CTL 7013: Connected and Automated Vehicles

Dr. Gokulnath

CART, IIT Delhi

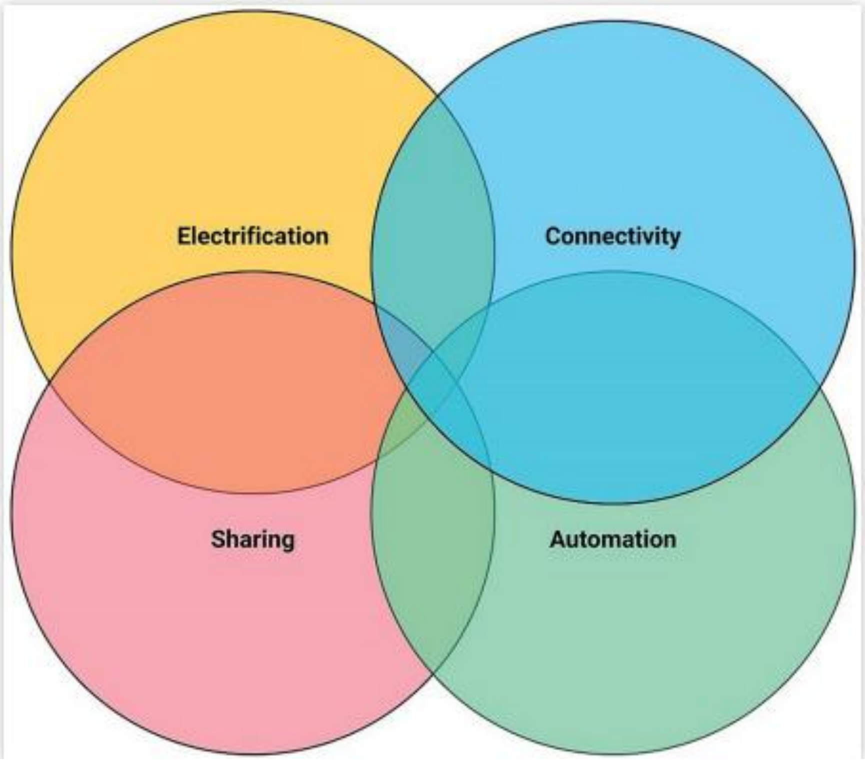
- Why is the automotive industry changing now?
- What exactly are “connected” and “automated” vehicles?
- How did we get here historically?
- And what barriers remain?

The automotive industry is in flux

- Driver-centered paradigm stayed stable for ~100 years
  - Only incremental improvements
  - Human driver controls steering + pedals
  - Minimal communication (turn signals)

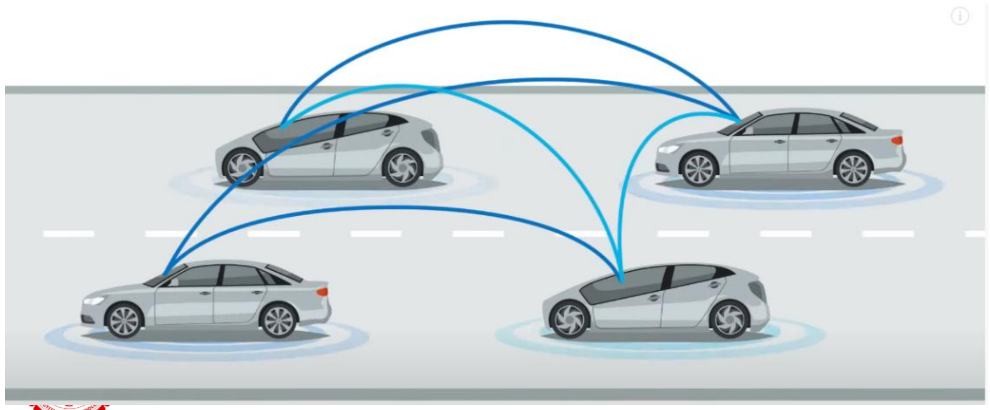
- Automotive industry
  - Improves safety, efficiency, onboard computing

