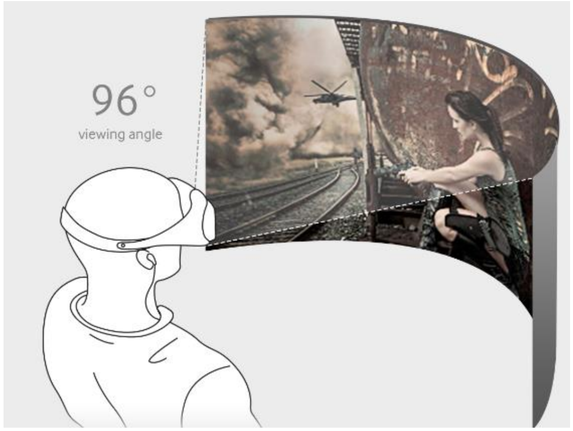
Leveraging **edge compute** and **3D vision-based** AI to deliver high-quality immersive experiences at scale


AR/VR is set to Transform the way we
LIVE and WORK

Evolution of Mixed Reality

Mixed Reality is evolving from simple 3D visuals to fully immersive experience

Beginning



- Low Resolution, Small Field of View
- Information Overlay, Rudimentary Games/Apps (e.g. Pokémon Go, IKEA AR App, etc.)

Now

- 3D virtual world with better sense of “presence”, “immersive” yet distinct real and virtual worlds, require dedicated and expensive equipment
- 3D games, Simple visualizations and holograms

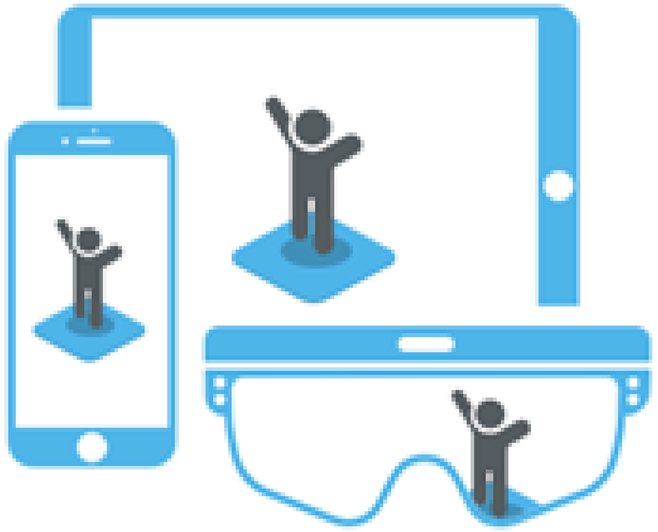
Future

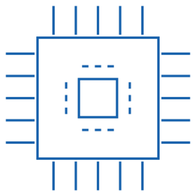
- Totally Immersive “Mixed Reality” experience, accessible on mobile AR devices, fusion of real and virtual worlds, powered by cloud.
- Immersive games, concerts, entertainment; 3D rendering of complex worlds

Mobile is the opportunity

But limitations of the mobile devices severely restricts immersive experiences

DEVICE LIMITATIONS

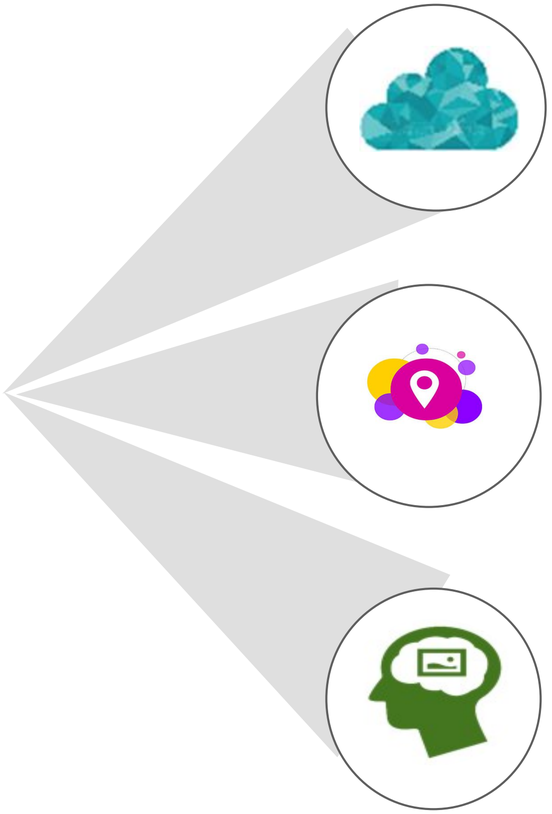




Limited Compute

Limited Battery

MR CHALLENGES



Low quality visual rendering

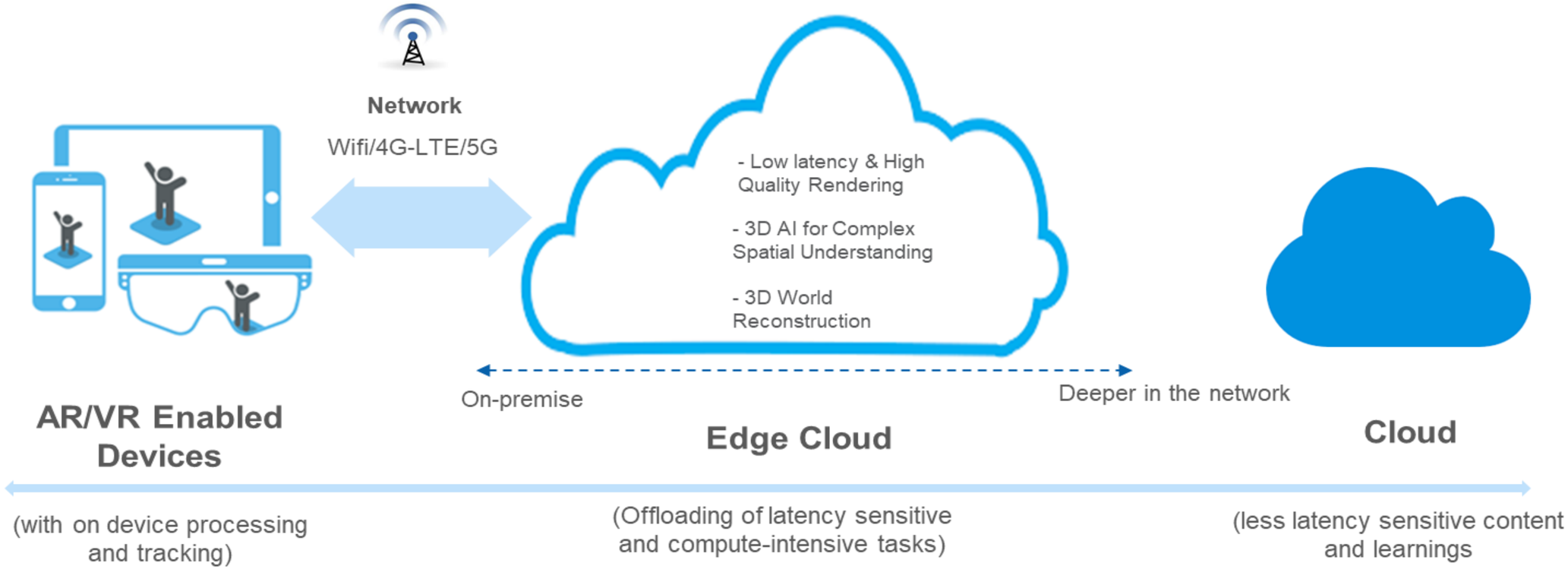
Restricted persistence and precision of spatial data

