# LOCOMATION

## OTONOM SÜRÜŞ: DÜNDEN BUGÜNE, OTONOM KAMYONLAR


BYÖYÖ 2020

2 TEMMUZ, 2020

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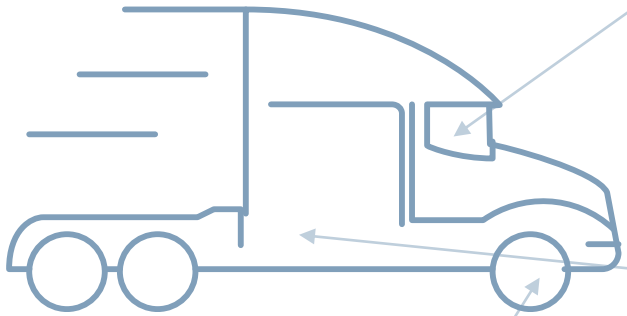
# ANATOMY OF AN AUTONOMOUS VEHICLE



## Sense

- Object detection (vehicles, pedestrians, traffic signs)
- Road detection (lane markings, road surface,…)
- Intent prediction (e.g., what will this car do in two seconds?)
- Self-localization (where am I?)

## Plan

- Mission planner
- Path planner (think Google Maps)
- Trajectory planner
- Vehicle control
  - Lateral
  - Longitudinal

## Act

- Steering position/torque control
- Speed control (brake, acceleration
- Behaviors (headlights, vipers,…)

10-100 times/second

- Sense
- Plan
- Act

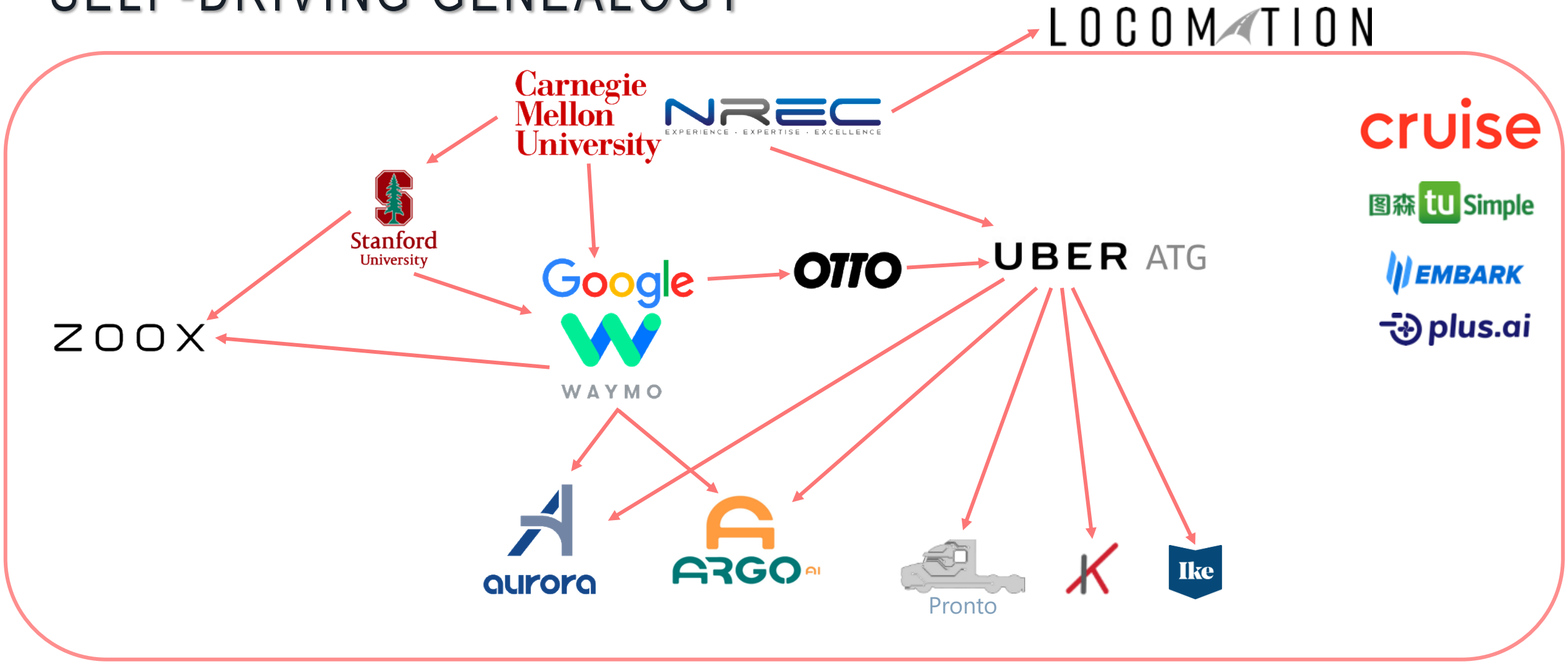
# DARPA GRAND CHALLENGES

- Grand Challenge 1(2004), 2 (2005)
- Urban Challenge (2007)


- Talent pool
- Public awareness

Caveat: set the ultimate problem as the *first frontier*

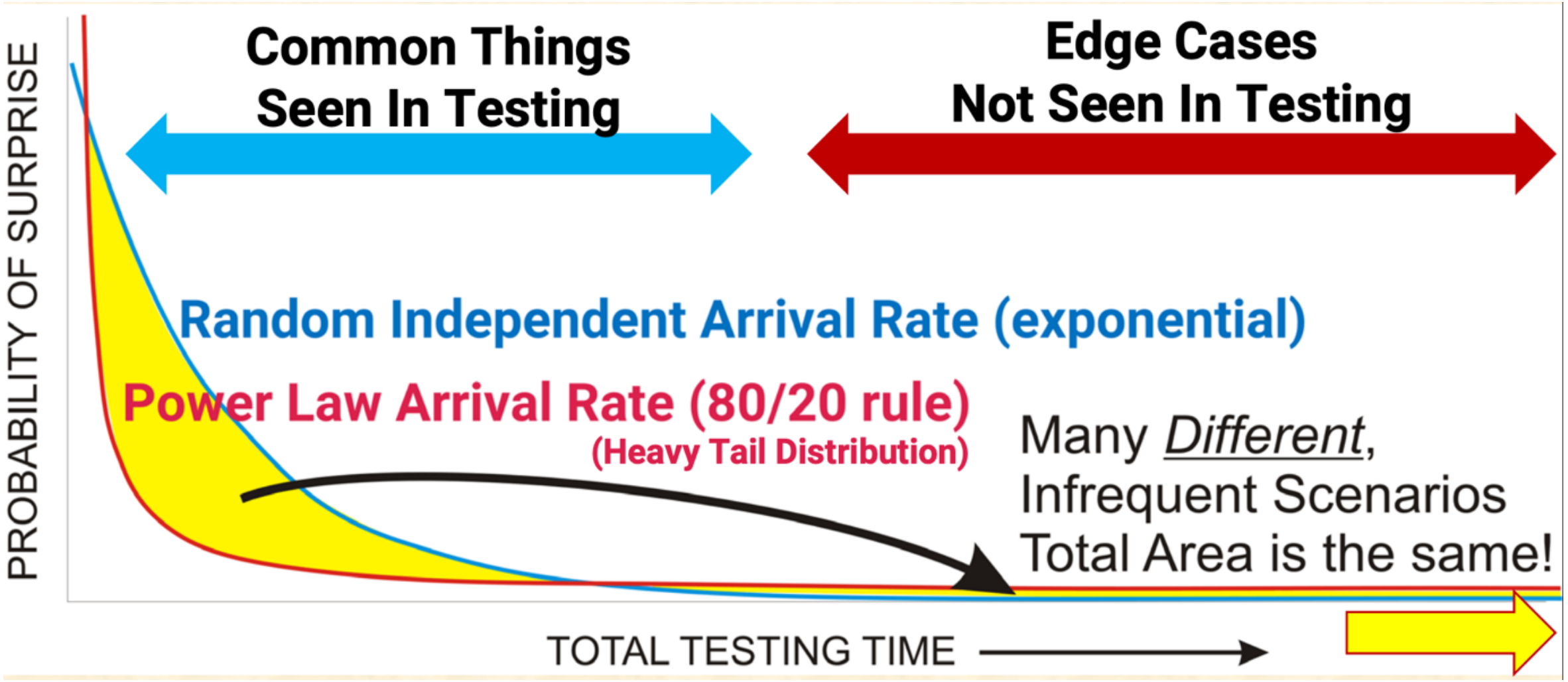
# SELF-DRIVING GENEALOGY



# A SINGLE PLAYBOOK

- Focus on a geofenced area and think it simplifies complexity
- Build HD maps
- Use maps for localization + obstacle detection
- Build a large test fleet and continuously collect test data and update maps
- Heavily rely on supervised learning + deep learning
  - Starting to change
- Rinse and repeat

# FIELD TESTING: HEAVY TAIL DISTRIBUTION




https://users.ece.cmu.edu/~koopman/lectures/Koopman19_SSS_slides.pdf

# SELF-DRIVING 2020: RECTIFIED EXPECTATIONS

Quartz

**Ford (F) will have a self-driving car with no steering wheels or pedals in 2021**

At an event in Silicon Valley, Ford CEO Mark Fields announced that in five years' time, the company intends to have a fully autonomous vehicle on the road.

