Navigation/localization Performance of Autonomous Vehicles

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Content

- Smart city and smart mobility
- Autonomous driving in a smart city
- Autonomous vehicles requirements: localization, positioning and high definition maps
- Autonomous vehicles: testing requirements
- Autonomous vehicles: testing challenges
- Summary and conclusions

Smart city

- Smart Cities are those that have a base level of connectivity and integrated municipal services
- Cities built on *Smart* and *Intelligent* solutions and technology that will lead to the adoption of at least 5 of the 8 following smart parameters
  - smart energy
  - smart building
  - smart mobility
  - smart healthcare
  - smart infrastructure
  - smart technology
  - smart governance and
  - smart education, smart citizen

Credit: VINCI Energies, https://www.youtube.com/watch?v=Br5aJa6MkBc

What is smart mobility?

- Advanced traffic management system (ATMS)
- Parking management
- ITS-enable transportation pricing system
- *Connected vehicles/cooperative navigation*
- *Automated/Autonomous vehicles*
- Electric vehicles
- Shared rides
- Integrated multimodal transportation system
- **Goals**: three zeros
  - low or no emissions and low or no carbon footprint
  - low or no congestion = more efficient and less stressful mobility
  - no accidents and fatalities

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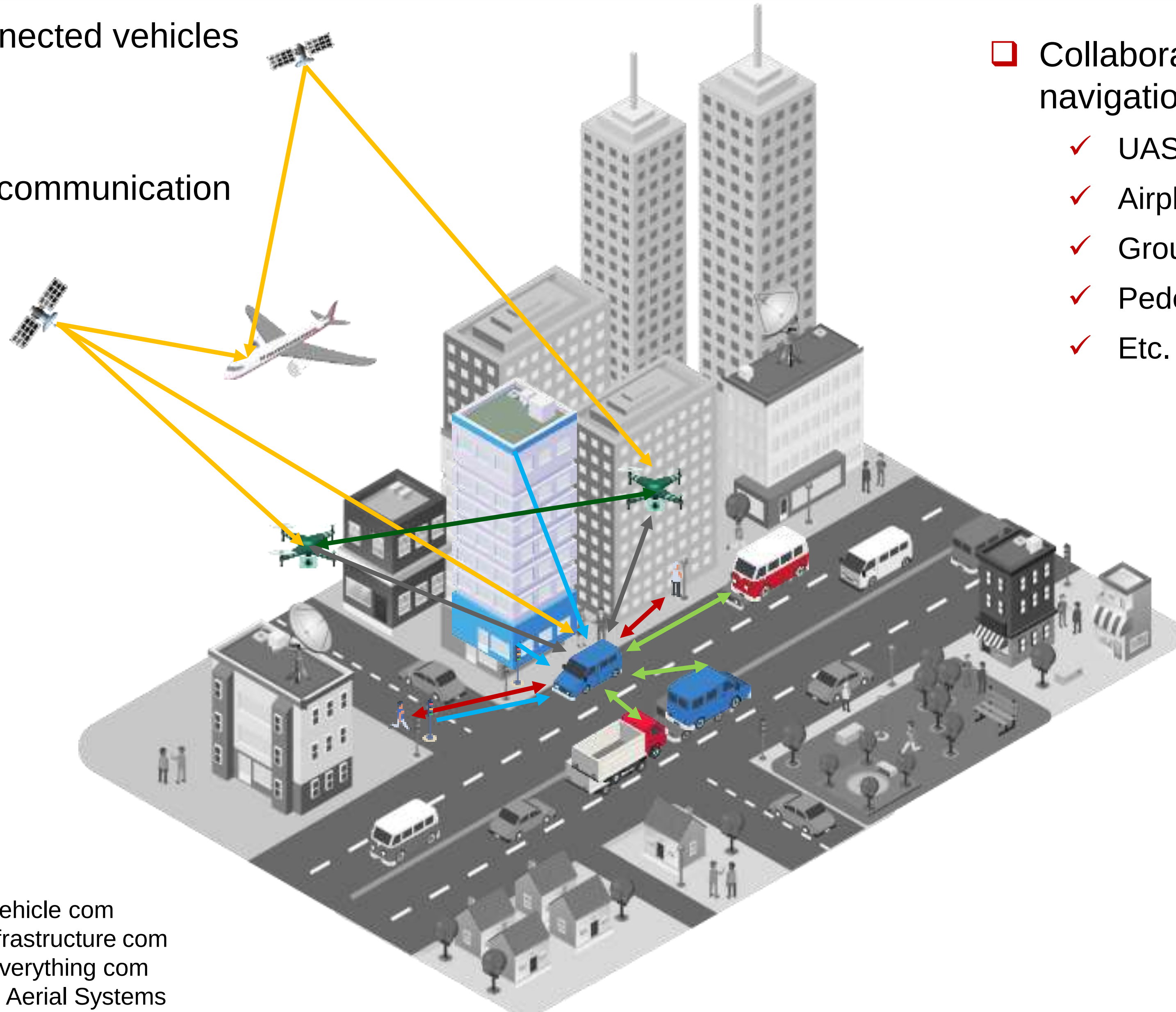
But wait, there is more….

- V2V/connected vehicles
- V2I/V2X
- Layered sensing/communication



- Collaborative navigation
  - ✓ UAS
  - ✓ Airplanes
  - ✓ Ground vehicles
  - ✓ Pedestrians
  - ✓ Etc.

VTV = vehicle to vehicle com
V2I = vehicle to infrastructure com
V2X = vehicle to everything com
UAS = Unmanned Aerial Systems

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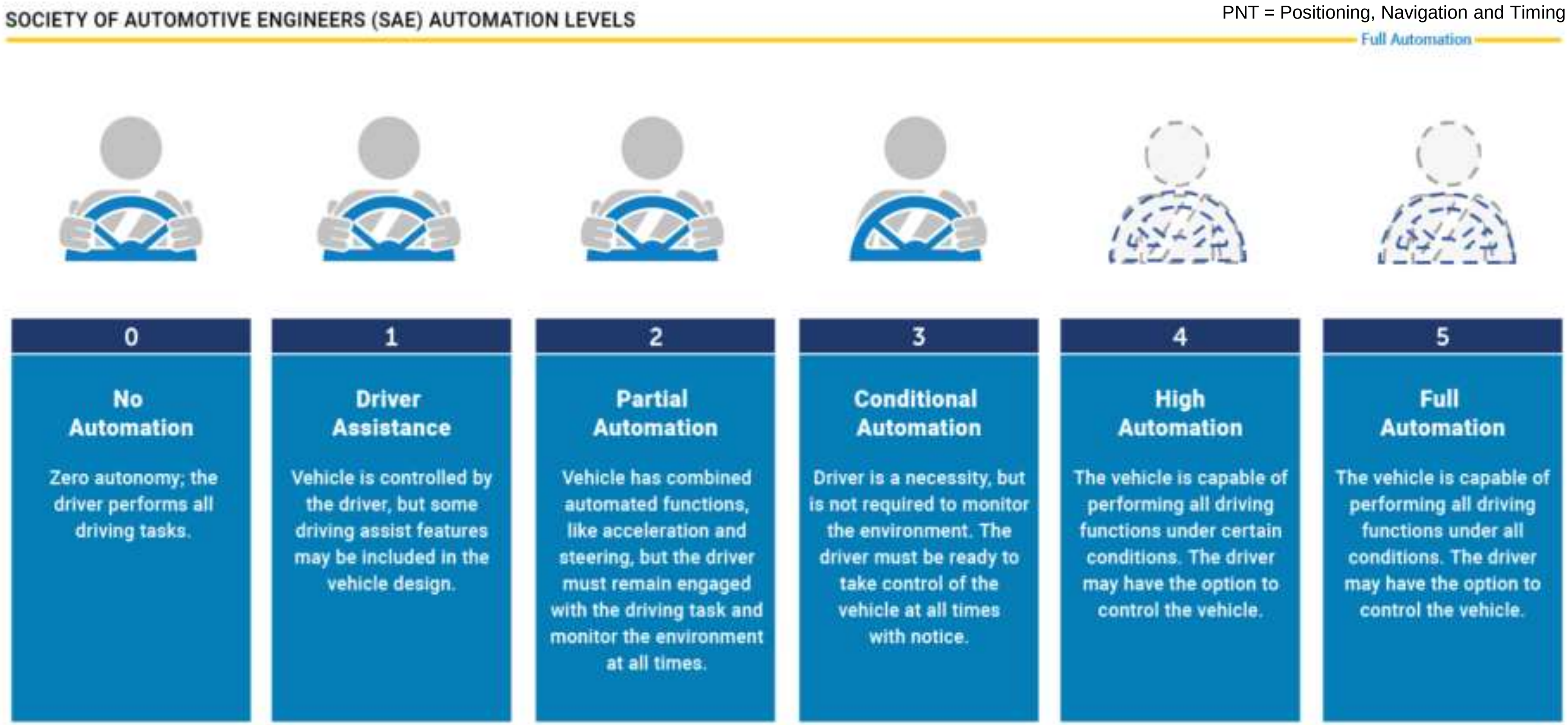
Ultimate goal: autonomous driving?

- Automated/autonomous technology is rapidly evolving
- High-definition geospatial data+PNT: enablers of high-accuracy localization and higher safety
- Crowdsourcing: becoming a dominant data acquisition technology (Big Data, Big Geo-Data)
- Communication: crucial aspect!
- Full autonomy… is still a long way

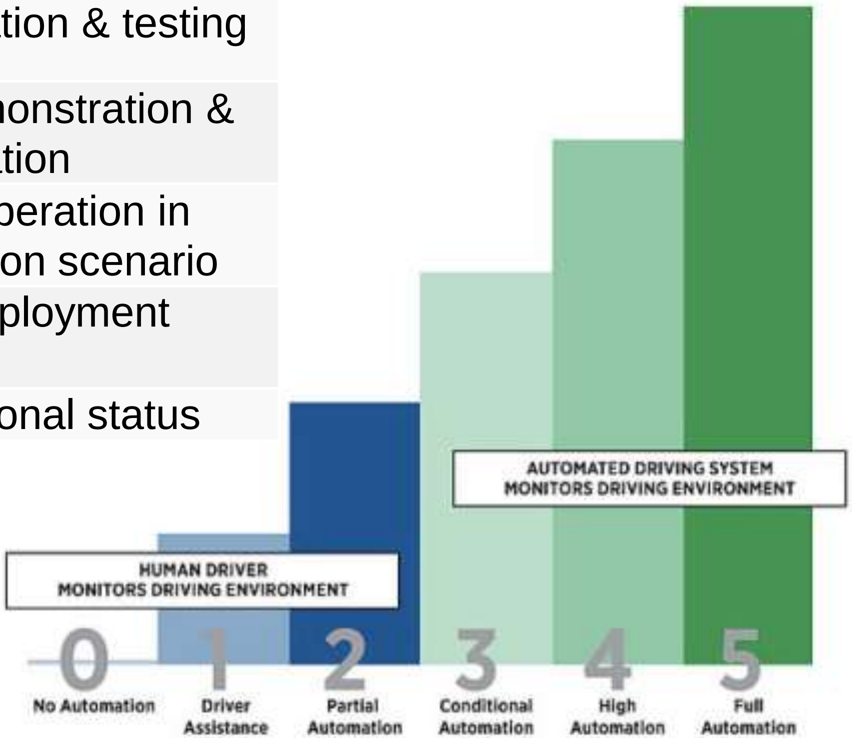
PNT = Positioning, Navigation and Timing



SAE J3016 Standard Core Reference for Automated Vehicles

Level`	Autonomy level	Technology readiness level
1	Remote control	Basic principles
2	Automatic motion control	Application formation
3	System fault adaptive	Technology concepts & research
4	GPS assisted navigation	Tech development & proof of concept
5	Path planning & execution	Low fidelity/laboratory component testing
6	Real time path planning	System integration & testing
7	Dynamic mission planning	Prototype demonstration & operation
8	Real time collaborative mission planning	Prototype operation in realistic mission scenario
9	Swarm group decision making	Mission deployment
10	Full autonomous	Fully operational status

First development of automated function was concentrated on technology goals. **Without appropriate validation steps for safety-critical automated functions, AVs cannot be established on the consumer market**.



