SMASH

machine learning for science and humanities postdoctoral program

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IZUM Institute of Information Science, Maribor

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AI usage is for demonstrational purpose only and does not reflect reality. The image in the title slide is generated with AI

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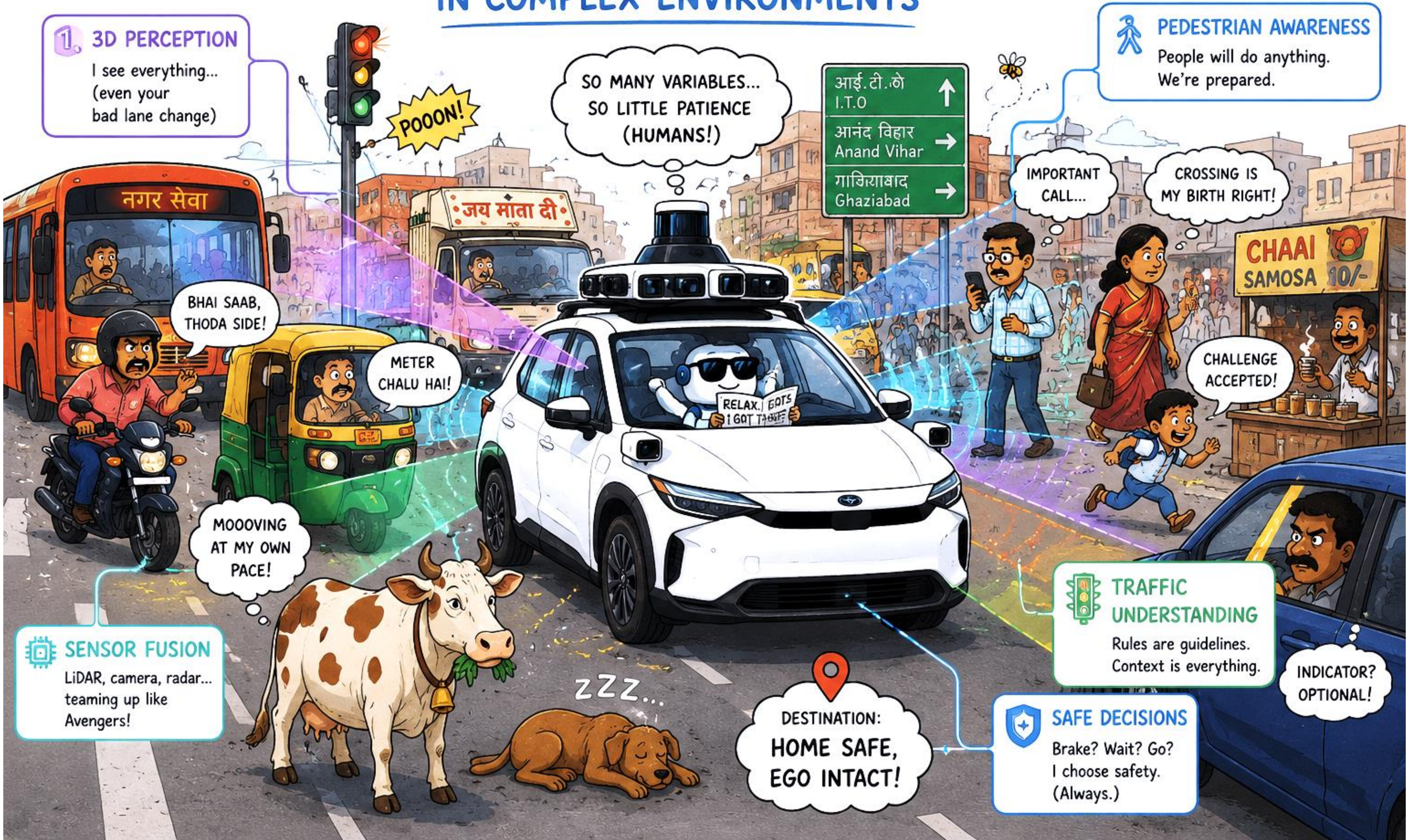
AUTONOMOUS DRIVING
IN COMPLEX ENVIRONMENTS



AI Usage


MakeAGIF.com


TOYOTA
ViralHog


नगर सेवा
•जय माता दी•
आई.टी.ओ
I.T.O
आनंद विहार
Anand Vihar
गाज़ियाबाद
Ghaziabad
SHREE GARMENTS
साई
मेडिकल स्टोर
DL1R
P5166

AI Usage


GOODS CARRIER
TATA
542 कश्मीरी गेट
चांदनी चौक
Chandni Chowk
MEENA BAZAAR
श्री जी
READYMADE
ARORA
65
इंडिया गेट
India Gate
प्रगति मैदान
Pragati Maidan
PWD
WORK IN
PROGRESS