Aug 16, 2016

2016

Bloomberg

**Uber's First Self-Driving Fleet Arrives in Pittsburgh This Month**

Sebastian Thrun, the creator of Google's self-driving car project, spent seven years researching autonomous robots at CMU, and the project's former director, ...

Highly Cited · Aug 18, 2016

2016

Los Angeles Times

**Look, Ma, no hands: Google to test 200 self-driving cars**

Look, Ma, no hands: Google to test 200 self-driving cars ... space for your belongings, buttons to start and stop, and a screen showing where the car is going.

May 28, 2014

2014

Wired

**The World's First Self-Driving Semi-Truck Hits the Road**

(An autonomous truck could exit the interstate near the end of its journey, park in a designated lot, and wait for a human to come drive it on surface streets to its ...

In-Depth · May 5, 2015

2015

Bloomberg

**Ford CEO Tamps Down Expectations for First Autonomous Vehicles**

Too much hype has built up about how soon self-driving cars will hit the road, but they will ultimately change the world, Ford Motor Co.'s chief executive officer ...

Apr 9, 2019

2019

VentureBeat

**Uber expects a long wait before self-driving cars dominate**

Urtasun's comments fall in line with the rest of the self-driving industry, which after much hype and bold promises has tempered expectations and pushed out ...

Apr 8, 2019

2019

CNBC

**Alphabet exec says self-driving cars 'have gone through a lot of hype,' but Google helped drive that hype**

Waymo executives think people have taken its promises of self-driving cars too seriously. The Alphabet subsidiary went "through a lot of hype that was sort of ...

Oct 23, 2019

2019

Washington Post

**Shaken by hype, self-driving leaders adopt new strategy: Shutting up**

PALO ALTO, Calif. — Three former executives at Google, Tesla and Uber who once raced to be the first to develop self-driving cars have adopted a new ...

Oct 18, 2018

2018

# WHY AUTONOMOUS DRIVING IS HARD?

- Easy to demonstrate, hard to turn into a robust product
- Uncertainty in the real world is very difficult for robots to model and cope with
  - Humans cause most of the uncertainty
  - Humans are very good at interpreting and coping with each other

# IT IS MORE THAN JUST DETECTING OBJECTS

Maybe careless?

Distracted driver

Not a cone, not a stop sign!


Why did the chicken cross the road?

Have a fighter jet in training data?

Is half a pick-up still a pick-up?

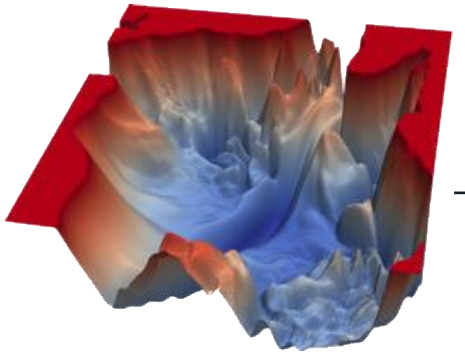
# EXAMPLE: PROBABILITY OF JAYWALKING

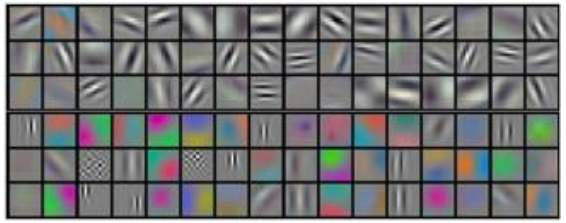
# ISSUES WITH ML BASED SYSTEMS

Lack of robustness against adversarial perturbations

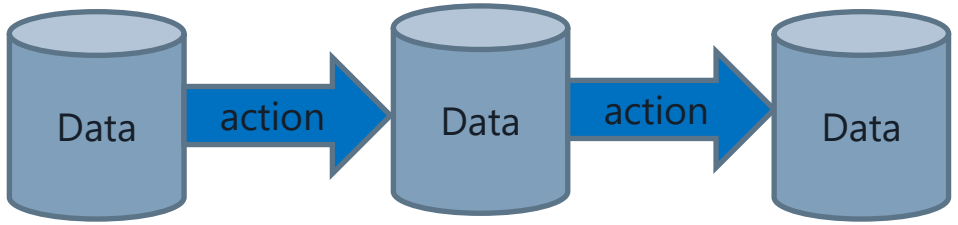


Lack of introspection and formal frameworks to provide bounded performance guarantees





Real world continuous data from robots violating the i.i.d. assumption



# PROGRESS HAS STALLED / SLOWED DOWN

- Open ended definition of full autonomy
- Linearly probing an exponentially large state space
- Negative unit economics limit test fleet size

# THE LOCOMATION APPROACH TO AUTONOMY

Distillation of vast “know-how” and “know-how-not-to”

- **Embrace** the long path ahead for full autonomy, start with a **tangible scope**
- Build a **robust, safe** hardware and the software autonomy stack at the core (L4 / L5 capable)
- Build a true **minimum viable product** and start adding significant value **now**, then iterate quickly
- Make sure there is a **viable business** with **positive unit economics** at every iteration
- **Incrementally validate** the system for increasingly complex applications / domains

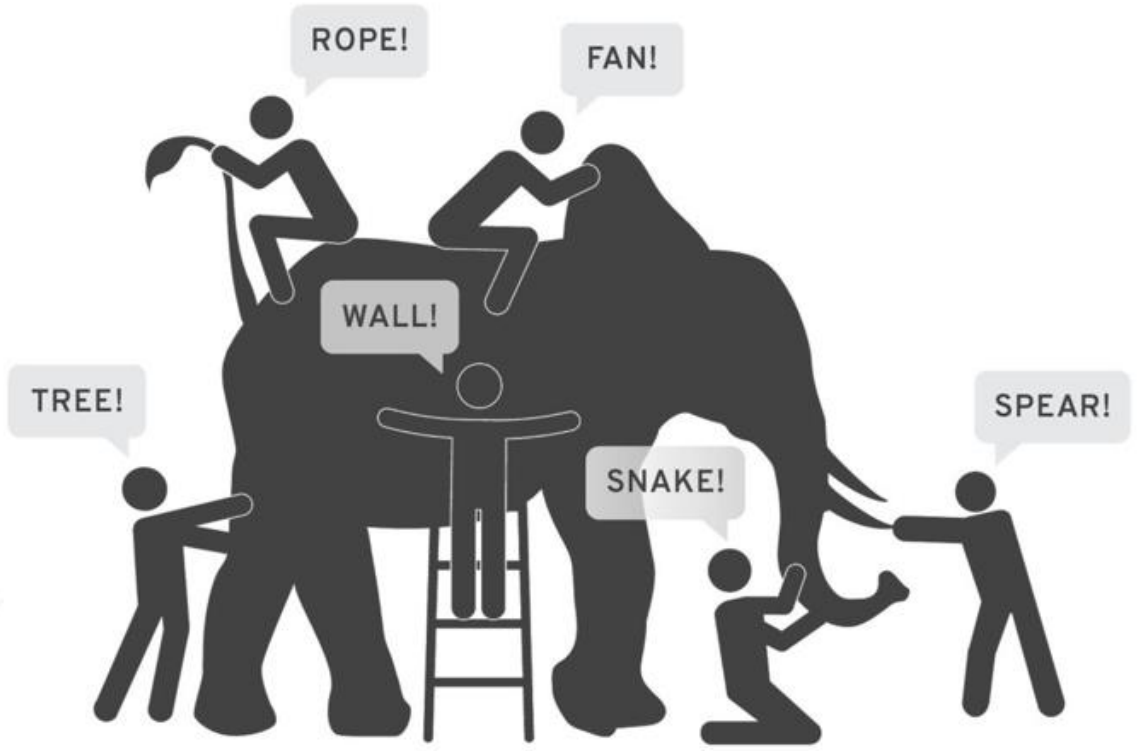
# SELF-DRIVING TRUCKS: DIFFERENCES

- Safety
  - A fully loaded truck is a 80,000 pound projectile going at 70mph
    - ~30m/s displacement
  - Highways are more structured, but semi-trucks pose higher safety risks
    - Zero room for any mishap
    - All it takes is one bad accident
    - Edge cases are less frequent but equally rich
- Autonomy technology
  - Motion planning / vehicle control
    - Different trailers, changing tire, brake, etc. performance
  - Sensing
    - Moving cab, hard to correlate what a sensor sees with where the vehicle is