Credit: http://articles.sae.org/15021/

Geospatial technology/PNT and autonomy

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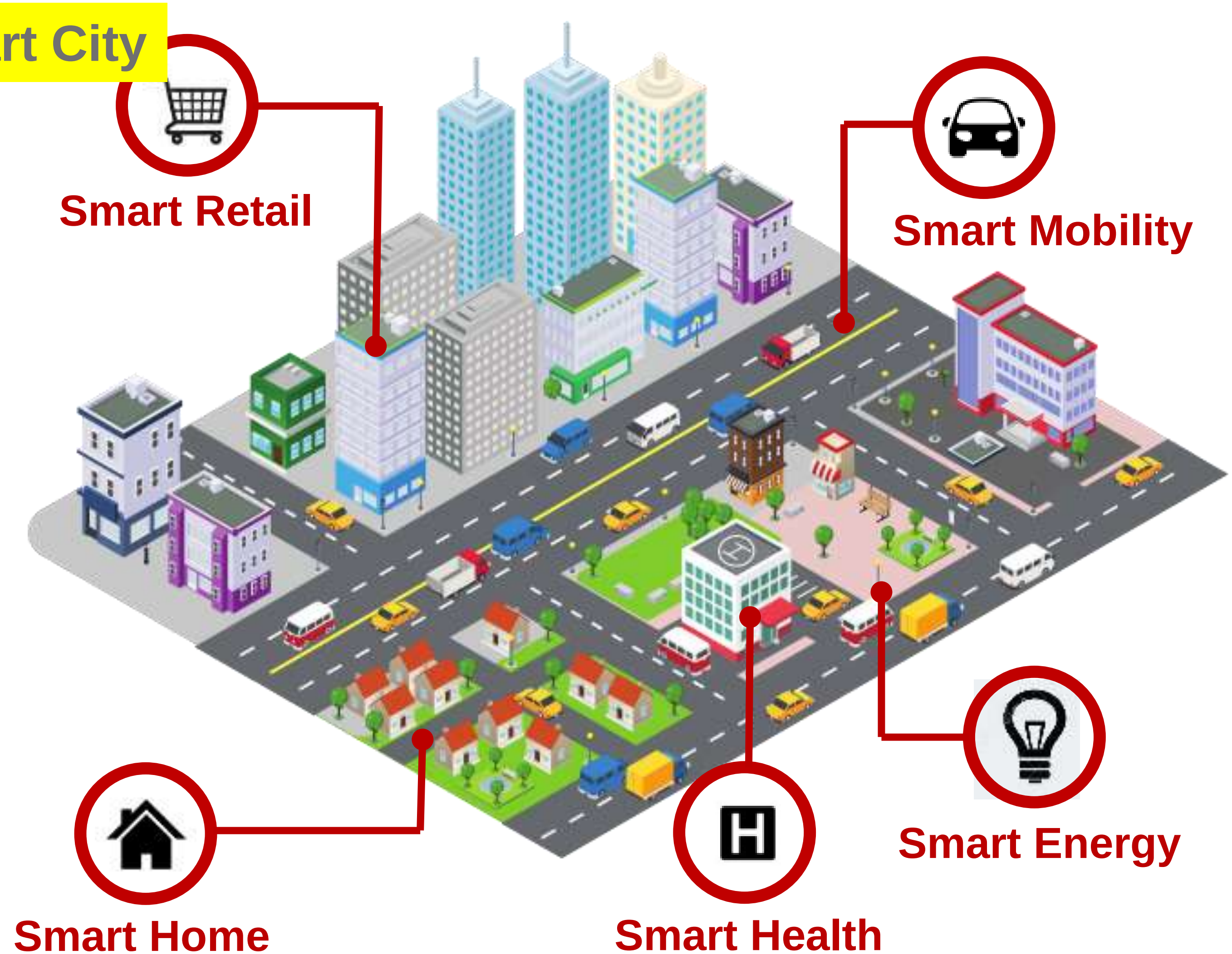
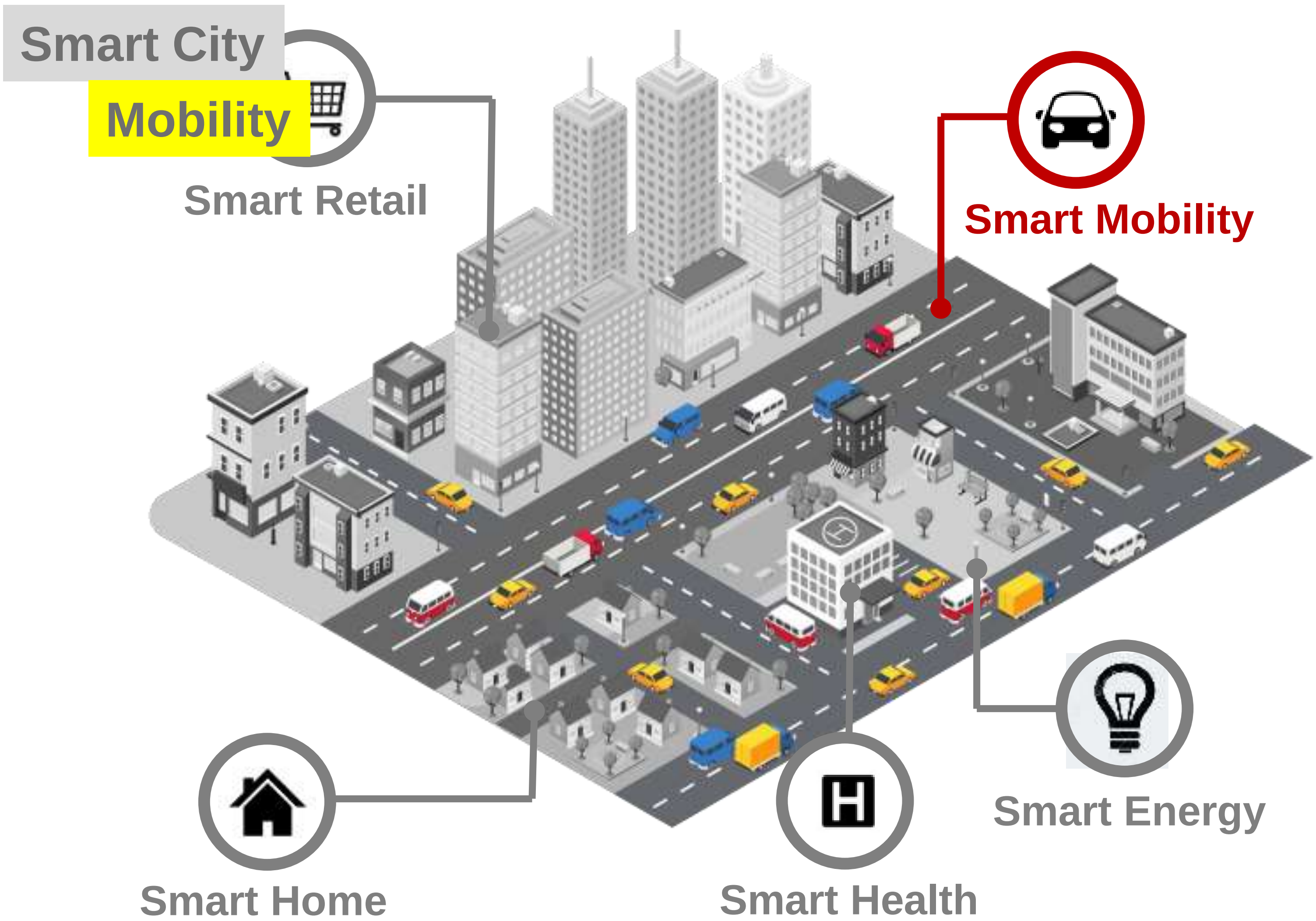


GNSS = Global Navigation Satellite Systems
PNT = Positioning, Navigation and Timing

Geospatial technology/PNT and autonomy



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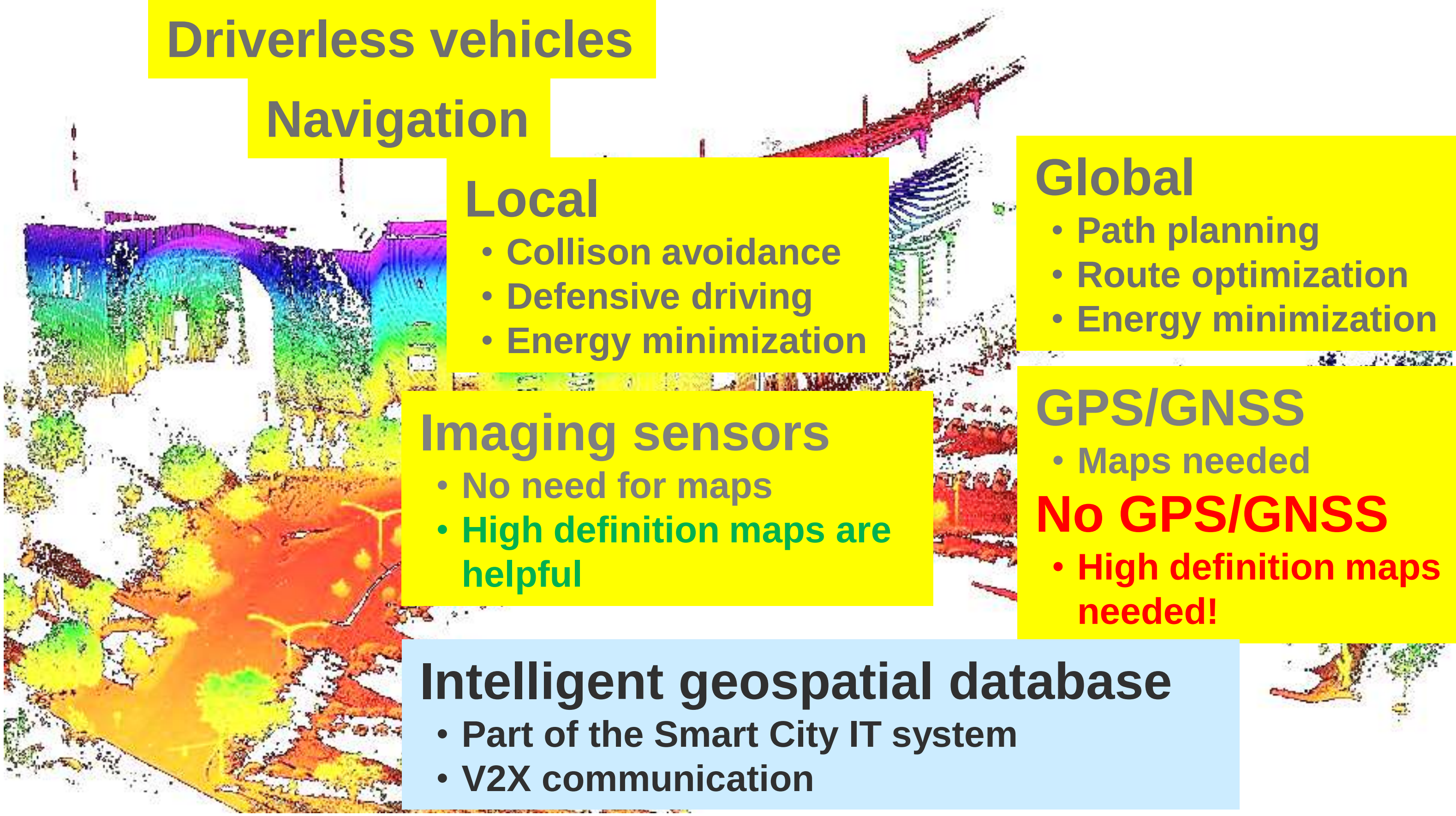
Geospatial technology/PNT and autonomy



Smart City

Mobility

Driverless vehicles

Navigation

Local
- Collison avoidance
- Defensive driving
- Energy minimization

Global
- Path planning
- Route optimization
- Energy minimization

Imaging sensors
- No need for maps
- High definition maps are helpful

GPS/GNSS
- Maps needed

No GPS/GNSS
- High definition maps needed!

Intelligent geospatial database
- Part of the Smart City IT system
- V2X communication

GNSS = Global Navigation Satellite Systems
PNT = Positioning, Navigation and Timing

Vehicle localization vs. navigation/steering

- ✓ **Localization**: lower accuracy, 10s on meters is sufficient for applications needing fraud protection, such as: car sharing, insurance apps, dynamic toll charging, parking apps, car theft/carjacking detection, etc.
- ✓ **Navigation/steering**: high accuracy, <10 cm required

Vehicle navigation/steering

Navigation accuracy required by autonomous driving:

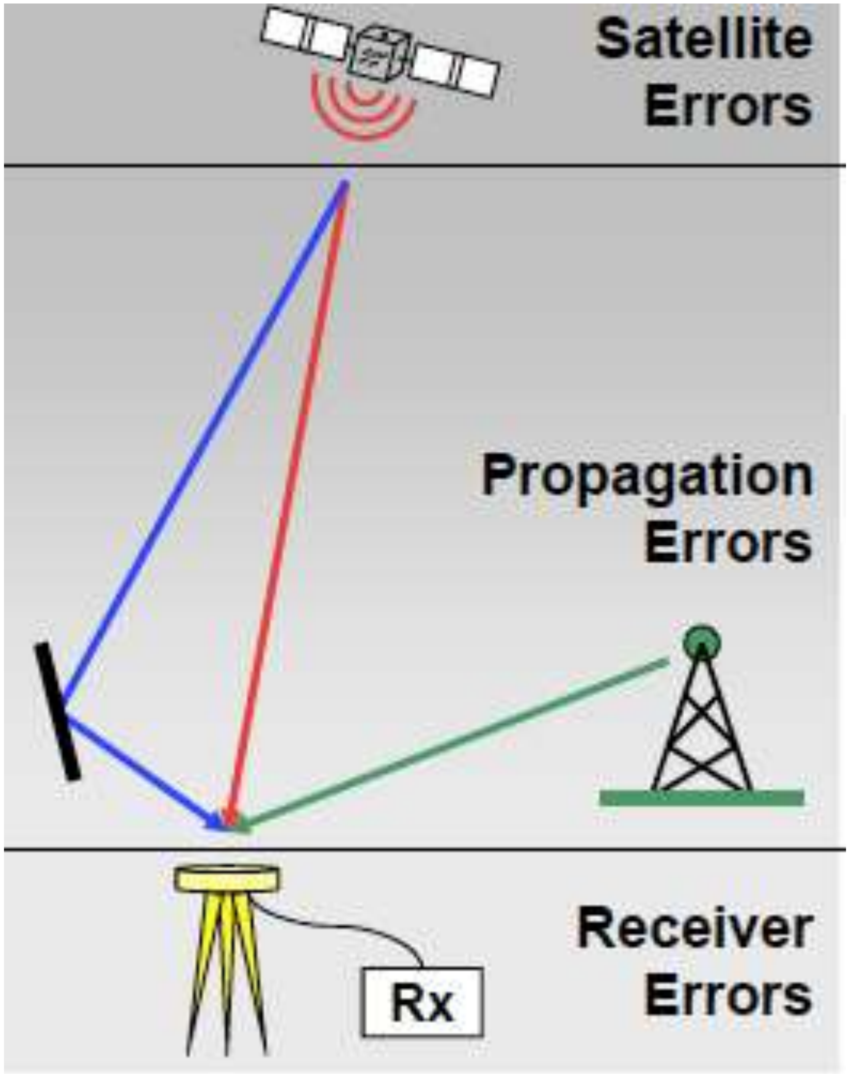
- High accuracy: 3-10 cm
- Single frequency GPS is not enough (2-5 m)
- More complex GPS/GNSS processing requires communication and special infrastructure to apply advanced algorithms (RTK, PPP)
- "Urban canyon effect" still a problem
- Commercial grade IMUs suffer from large drift errors and navigation-grade IMUs are still expensive
- Integrity information must be provided

Additional support:

- Map matching algorithms: reliable and accurate localization solution
- Map matching requires precise *a priori* map

RTK = Real Time Kinematic GPS solution
PPP = Precise Point Positioning GPS solution
IMU = Inertial Measurement Unit

Why is GNSS alone insufficient to provide vehicle steering information?

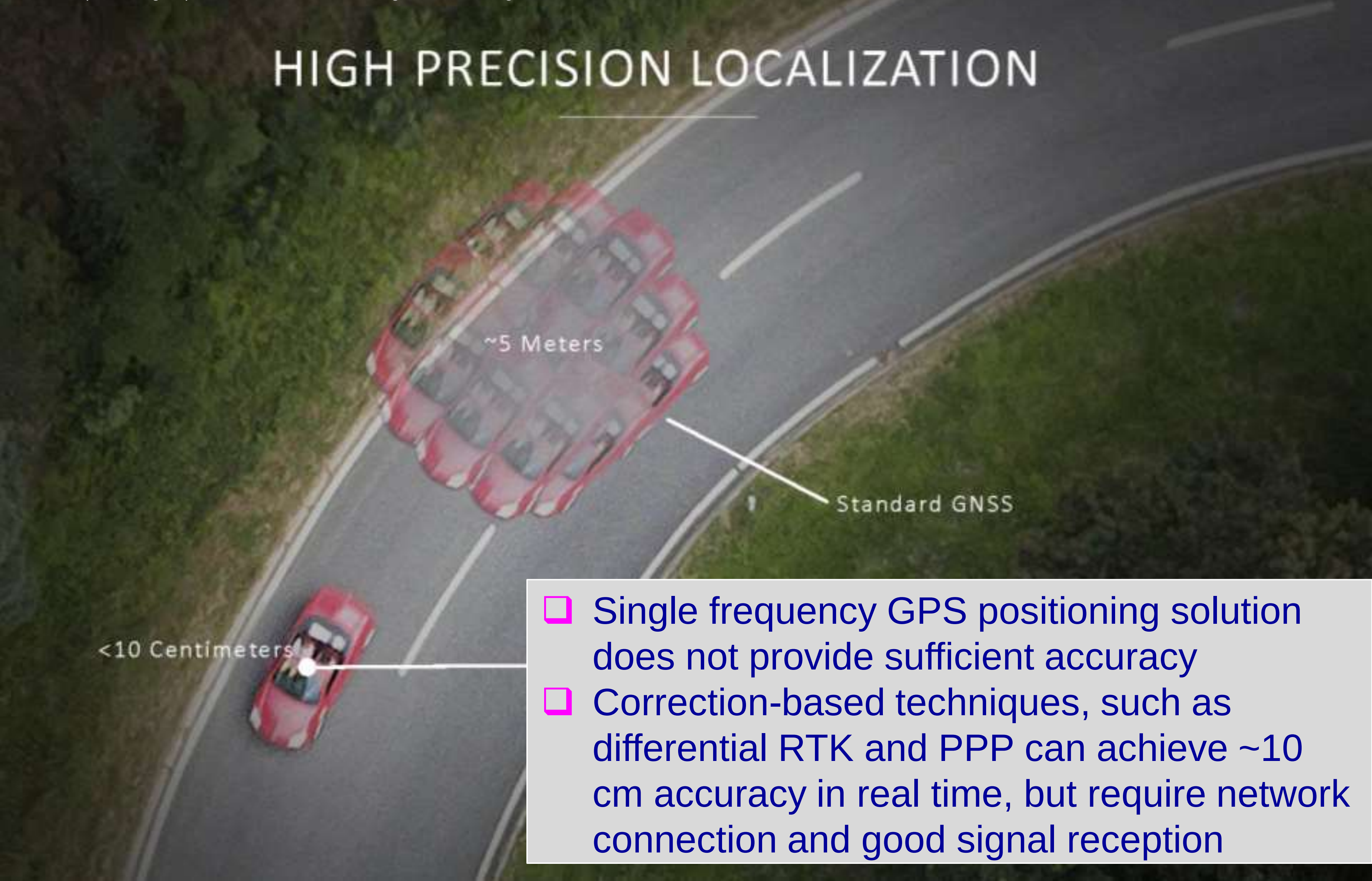


- Satellite-based errors
  - Orbit errors
  - Satellite clock error
  - Selective Availability (SA) – turned off to 0 in 2001
- Propagation errors
  - Ionospheric (dispersive)
  - Tropospheric (non-dispersive)
  - Multipath
  - Jamming, spoofing and unintentional interference
- Receiver-based errors
  - Receiver clock
  - Inter-channel bias
  - Hardware delays
  - Antenna errors
  - Noise