Limited 3D spatial and contextual understanding


NO high quality immersive system exists today
that can provide both performance and scale

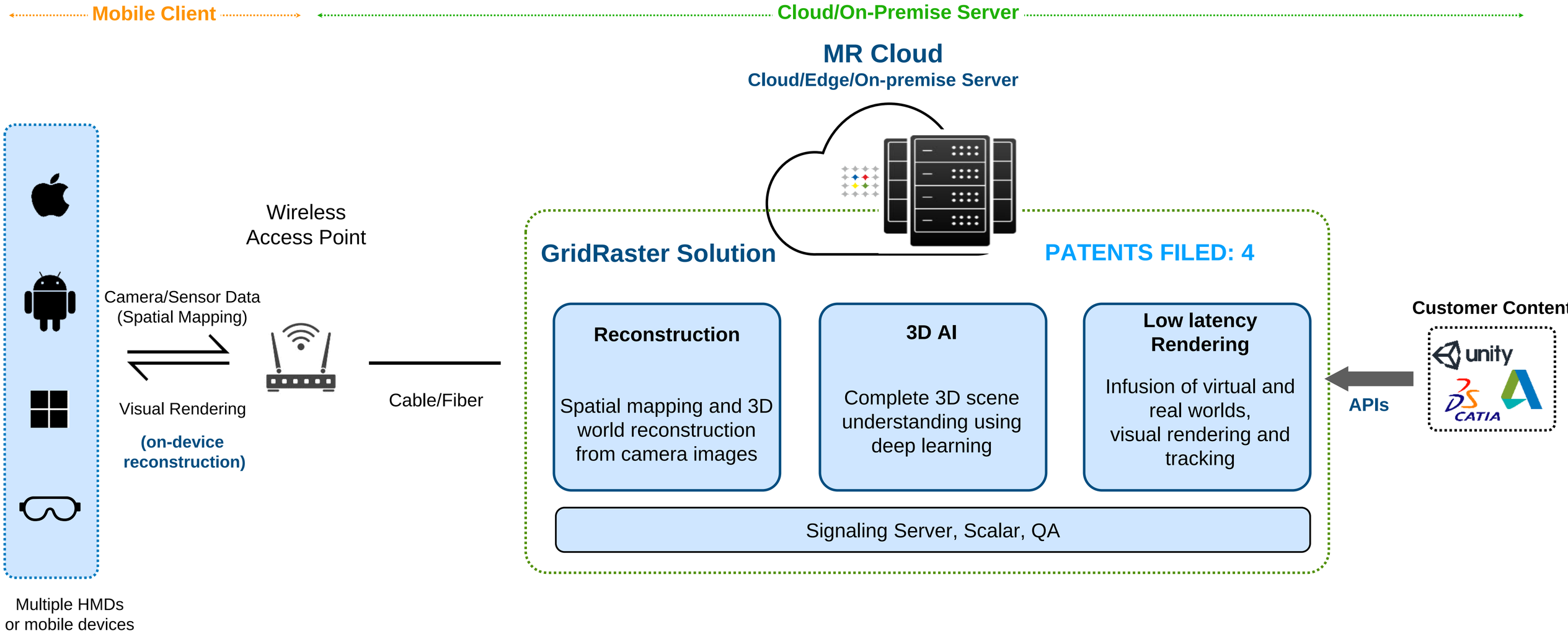
Solution: Intelligent Cloud based Augmentation

Offloading compute-intensive rendering, 3D world Reconstruction and 3D AI to remote server



GridRaster: Cloud Platform for Immersive Mixed Reality

True Immersive MR: Powered by Edge Compute and Vision Based 3D AI



Complete end-to-end solution: Leveraging Hybrid Computation, Integrating with Standard APIs.

Performance Summary

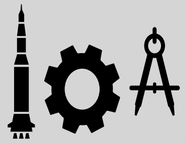
Delivering high-quality low latency rendering and accurate merging of virtual and physical world

Metric	Standalone HMD	HMD with GridRaster Solution
Polygon count of virtual objects rendered	~ 100K (heavily decimated models)	**50 Million[1] (with no decimation)**
Frame-Rate	60 FPS	**60 FPS[2]**
Motion-to-Photon Latency	20 ms	**< 20 ms (with network RTT < 80 ms)[3]**
3D Spatial Mapping	< 1 FPS	**60 FPS**
Rendering Precision	1 inch[4]	**1 mm**
Industry vertical-specific 3D Vision based AI	No	**Yes**

[1]With single GPU. Number of Polygons can be increased using multiple GPUs in parallel.
[2]Frame-rate is limited by the hardware of the HMD. GridRaster solution can support higher frame rates.
[3]On-device visual reconstruction to compensate for network delay.
[4]Rendering Precision can be improved by using finer mesh, which would limit the object size.

Enterprise first and proven verticals

MR serves broad spectrum use case in Enterprise, focused on high ROI applications

 **Design & Engineering**	 **Operations & Manufacturing**	 **Training**	 **Customer Experience**
Augmented Interface: Fuse virtual and real worlds	Improved Safety: Failure Predictions & Preventative Maintenance	Knowledge Transfer: “Know What I Know”	Higher win rates: customers can better visualize products
Collaborative Design Review	Operator & Assembly Work Instructions	Minimized Time to Build Work Instruction in 3D	Shorter sales cycles: easy access to all products - anywhere/anytime
Quick Iterations through multiple steps/teams	Benefits of Planning: more predictable time to complete tasks	Reduced Cognitive Load: Workers can operate at higher levels	Augmented Brand Experience

INDUSTRIAL

$6.5B

AUTOMOTIVE

$3.3B

AEROSPACE

$1.5B

(By 2024, CAGR of 65% from 2017-2024)

Source: https://www.gminsights.com/industry-analysis/augmented-reality-ar-market

Future Trends

The world is going to be painted with data

- 5G to further accelerate the adoption of AR/VR
  - Ultra low latency
  - 3-4x better throughput
  - Better use of the spectrum
- Enterprise AR/VR deployments to help propel the adoption of consumer AR/VR
- Utilization of the peer-to-peer network to share data locally and reduce the load on the core network

Thank You

Join us as we shape the future.

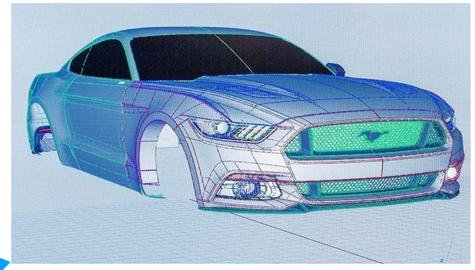
DIJAM PANIGRAHI | COO/Co-founder | dijam@gridraster.com | gridraster.com


Some examples...