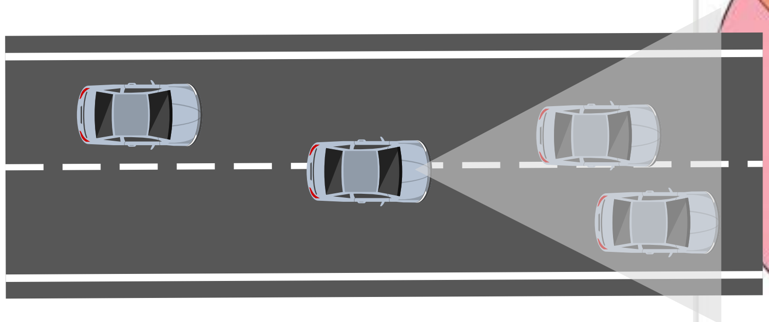
- Electrification
  - Electrification is the most mature of the four trends
  - Powertrain shift from Internal Combustion Engines (ICE) → hybrid/EV (electric motors)
  - R&D work in vehicle electrification is only two decades old
  - Norway, the percentage was 54% in 2020
  - More efficient at converting energy to vehicle motion
  - Fewer moving, mechanical parts → lower maintenance
  - Drastically reduce emissions

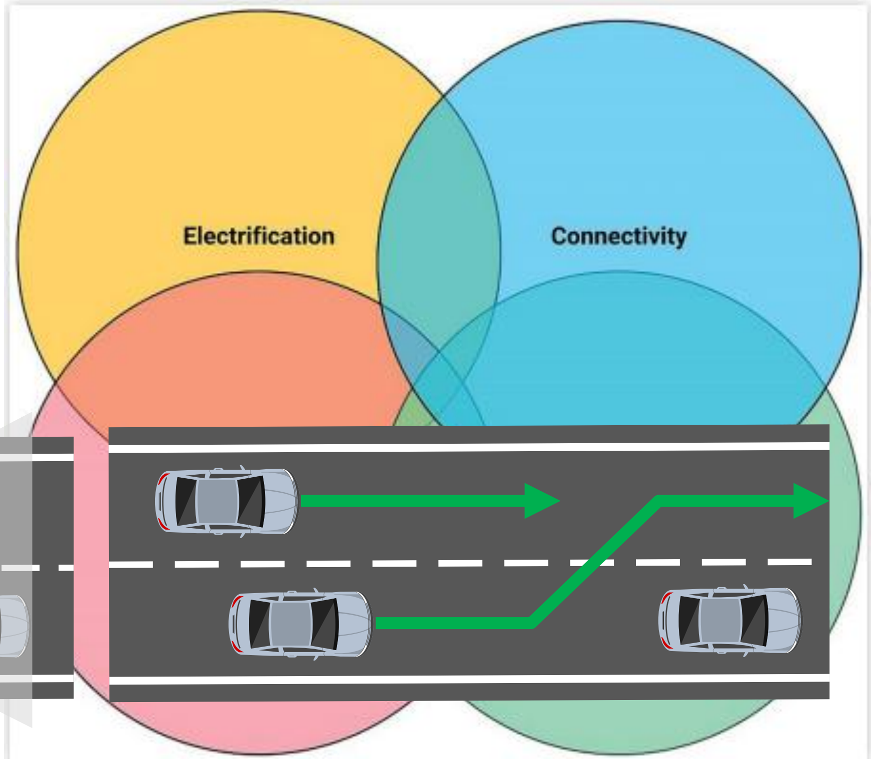


CASE: Electrification + Connectivity + Automation + Sharing

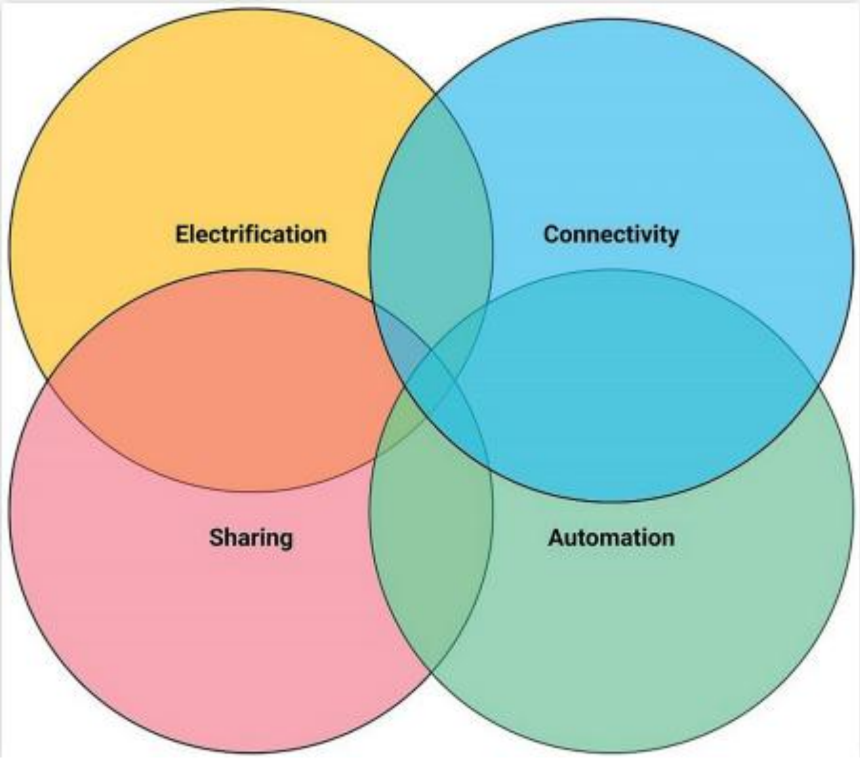
- Connectivity
  - Connectivity is the next mature trend
  - GPS-equipped vehicles were introduced by Oldsmobile ciera 1994
  - Early vehicles can receive Signal Phase and Timing (SPaT) information from traffic signals