AI Usage

SUBURBAN ROADWAYS

URBAN ROADWAYS

SUBWAYS / METROS

MOTORWAYS / HIGHWAYS

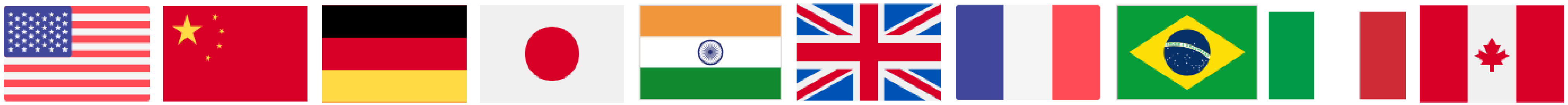
LOW-SPEED RAILWAYS

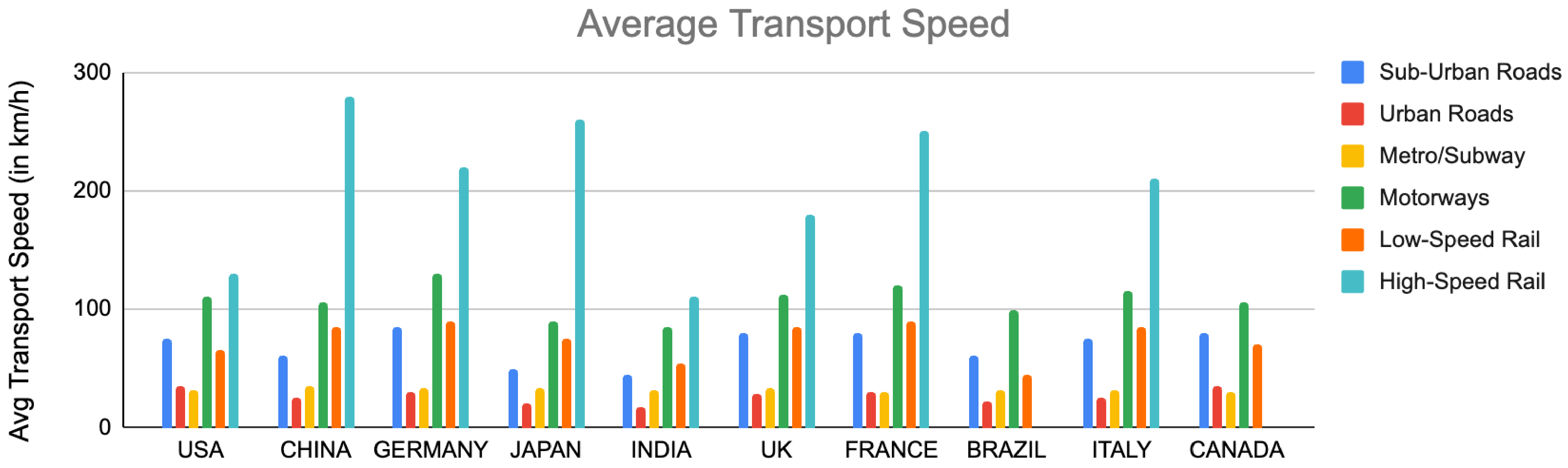
HIGH SPEED RAILWAYS

Data Sources & Methodology

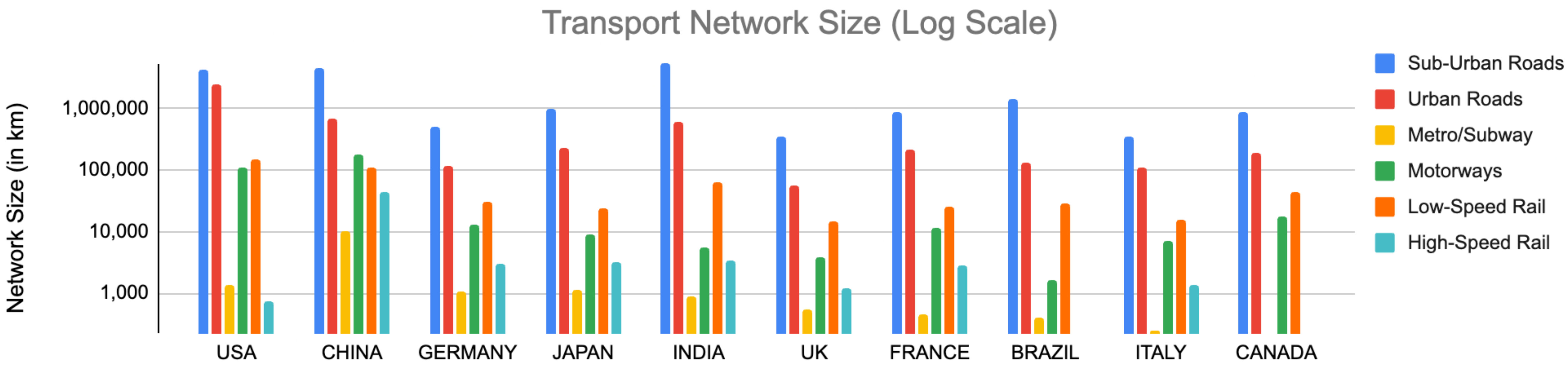
Data is synthesized from 2023-2025 reporting periods across the following primary institutional databases:

- **Roadways & Motorways:**
  - *International Road Federation (IRF)* World Road Statistics.
  - *World Bank Open Data* (Logistics Performance Index & Infrastructure datasets).
  - *OECD iLibrary* (Road transport infrastructure exposure).
  - *World Health Organization (WHO):* Global Status Report on Road Safety.
  - *European Commission (2026):* Preliminary Road Safety Statistics (detailing the 53% rural / 38% urban / 8% motorway fatality split).
  - *National Highway Traffic Safety Administration (NHTSA):* Fatality Analysis Reporting System (FARS).
- **Railways (Metro & HSR):**
  - *International Association of Public Transport (UITP)* Statistics Briefs on World Metro Figures.
  - *International Union of Railways (UIC)* High-Speed Rail reports and Atlas.
  - *Statista* Rail Industry reports (Passenger volume by country).
  - *Eurostat:* Railway safety statistics (accidents to persons by rolling stock).
  - *International Union of Railways (UIC):* Safety Performance Reports.
  - *Ministry of Railways (India):* Annual Statistical Statements (reflecting high numbers due to level crossing and trespassing incidents).
- **Daily Usage & Intensity:**
  - *National Bureau of Statistics* (various: e.g., US Bureau of Transportation Statistics, China Ministry of Transport).

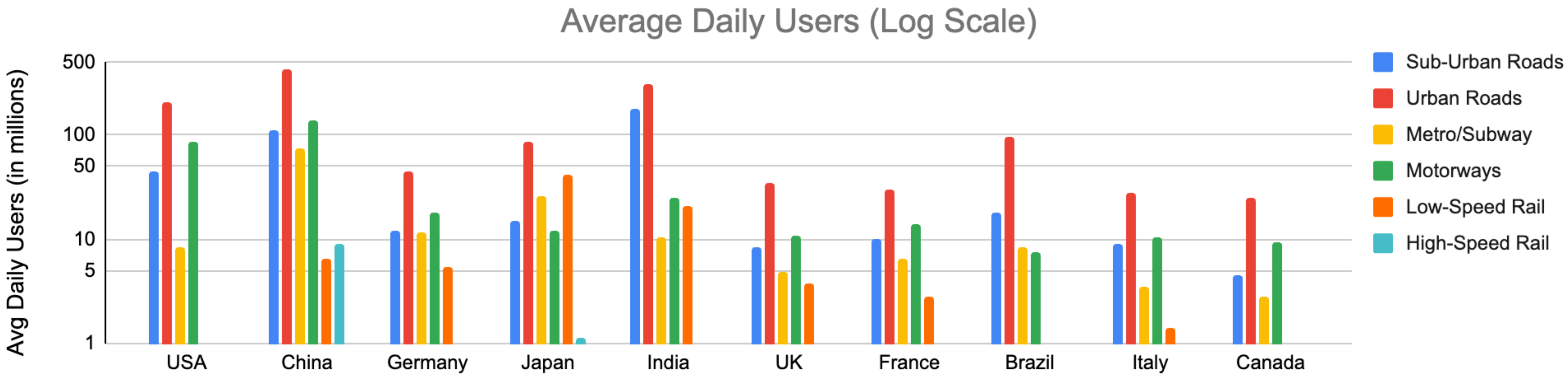


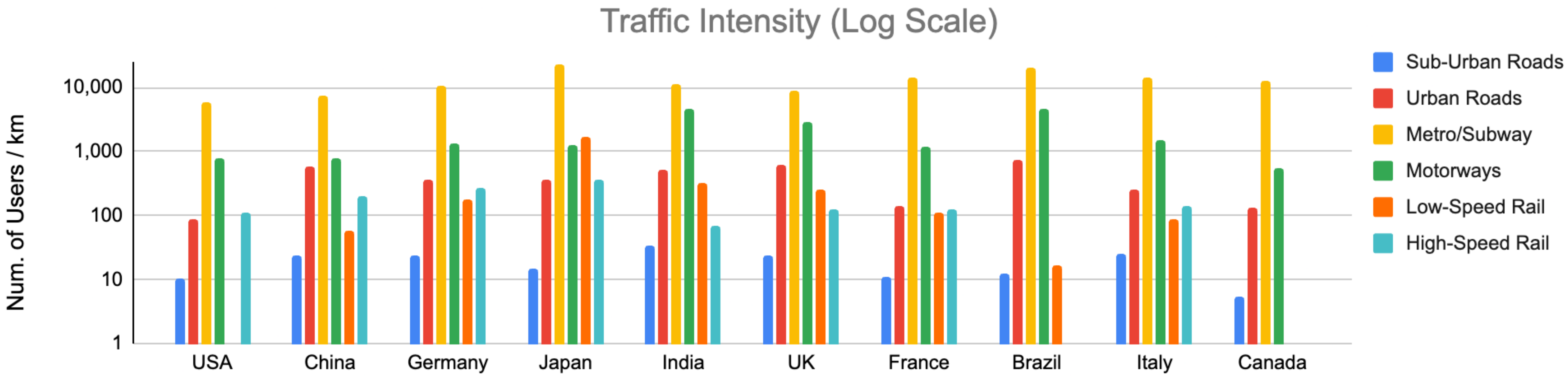


Average Transport Speed
Avg Transport Speed (in km/h)
300
200
100
0
USA
CHINA
GERMANY
JAPAN
INDIA
UK
FRANCE
BRAZIL
ITALY
CANADA
Sub-Urban Roads
Urban Roads
Metro/Subway
Motorways
Low-Speed Rail
High-Speed Rail