Image courtesy of Mark Petovello, U. of Calgary

Autonomous driving: requirements

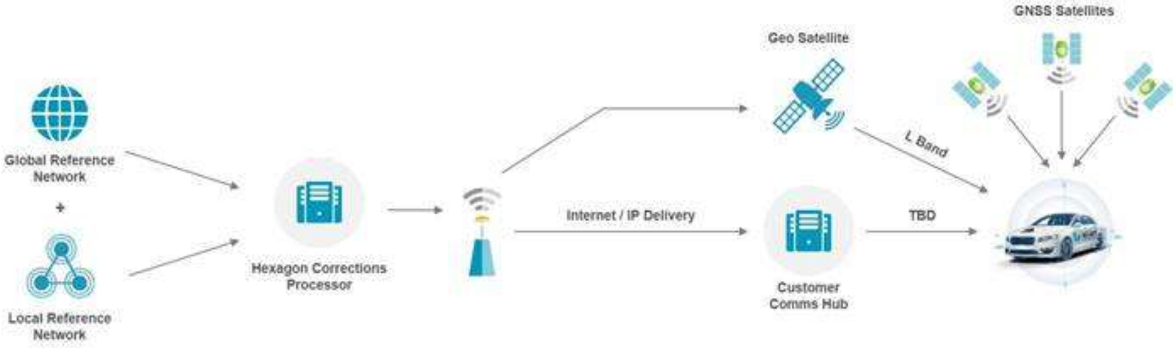
Source: https://www.geospatialworld.net/news/swift-navigation-launches-gnss-service-autonomous-vehicles/



- Single frequency GPS positioning solution does not provide sufficient accuracy
- Correction-based techniques, such as differential RTK and PPP can achieve ~10 cm accuracy in real time, but require network connection and good signal reception

Example positioning system

Hexagon PI
TerraStar X GNSS



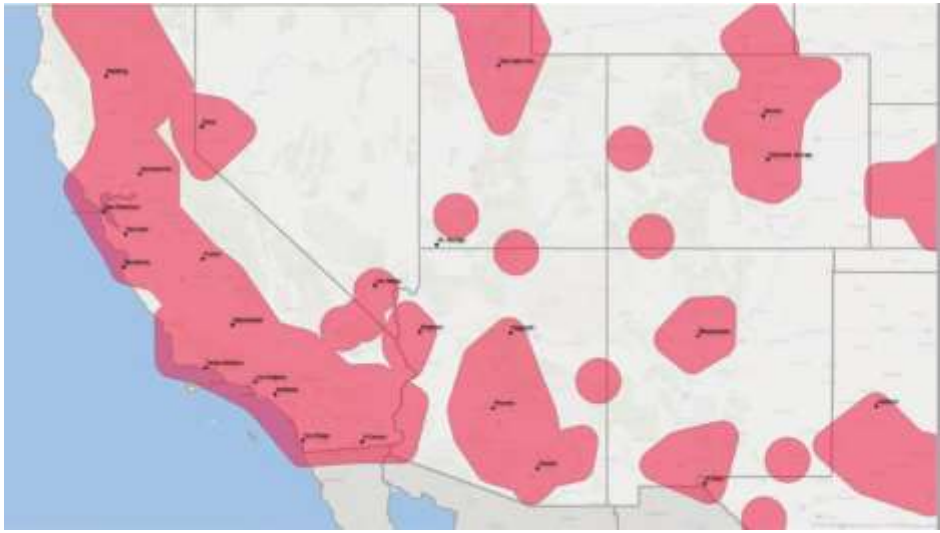
- ✓ Correction technology
- ✓ Enables lane-level vehicle positioning
- ✓ Precise Point Positioning (PPP) algorithm
- ✓ Combines existing TerraStar global clock and orbit data with regional ionospheric correction model
- ✓ Forms a foundation for correction services from Hexagon's SmartNet reference network (4500 stations) for connected and autonomous vehicles, UAVs, trains, etc.
- ✓ Correction delivery through satellite and cellular connections

Source: Precise positioning drives lane-level accuracy in the automotive industry, T. Wong Ken, S. Masterson, *GPS World*, August 2018

Example positioning system: Hexagon PI TerraStar X GNSS

- ✓ Can be integrated with various GNSS chipsets
- ✓ Processing engine is being developed to Automotive Safety Integrity Level (ASIL)-B standards and will include GNSS integrity solution
- ✓ Tested so far in Michigan and Germany: accuracy better than 1 m 95% of the data collected using GNSS/INS system
- ✓ Will be available in North America and and Europe by 2019

The HxGN SmartNet commercial GNSS network coverage in the US



Source: Precise positioning drives lane-level accuracy in the automotive industry, T. Wong Ken, S. Masterson, *GPS World*, August 2018

Example positioning and application systems

- **Swift Navigation,** a San Francisco-based tech firm building centimeter-accuracy GNSS (GPS/BeiDou, Galileo, Glonass, SBAS) technology and a Cloud-based Corrections Service, **Skylark,** to support AVs
- **Voyage** deploys self-driving taxis that use Skylark in private communities across the US
  - ✓ Mission: to provide communities with autonomous vehicles, to power everyday services designed to enhance each resident’s quality of life
  - ✓ Enables community members to summon an autonomous vehicle and move effortlessly from A to B

Source: http://gpsworld.com/swift-navigation-launches-cloud-based-gnss-service-for-autonomous-vehicles/?utm_source=gps_navigate&utm_medium=email&utm_campaign=gps_navigate_03202018&eid=377045544&bid=2040950
https://voyage.auto/about/

High definition (HD) maps

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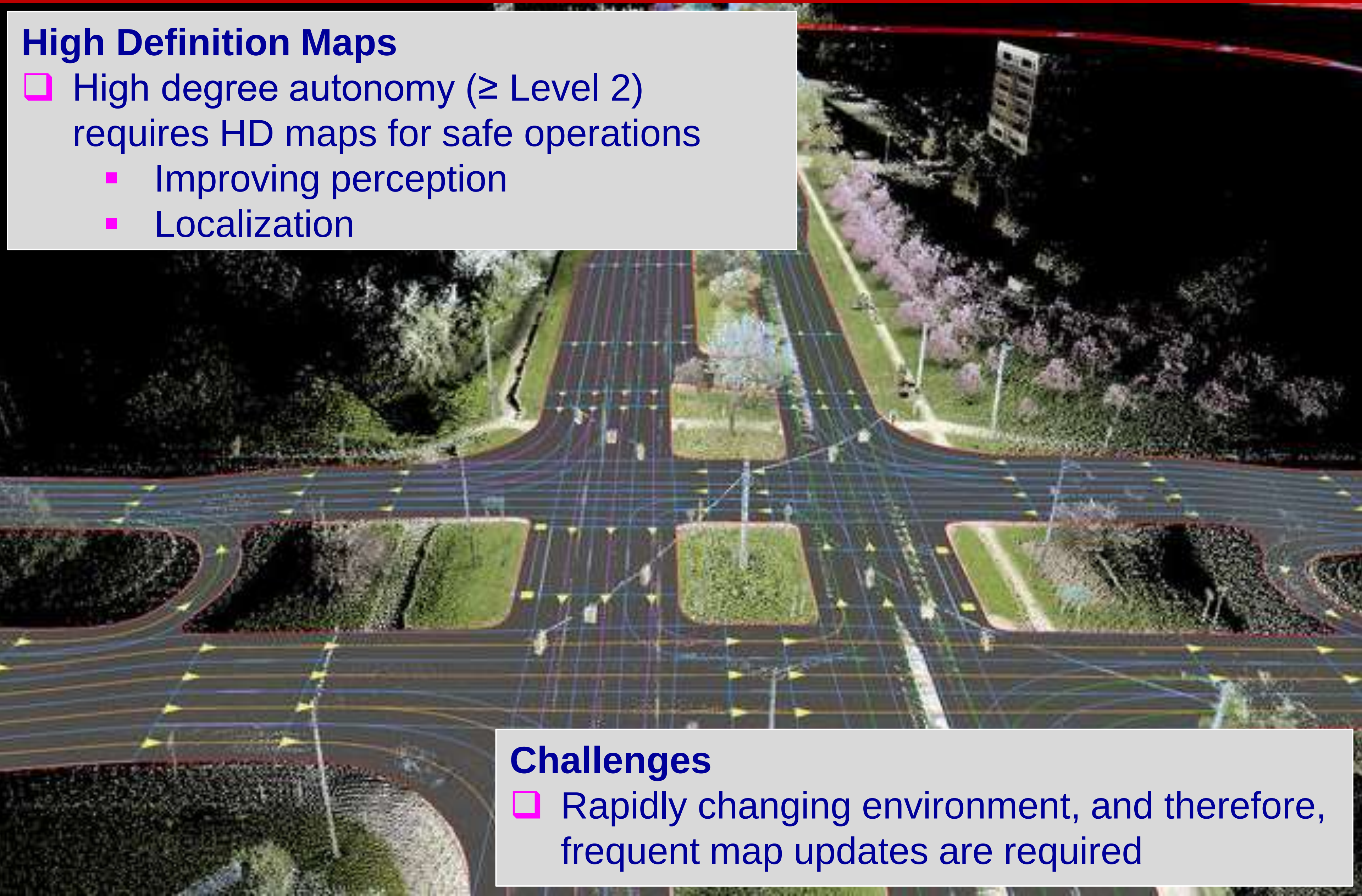
High Definition Maps

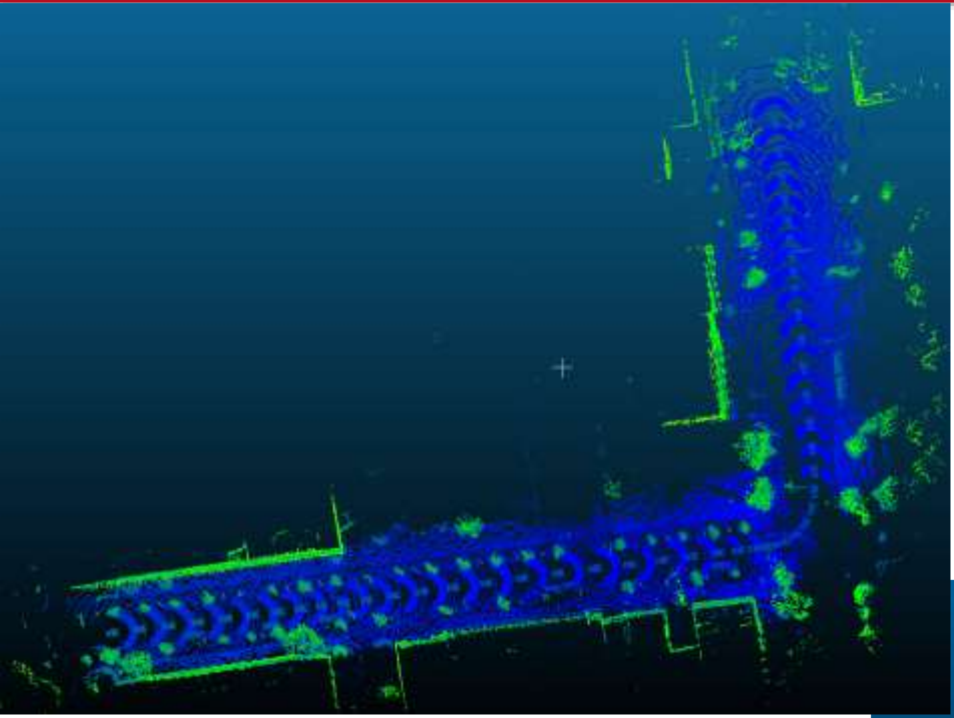
- ❑ High degree autonomy (≥ Level 2) requires HD maps for safe operations
  - Improving perception
  - Localization



Challenges

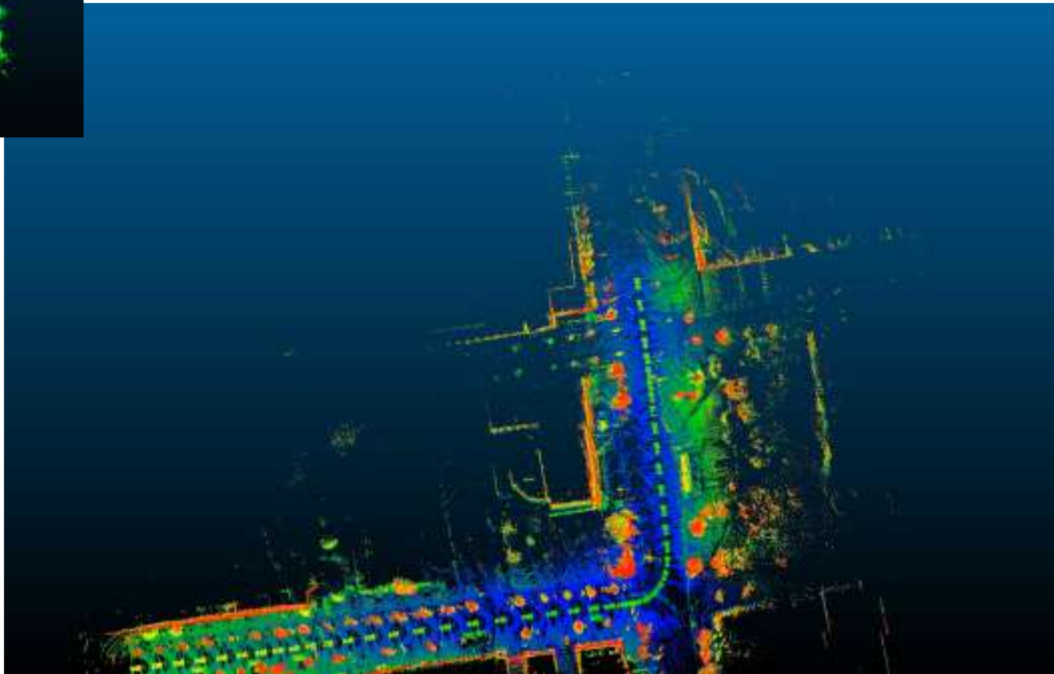
- ❑ Rapidly changing environment, and therefore, frequent map updates are required