*“If you think safety is expensive, try having an accident.”*

# SAFETY - VALIDATION

- Functional safety – ISO26262, etc.
- Graceful degradation (lizard brain)
- MTBFs - Hardware redundancy
- Top down (e.g., Functional Hazard Analysis, Fault Trees)
- Bottom up (e.g., field testing)
- Safety at the system architecture level



# LOCOMATION TECHNOLOGY READINESS ROADMAP

Mainly long-haul / over-the-road

**AUTONOMOUS RELAY CONVOY (ARC™)**

**(pilot: 2019 – commercial: 2021)**

+ Short-haul, dedicated linehaul / relays

**AUTONOMOUS DRONE FOLLOWER, 3 TRUCK CONVOYS**

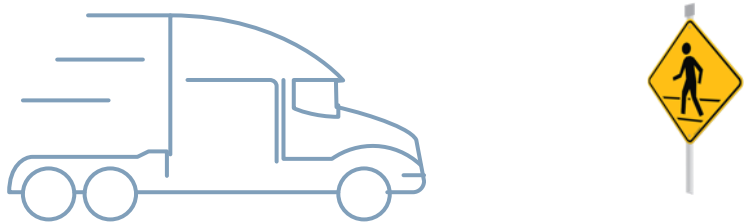
**(pilot: 2020 – commercial: 2023)**

Initially short-haul, expand the range over time

**HIGHWAY FULL AUTONOMY**

**(pilot: 2021 – commercial: 2024)**

Initially short-haul, expand the range over time



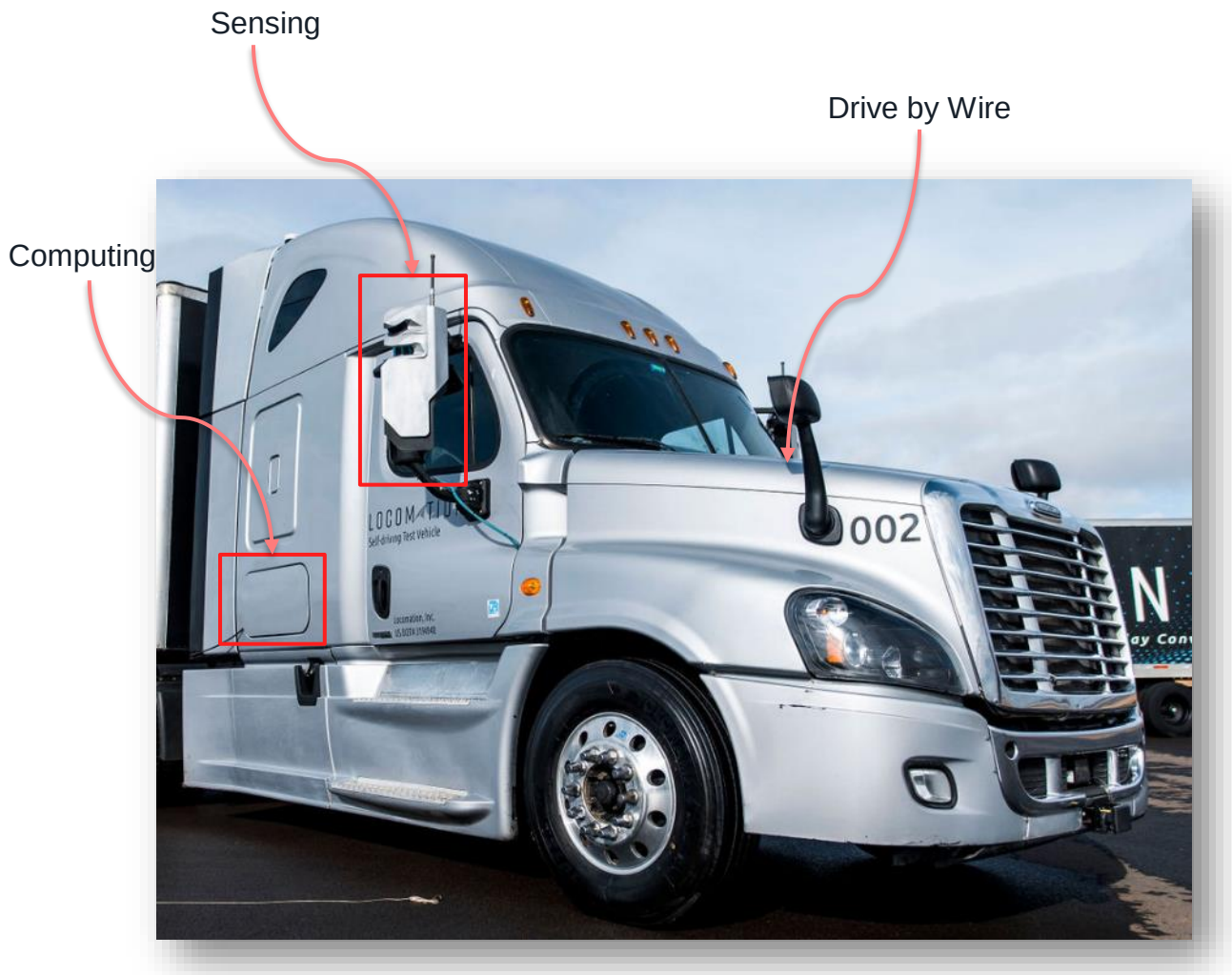
**HUB-TO-HUB FULL AUTONOMY**

**(pilot: 2022 – commercial: 2025+)**

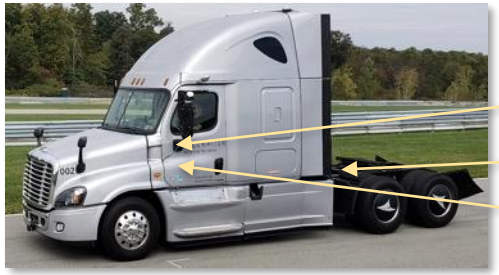

# AUTONOMOUS RELAY CONVOY

# LOCOMATION STACK

- Autonomy retrofit kit
  - OEM installation in the future
- Compatible with major truck makes/models
  - ~70% of all trucks, >90% of large fleets in US
- Robust, safe, future compatible design
  - Full L4 self-driving capable
- Rapid deployment/scaling on new routes
  - No reliance on infrastructure or HD maps
- Integration with the fleet management systems
  - Optimization/scheduling for convoy dispatching