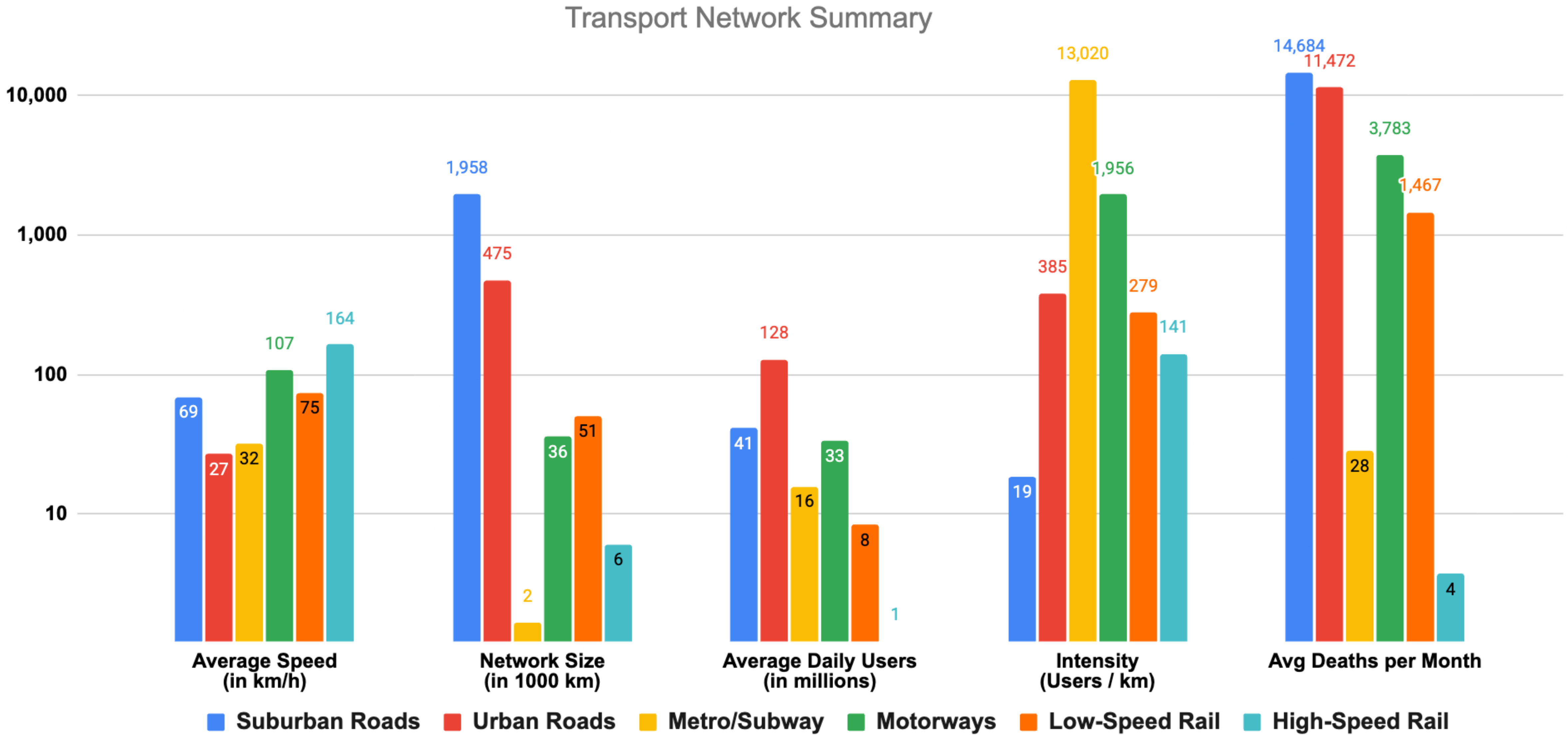


Transport Network Size (Log Scale)
Network Size (in km)
1,000,000
100,000
10,000
1,000
USA
CHINA
GERMANY
JAPAN
INDIA
UK
FRANCE
BRAZIL
ITALY
CANADA
Sub-Urban Roads
Urban Roads
Metro/Subway
Motorways
Low-Speed Rail
High-Speed Rail


Average Daily Users (Log Scale)
Avg Daily Users (in millions)
500
100
50
10
5
1
USA
China
Germany
Japan
India
UK
France
Brazil
Italy
Canada
Sub-Urban Roads
Urban Roads
Metro/Subway
Motorways
Low-Speed Rail
High-Speed Rail



Traffic Intensity (Log Scale)
Num. of Users / km
10,000
1,000
100
10
1
USA
China
Germany
Japan
India
UK
France
Brazil
Italy
Canada
Sub-Urban Roads
Urban Roads
Metro/Subway
Motorways
Low-Speed Rail
High-Speed Rail



ROADS ARE SLOWER

ROAD NETWORK IS MASSIVE

ROADS CARRY MOST PEOPLE

SUBWAYS OPTED OVER ROADS

ROADWAYS ARE DANGEROUS

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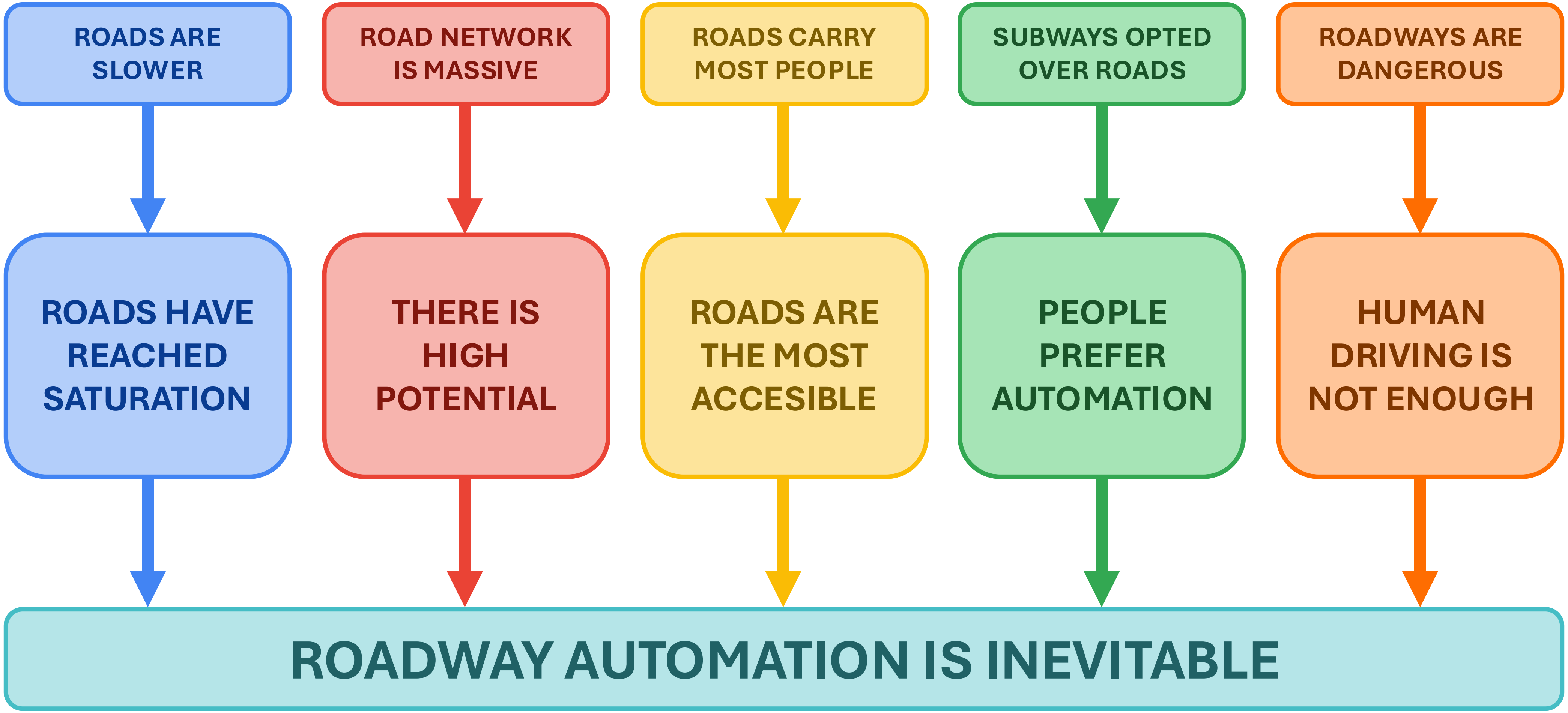

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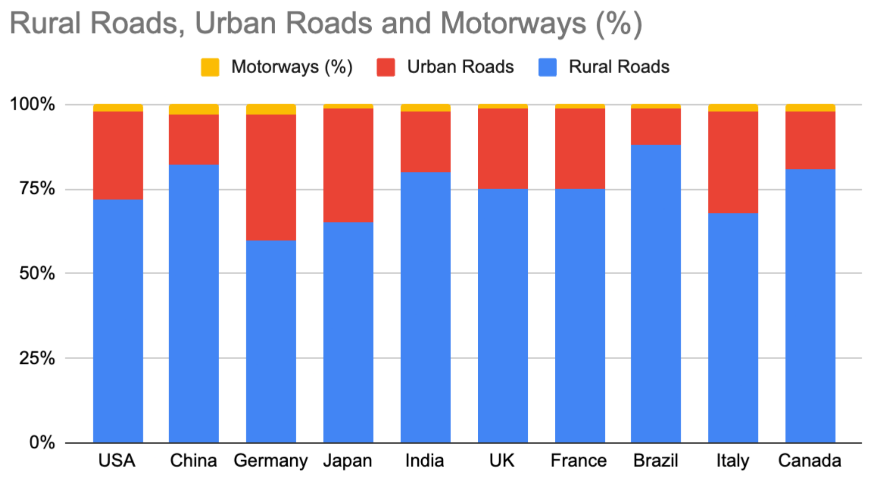
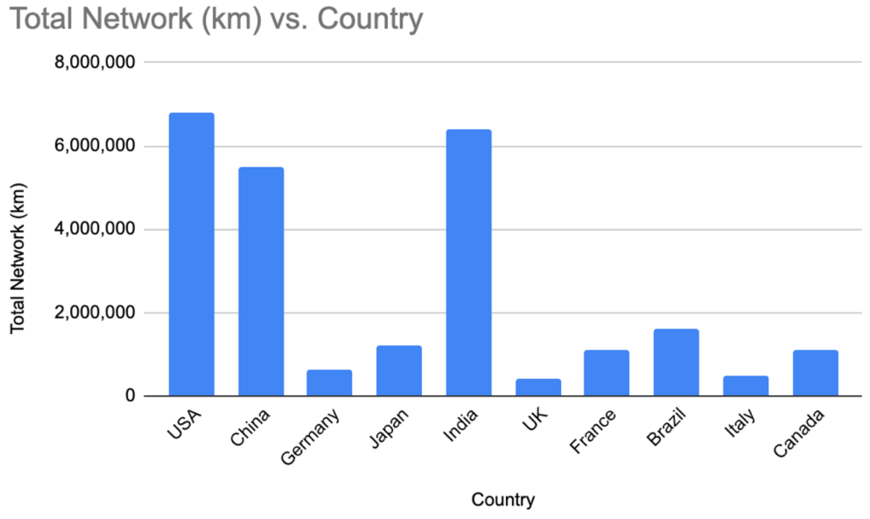
- **The Rural Dominance**
  - from "lane-keeping" to handling unmapped road
  - lack of infrastructure (V2X)
  - and high-speed edge cases.
- **The "Urban" Intensity:**
  - **Interactive complexity** (pedestrians, cyclists, and traffic signals).
- **Infrastructure Gaps:**
  - Low motorway percentages.
  - Infrastructure-agnostic navigation systems
- **The Scalability Challenge:**
  - Human driven traffic monitoring and regulation is a major challenge