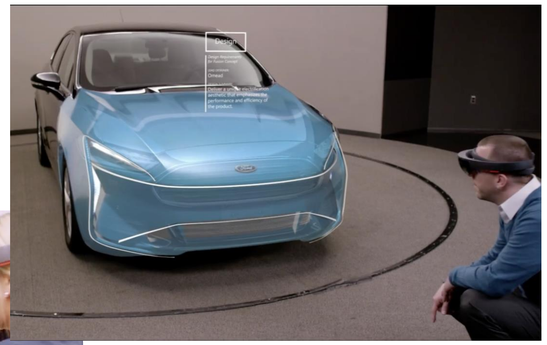
Automotive: Car Design Process

Rapid Iteration, Clearer Communication, Quick Decision

Now



Impact of Mixed Reality

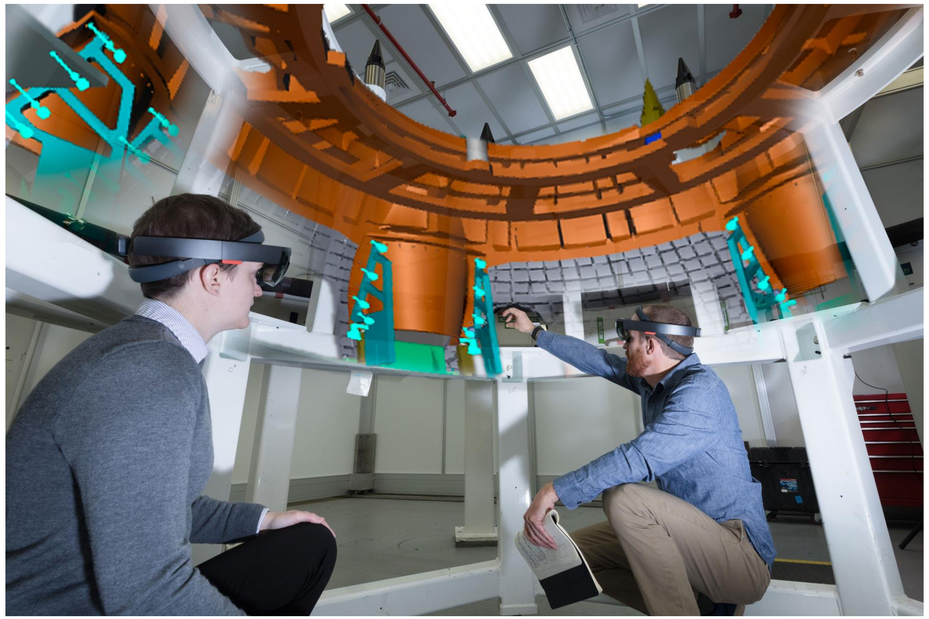


Speeds up design process from months to days

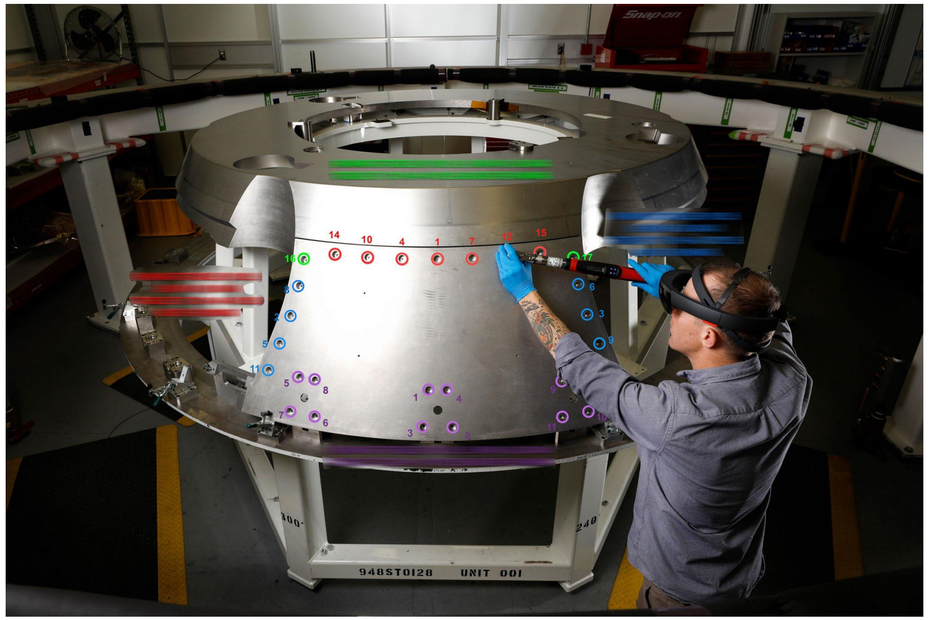
Aerospace: Design/Manufacturing Process/Maintenance

Minimize errors using MR: Instructions overlay, remote assistance, better planning and visualization

Design



Manufacturing/Maintenance



More than 40 percent increase in productivity

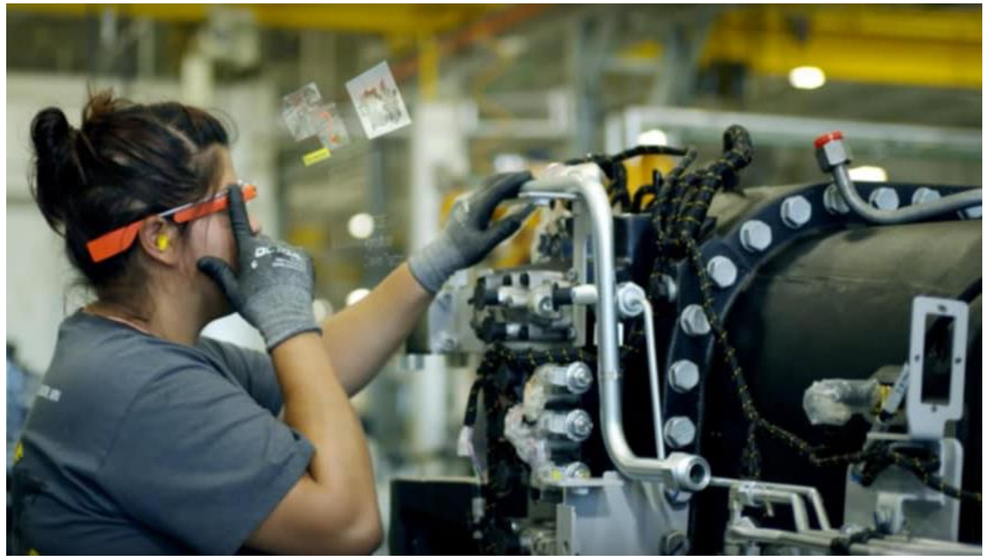
AR/MR Technologies provide Significant Time Savings to the Manufacturing Build Process through Optimized Decision Process, positively impacting the entire OODA Loop (Observe, Orient, Decide, Act).