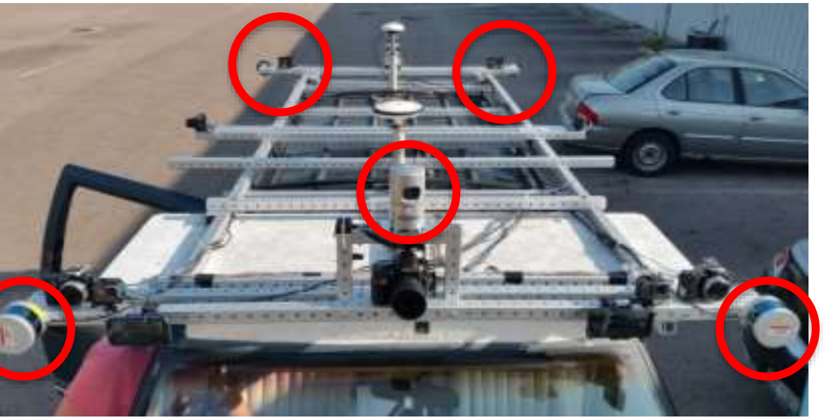
Creating high-definition maps: OSU system



Central front LiDAR sensor, Velodyne HDL-32

All LiDAR sensor data combined





Open questions

- How to map the transportation corridors by autonomous vehicles?
  - ✓ Presently, HD maps are acquired by dedicated surveys (expensive, labor intensive)
  - ✓ HD map accuracy verification: RTK, PPP or post-processed differential GNSS
  - ✓ Going forward, AV technologies will likely be the prime provider of geospatial data along transportation networks (mobile mapping platforms), and create a live transportation management and control system (smart CAD/GIS), which is continuously updated
    - crowdsourcing/crowdsensing
    - the key issue is communication!
  - ✓ Data Science (Big Data) indispensable in data processing
- What's the optimal sensor configuration that delivers the best HD maps? What HD accuracy and level of details are needed?
- Unmodeled sensor errors: unavoidable problem in positioning and sensing

Autonomous driving: requirements

- ✓ Full situational awareness of the vehicles: **sensing, navigation, communications** (V2V, V2I/V2X)
  - Requires added infrastructure, however, the autonomous system must still be able to function correctly when none of that is available
- ✓ Reliability, accuracy, coverage and security of the navigation systems
  - Standards and performance requirements of GNSS SW, HW, and differential services: meet the requirements of autonomous vehicles
  - Ability to rely on GNSS in auto-guidance applications requires incorporation of integrity functionalities into GNSS products
  - GNSS alone will not meet all of these stringent requirements due to signal attenuation, interference, spoofing

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Autonomous driving: requirements

✓ Reliability, accuracy, coverage and security of the navigation systems (*cont.*)

- IMUs, LiDARs, Radars, cameras, acoustic sensors, and ambient signals of opportunity, such as Wi-Fi, cellular and digital TV must augment GNSS
  - Cost? Complexity? Reliability?
  - Measurement errors
  - Unmodeled sensor errors and faults
- *Alternative signal*: stronger than GNSS, encrypted format, allows for authentication, e.g., STL (Iridium satellites), PRS from Galileo
- *Collaborative* real-time tracking mechanisms are required to assure reliable navigation when a component of the *self-driving network* malfunctions

Satellite Time and Location (STL)
Public Regulated Service (PRS)

SLAM and collaborative navigation

SLAM – simultaneous localization and mapping

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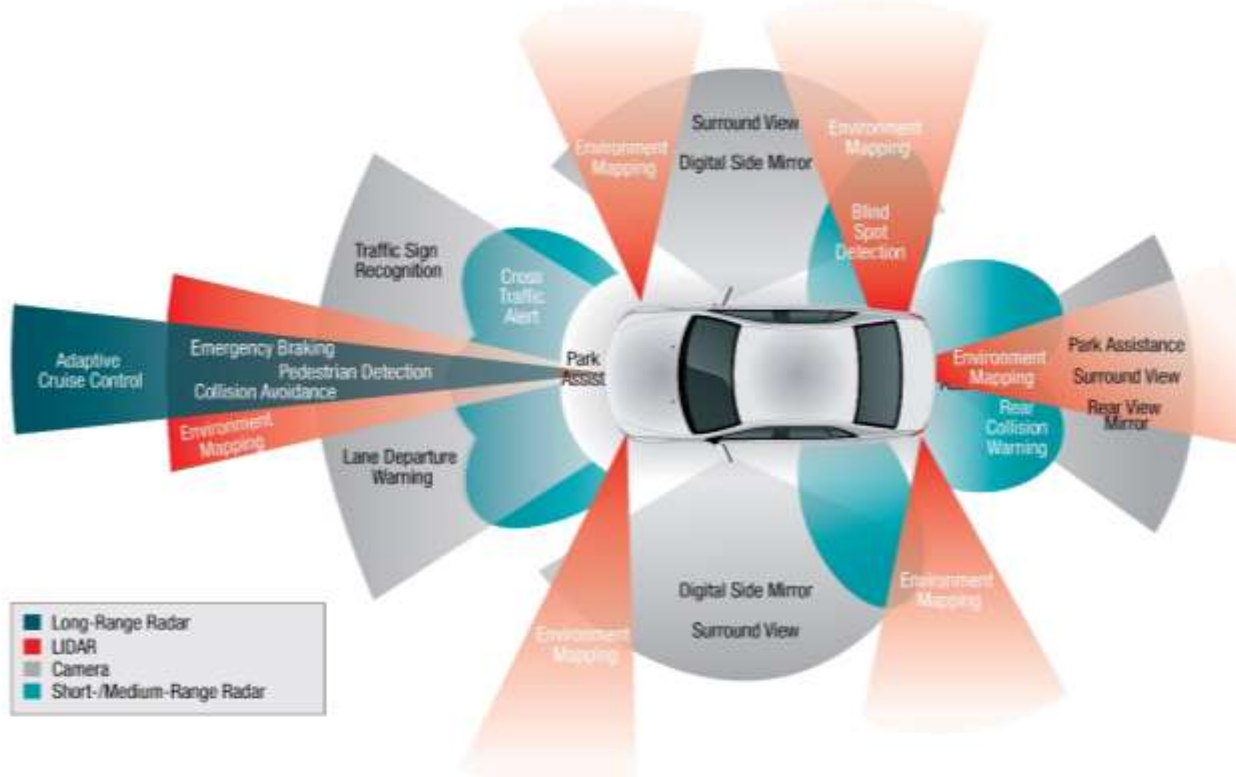
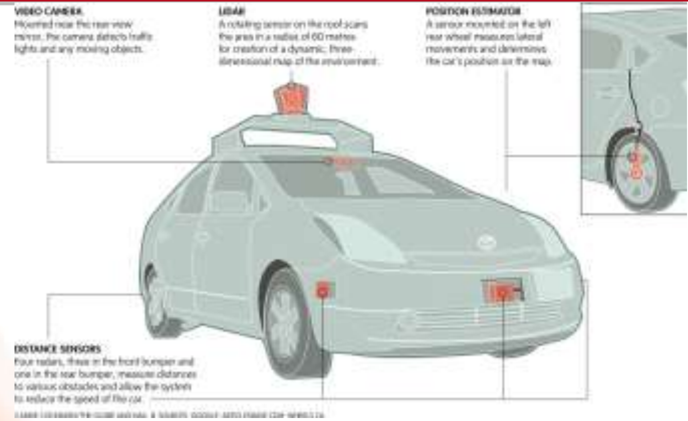
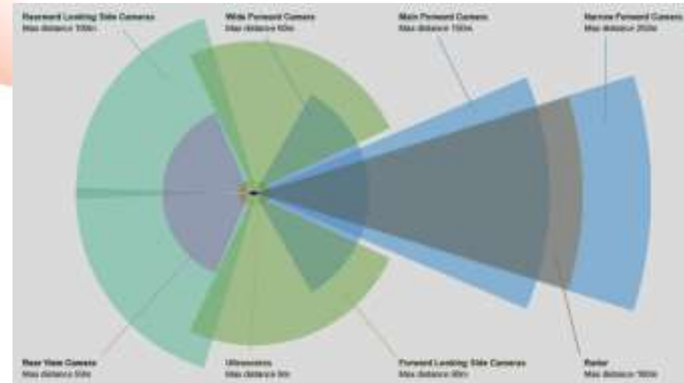
Perception/navigation sensors



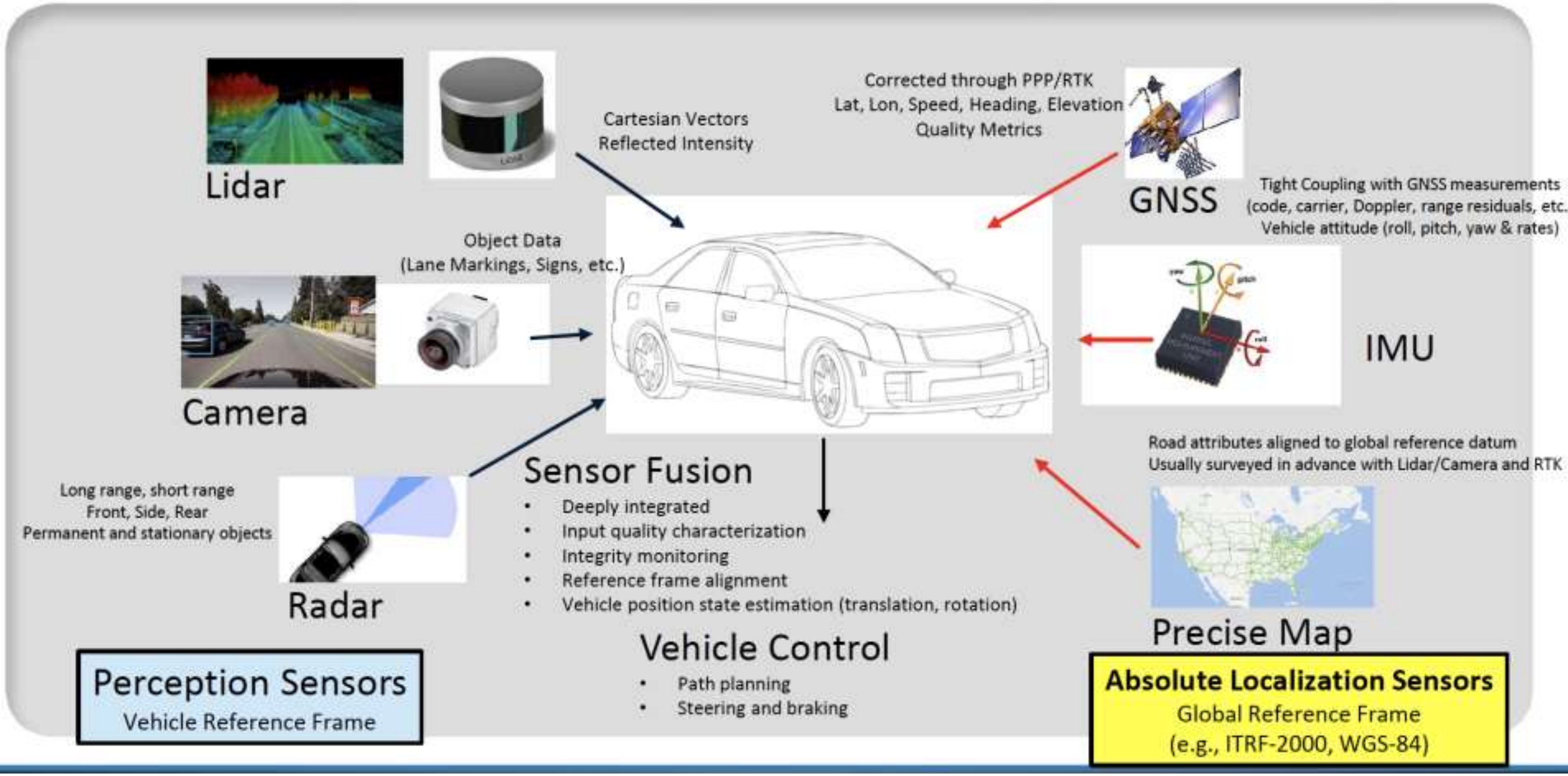




Model	Cameras	LiDAR	Other
Tesla M3	7	0	
Waymo	1	1	Route info
Cadillac ST6	8	0	HD map, RTK
Ford (res. veh.)	7	4	HD map

Sensors: various data streams

Autonomous vehicle sensor fusion



Source: Beyond GNSS: A system of systems. Testing solutions for autonomous vehicles and robotics, *Inside GNSS* webinar, 7/25/2018 (Curtis Hay, GM)

Autonomous vehicle sensor characteristics

Localization/Ref. system type		Sensors	Pros	Cons
Relative/perception	Vehicle/body reference system	Radar	Relatively low cost Good ranging accuracy	Cannot detect road markings
		LiDAR	Highly accurate ranging Dense 3D point clouds	Higher cost Less effective in featureless areas Typically requires LiDAR maps as reference
		Camera	Relatively low cost Good object representation	Less effective in featureless areas Impacted by weather and lighting conditions
Absolute localization	Global reference system (e.g., WGS84, NAD83, GTRF, etc.)	HD maps	Excellent accuracy (<10 cm 95%)	Requires continuous updates High acquisition cost
		Motion (DR) sensors: accelerometers, gyroscopes, wheel sensor data	Relatively low cost	High drift rate for MEMS sensors High cost of more stable sensors (still need real-time sensor calibration)
		GNSS (GPS, GLONASS, Galileo, BeiDou, etc.)	Relatively low cost Global availability Excellent accuracy (<10 cm with differential corrections/PPP)	Line-of-sight system Poor performance in urban canyons (multipath, signal blockage) Easy to spoof and jam

Based on: Beyond GNSS: A system of systems. Testing solutions for autonomous vehicles and robotics, *Inside GNSS* webinar, 7/25/2018 (Curtis Hay, GM)

Implementation challenges

- **High accuracy localization within predefined reference system requires:**
  - ✓ High-accuracy maps (HD maps)
    - Traditional surveying, mobile mapping
    - Crowdsourcing - opportunity?
  - ✓ High-accuracy GNSS
    - Supported by multisensor assembly in urban environments
  - ✓ Availability of low cost and high accuracy/stability IMU
- **Efficient testing methodology**
  - ✓ Simulations
    - Hardware in the loop testing; expensive but valuable for efficient testing
    - Repeatability must be assured in simulations and real world testing
  - ✓ Test track testing: e.g., TRC, VRC, M-city
  - ✓ Real-world testing; state-specific regulations for testing

Source: Beyond GNSS: A system of systems. Testing solutions for autonomous vehicles and robotics, *Inside GNSS* webinar, 7/25/2018 (Curtis Hay, GM)

Autonomous driving: safety standards

- Crucial requirement: *develop new safety standards for new motor vehicles and motor vehicle equipment*, and
  - ✓ To modify existing standards as necessary to respond to changing circumstances such as the introduction of new technologies and modes of mobility