The Society of Automotive Engineers

AE International (formerly the Society of Automotive Engineers) is a global association of more than 128,000 engineers and related technical experts in the aerospace, automotive, and commercial-vehicle industries.

Core Mission & Influence

- **Standards Development:** Maintains over 10,000 active standards that ensure safety, quality, and interoperability across global transport sectors.
- **Professional Development:** Provides lifelong learning resources, certifications, and technical publications for mobility professionals.
- **STEM Outreach:** Encourages future talent through programs like the Collegiate Design Series (e.g., Formula SAE).

J3016 - Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles

Standardization

Provides a functional terminology for driving automation to eliminate confusion among policymakers, engineers, and the public.

Operational Scope

Applies specifically to "on-road" motor vehicles (highways and surface streets).

Levels of Automation

Describes six levels of driving automation ranging from "No Driving Automation" (Level 0) to "Full Driving Automation" (Level 5)

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J3016 - Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles

DDT (Dynamic Driving Task) ✓

The DDT is generally split into two main categories of functions:

Operational Functions (Physical Control):

- **Lateral Motion Control:** Steering the vehicle.
- **Longitudinal Motion Control:** Accelerating and braking (managing speed).

Tactical Functions (Planning and Response):

- **OEDR (Object and Event Detection and Response):** Monitoring the environment (detecting pedestrians, other cars, traffic lights) and reacting to them.
- **Maneuver Planning:** Deciding to change lanes, turn at an intersection, or signal a turn.
- **Enhancing Conspicuity:** Using lights, signals, or the horn to communicate with other road users.

✗

Trip Scheduling: Deciding what time to leave.
Destination Selection: Deciding where to go.
Waypoint Selection: Choosing which route to take (e.g., "Take the highway instead of the scenic route").

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Level 0: No Driving Automation

Description

- The driver is always in full control of the vehicle.
- Car may provide warnings or momentary assistance (like emergency braking),
- No sustained control of steering or acceleration.

Example Features:
Forward collision warning, lane departure warning, and blind-spot monitoring.

Real-World Examples: Most older vehicle models and basic modern economy cars without "active" cruise control.

⚠ AI Usage

Level 1: Driver Assistance

Description:
- The vehicle can assist with either steering or acceleration/braking, but not both simultaneously.
- The driver must remain fully engaged and keep their hands on the wheel.

Example Features:
Adaptive Cruise Control (maintains distance) or Lane Keep Assist (corrects steering).

Real-World Examples:
Standard Adaptive Cruise Control found in many modern Toyotas, Hondas, and Fords.

AI Usage

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Level 2: Partial Driving Automation

Description

- The vehicle can control both steering and acceleration/braking at the same time.
- Driver is still "driving" and must supervise the system constantly,
- Often requiring hands on the wheel or eyes on the road via camera monitoring.

Features:

Cruise on a highway. Both speed & steering control

Real-World Examples:

Tesla Autopilot, Volvo Pilot Assist, Hyundai Highway Driving Assist, GM Super Cruise, Ford BlueCruise.

AI Usage

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Level 3: Conditional Driving Automation

Description
Under very specific conditions (such as clear weather on divided highways at lower speeds), the vehicle can take full control. The driver can take their eyes off the road but must be ready to take over immediately when the system requests it.
Example Features:
Environmental monitoring and traffic jam pilot systems. stop and go motions, cruising on emptier roads
Real-World Examples:
Mercedes-Benz DRIVE PILOT (available in select regions like Germany and Nevada/California) and Honda Legend Sensing Elite (Japan).

AI Usage

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Level 4: High Driving Automation

Description

- Vehicle can perform all driving tasks and monitor the environment in specific geographic areas (geofencing) or under certain conditions.
- No driver intervention is required within these "Operational Design Domains."
- In many cases, the vehicle might not even have pedals or a steering wheel.

Example Features:

- Autonomous urban taxi services performing door to door service.

Real-World Examples:

- Waymo One (operating in Phoenix, San Francisco, and Los Angeles) and Cruise (robotaxi services).

AI Usage

Level 5: Full Driving Automation

Description
Vehicle can drive itself anywhere a human can drive, under any conditions (weather, off-road, etc.).
No human interaction is required, and the "driver" is effectively just a passenger.

Example Features:
A car with no steering wheel that can navigate a blizzard on an unmarked dirt road just as well as a paved highway.

Real-World Examples: There are **no** commercially available Level 5 vehicles currently deployed. This remains a goal for the future of automotive technology.

AI Usage

	SAE LEVEL 0™	SAE LEVEL 1™	SAE LEVEL 2™	SAE LEVEL 3™	SAE LEVEL 4™	SAE LEVEL 5™
What does the human in the driver's seat have to do?	**You are driving** whenever these driver support features are engaged – even if your feet are off the pedals and you are not steering			**You are not driving** when these automated driving features are engaged – even if you are seated in "the driver's seat"		
	You must constantly supervise these support features; you must steer, brake or accelerate as needed to maintain safety			When the feature requests, you must drive	These automated driving features will not require you to take over driving	
	These are driver support features			**These are automated driving features**		
What do these features do?	These features are limited to providing warnings and momentary assistance	These features provide steering **OR** brake/ acceleration support to the driver	These features provide steering **AND** brake/ acceleration support to the driver	These features can drive the vehicle under limited conditions and will not operate unless all required conditions are met		This feature can drive the vehicle under all conditions
Example Features	• automatic emergency braking • blind spot warning • lane departure warning	• lane centering **OR** • adaptive cruise control	• lane centering **AND** • adaptive cruise control at the same time	• traffic jam chauffeur	• local driverless taxi • pedals/ steering wheel may or may not be installed	• same as level 4, but feature can drive everywhere in all conditions

DISCLAIMER

THE NEXT FEW SLIDES ARE A CASE STUDY OF THE WAYMO AUTONOMOUS DRIVING SYSTEM

I am not an authorised spokesperson of Waymo
I am only showcasing information provided by Waymo publicly in their websites and blogs

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20M+ rides served

And counting - with a 93% satisfaction rate from our riders.*

2009

- The Google self-driving car project begins
- 10 uninterrupted 100-mile routes in a Toyota Prius