# DRIVE-BY-WIRE KIT



Locomation B-Kit

- Steering Control
- Brake Control
- Throttle Control

Platform Control Kit

Locomation A-Kit

Hardware

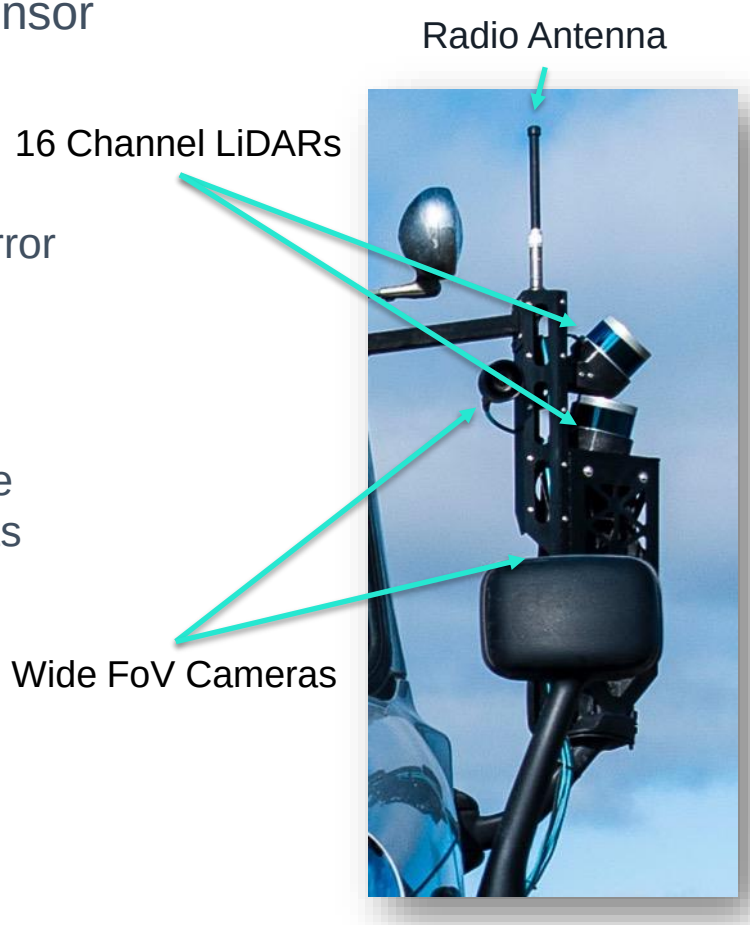
- Sensors, Computing

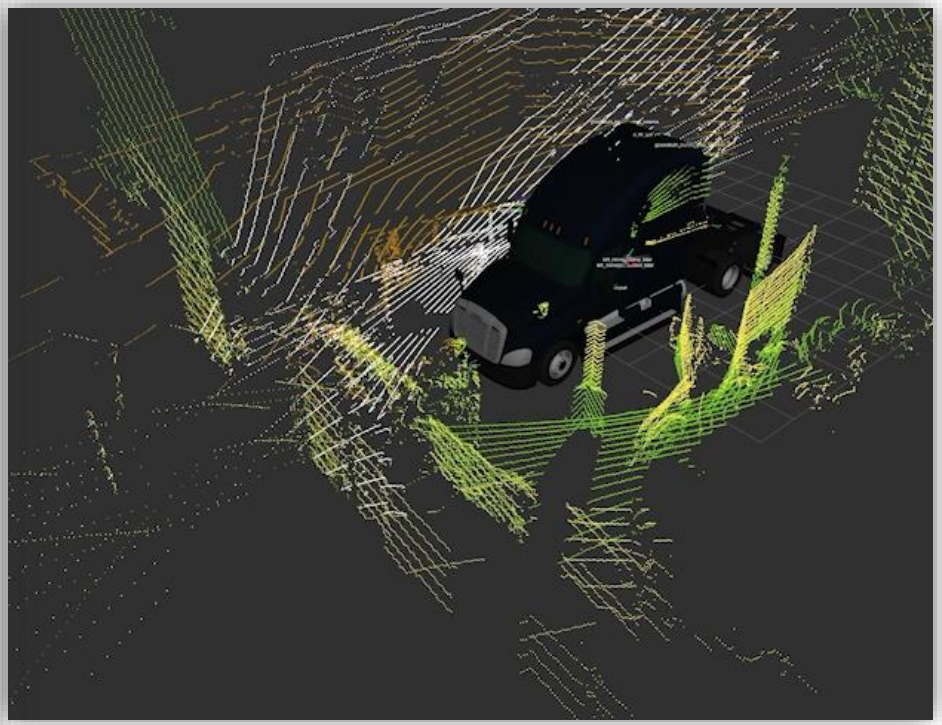
Software

- Autonomy Stack

# SENSING

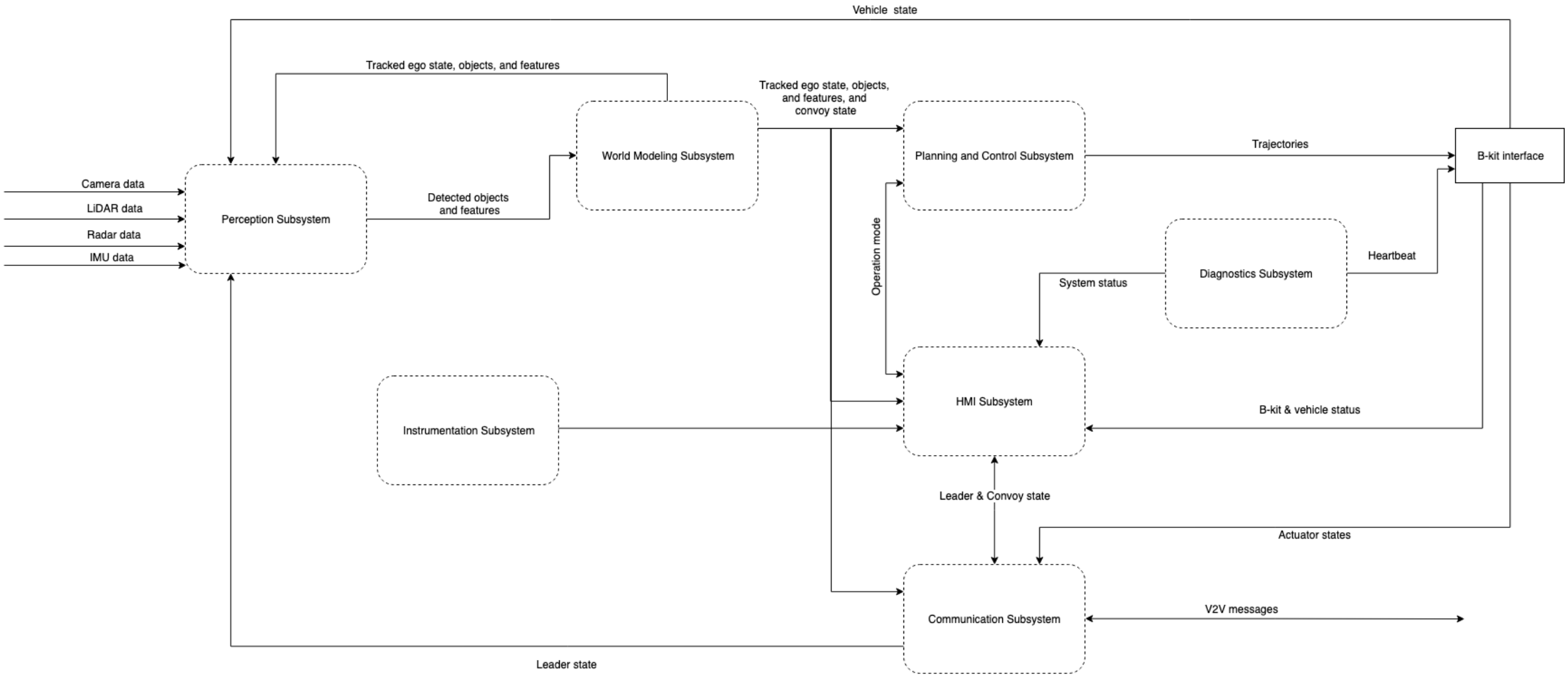
- Custom software to optimize sensor configuration
- MirrorPod sensing unit
  - Easy to install –similar to a mirror replacement
  - “Hammerhead effect” to see through traffic on the sides
  - Adequate coverage around the vehicle with minimal blind spots
  - Easy to “factory calibrate”
  - **Patent pending**
- INS
  - Low cost: VectorNav
  - Ground truth: NovAtel Span