- Shelley Peterson, Emerging Technologies Lead, Lockheed Martin

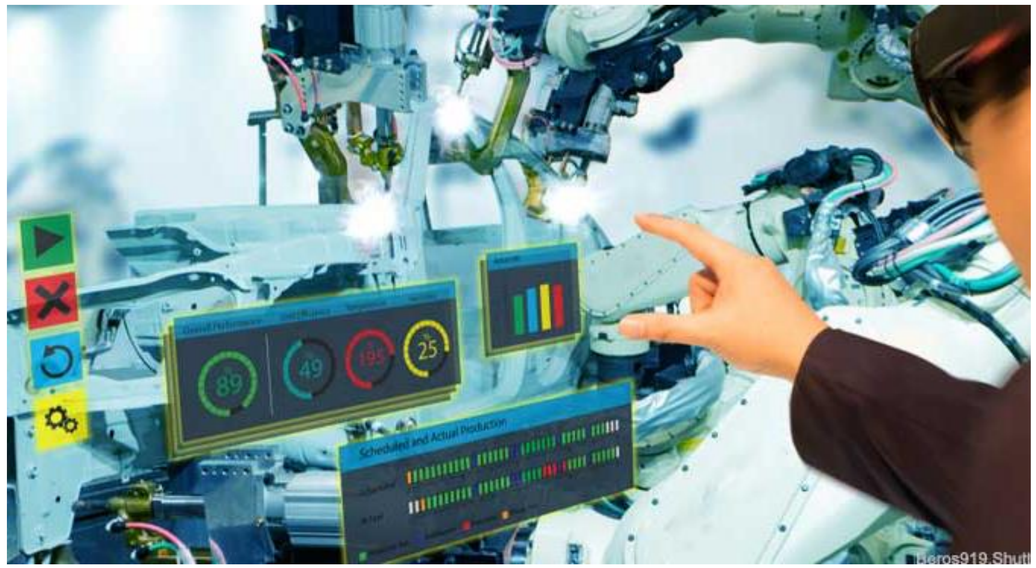
Industrial Manufacturing: Training/Maintenance

Reduce skill gap, enhance employee proficiency level, predictive maintenance improving safety

Training/Enhance Knowledge



Maintenance



Up to 85 percent reduction in training time

“AR lets users learn at their individual speed, and lessons can be repeated again and again without needing to involve the trainer or interrupt other trainees.”

- Frank Voßnacker, Innovation Manager, Siemens Power Generation Services

3%
Penetrated

Edge Computing and the Evolution of AR/VR

Stanford University, 11/21/19

DJ Lal, Charter Communications

Key Points

- Immersive in its various forms is the next frontier for entertainment
- Its realization requires that technical challenges and the cost of compute be resolved
- Service providers can help by embedding “network compute”
- This is a hard problem, but it can be solved
- Bandwidth + Low Latency + Compute = Superior experiences enabled by the network

Immersive is the Next Evolution of Storytelling

The network will democratize compute

	2D Streaming Video	Cloud Gaming	Cloud VR / AR, Light-fields and beyond
What is it:	Today's mass audience immersive experience	Growing genre, that introduces interactivity into the experience. Compounded by popularity of P2P, multi-player titles, and game broadcasting.	Emerging genre, that aims to replicate and interact with the real world
Level of Interactivity:	No interactivity. Content is rendered a priori	Content is rendered on the fly based on user input but in 2D	Content is rendered on the fly, in 3D, and directly interfaces with the human sensory system
Bandwidth:	15 Mbps	Up to 50 Mbps (if streamed)	> 100 Mbps (if streamed), >1 Gbps with full viewport experience
Latency:	Tolerant to most latency conditions	<50 milliseconds latency	<15 milliseconds latency
Compute:	No special compute required	High end GPU (5-10 TFLOPS) required for latest gaming titles	High end GPU (>10 TFLOPS) required

Spectrum

Current Barriers Make Mass Adoption Challenging

Extant industry challenges need to be solved to stimulate market adoption

Virtual Reality

1 **HMDs available at a wide variety of price points, but premium experiences require large investment in PC/console**

Low cost HMDs

- ✓ Price encourages user adoption (~$200)
- X Lower res., frame rate experiences

Premium HMDs

- ✓ Provide great immersive experiences
- X High TCO for HMD + PC/console to drive immersive experience

Oculus Go

Oculus Quest

HTC Vive Pro

Pimax

2 **Vertically integrated, fragmented content stores create a barrier to consumer investment in VR HMDs**

VIVEPORT

oculus

PlayStation.Store

Augmented Reality

1 **Smartphone based AR requires low latency and high intensity compute to enable good consumer experiences**

Limited GPU power prevents smartphones from being able to run high fidelity AR experiences

Battery limitations in smartphones result in immersive experiences draining them very quickly

2 **High price point of AR HMDs causes price friction and prevents mass adoption ($1300 - $3500)**

Magic Leap One
(Standalone)

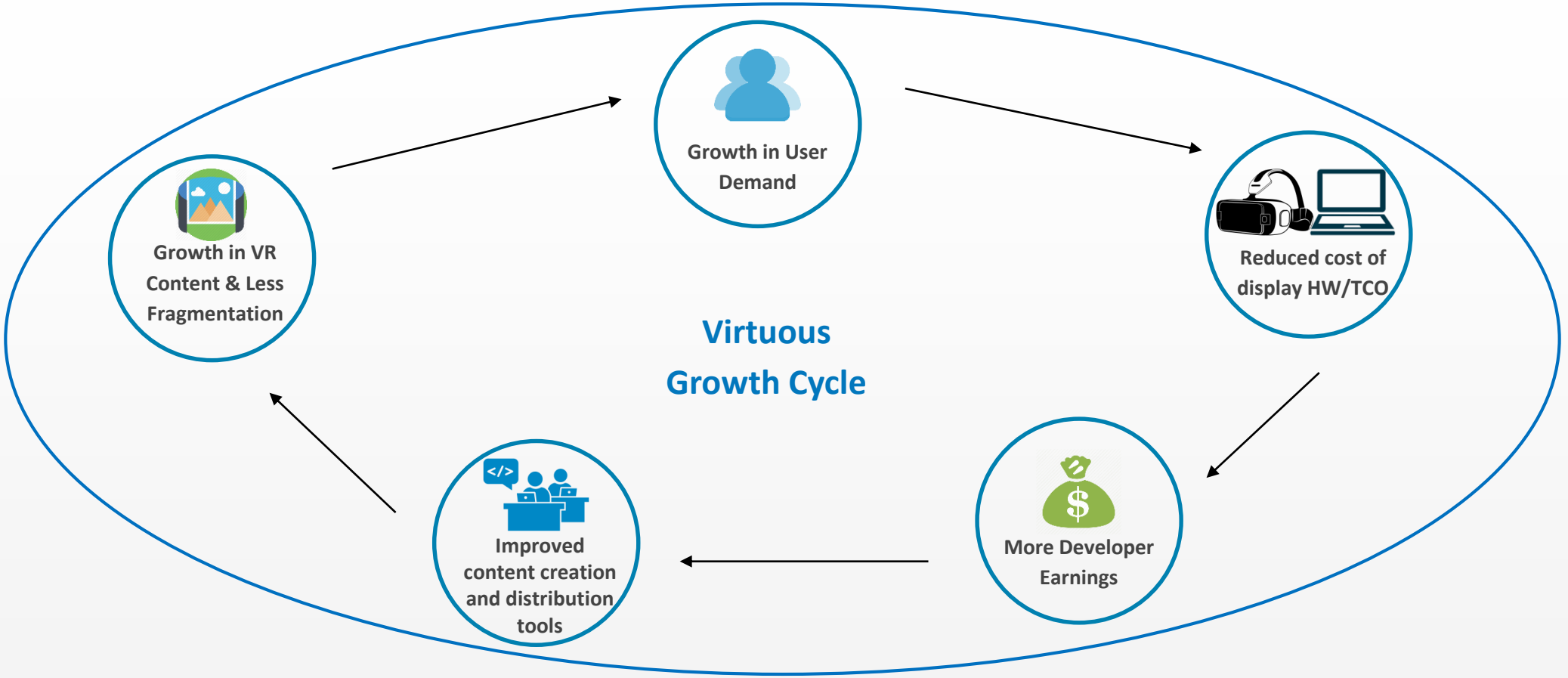
Hololens 2
(Standalone)