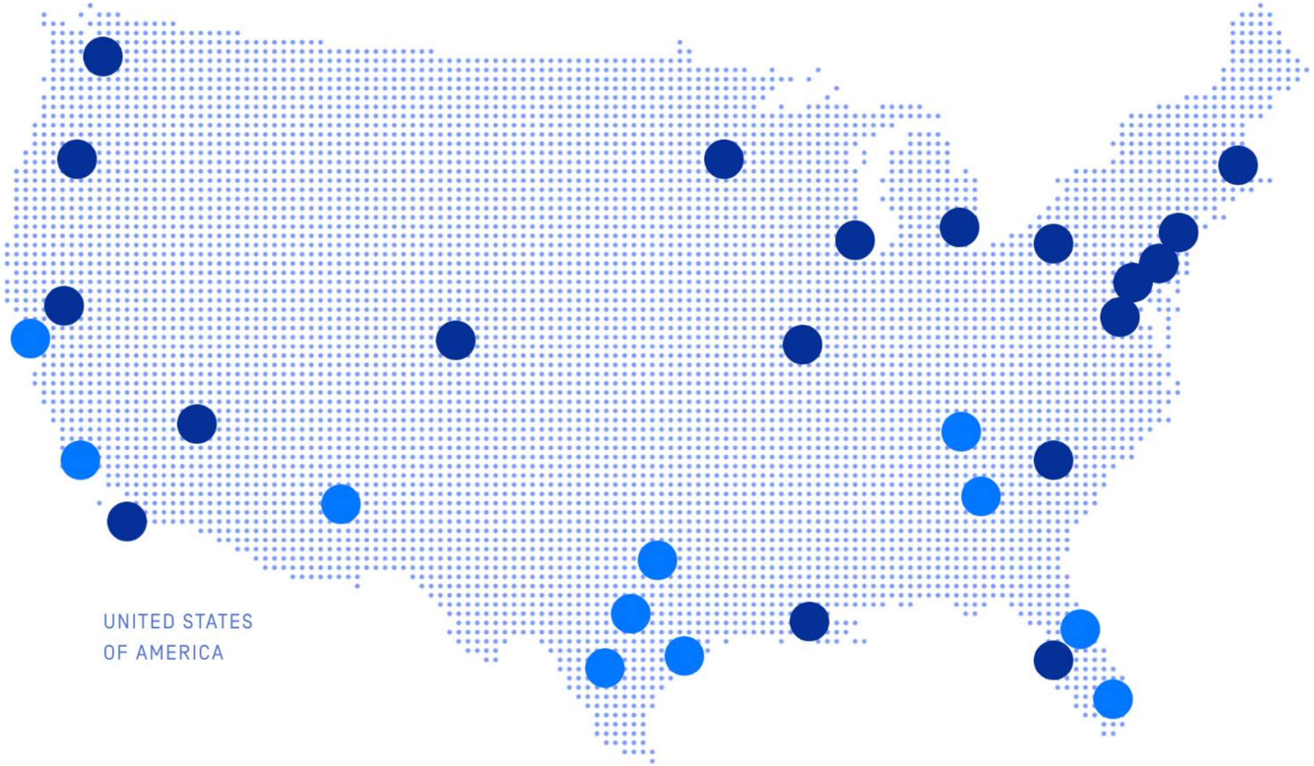
2015

- First fully autonomous ride on public roads.
- Steven Mahan took the world's first fully self-driving ride on public roads in Austin, TX. Steve is legally blind.

2016

- Waymo becomes independent

Where Waymo is driving



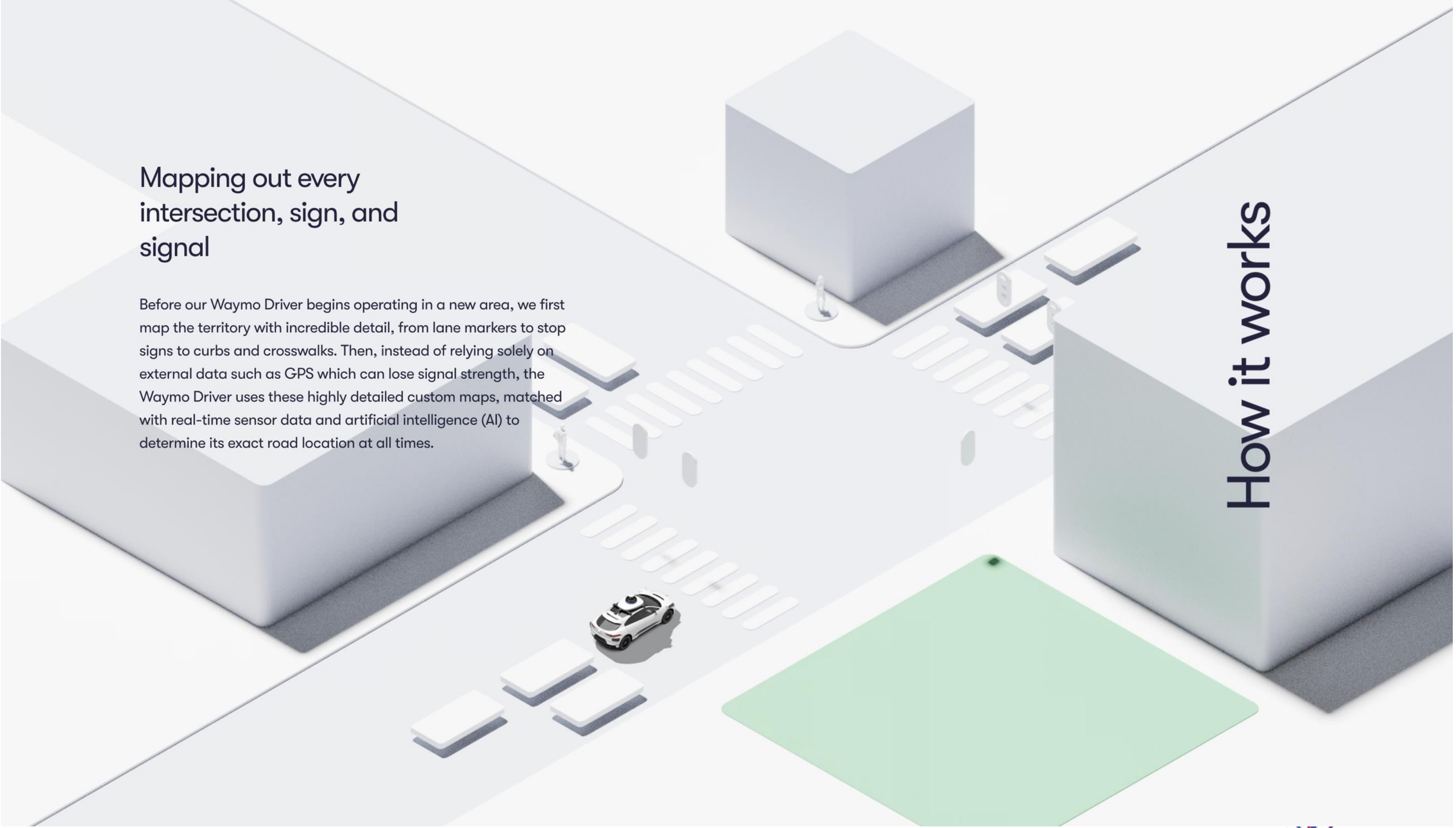
SERVING RIDERS IN

UP NEXT

How it works

Mapping out every intersection, sign, and signal

Before our Waymo Driver begins operating in a new area, we first map the territory with incredible detail, from lane markers to stop signs to curbs and crosswalks. Then, instead of relying solely on external data such as GPS which can lose signal strength, the Waymo Driver uses these highly detailed custom maps, matched with real-time sensor data and artificial intelligence (AI) to determine its exact road location at all times.