Optimal sensor coverage

# AUTONOMY STACK





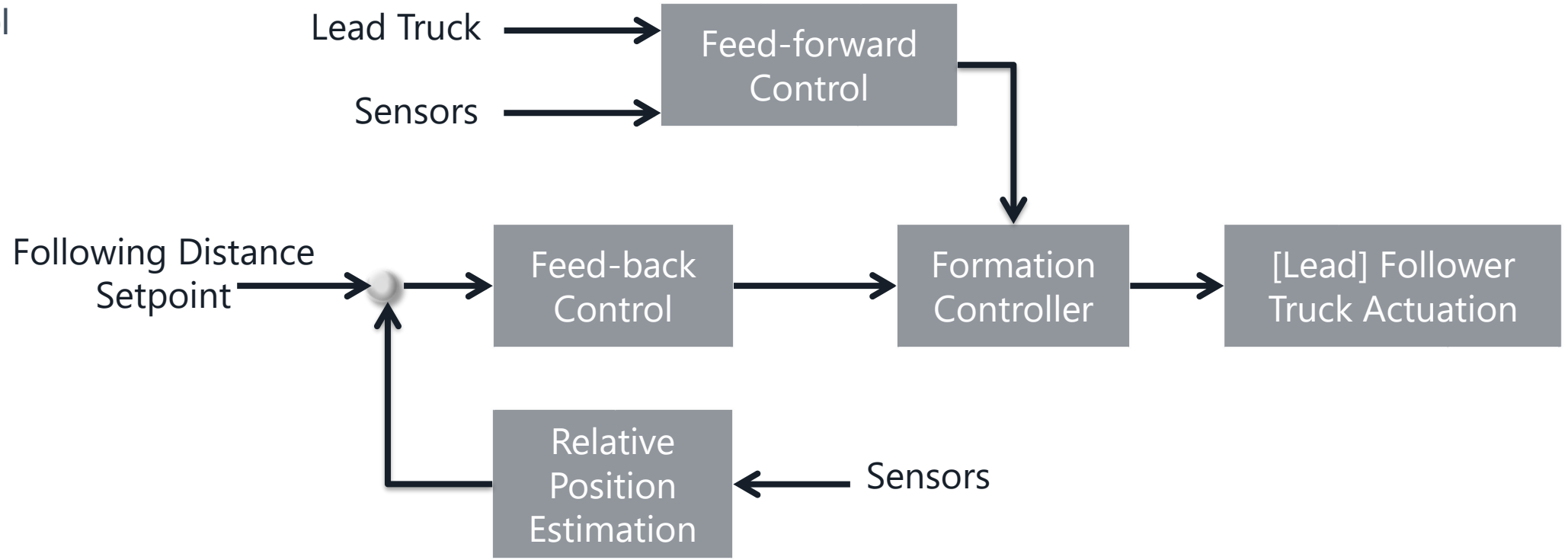

Note: very simplified block diagram due to confidentiality of the full design

# IMPLEMENTATION OVERVIEW

Tight following distance requires impeccable motion planning

Accurate system identification (braking distance, mass distribution)

Formation control

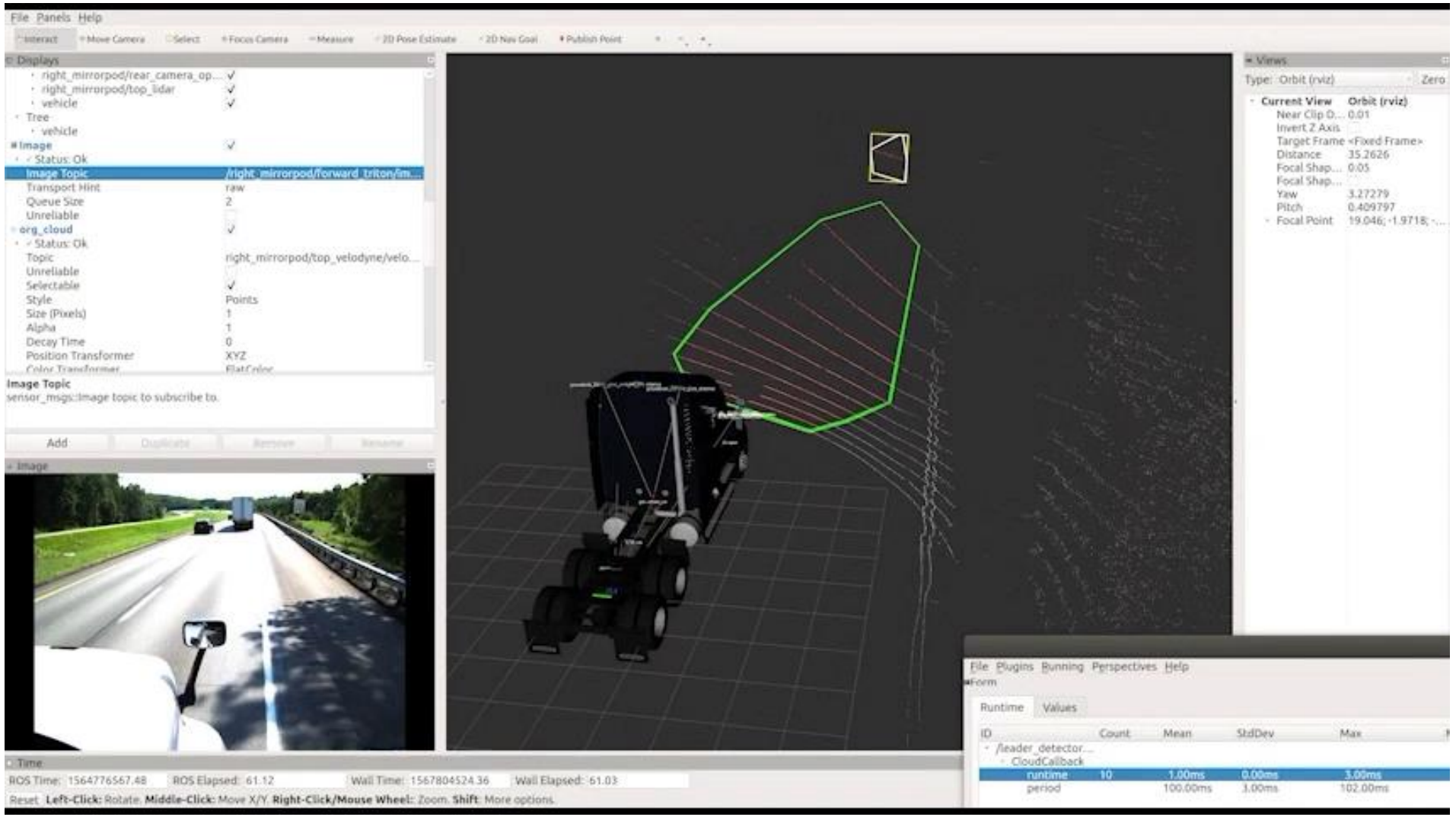


# PERCEPTION

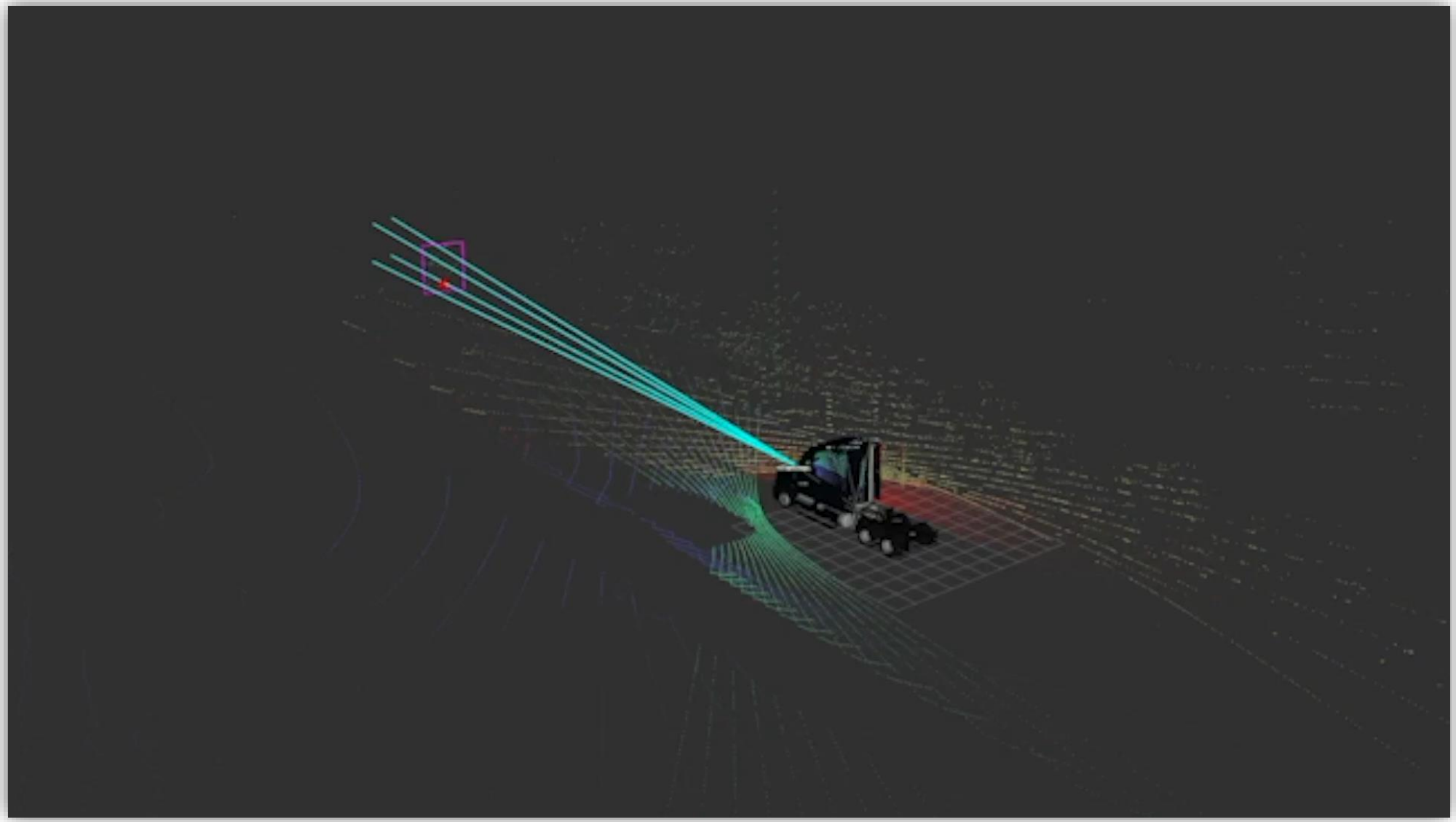
- Core elements implemented using geometric vision algorithms
  - Contrast and continuity based lane detector & tracker
  - Shape and template based leader truck detector & tracker
  - Multi-modal pre and post detection sensor fusion
  - White box, verifiable
  - Lightweight, does not require a GPU farm to run
- Future expansions will use ML ”doers” with verifiable “checkers” as the safety net for complex semantic understanding and prediction