    - Provide information on the traffic light sequence and timing
- Possible information exchanged between vehicles
  - Own dynamic properties: position, speed, acceleration
  - Sensor detected object: position, speed, acceleration
  - Driving intentions: future trajectories and waypoints
  - Traffic management procedures and guidelines



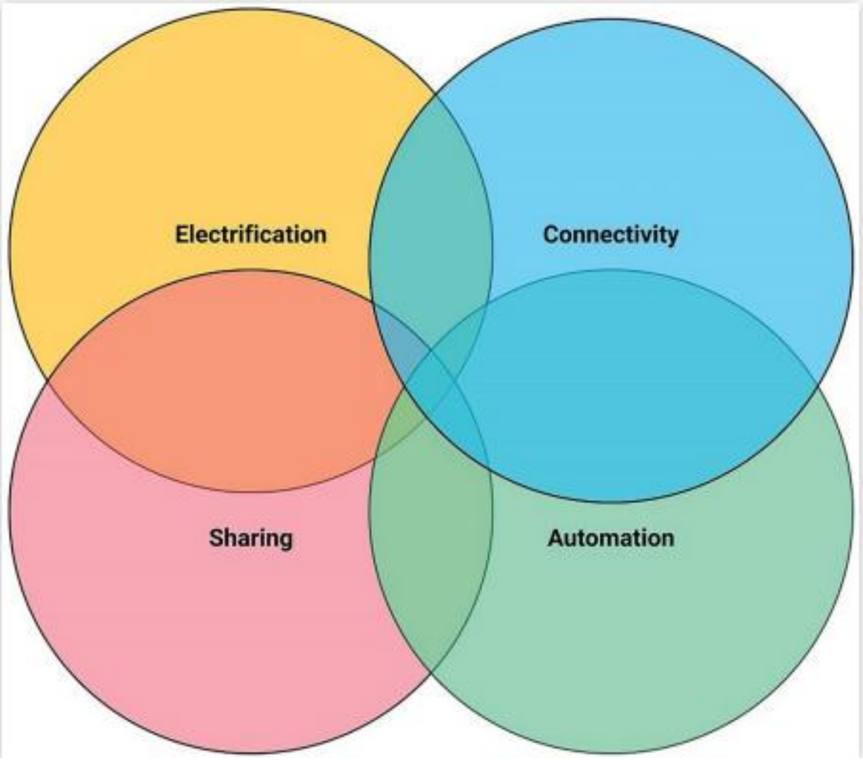




- Sharing
  - Sharing is the second-least mature trend
  - Sharing includes ride hailing (Uber) and car sharing (AutoShare)
  - Sharing is also known as multi-modal transportation
    - From scooters to bicycles to cars to buses and trains
  - Sharing provide enhanced mobility for individuals including
    - disabled persons, seniors, children, etc.
  - Sharing allows for lower levels of vehicle ownership