How it works

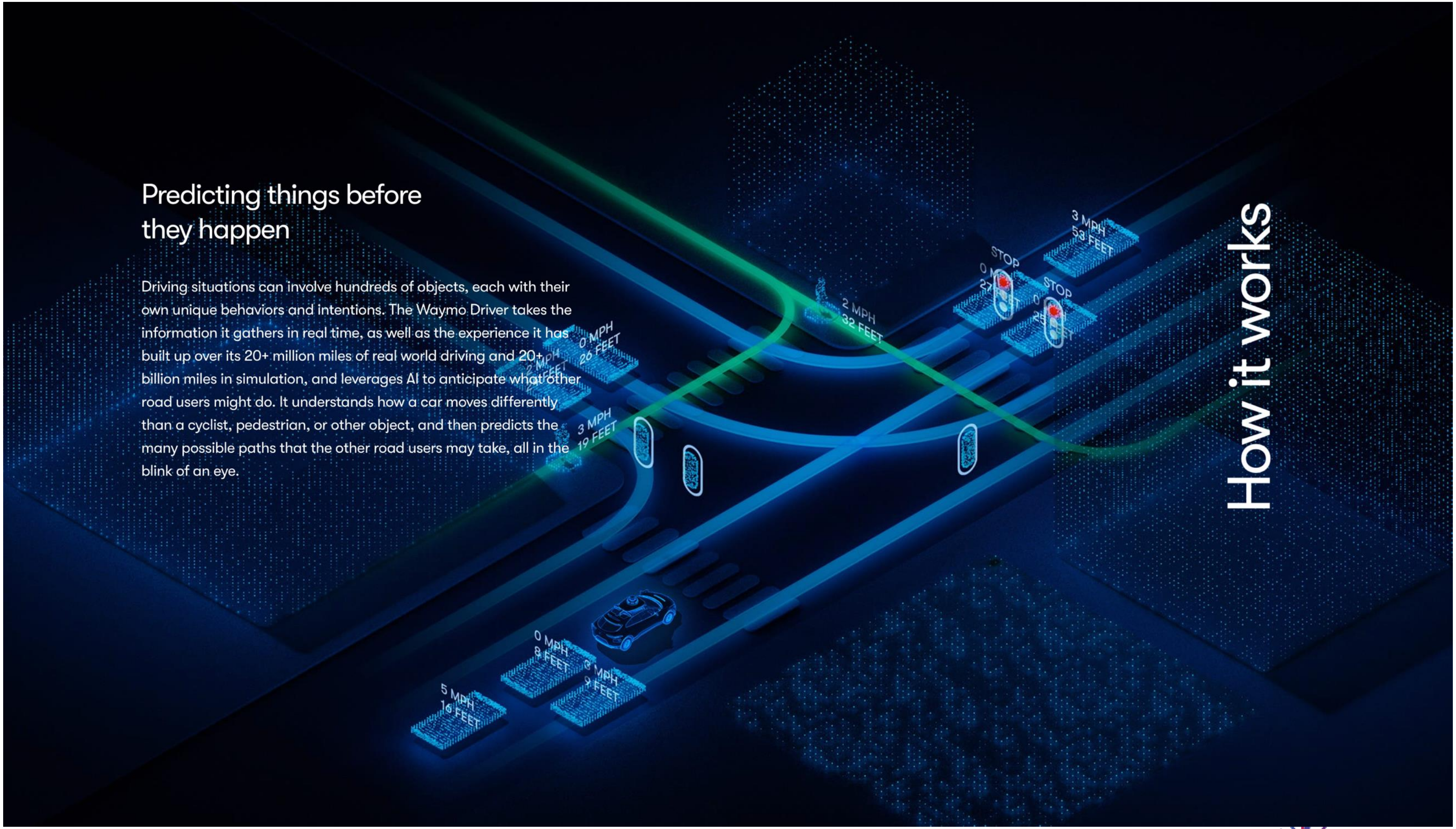
Keeping an eye on everything, all at once

The Waymo Driver's perception system takes complex data gathered from its advanced suite of car sensors, and deciphers what's around it using AI - from pedestrians to cyclists, vehicles to construction, and more. The Waymo Driver also responds to signs and signals, like traffic light colors and temporary stop signs.

How it works

Predicting things before they happen

Driving situations can involve hundreds of objects, each with their own unique behaviors and intentions. The Waymo Driver takes the information it gathers in real time, as well as the experience it has built up over its 20+ million miles of real world driving and 20+ billion miles in simulation, and leverages AI to anticipate what other road users might do. It understands how a car moves differently than a cyclist, pedestrian, or other object, and then predicts the many possible paths that the other road users may take, all in the blink of an eye.



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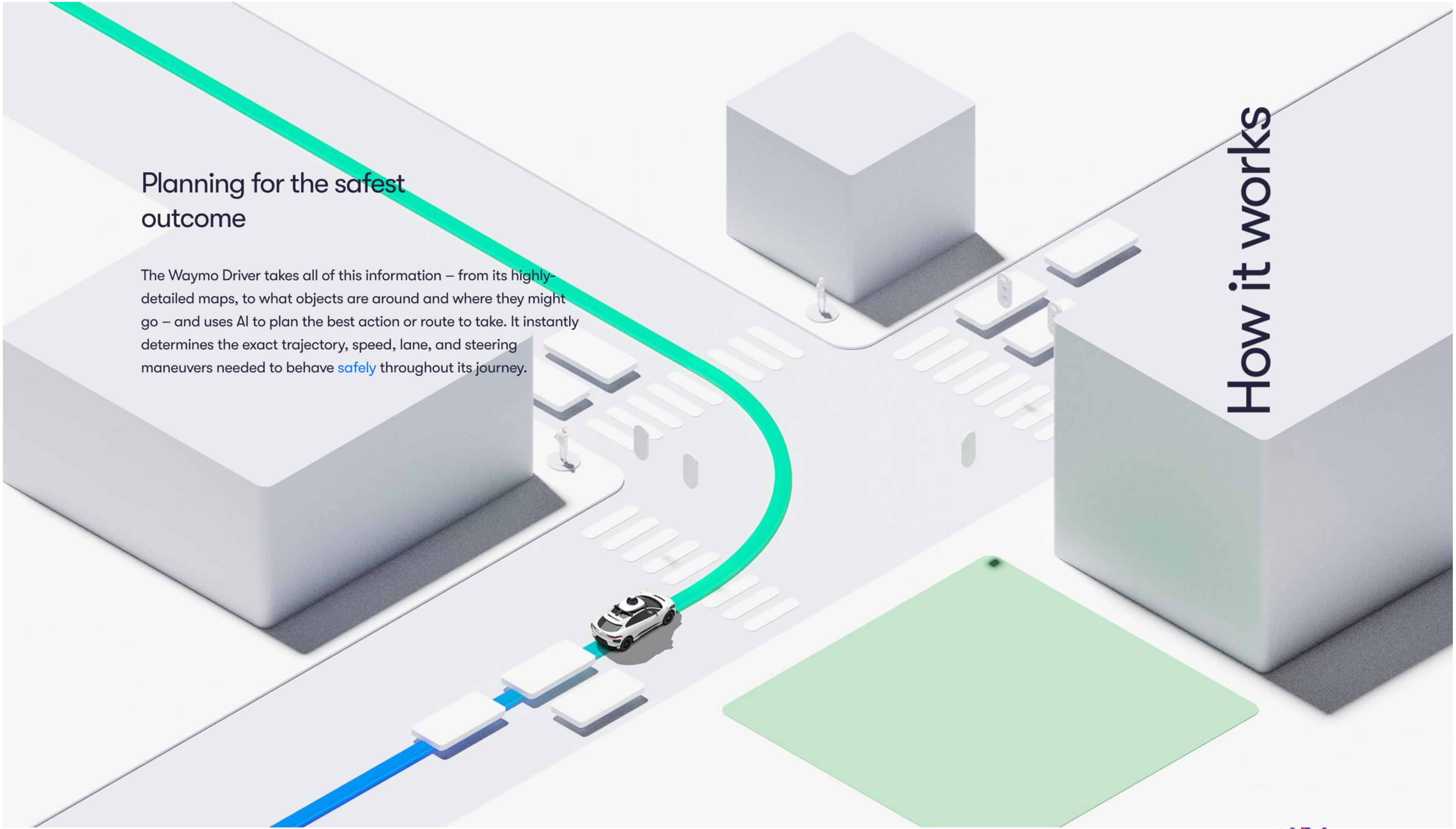
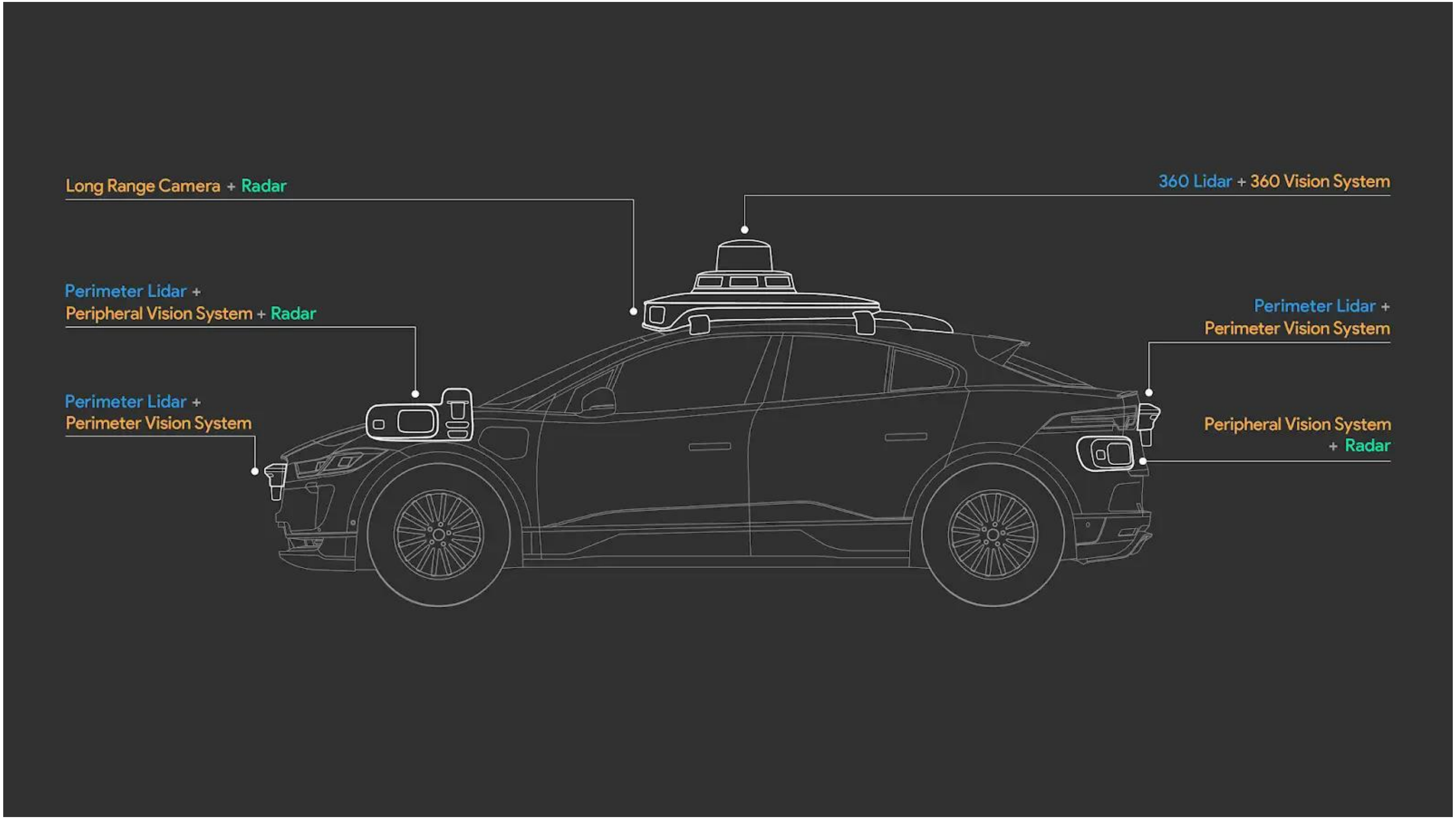
How it works