# PERCEPTION – LEADER TRACKING - CAMERA

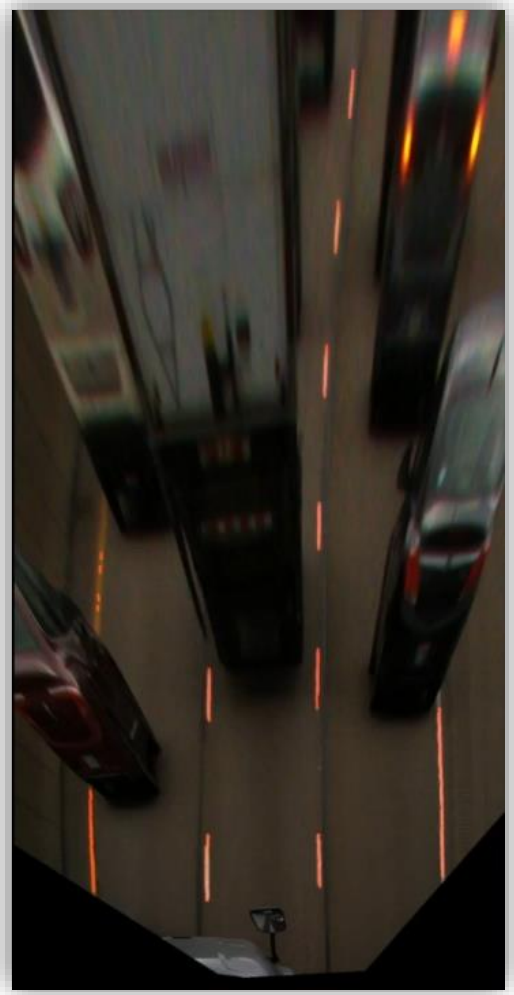
# PERCEPTION – LEADER TRACKING - LIDAR

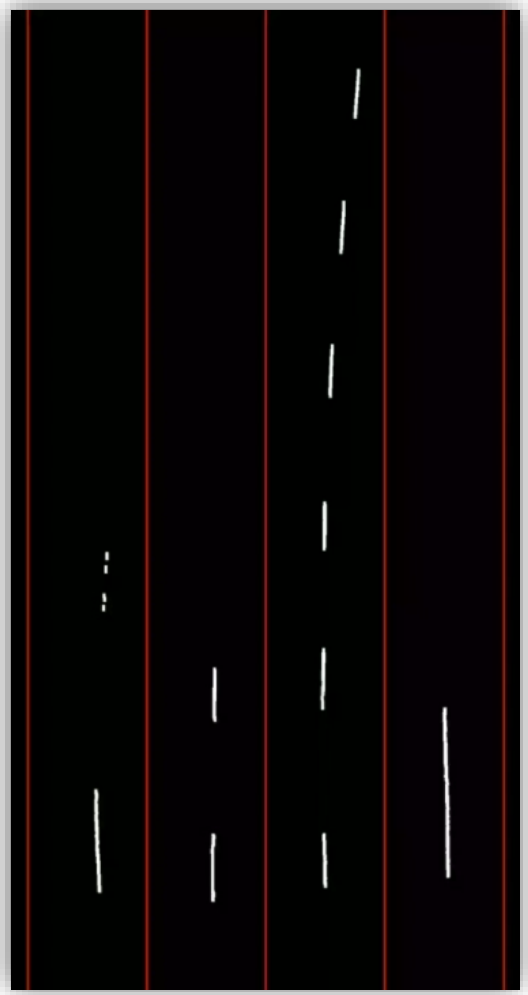


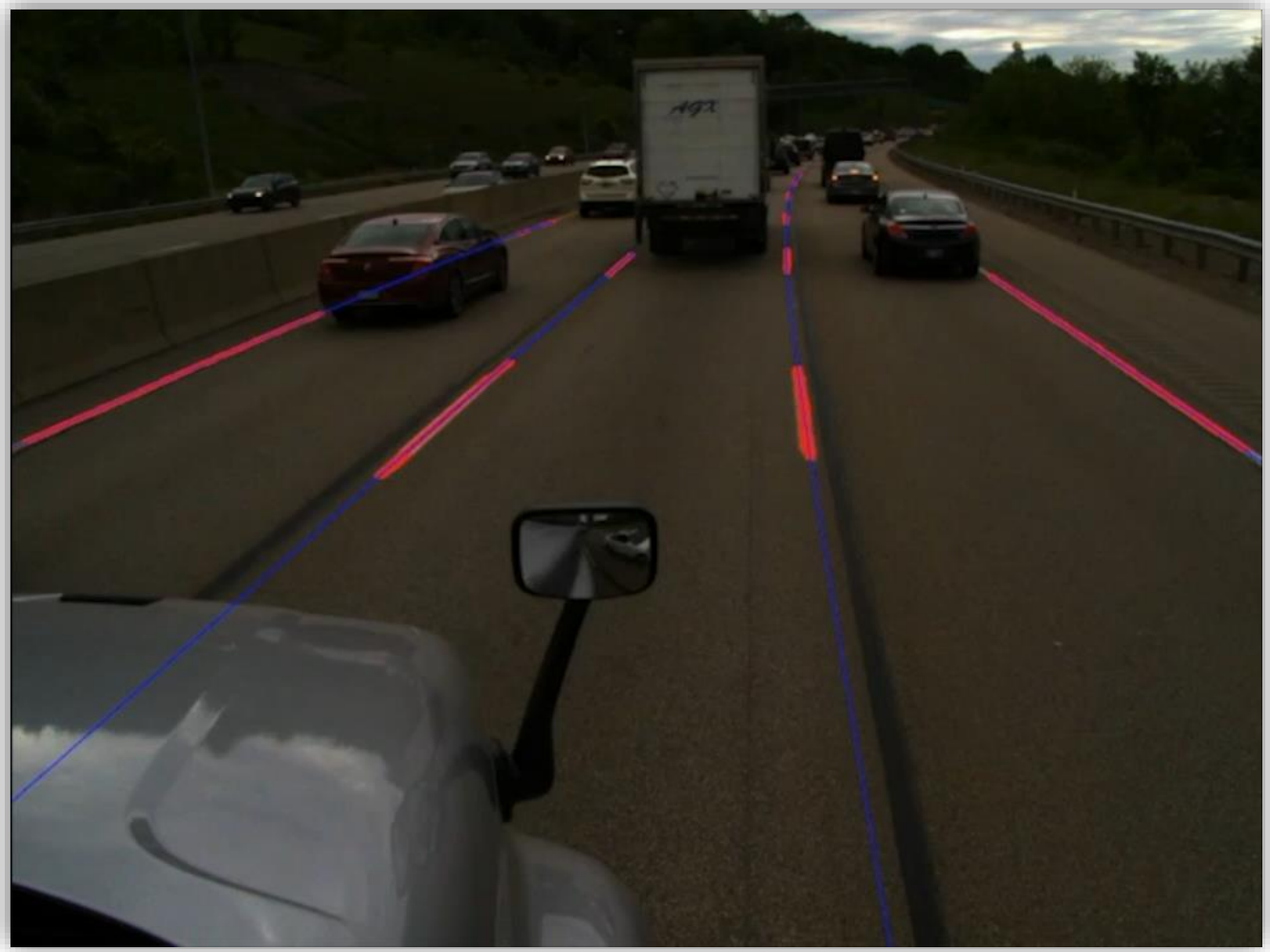
# PERCEPTION – LEADER TRACKING – 3-WAY FUSION