Automotive safety standards

- **ISO 26262** *Road Vehicles—Functional Safety*: automotive industry-specific derivation of generic industrial functional safety standard IEC 61508
- ISO 26262 was released in November 2011 as the state-of-the-art international standard for E/E systems in passenger cars
  - Provides a structured and generic approach for the complete safety lifecycle of an automotive E/E system, including design, development, production, service processes and decommissioning
  - *Defines the Automotive Safety Integrity Level (ASIL) as a risk classification parameter for the safety-critical hazardous situation of an item*
  - ASIL can be seen as a parameter that indicates a reduction of risk requirement in order to achieve a tolerable risk level
  - ISO 26262 standard provides guidance by introducing requirements and recommendations to reduce the risk of systematic development failures and to handle the complexity of E/E systems

https://link.springer.com/chapter/10.1007/978-3-319-31895-0_16

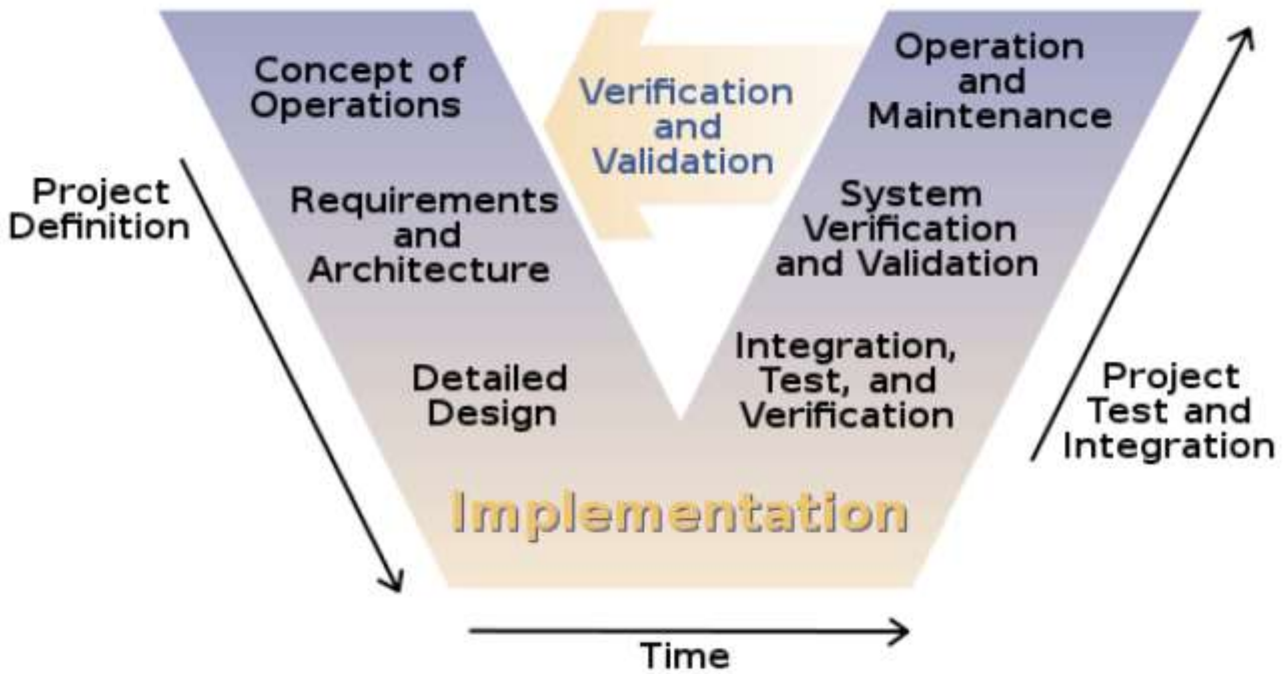
Automotive safety standards

- ✓ Well-established safety principle: *computer-based systems should be considered unsafe unless convincingly proven otherwise*
  - safety must be demonstrated, not assumed
  - therefore, autonomous vehicles cannot be considered safe unless and until they are shown to conform to ISO 26262
- ✓ ISO 26262 Part II of the standard to be released in 2018
- ✓ Updated standard does not address the issue of autonomous driving per se, leaving industry insiders wondering: *What challenges does autonomous driving pose to the revised ISO 26262 functional safety standard?*
- ✓ The ISO 26262 development **V process** is a good foundation from which to work
  - however, adapting the process to deal with the types of novel testing problems that autonomous vehicles bring, also introduces several new challenges

Based on: Safety testing in indoor and challenged environments, D. Aylord et a.,,, *GPS World*, August 2018.

The V model of the system engineering process

Image credit: Deploying function safety all the way to autonomous driving system, O. Shen, ARM Tech Forum, Taipei, 2017



✓ **V model of development**: the right side of the V provides a traceable means of checking the result of the left side (verification and validation)

- Scrutiny is based on an *assumption that the requirements are actually known, are correct, complete, and unambiguously specified*
- In the world of the autonomous vehicle *this assumption can be challenging*

Vehicle safety testing

- **Consumer information organization, such as Insurance Institute for highway Safety (IIHS) design test procedures to compare different auto manufacturers' safety systems**
  - IIHS Vehicle Research Center (VRC): Tests Forward Collison Warning (FCW) and Automatic Emergency Breaking (AEB)
  - To simulate potential crashes for safe, repeatable and accurate testing, driving robots with steering and pedal actuators are used
    - Control the vehicle steering wheel, break and throttle pedal with high level of accuracy and repeatability
    - When coupled with accurate positioning, cm-level path following is possible
  - High-accuracy positioning solution is provided by either Locata/INS or GNSS/INS high accuracy integrated systems: essential for testing and robot operations

Based on: Safety testing in indoor and challenged environments, D. Aylord et a.,,, *GPS World*, August 2018.

Vehicle safety testing

- Various driving scenarios and speeds
- Data analysis focuses on **accuracy** and **repeatability** of the automated test set up: each repetition is extracted from the robot system software and coupled with the positioning solution
- Positioning system accuracy must be high, at cm-level (allowed up to 10 cm 95% by IIHS) and test repeatability is expected at a few-cm level 95%

FIGURE 2 Driving robot.

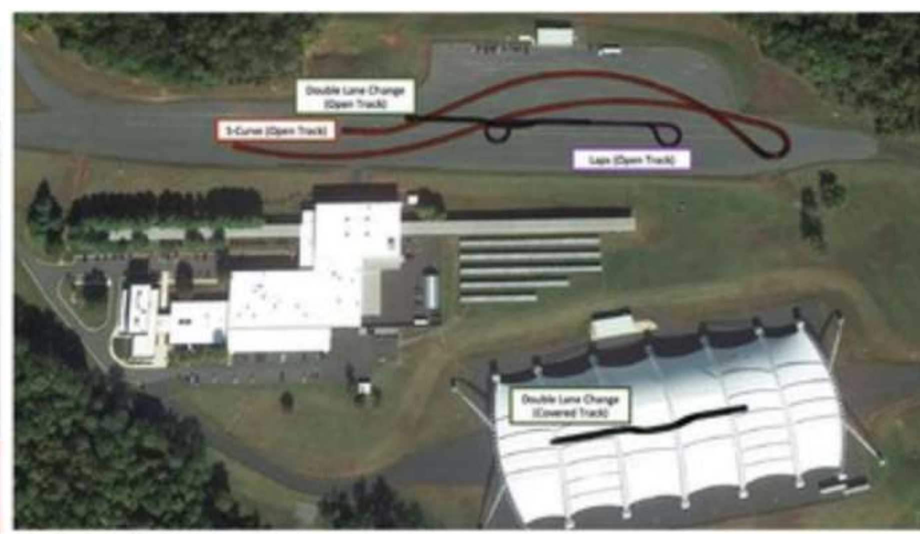
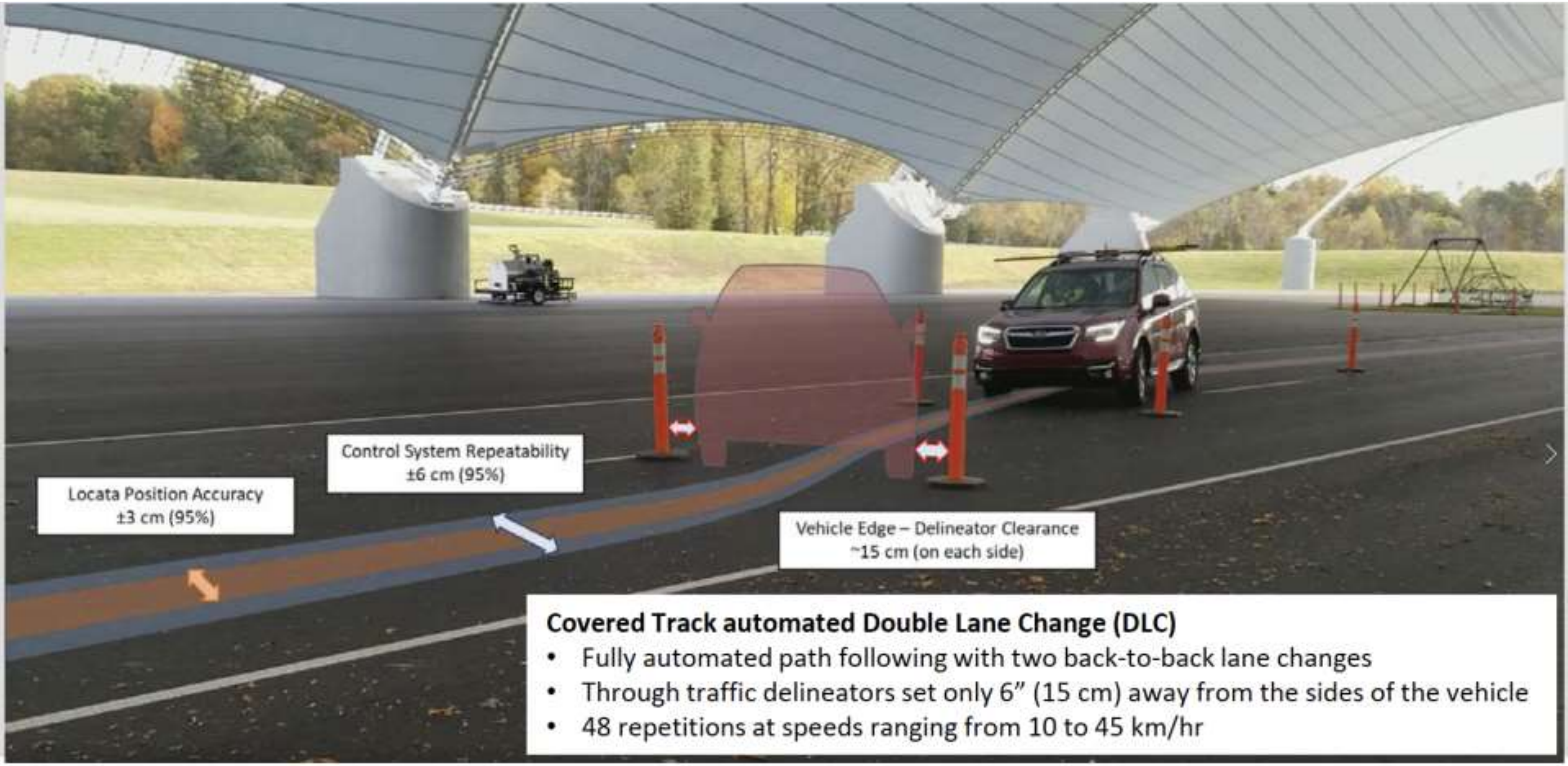


FIGURE 3 Test Scenarios.

Based on: Safety testing in indoor and challenged environments, D. Aylord et al., *GPS World*, August 2018.

Vehicle safety testing



Source: Beyond GNSS: A system of systems. Testing solutions for autonomous vehicles and robotics, *Inside GNSS* webinar, 7/25/2018 (Dr. Chaminda Basdnayake, Locata Corp)

Challenges in autonomous vehicle testing and validation

- ✓ *Vehicle level testing is insufficient to ensure safety*
- ✓ Safety requirements are inevitably intertwined with functional performance
- ✓ Artificial intelligence, heavily used in self-driving cars, learns based on training data and it *may not be possible to separate safety-critical from operational aspects or replicates the training scenarios*
- ✓ Challenges of stochastic systems: non-deterministic algorithms (e.g., route planning, perception systems) are based on random generation of candidates and are virtually impossible to reproduce
  - Sensor models are based on physics of sensors but their error models include stochastic part
  - There is effectively no unique correct behavior for a given test case

https://link.springer.com/chapter/10.1007/978-3-319-31895-0_16, Challenges in autonomous vehicle testing and validation, P. Koopman, M. Wagner, 2016-01-0128/16AE-0265
http://www.techdesignforums.com/practice/technique/iso-26262-the-second-edition-whats-in-it-and-what-isnt/

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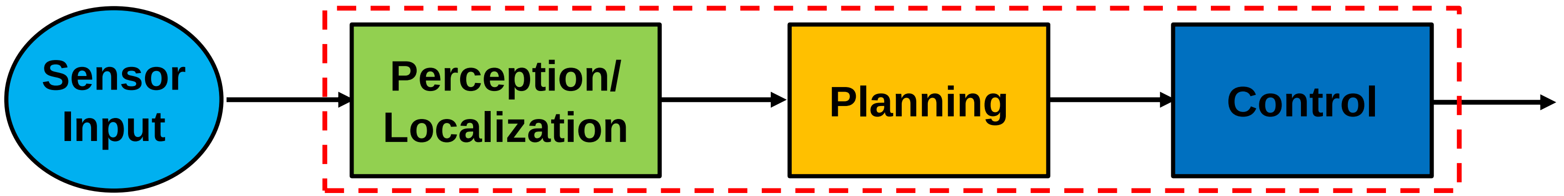
OSU's autonomous navigation system based on deep learning



Challenges in autonomous vehicle testing and validation

- *Alternative methods of validation are required*:
  - ✓ simulations
  - ✓ formal proofs
  - ✓ fault injection
  - ✓ bootstrapping based on steadily increasing fleet size
  - ✓ gaining field experience with component technology in non-critical role
  - ✓ public reviews/input

https://link.springer.com/chapter/10.1007/978-3-319-31895-0_16, Challenges in autonomous vehicle testing and validation, P. Koopman, M. Wagner, 2016-01-0128/16AE-0265
http://www.techdesignforums.com/practice/technique/iso-26262-the-second-edition-whats-in-it-and-what-isnt/

Challenges in autonomous vehicle testing and validation

ASIL = automotive safety integrity level

- ✓ It may be practical to *separate a set of requirements allocated strictly to safety and another one to operational/functional requirements*
  - E.g., “what is the speed for optimal fuel consumption?” or “what is the optimal path?” vs. “are we going to hit anything?”
  - Using this approach calls for dividing the set of requirements into two parts of the V model
- ✓ Non-technical challenge: e.g., liability problem
  - Likely to have impact on technical solutions
- ✓ **Most promising general approaches to testing autonomy**:
  - *Phased deployment*
  - *Monitor/actuator architecture*: can help mitigate many challenges of autonomous vehicle safety and complexity of the system, that is primary functions are performed by one module (actuator) and a paired module (the monitor) performs the acceptance test
    - If properly designed, actuator can be low ASIL and monitor high ASIL
  - *Fault injection*: applies to traditional testing and non-test-based validation

https://link.springer.com/chapter/10.1007/978-3-319-31895-0_16, Challenges in autonomous vehicle testing and validation, P. Koopman, M. Wagner, 2016-01-0128/16AE-0265
http://www.techdesignforums.com/practice/technique/iso-26262-the-second-edition-whats-in-it-and-what-isnt/

Methods of autonomous vehicle testing

- A complete profile for autonomous vehicle testing methodologies covers functional development and testing, system integration and verification, test drive and validation
- ✓ *Autonomous driving testing*: software testing, X-in-the-loop simulation testing
- ✓ *Autonomous vehicle functional testing*
  - System architecture
  - Functional testing
    - perception layer function testing
    - decision layer function testing
    - navigation layer function testing
    - action layer function testing
  - Autonomous vehicle system validation: modeled in functional levels
- ✓ *Autonomous vehicle evolutionary testing*: test drive and vehicle simulation with feedback between development and testing. Includes top level design and integration, module verification
- ✓ *Test range testing* (M-City, UM, TRC – under development at OSU
- ✓ *Real driving testing* (billions of hours of driving required)

Source: Autonomous vehicles testing methods review, W. Huang et al., IEEE 19TH International Conference on ITS, Rio De Janeiro, Brazil, Nov. 1-4, 2016.