Planning for the safest outcome

The Waymo Driver takes all of this information – from its highly-detailed maps, to what objects are around and where they might go – and uses AI to plan the best action or route to take. It instantly determines the exact trajectory, speed, lane, and steering maneuvers needed to behave safely throughout its journey.





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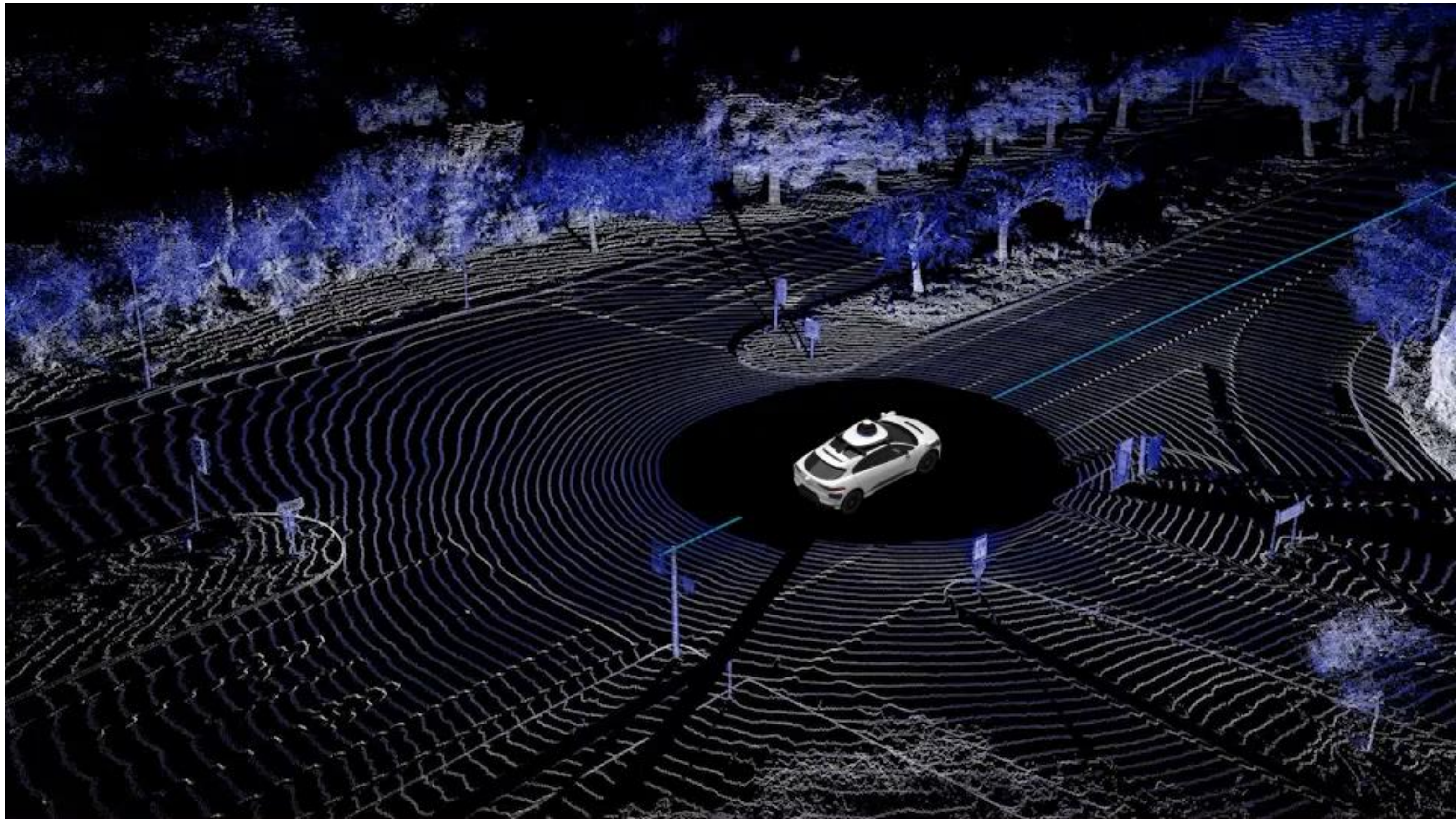
LiDAR: The 3D Architect

(Light Detection and Ranging)

- **Primary Function:** High-precision 3D geometry and depth mapping.
- **360° Vision:** Top-mounted and perimeter sensors eliminate all blind spots.
- **Spatial Accuracy:** Centimeter-level precision for object shape and distance.
- **Lighting Independent:** Consistent performance in total darkness.