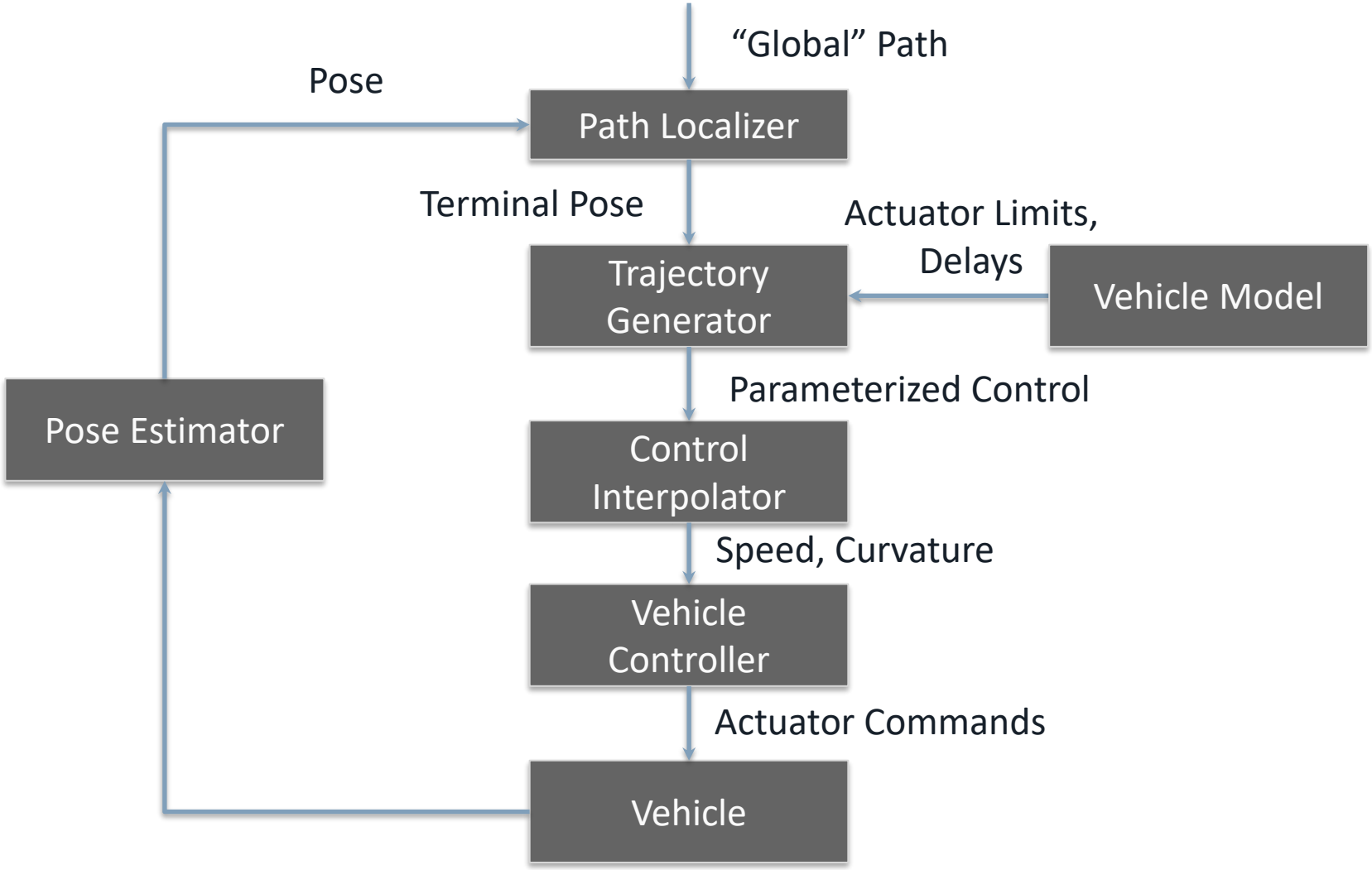
# PERCEPTION – LANE TRACKING



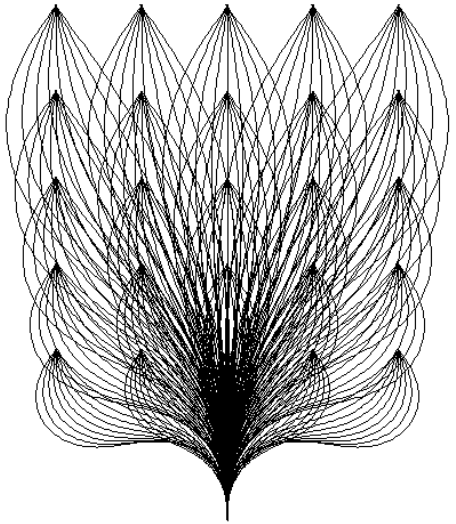




# PATH FOLLOWING

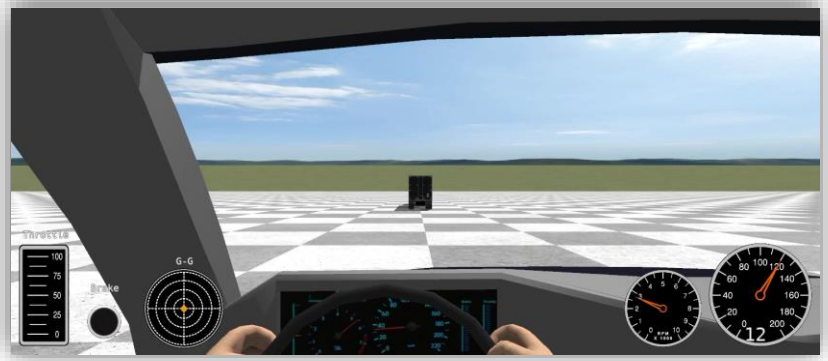


# TRAJECTORY PLANNING AND CONTROL



- Model Predictive Control (MPC)
- Inverse dynamics based trajectory planning
  - Nominal (in-lane) lateral control
  - Lane change
  - Accel and decel profiles
- Evasive planning
  - Plan next actions for not just the benign expectations, but also for a list of abnormalities
  - Full stop, swerve, pull to side, etc.
- System identification for braking, CG, tire-terrain interaction, etc.
  - Characterize what the vehicle can (and will) do
  - Comprehensive initial calibration
  - Continuous online calibration

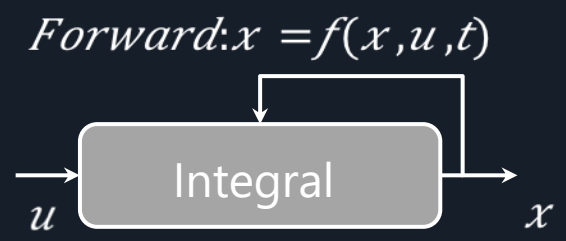


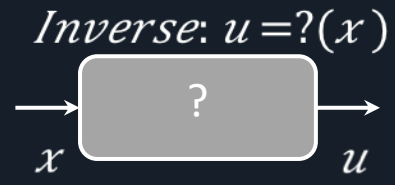


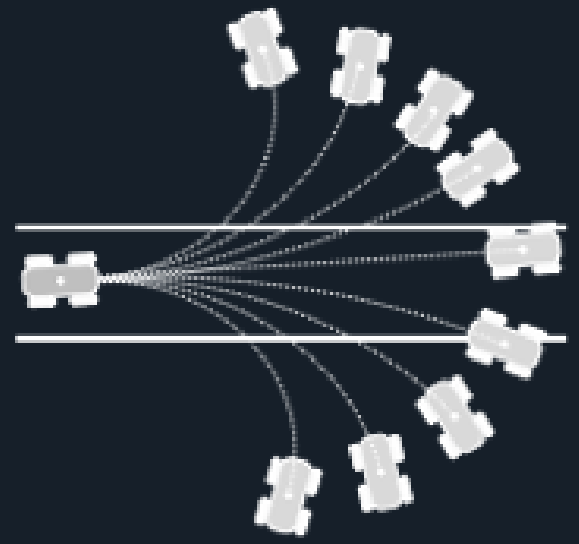
# INV. DYNAMICS BASED TRAJECTORY PLANNING

Generate motions consistent with

- vehicle dynamics
- road surface conditions
- rules of road (lanes).