Nreal
(HMD + Phone)

Spectrum

Ramping the Growth Cycle will Stimulate the Market

Additional content availability and increased HMD penetration



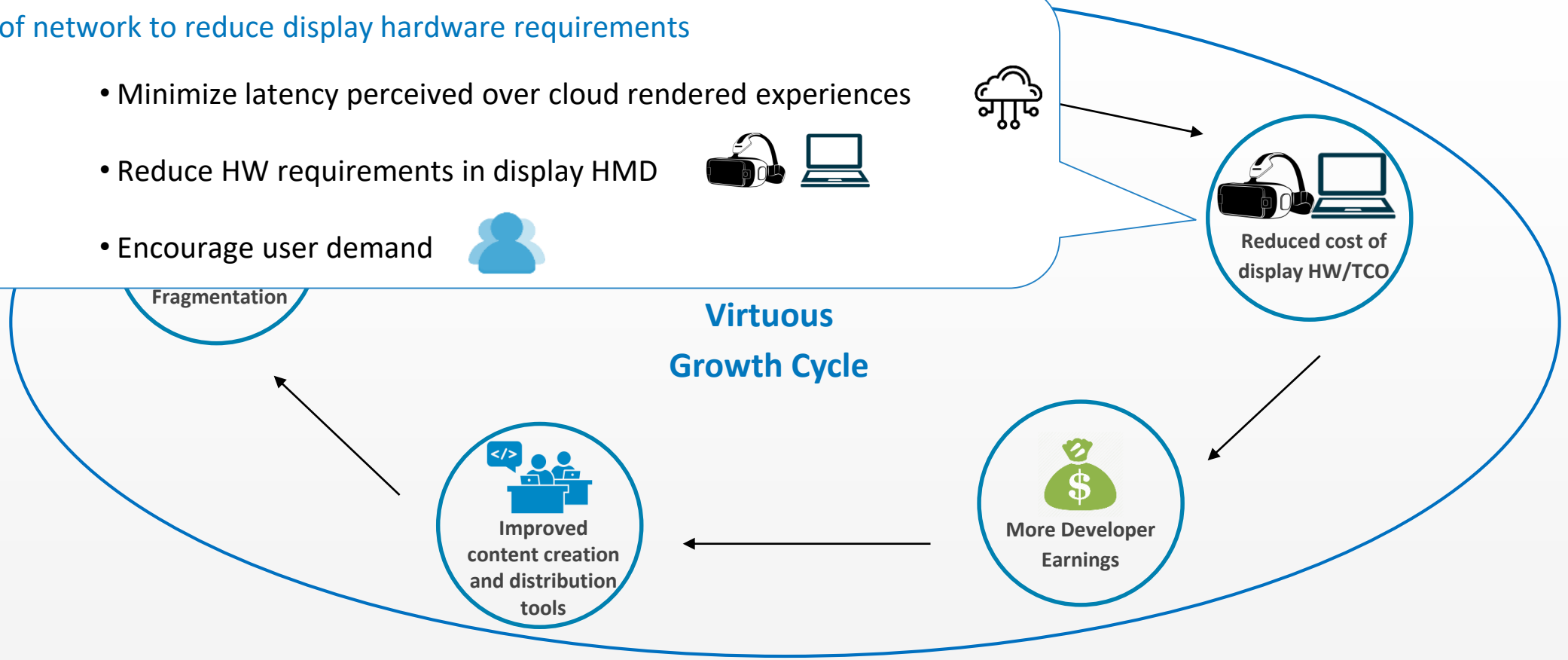
A self-feeding sequence with **increasing user base** and **variety of content** provides a **Virtuous Growth Cycle** that **attracts more creators** and **encourages overall growth**

Ramping the Growth Cycle will Stimulate the Market

Additional content availability and increased HMD penetration

Use of network to reduce display hardware requirements

- Minimize latency perceived over cloud rendered experiences
- Reduce HW requirements in display HMD
- Encourage user demand

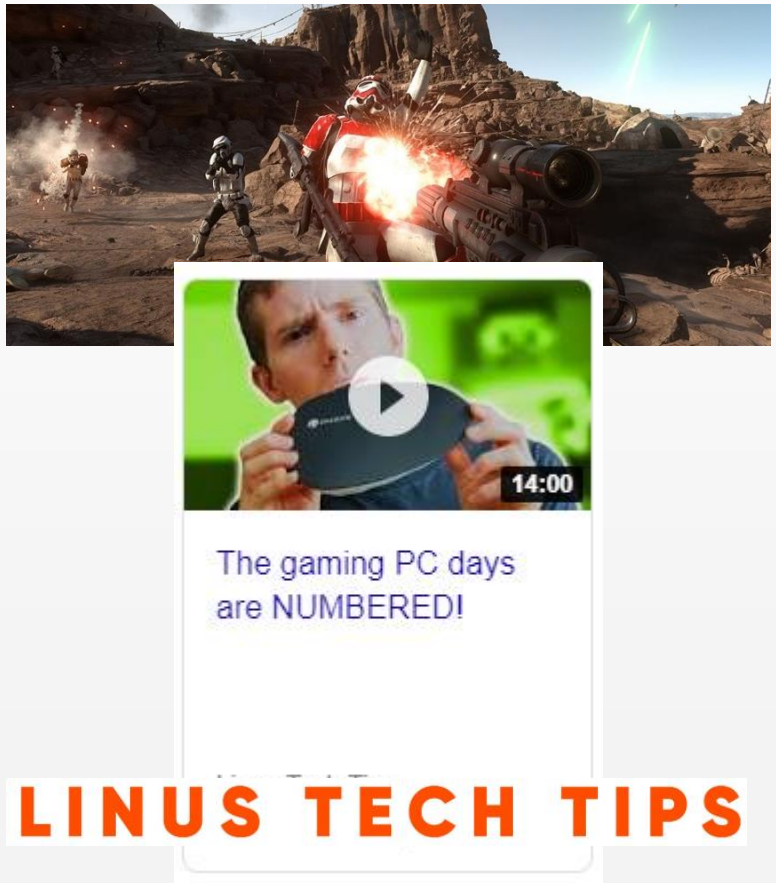


A self-feeding sequence with **increasing user base** and **variety of content** provides a **Virtuous Growth Cycle** that **attracts more creators** and **encourages overall growth**