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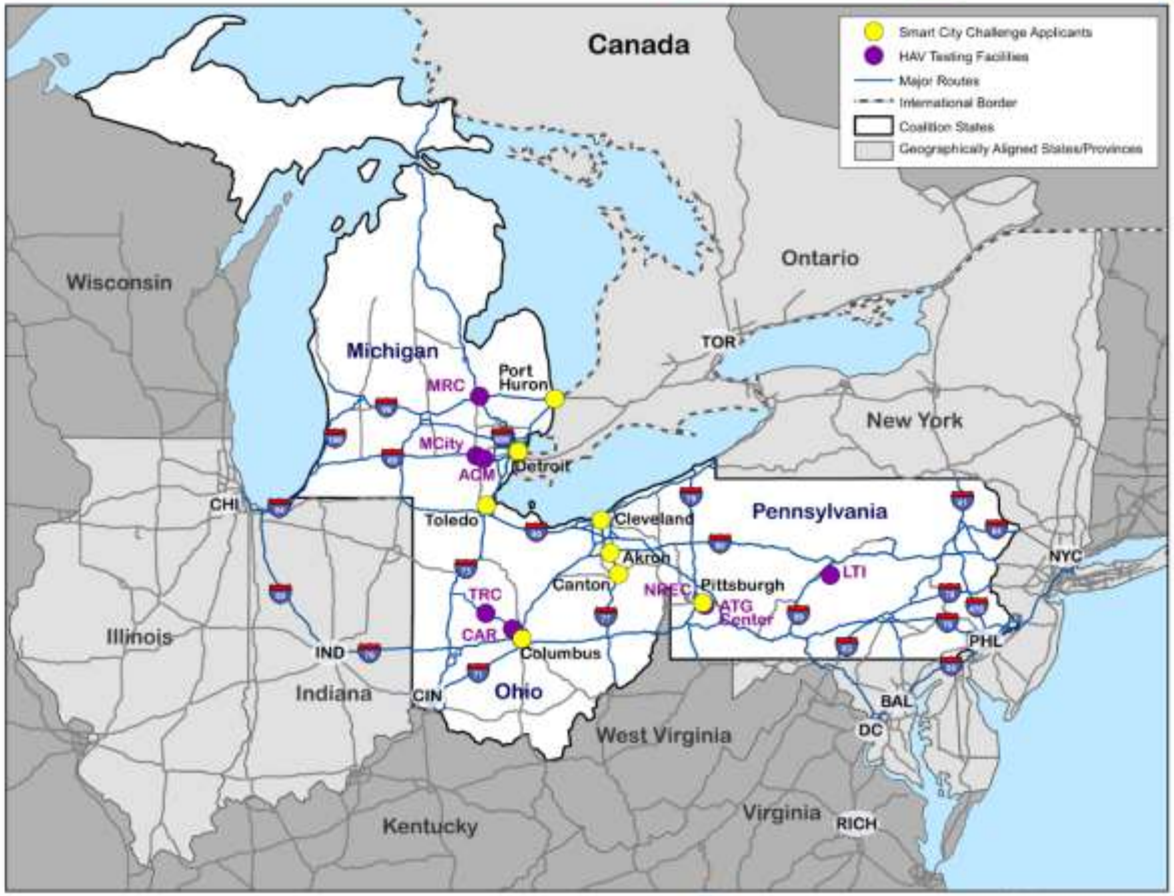
http://www.trcpg.com/about-us/

OSU Transportation Research Center (TRC)

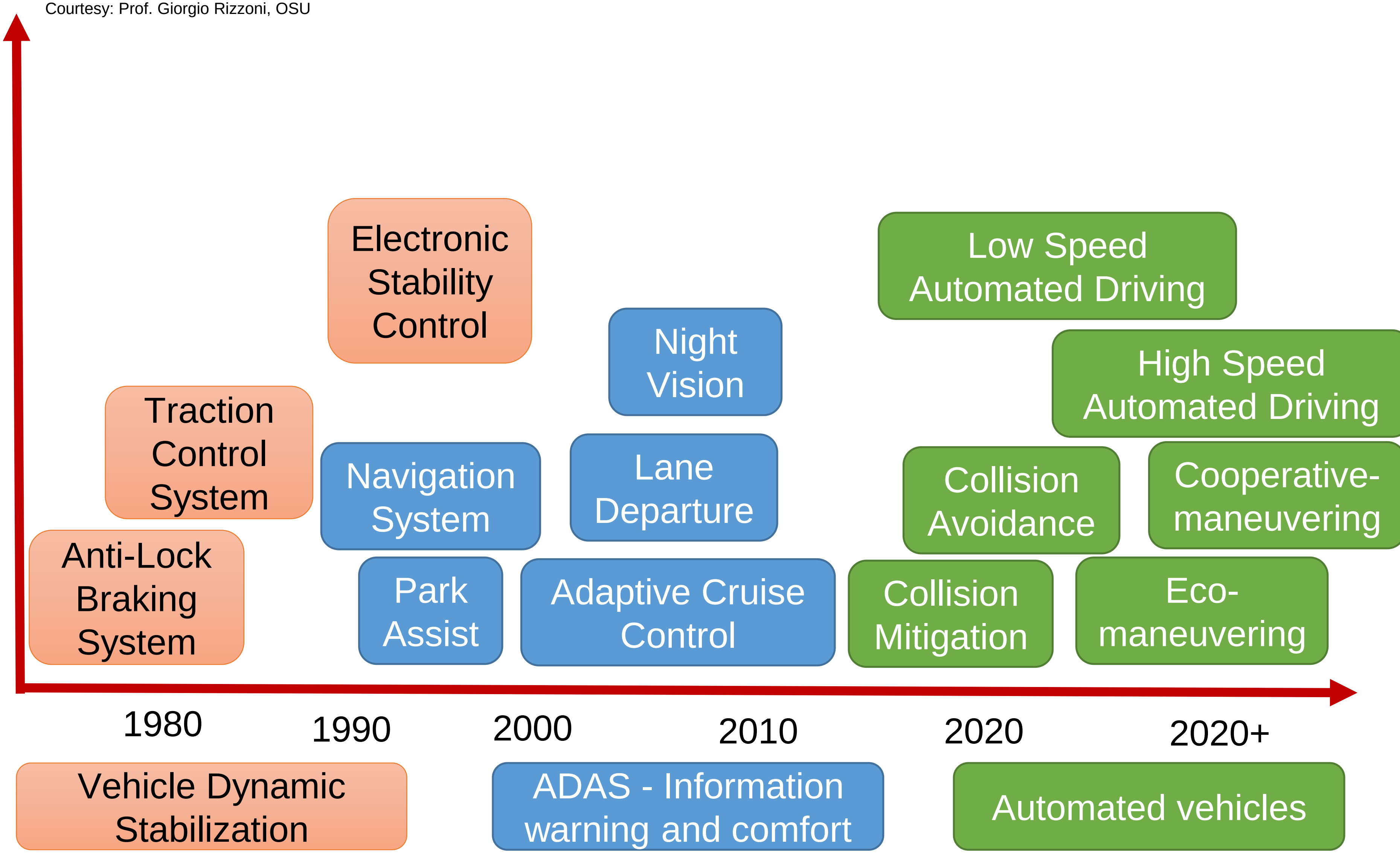
- TRC: largest independent vehicle testing facility and proving grounds in the U.S.
  - ✓ Operates 24/7 – with approximately 4,500 acres of road courses, wooded trails, 7.5-mile High-speed Oval Test Track, 50-acre Vehicle Dynamics Area
  - ✓ Provides comprehensive Vehicle Testing, Crash Testing, Emissions Testing, Durability Testing, development services, and facilities to manufacturers, industry organizations and government agencies worldwide
  - ✓ $45M 540-acre **SMART Center** under development: 10 football fields long and 50 highway lanes wide
    - ✓ **Largest autonomous vehicle testing center in North America**
- The **nation's first intelligent corridor** runs from East Liberty, Ohio (home of TRC) to Columbus, along Route 33
- Honda is building advanced wind tunnel at Ohio State-affiliated TRC

Smart belt coalition



Automation in vehicles

Courtesy: Prof. Giorgio Rizzoni, OSU



ADAS = advanced driver assistance systems

What will a driverless future look like?

- **The end of private car ownership?**
  - ✓ "Mobility as a service"
- **AVs' impact on the way we live will be transformative**
- **AVs should be thought of not as a single new product but rather as an entirely new ecosystem in the economy**
  - ✓ Sensors and other physical components for the vehicles
  - ✓ Cybersecurity
  - ✓ High-performance computing chips to power the cars' decision-making processes
  - ✓ Consumer electronics for the cars' interiors
  - ✓ Mapping and geolocation software to enable the car to navigate

https://techcrunch.com/2016/03/19/what-will-a-driverless-future-actually-look-like/

https://www.google.com/search?biw=1264&bih=785&tbm=isch&sa=1&ei=WwZlWpWMNeKHggetnYqQBg&q=car+of+the+future&oq=car+of+the+future&gs_l=psy-ab.3..0l4j0i30k1l3j0i5i30k1l3.14520.17504.0.17697.17.16.0.1.1.0.196.1686.11j5.16.0....0...1c.1.64.psy-ab..1.16.1582...0i67k1j0i24k1.0.VWzJnEUix6Q#imgdii=JE5SeVw8qY2ChM:&imgrc=qb9KmbO0bJM9AM:

Thank you!

Backup slides

PNT in smart cities supports many emerging applications

- **GNSS/PNT** is an essential element of major contemporary technology developments notably including the ***IoT, Big Data, Augmented/Virtual Reality, Smart Cities/Mobility and Multimodal Logistics***
- In turn, the advent of ***5G, Automated Driving, Smart Cities and the IoT*** will accelerate further proliferation and diversification of GNSS-enabled added-value services
  - ✓ Their annual revenues will hit $225 bln in 2025, more than 2.5 times higher than the expected GNSS device and service revenues, ***mostly within, across and beyond conventional GNSS market segments***

GNSS = Global Navigation Satellite Systems
PNT = Positioning, Navigation and Timing
IoT = Internet of Things




Automotive safety standards

- ✓ Using the V model as the basis for autonomous vehicle validation: five key challenge areas:
  - Driver out of the loop
  - Complex requirements
  - Non-deterministic algorithms
  - Inductive learning algorithms
  - Fail-operational systems
- ✓ ISO 26262 2018 delivers a minimum set of requirements to fulfill functional safety aspects, but it does not – and cannot – cover all safety aspects of a product.
- ✓ Open question: how driverless vehicles (level 4 and up) should be designed and validated within ISO 26262 V framework?

https://link.springer.com/chapter/10.1007/978-3-319-31895-0_16
http://www.techdesignforums.com/practice/technique/iso-26262-the-second-edition-whats-in-it-and-what-isnt/

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Automated Vehicle Policy

- ✓ In September 2016, NHTSA and the U.S. Department of Transportation issued a Federal Automated Vehicle Policy that set a proactive approach to providing safety assurance and facilitating innovation.
- ✓ Paves the way for the safe deployment of advanced driver assistance technologies by providing voluntary guidance that encourages best practices and prioritizes safety.
- ✓ The document also provides technical assistance to States and best practices for policymakers.
- ✓ As automated technologies continue to advance, DOT and NHTSA are already planning for version 3.0 in 2018.

https://www.google.com/search?q=images+of+self+driving+cars&tbm=isch&tbo=u&source=univ&sa=X&ved=0ahUKEwjDg5i08-nYAhUR71MKHWNNDz4QsAQIKg&biw=1264&bih=785



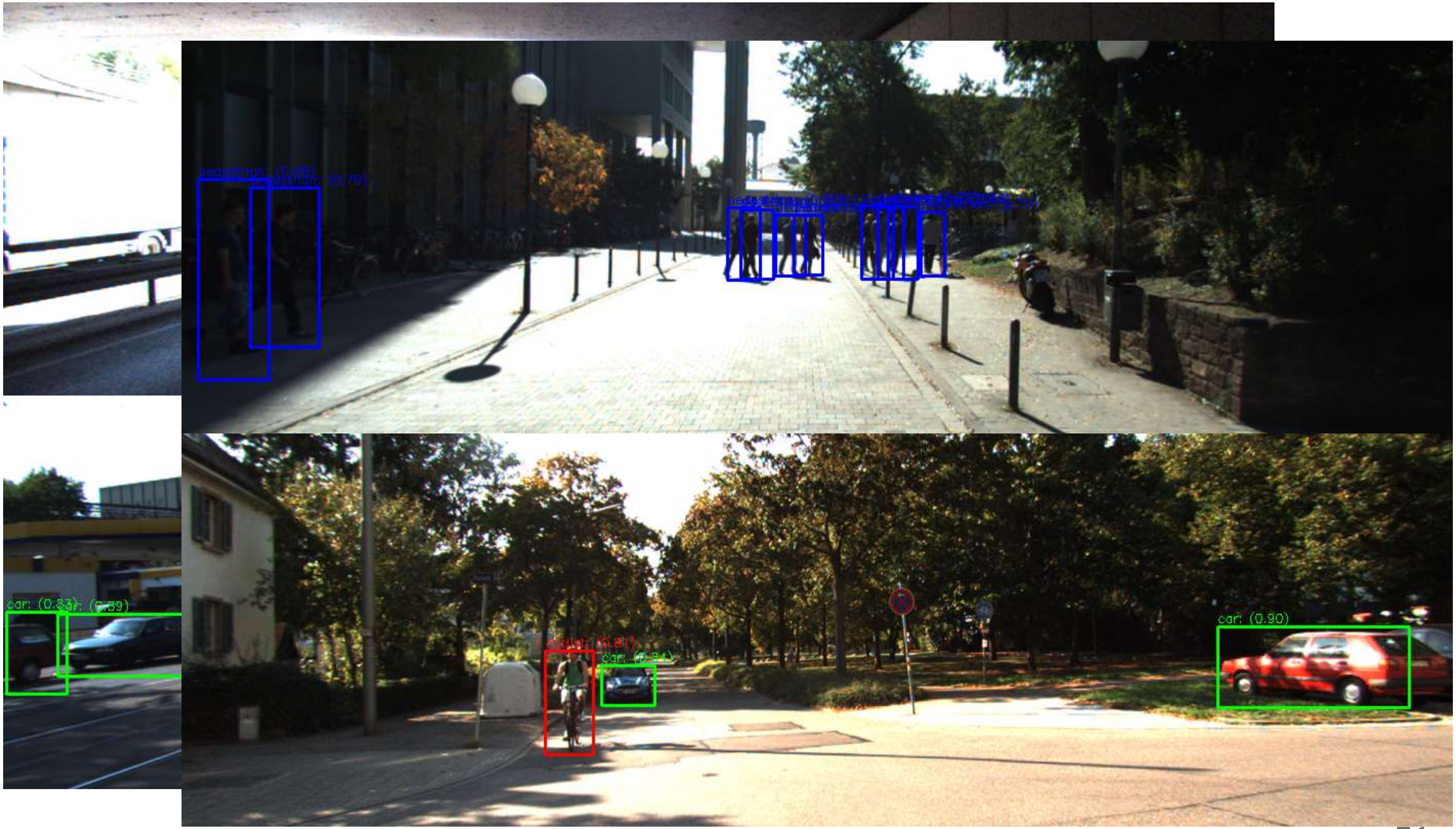

Vehicle safety testing

- **Consumer information organization, such as Insurance Institute for highway Safety (IIHS) design test procedures to compare different auto manufacturers' safety systems**
  - IIHS Vehicle Research Center (VRC): 5-acre fabric-covered and 15-acre outdoor test track
    - Tests Forward Collison Warning (FCW) and Automatic Emergency Breaking (AEB)
  - To simulate potential crashes for safe, repeatable and accurate testing, driving robots with steering and pedal actuators are used
    - Control the vehicle steering wheel, break and throttle pedal with high level of accuracy and repeatability
    - When coupled with accurate positioning, cm-level path following is possible
  - High-accuracy positioning solution is provided by either Locata/INS or GNSS/INS high accuracy integrated systems: essential for testing and robot operations

Based on: Safety testing in indoor and challenged environments, D. Aylord et a.,,, *GPS World*, August 2018.