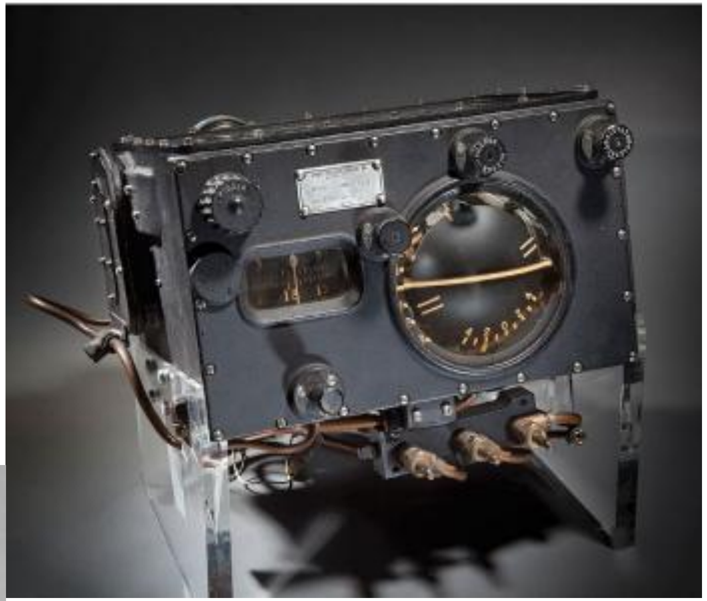


- Automation
  - Automation = vehicles with **Automated Driving Systems (ADS)**
  - **Automation Spectrum (SAE J3016):**
    - Low Level: Driver Assistance (e.g., Adaptive Cruise Control)
    - High Level: Full Automation (No human supervision required)
  - Automation helps humans to focus on other tasks
  - Automation reduce accidents by removing human error
  - Automation helps for those who cannot drive themselves
  - Automation is the **biggest change** in the vehicle industry
    - Since the invention of the automobile itself
  - Automation is the "last in maturity" compared to other trends
    - Holds the highest potential for total sector disruption



HISTORY AND ORIGINS

- Airplane autopilot enabled flying + navigation simultaneously
  - Example: Sperry Gyroscope Autopilot (1930s)
  - Automatically maintain a desired compass heading and altitude
- Early torpedoes: maintain course + depth (1860s)
  - Later: added sonar targeting by WWII
- German V2 rocket: gyroscope-based guidance
  - Early human-made object into outer space



HISTORY AND ORIGINS

- Cockroach-like motion: Sensing → Processing → Reacting
  - Sensing and reacting were possible
  - Hardest part historically: **processing (machine intelligence)**

- 1980s–1990s: High-Speed Autonomy
  - The Mercedes Van (1980): Travel on highways using a primitive automated driving version
  - VaMoRs Van (1997): Third generation of advanced vision systems for autonomous navigation