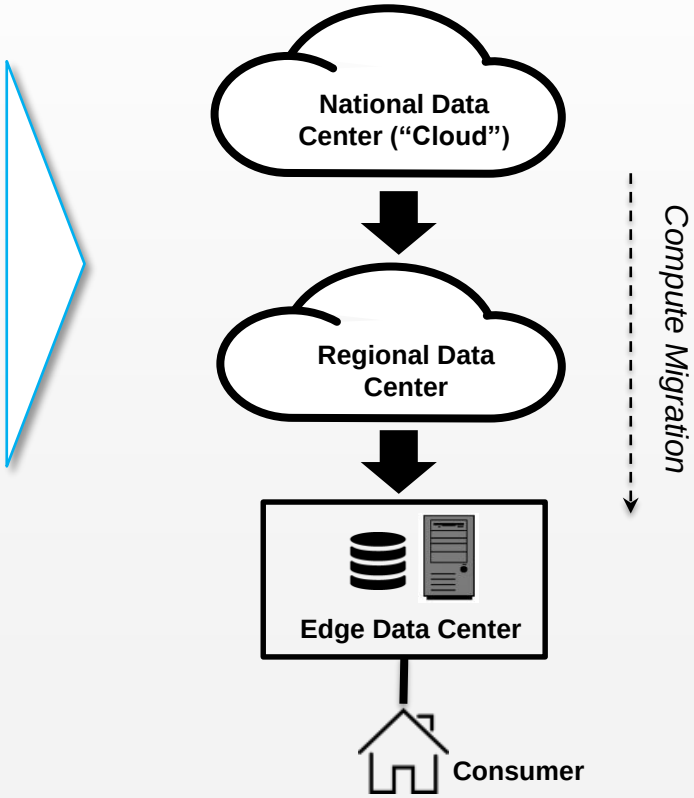
The Network is the Computer (*Again*)

A $2,000+ computer is migrated to a network datacenter to deliver immersive

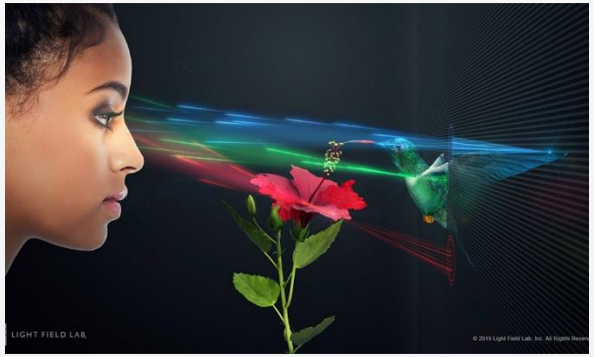
1. Modern day GPUs have been successfully migrated to the cloud to deliver high quality “PC grade” gaming



2. Streaming future immersive content from the network necessitates rendering closer to the consumer to deliver a low latency, high quality experience



3. Head-mounted and Light Field displays will continue to push the compute, bandwidth and latency envelop



Light Field Lab concept art demonstrating Light field display

Spectrum

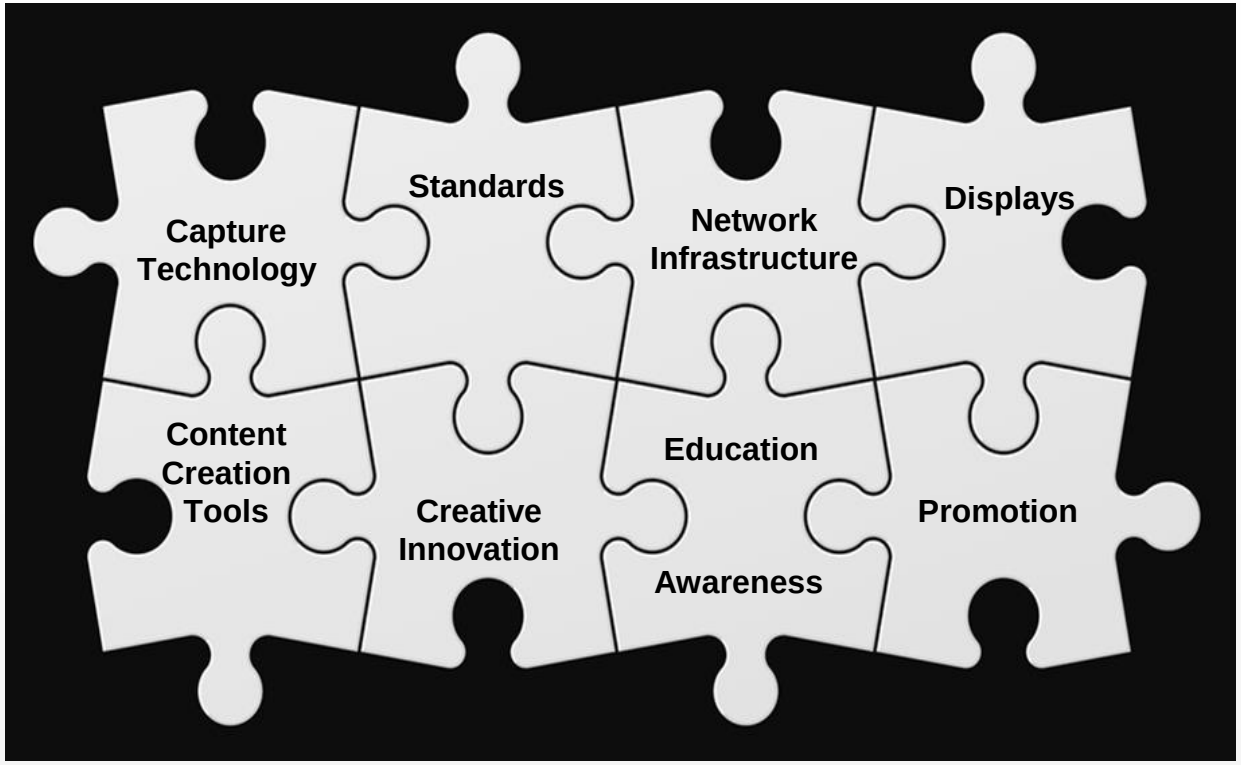
Immersive Digital Experiences Alliance (IDEA)

Created with the purpose of

- Developing a family of royalty-free technical specifications to support the end-to-end conveyance of immersive media
- Gathering marketplace and technical requirements to define and support the immersive media specifications
- Facilitating interoperability testing and demonstration of immersive technologies
- Producing educational events and materials
- Providing a forum for the exchange information and news relevant to the immersive media ecosystem