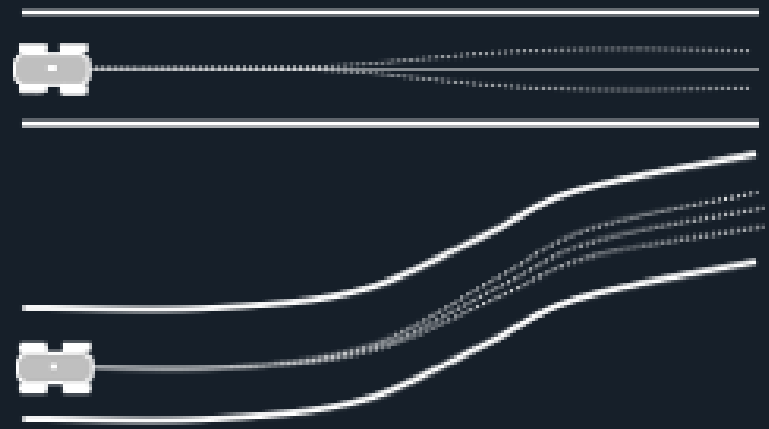



## Options and Analysis

Continuum Search – not convex

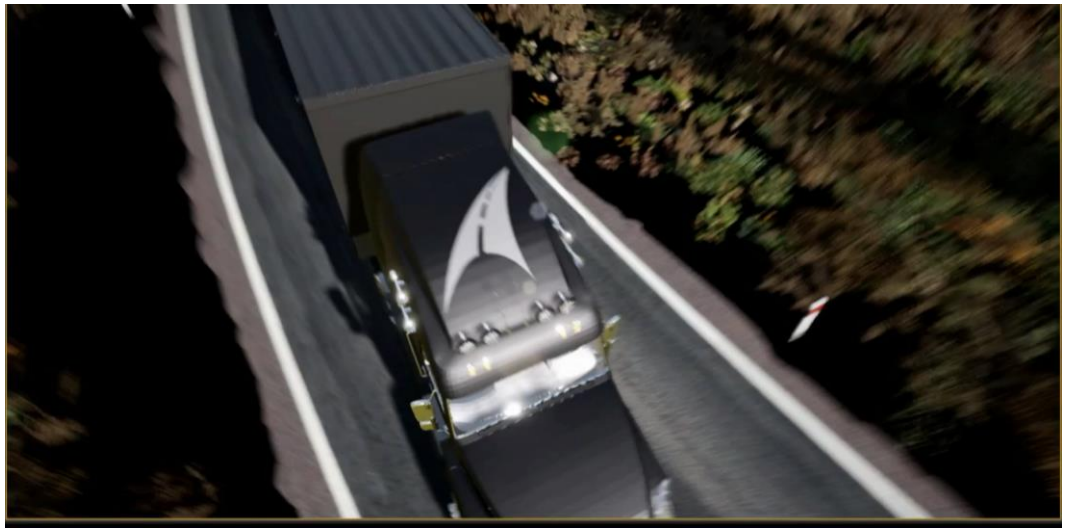
Command Space Sampling – too hard to meet constraints

Workspace Sampling – hard but ***doable***



# SIMULATION

Custom in-house simulator for photorealistic perception development/testing



Ultimate one-stop-shop simulation environment

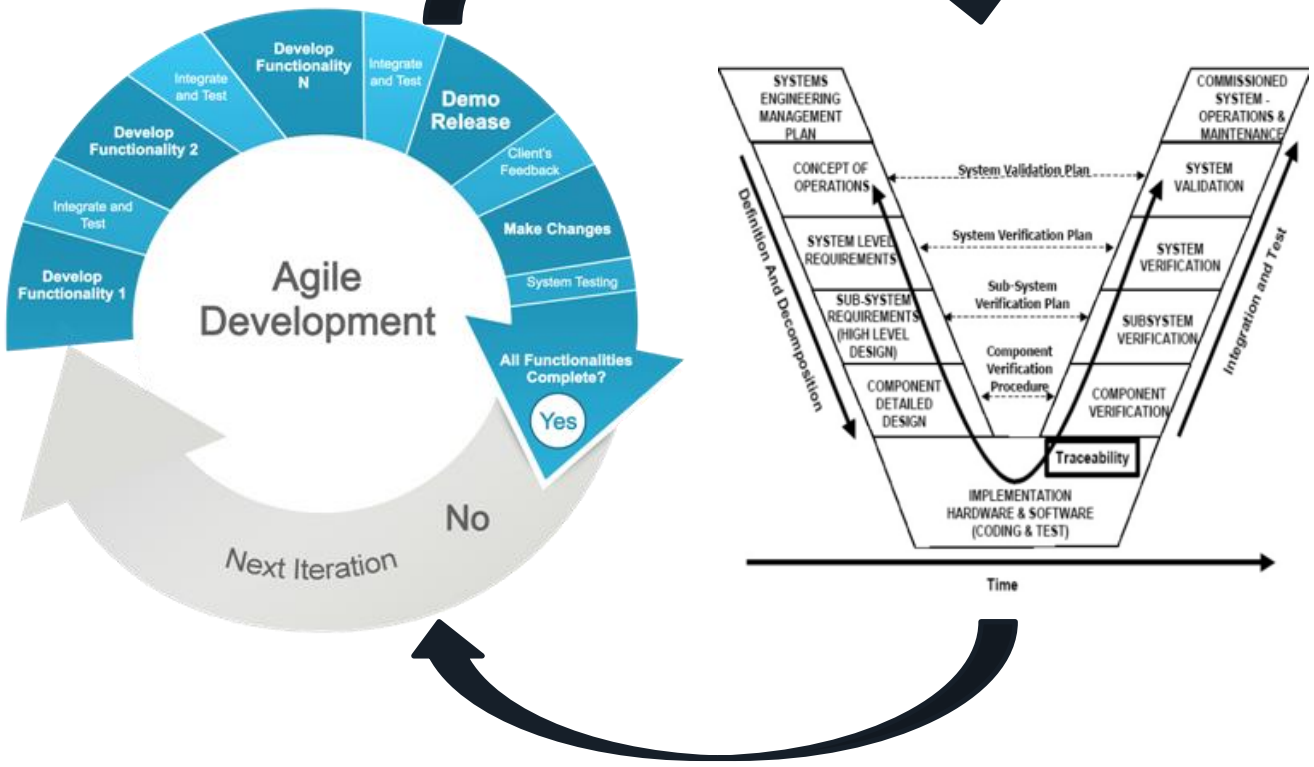


Commercial vehicle dynamics simulator

# DEVELOPMENT AND V&V FOR SAFETY

- Rapid development vs. rigorous engineering
- Agile is good for quick prototyping
- Proven concepts need “hardening”
- Even prototype needs to be safe
- No “Go fast and break things”

Proven proof of concepts




Tested and verified components

# TEAM

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**TOM KROSWEK**
BUSINESS DEVELOPMENT

**BRETT BATTLES, PH.D.**
BOARD ADVISOR

**JOHN FORMISANO**
BOARD ADVISOR

- ✓ 100+ years founder experience, 50+ AV systems deployed
- ✓ Multiple trucking products launched, thousands of units sold
- ✓ Deep expertise in freight analysis and optimization
- ✓ 22 headcount, average engineer AV experience: **14 years**

# SELECT RELEVANT PAST WORK

# WRAP UP

- Humans are lousy drivers but replacing them with machines is still an open science question
- The industry had been suffering from the “Innovator’s Dilemma”
- A more efficient, “first principles” approach is viable
- Selecting a domain and application is important from sustenance point of view
- Locomation takes a very strong “last mover” position, filters every assumption through the “know-how” and “know how not to” filters
- Autonomy will first come to freight transportation, and incrementally


# Teşekkürler!

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