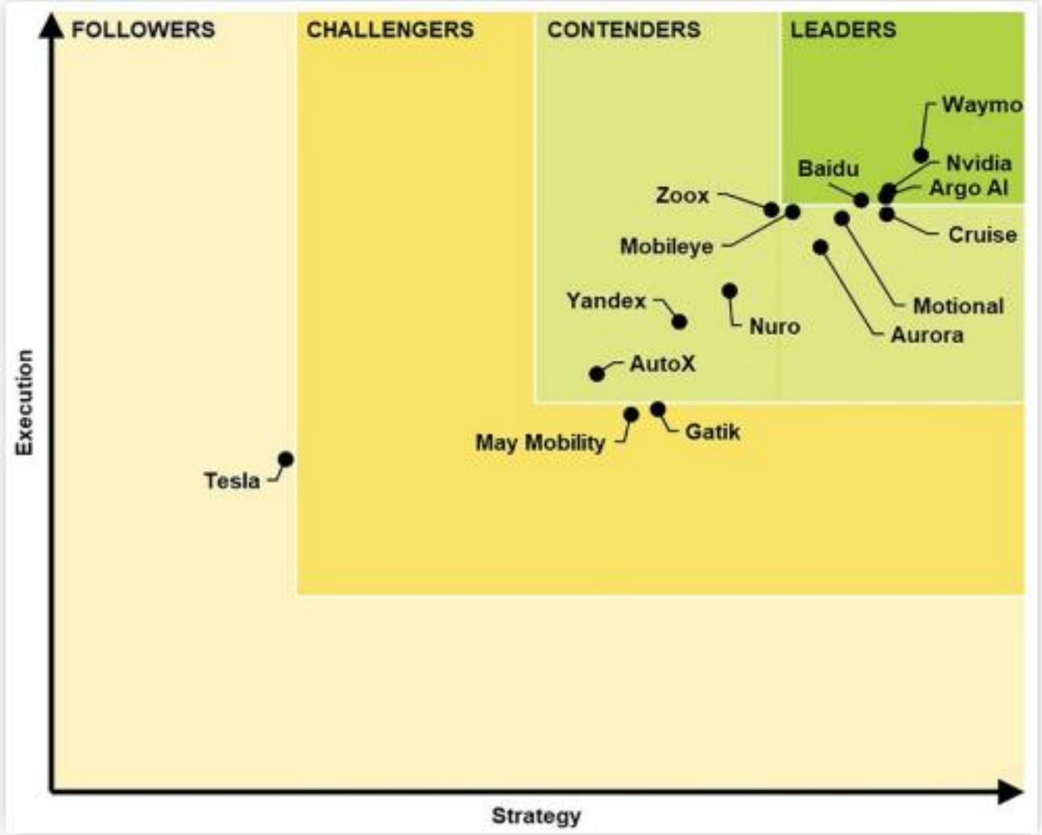
HISTORY AND ORIGINS

- DARPA Challenge (2004–2007)
  - First long distance competition for driverless cars in the world
  - Stanley (2005) and Boss (2007) winners
    - Used machine learning and sensor fusion (LiDAR/Radar) for automation
  - Modern AV industry born
    - Creating companies like Waymo, Tesla, and Uber

GuideHouse report on market analysis 2021

- CAV industry rankings criteria
  - Vision, Go-to market strategy, Partners, Production strategy, Technology, marketing, and distribution, Product capability, Product quality and reliability, Product portfolio, Staying power

- CAV industry leaders
  - Waymo, Nvidia, Argo AI, and Baidu
  - Tesla low in both strategy and execution
    - Public perception may differ