Initial Members

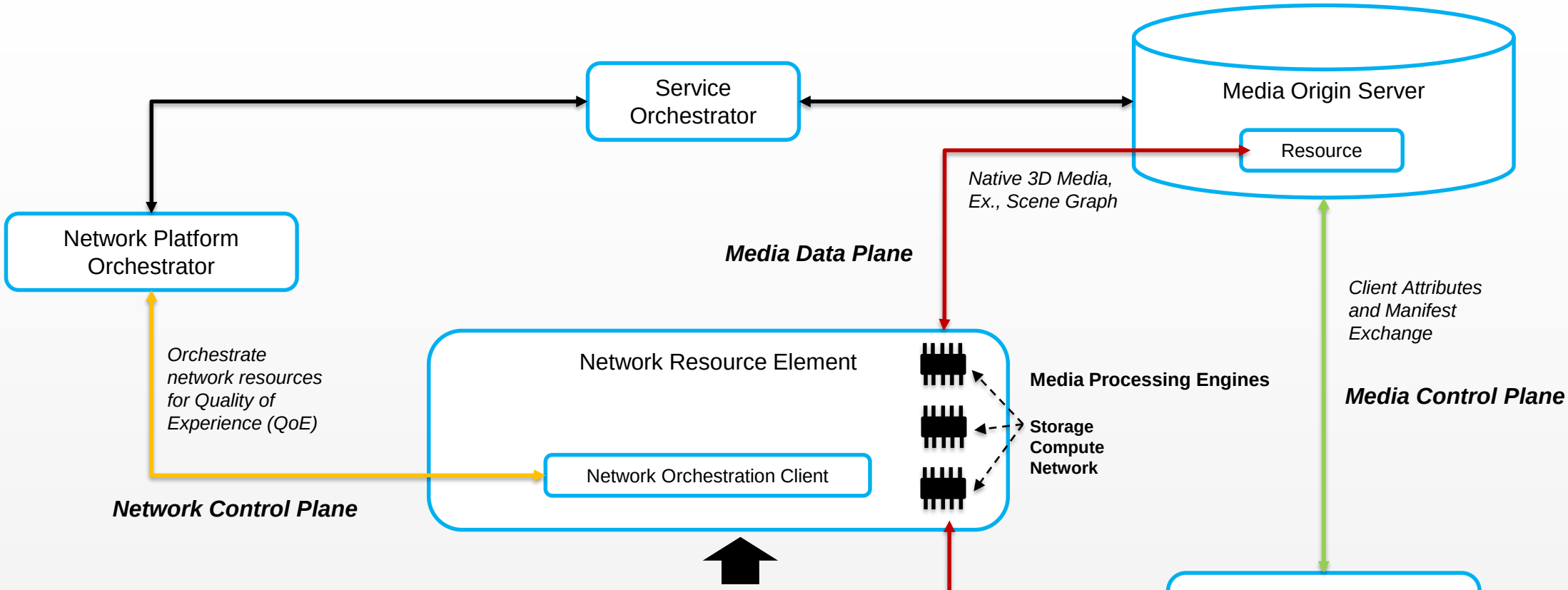
Charter COMMUNICATIONS
CableLabs
otoy
Visby
LIGHT FIELD LAB



The Network Architecture Workgroup explores network aware 3D media delivery, including highly photorealistic rendering and interactivity supported from the edge

IDEA Network Aware Media Processing

Engaging service provider network, storage and compute resources for media delivery*



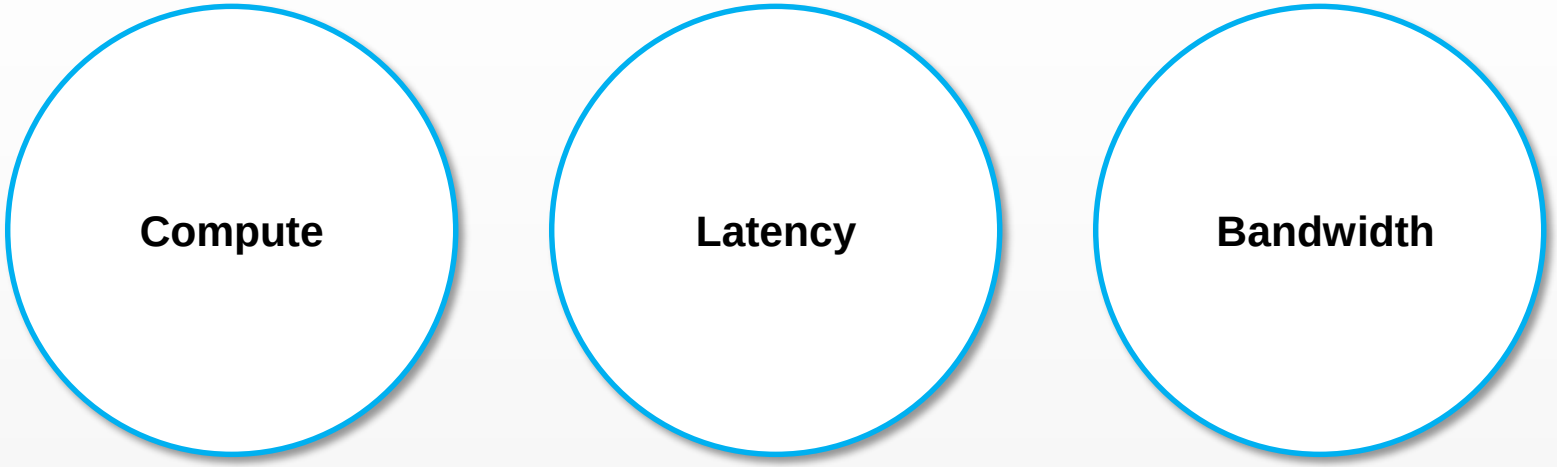
Network Aware Media Processing engages ***intermediate*** Media Processing Engines (MPEs) in the network to deliver QoE

*https://www.immersivealliance.org

Spectrum

Delivering Quality Immersive Experiences is a Balance

… of compute, latency, and bandwidth



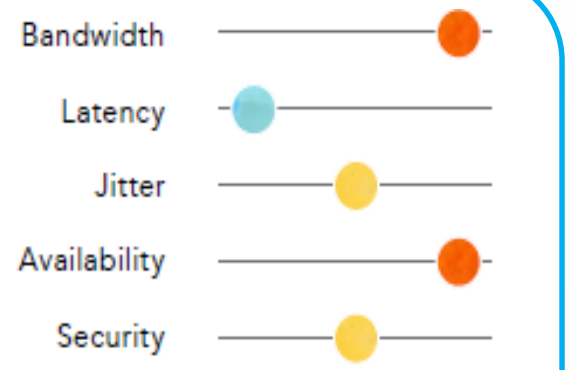
Considerable computation power is required to synthetically render, encode and stream the virtual environment

Experiences need to achieve the “motion to photon” experience of real life interactions