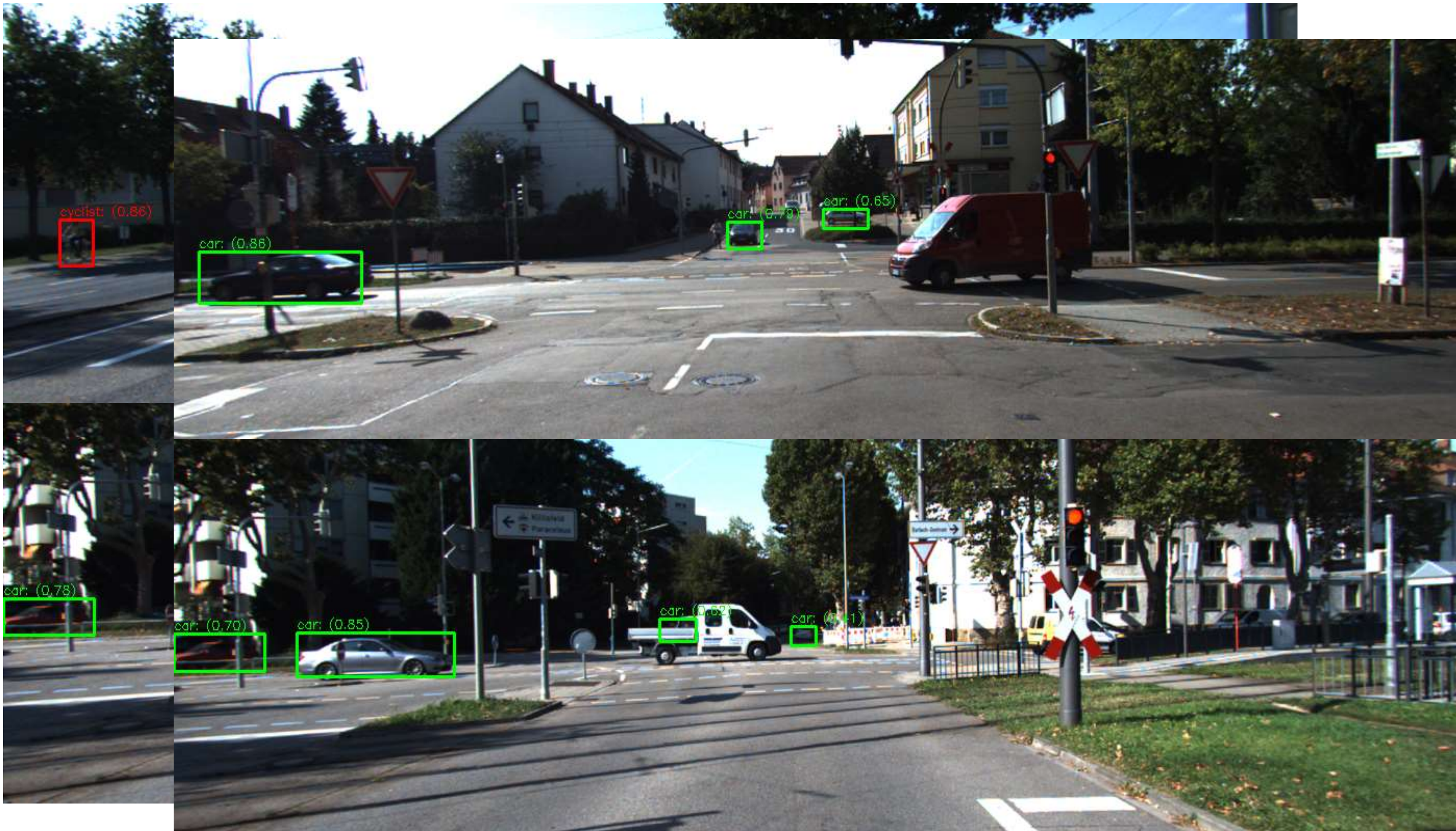
Detection results

Extractor: SqueezeNet V2 with three feature maps



Detection results

Extractor: SqueezeNet V2 with three feature maps

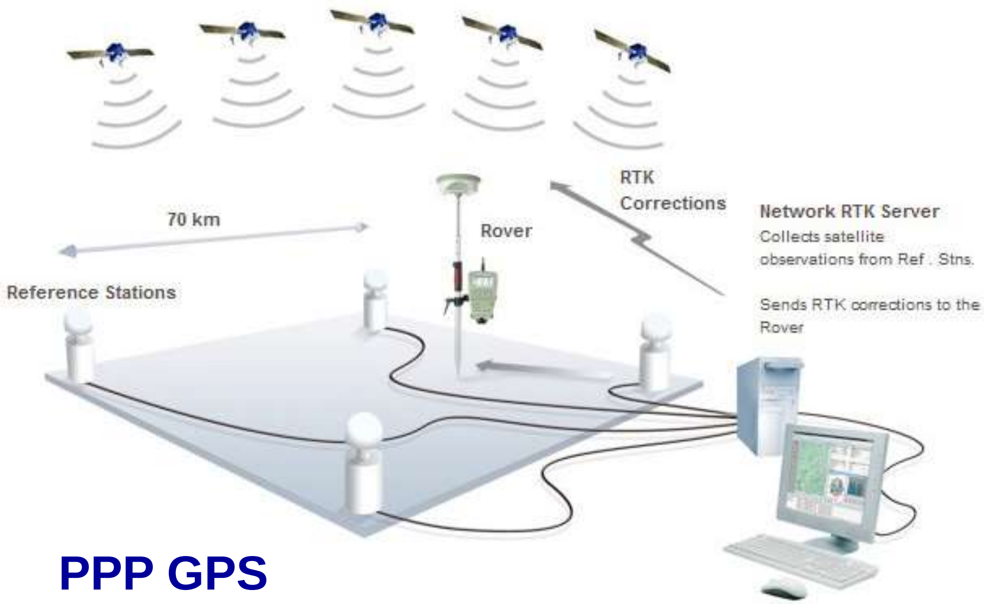


Challenges in autonomous vehicle testing and validation

- ✓ To assure high-level and dependable performance, redundant and complementary sensors must form a system, where each component has different rate of failures caused by different circumstances (e.g., integrating GNSS with INS, Radar with LiDAR and camera, etc.)
- ✓ Driver out of the loop: controllability challenges, driver cannot take corrective actions
- ✓ Difficult to detect when autonomy functions are not working properly, e.g., HW faults, SF faults, or deficient requirements…
- ✓ Very significant fleet of vehicles tested together over billions of hours in representative environments without endangering the public is impractical
- ✓ *Alternative methods of validation are required*: simulations, formal proofs, fault injection, bootstrapping based on steadily increasing fleet size, gaining field experience with component technology in non-critical role, public reviews/input.

https://link.springer.com/chapter/10.1007/978-3-319-31895-0_16, Challenges in autonomous vehicle testing and validation, P. Koopman, M. Wagner, 2016-01-0128/16AE-0265
http://www.techdesignforums.com/practice/technique/iso-26262-the-second-edition-whats-in-it-and-what-isnt/

Relevant GPS/GN SS positioning techniques



RTK GPS

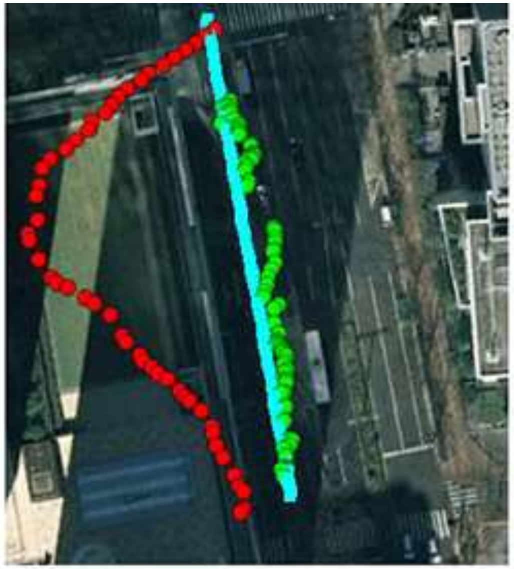
- Relative GPS positioning techniques required to achieve the desired <10 cm accuracy. RTK uses a network of reference GPS receivers along with computing centers to provide error corrections to achieve this accuracy.

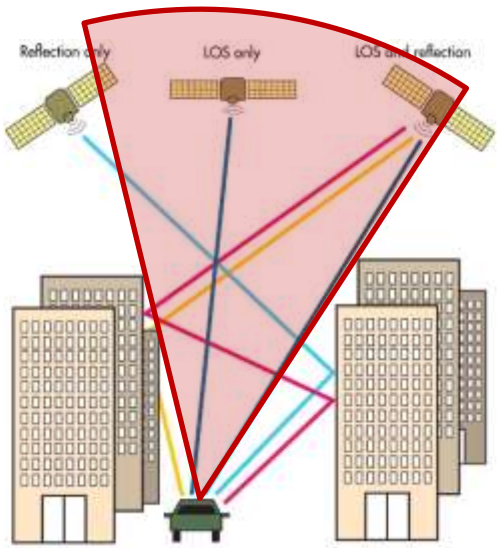
PPP GPS

- Alternative techniques, such as PPP, offer similar or slightly lower accuracy; based also on error corrections, but do not require baseline formation

Limitations: Urban Canyon

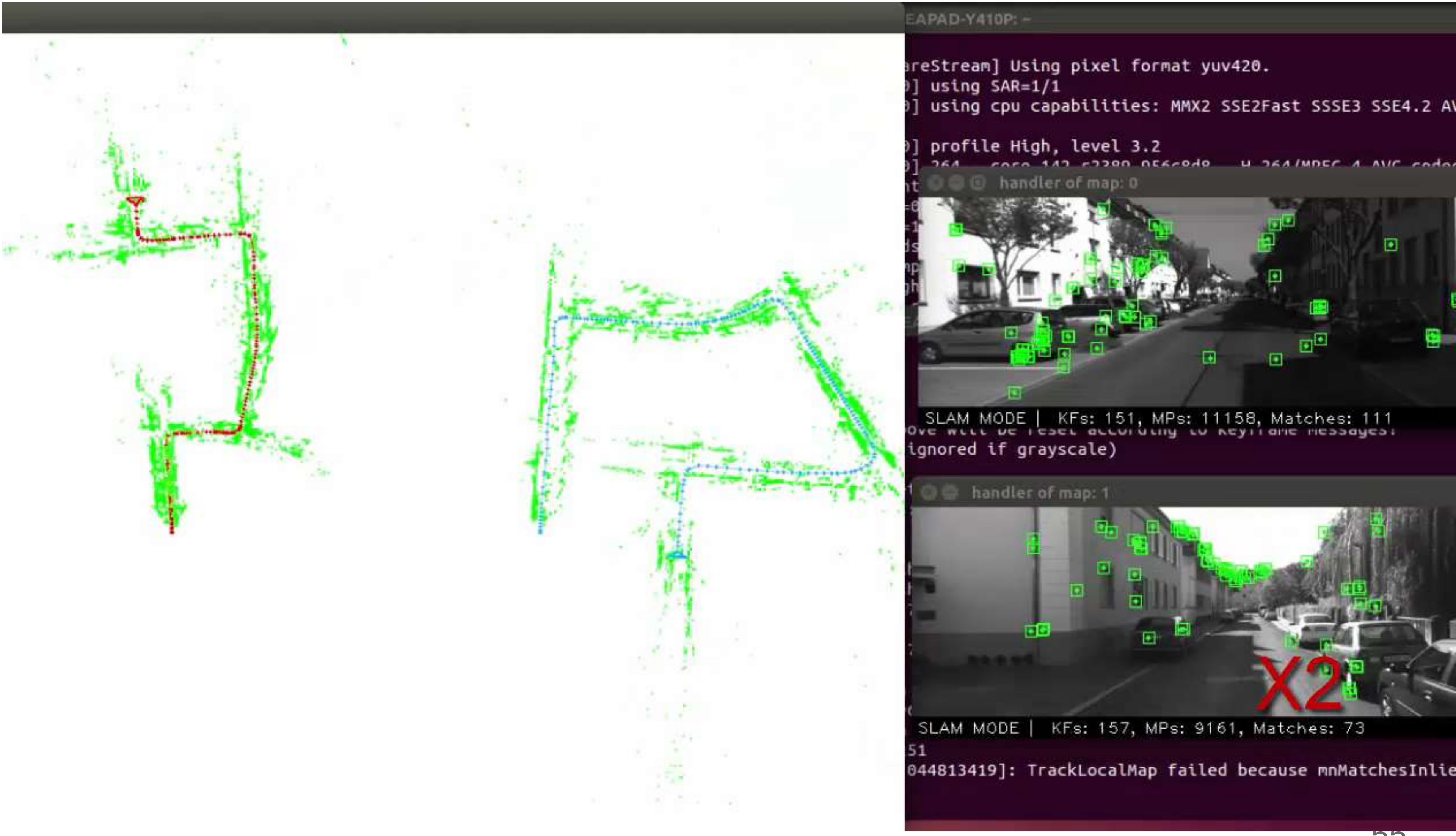
- Precise positioning in urban environment is challenging due to the “urban canyon” effect (multipath and map-matching)