The Reality Check: 2026 CAV Industry Status

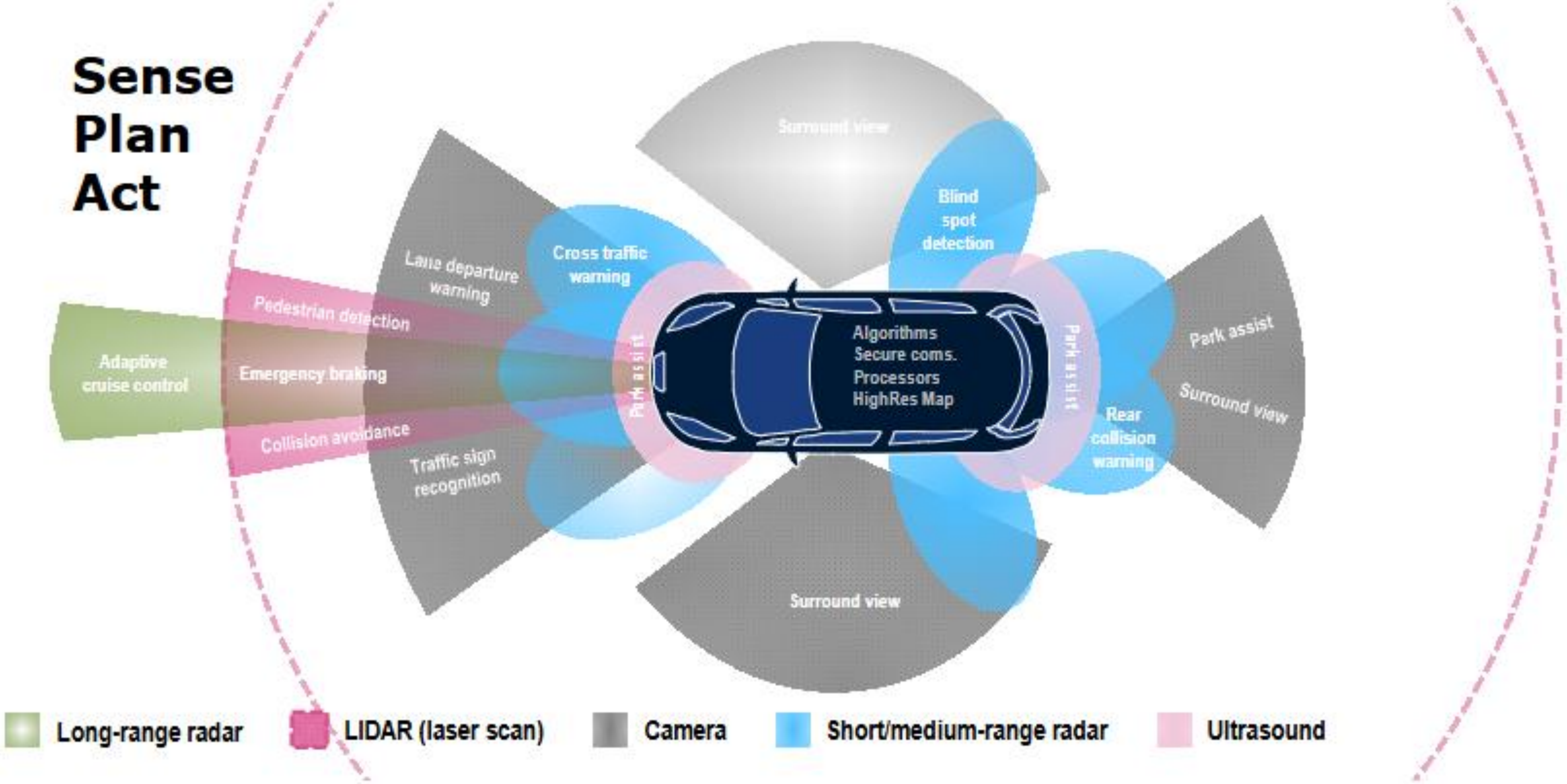
- Strong excitement from industry/government/public in 2020
  - But widespread deployment is not near-term

- **The 80/20 Rule:** The industry has mastered roughly 80–90% of driving tasks,
  - But the final 10–20% (corner cases) is proving exponentially more difficult
  - Perception must handle difficult scenarios:
    - Weather, temporary obstacles/restrictions, parking lots, heavy pedestrian/cyclist traffic, non-mapped areas

- **Timeline Debate:** Opinions are split
  - Some see mass commercialization by 2030, while others predict it is still decades away

Three Pillars of CAV Intelligence

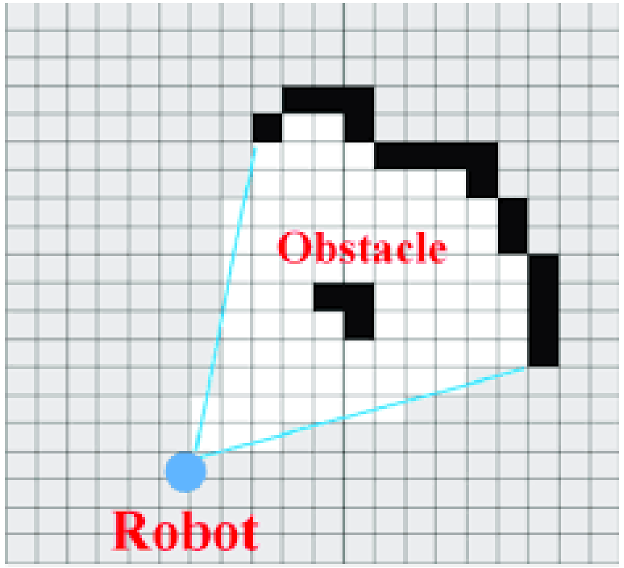
- A CAV works
  - Perception: Understanding the world
  - Planning: Deciding what to do
  - Actuation/Control: Executing safely