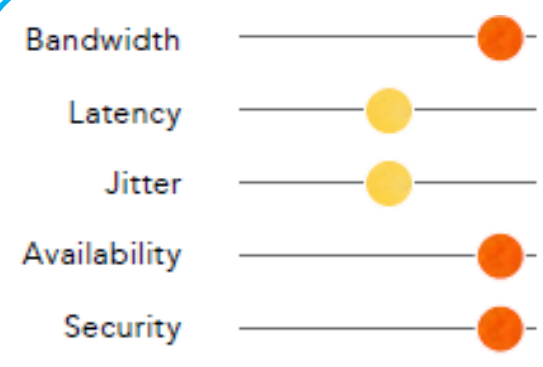
Delivery of immersive over large pipes is required to democratize the technology

Edge Computing Sample Use Cases*

A variety of existing and emergent applications shall drive compute to the edge

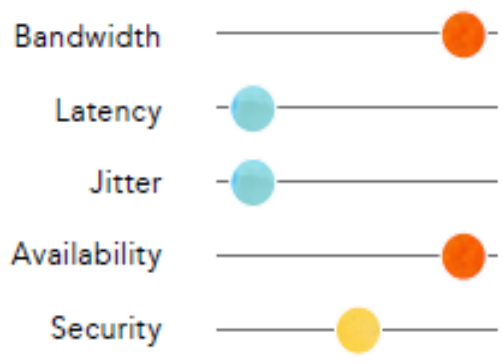


Edge Content Delivery



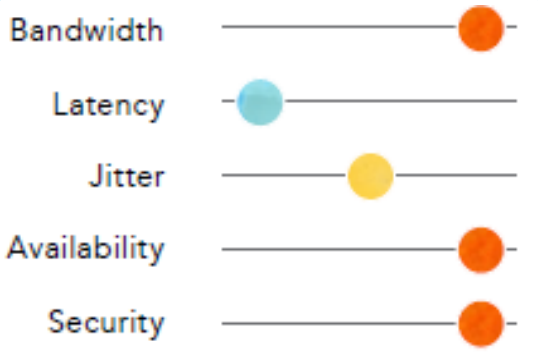
Video Surveillance

Video Gaming



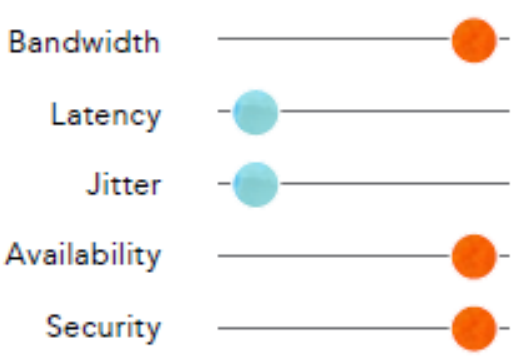
VR and AR

Large Scale IoT and IIoT



AI and Machine Learning

NFV and Access



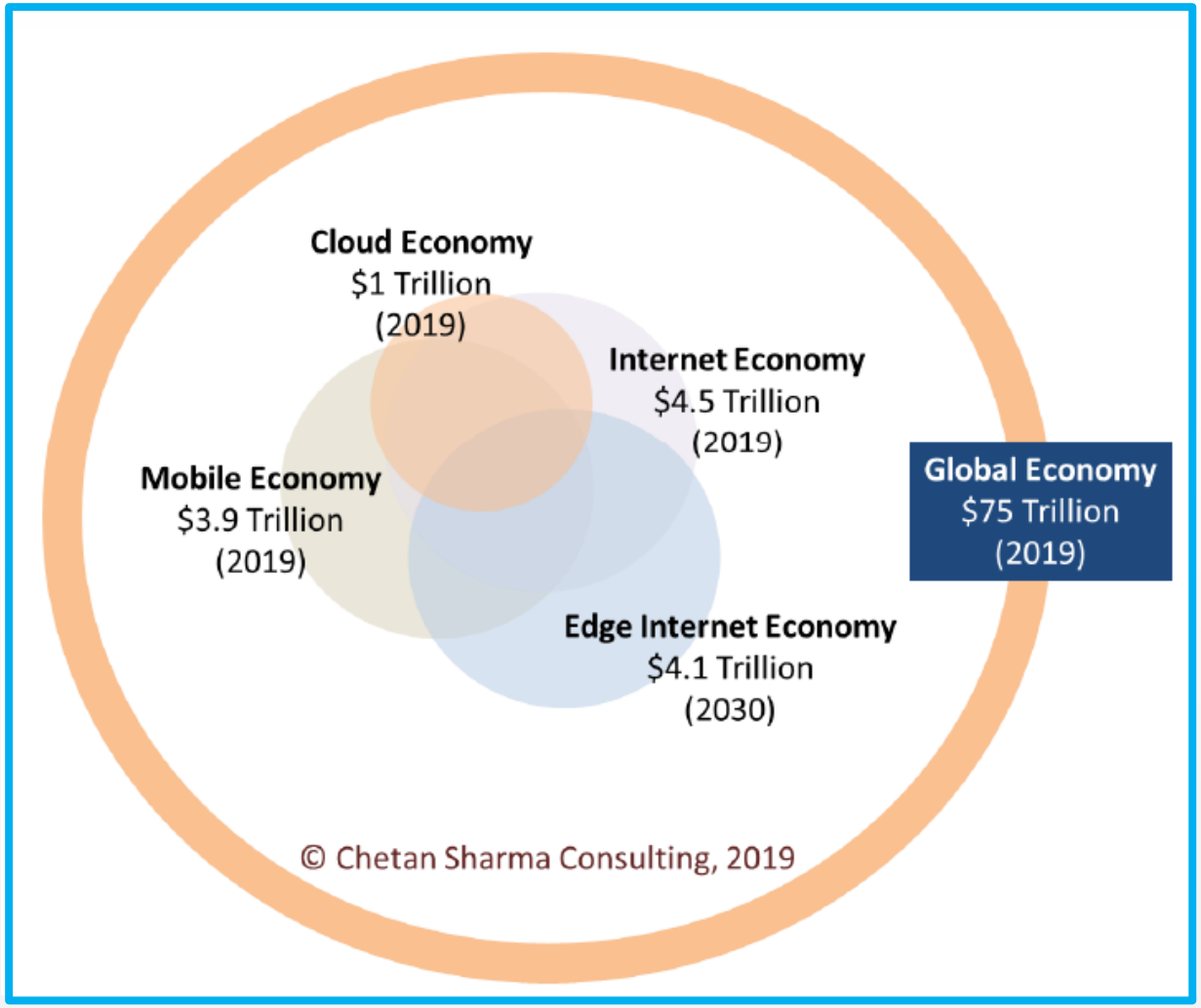
Autonomous Vehicles

*State of the Edge 2018: A Market and Ecosystem Report for Edge computing

Spectrum

In Conclusion…

- Network edge computing has the potential to democratize AR/VR and other immersive experiences
- Edge computing is agnostic of any one access network technology; albeit low latency / high bandwidth access is a prerequisite to reap the benefits of edge computing
- The edge internet economy has a potential to scale in value in a decade to the same level as the cloud or mobile economy of today*



*Edge Internet Economy: The Multi Trillion Dollar Ecosystem Opportunity, Chetan Sharma Consulting

Spectrum