Creating maps: SLAM

KITTI data, widely used benchmark, SPIN Lab CDD/IMU/SLAM solution



SLAM and collaborative navigation

KITTI data, widely used benchmark, SPIN Lab CDD/IMU/SLAM solution

Video object detection architecture: OSU solution

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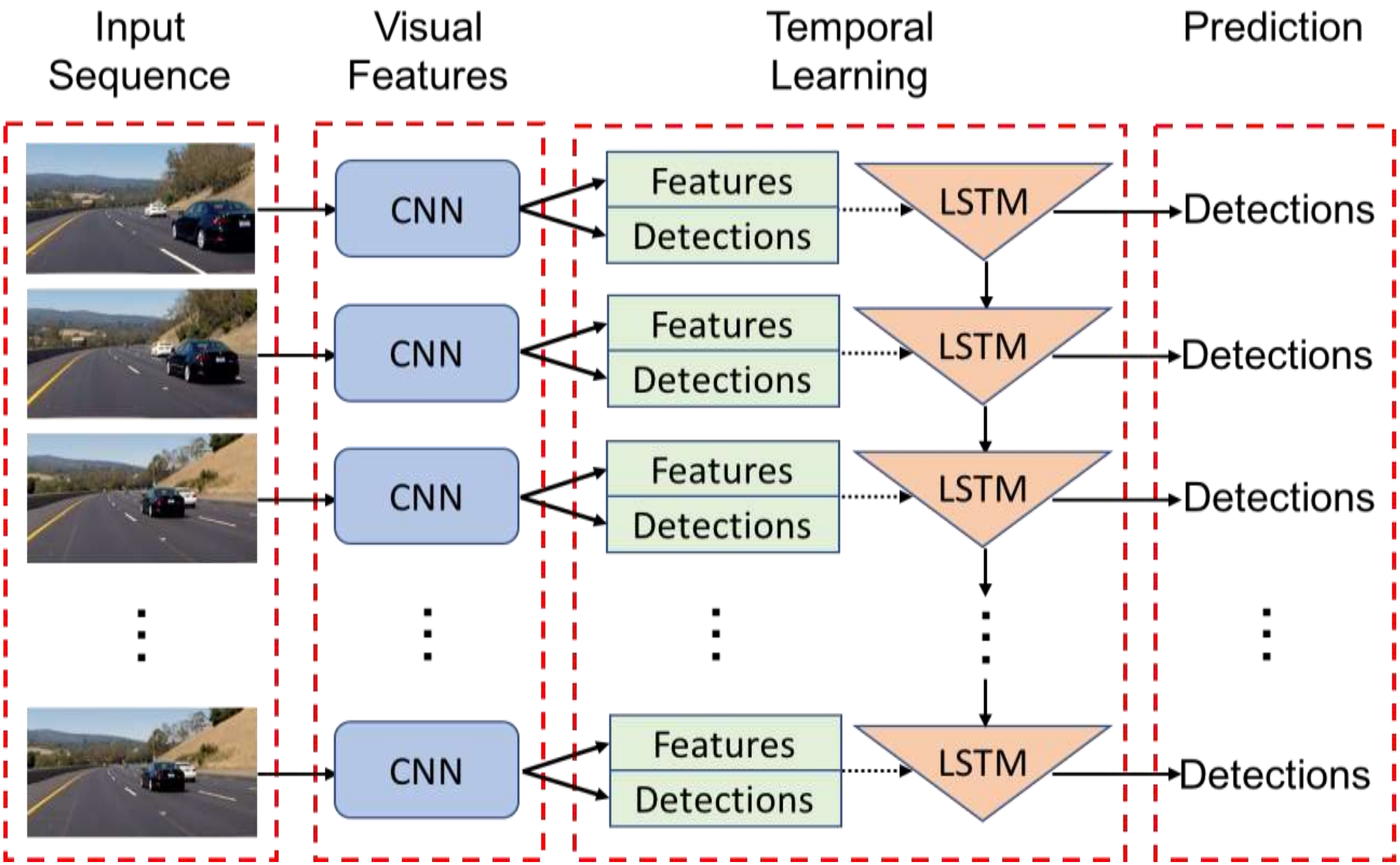
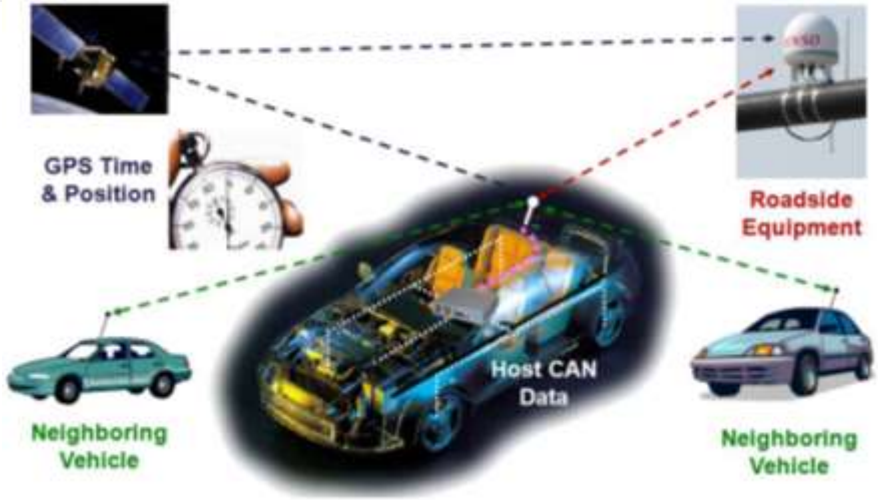
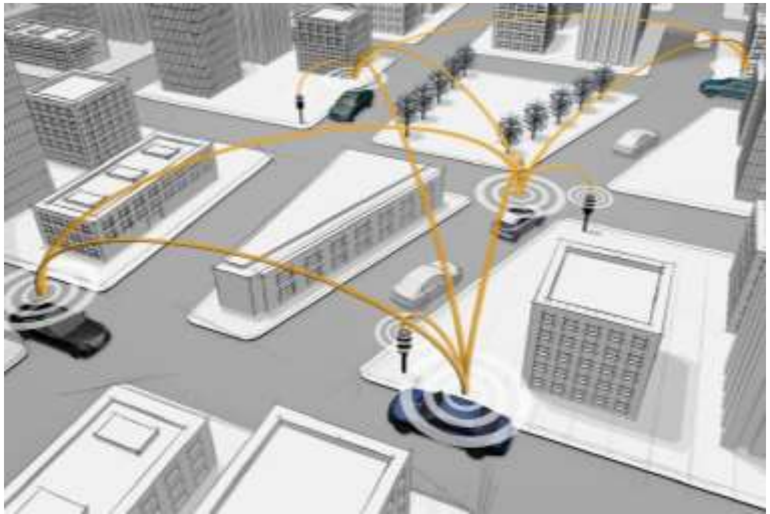


CNN - Convolutional Neural Network
LSTM Networks - Long Short Term Memory networks, a special kind of Recurrent Neural Network (RNN)

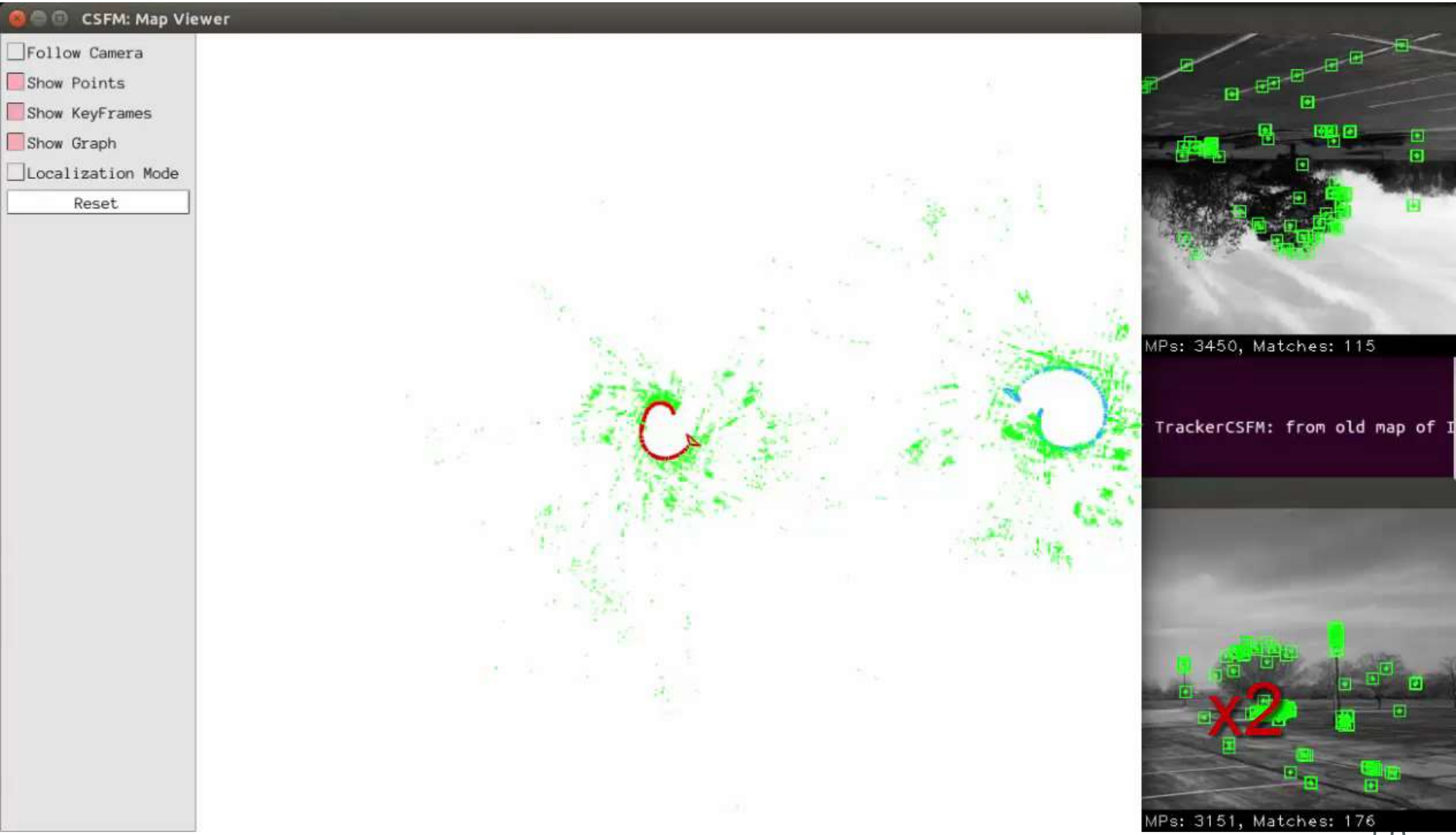
Connected vehicles



- Autonomous navigation and collision avoidance
- Connected vehicles → cooperative mobility; V2V, V2I, and V2X
- Geodetic infrastructure needed (e.g., CORS, WAAS)



Two vehicles with one camera each, SPIN Lab CDD/IMU/SLAM solution



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What’s buzzing?

❑ The biggest threat facing connected autonomous vehicles is cybersecurity

- ✓ Primary challenge in vehicle cybersecurity: various electrical components in a car, known as electronic control units (ECUs), are connected via an internal network
- ✓ Hackers gain access to peripheral ECU — for instance, a car’s Bluetooth or infotainment system — from there they may be able to take control of safety critical ECUs like its brakes or engine
- ✓ Cars today have up to 100 ECUs and more than 100 million lines of code — a massive attack surface

Image credit: https://www.google.com/search?q=connected+vehicles+image&tbm=isch&source=iu&ictx=1&fir=lSOqr7u45h9jKM%253A%252Cyu8Fj0DyqFwmzM%252C_&usg=__AmjEF1lraI2V7jgAd-uScHvoZbw%3D&sa=X&ved=0ahUKEwjQ1-6xpdbbAhVSja0KHXJFB-cQ9QEINjAB#imgdii=hh-UdTp_CMAh1M:&imgrc=ykZeJBf2vxs9jM:

Image credit: https://techcrunch.com/2016/03/19/what-will-a-driverless-future-actually-look-like/

https://techcrunch.com/2016/08/25/the-biggest-threat-facing-connected-autonomous-vehicles-is-cybersecurity/

What's buzzing?

Year of Incident	Exploited Models	Vulnerabilities	Attack Vectors
2015 and 2016	Jeep Cherokee	Incorrect Configuration (an open port on the infotainment system)	Dropper attack via the cellular network
2016 and 2017	Tesla	In-Memory vulnerability in the infotainment web browser	Wi-Fi Hotspot, man-in-the-browser, and full control of the infotainment ➔ Arbitrary CAN-bus and ECU remote controls, taking control of the brakes
2018	Audi A3/ VW Golf	Infotainment system configuration error, ➔ read arbitrary files from disk; extended into remote code execution	Dropper attack on the infotainment system
2018	BMW Models	14 in total: **In-Memory** (Bluetooth stack, USB-Ethernet stack, Cellular interface); **Improper configuration** (Stored passwords and keys)	Infotainment, Telematics, OBD-II Ethernet diagnostics service

CAN-bus = controller area network
OBD = on-board diagnostics

https://techcrunch.com/2016/08/25/the-biggest-threat-facing-connected-autonomous-vehicles-is-cybersecurity/

What will a driverless future look like?

❑ The end of private car ownership?

- ✓ Shared fleet of autonomous vehicles (AVs) that will be called for on demand
- ✓ "Mobility as a service" - individuals call for AVs when they need to get somewhere
- ✓ Under a subscription model, individuals would pay a flat fee on for unlimited access to a given fleet of vehicles (e.g., owned by auto manufacturers)

❑ AVs' impact on the way we live will be transformative

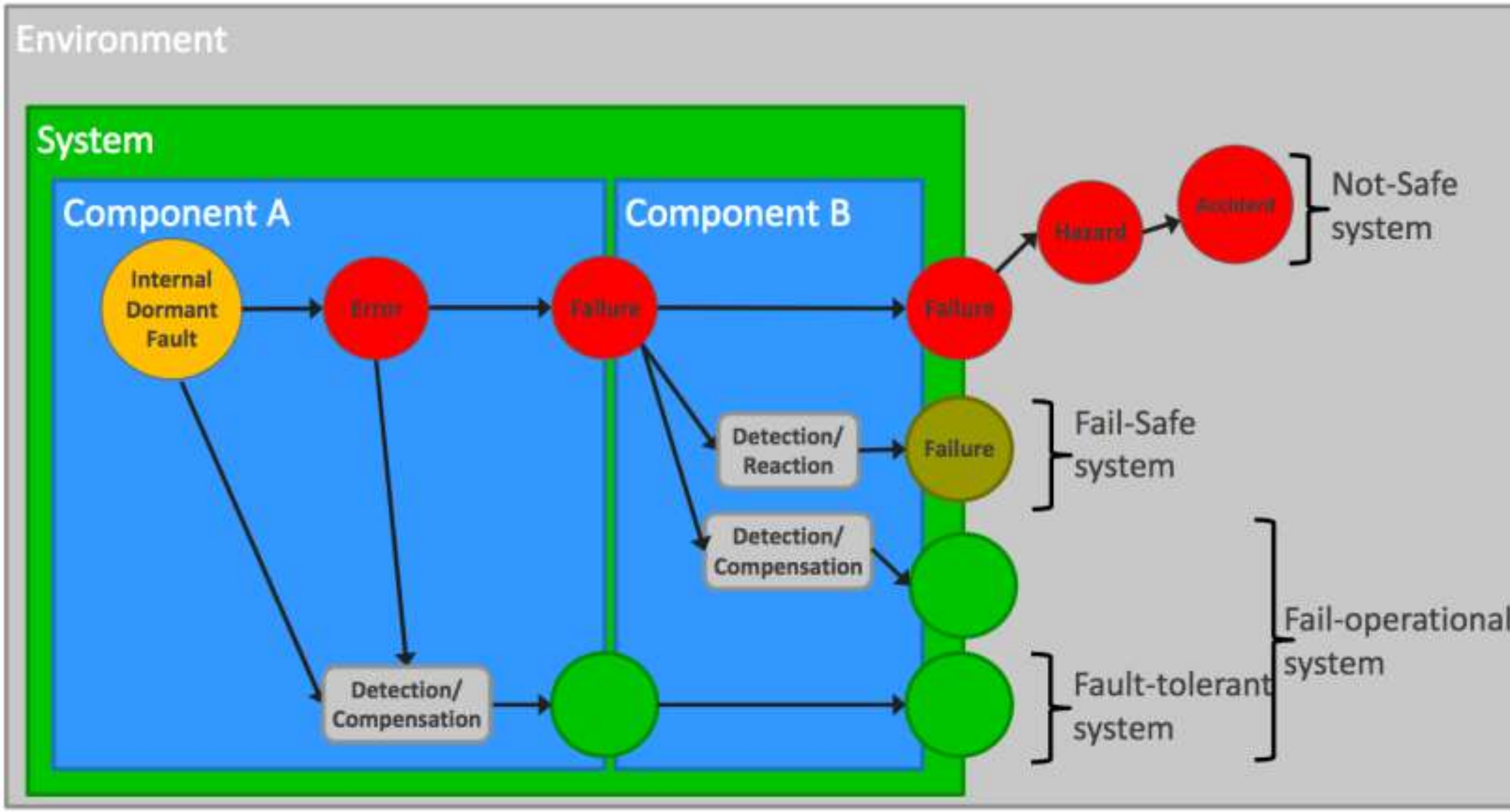
- ✓ Single-occupancy pods will make a significant portion of future AV fleets
- ✓ Multiple occupancy pods will exist in proportion to their demand, and customers can indicate their desired vehicle size when calling for a car
- ✓ *Consequently → increased fuel efficiency, lower materials costs and less space required on roads and parking lots/garages*

❑ AVs should be thought of not as a single new product but rather as an entirely new ecosystem in the economy

- ✓ Sensors and other physical components for the vehicles
- ✓ Cybersecurity
- ✓ High-performance computing chips to power the cars' decision-making processes
- ✓ Consumer electronics for the cars' interiors
- ✓ Mapping and geolocation software to enable the car to navigate

https://techcrunch.com/2016/03/19/what-will-a-driverless-future-actually-look-like/

Fault Propagation in Systems



Basic Concepts and Taxonomy of Dependable and Secure Computing, Avizienis et al., 2004