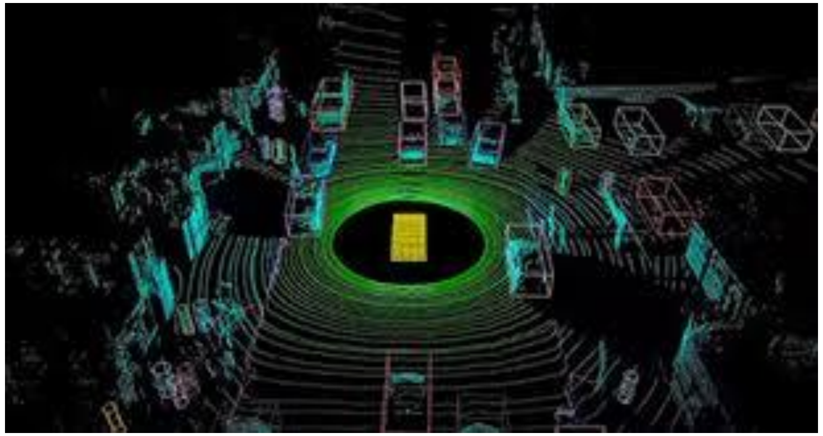


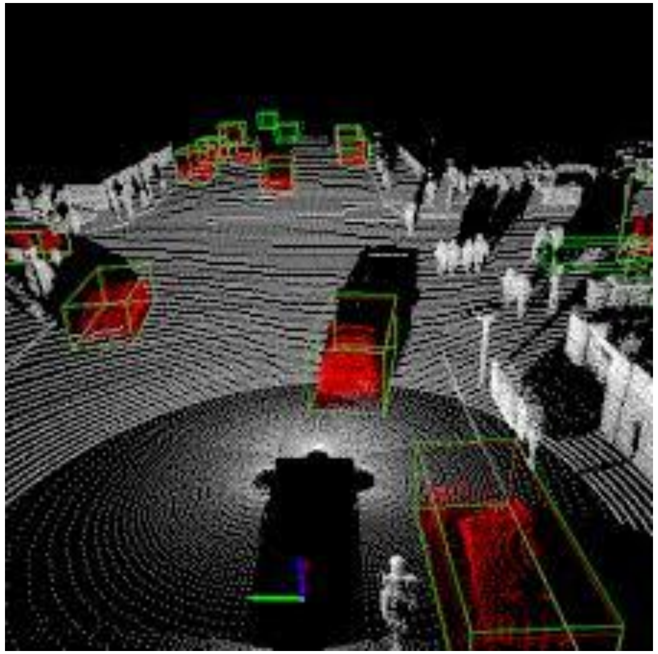
System 1: Perception

- Perception must produce a machine-readable scene of the environment
  - Ego-state: position, velocity, yaw rate, acceleration (vehicle's own motion)
  - Objects: detection + classification (car, truck, pedestrian, cyclist…)
  - Tracking: position/velocity/direction over time of objects
  - Free space: drivable area, boundaries, curbs, road edges
  - Traffic controls: signals, signs, lane markings, right-of-way cues

- **Outputs:** occupancy grid, tracked objects list







How perception is built

- Sensors (typical):
  - **Cameras:** rich semantics (lanes, signs), weak in glare/rain/night
  - **Radar:** strong range/velocity, weaker shape/class semantics
  - **LiDAR:** accurate geometry, cost/packaging concerns
  - **GNSS/IMU/Wheel odometry:** ego motion + localization backbone

- Fusion levels:
  - **Raw-data fusion** (hard, heavy compute)
  - **Feature-level fusion**
  - **Object-level fusion** (common, robust)

System 2: Planning

- Planning converts world model + mission into actions:
  - **Mission / Route planning:** where to go
  - **Behavior planning:** what maneuver (keep lane, yield, overtake, stop)
  - **Motion planning:** exact trajectory (path + speed profile) within constraints

- **Output:** a trajectory: $x(t), y(t), v(t)$ over next few seconds

- **Prediction**
  - Forecast trajectories of vehicles/pedestrians/cyclists
  - Estimate maneuver (will cut-in? will cross? will stop?)
- **Prediction Approaches:**
  - Physics-based (constant velocity/acceleration)
  - Rule-based (yielding, lane following)
  - Learning-based (data-driven intent + interaction)

System 3: Actuation/Control

- Control turns planned trajectory into commands:
  - **Lateral control:** steering to follow path
  - **Longitudinal control:** throttle/brake to follow speed profile
- Vehicle actuators:
  - Steering actuator, brake-by-wire, throttle, gear, etc.
  - Safety monitoring: actuator faults, degraded modes
- **Output:** steering angle + throttle/brake commands at high rate