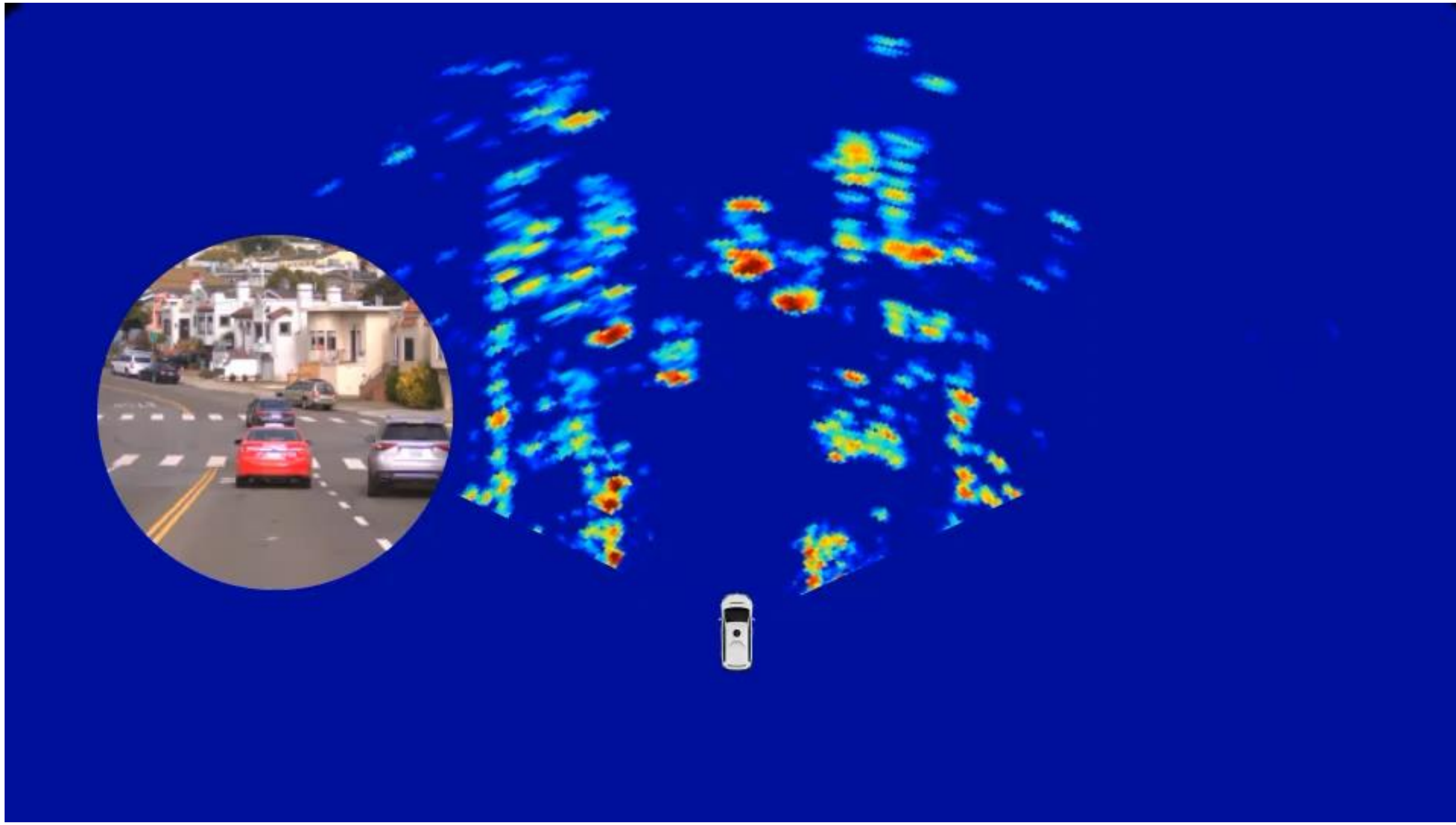


Cameras: The Semantic Eye

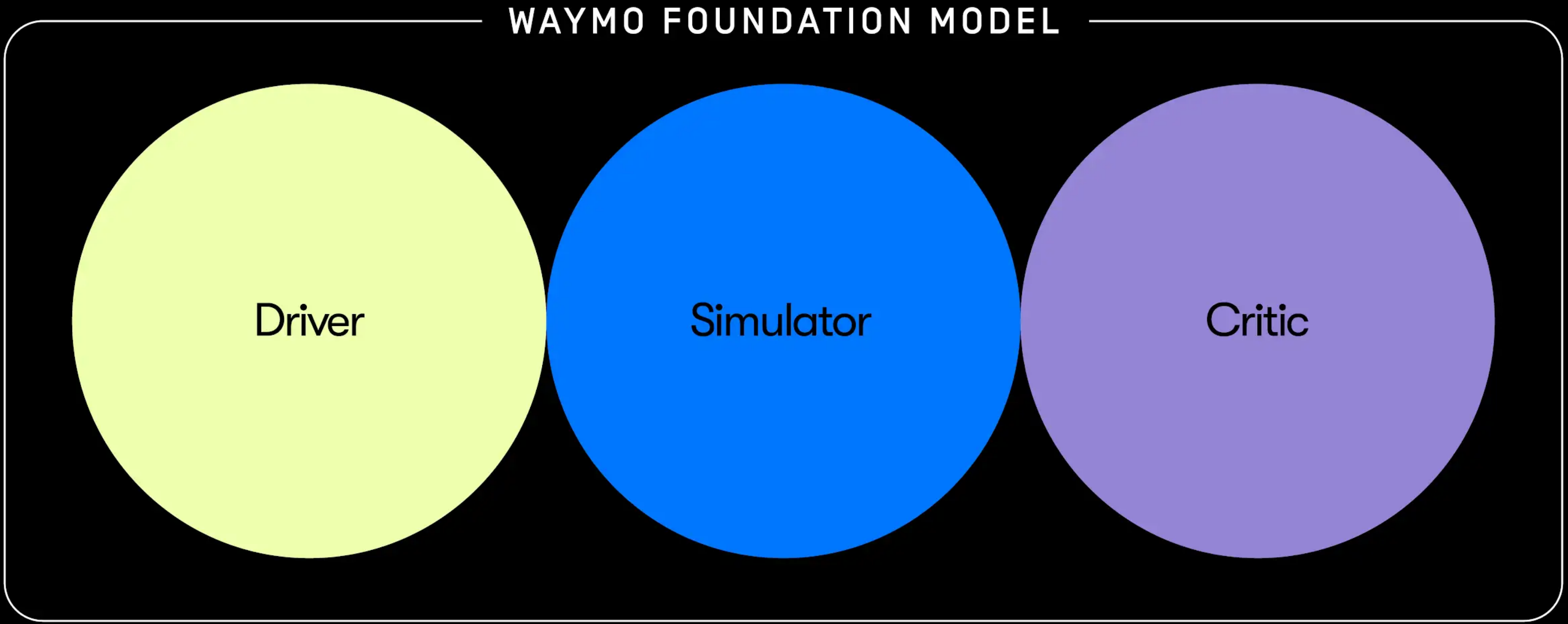
Primary Function: Classification and long-range visual context.
Object Identification: Reads traffic lights, road signs, and emergency signals.
Extreme Range: Detects small objects and obstacles over 500m away.
Multi-Lens Array: 13 overlapping cameras for a seamless visual field.

RADAR: The Weather Specialist

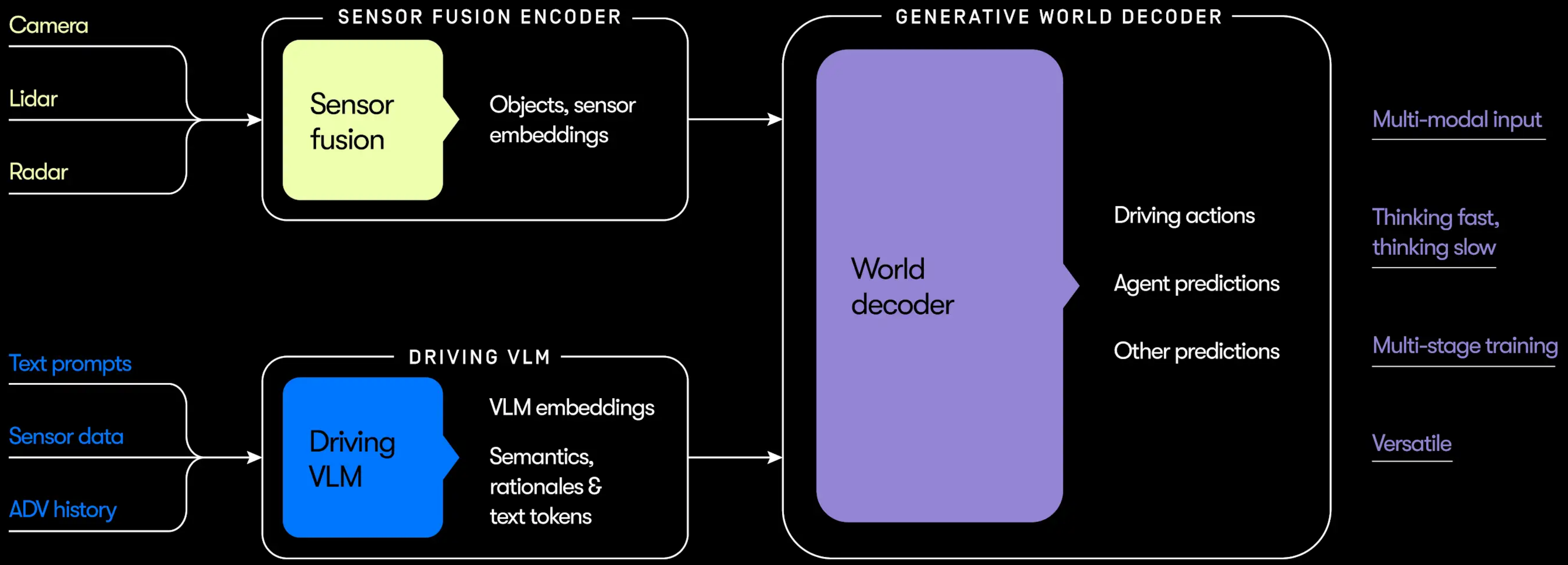
Primary Function: Velocity tracking and all-weather reliability.
Doppler Effect: Instant measurement of object speed and direction.
Environmental Immunity: Operates through heavy fog, rain, and snow.
Imaging RADAR: High-resolution detection of stationary and moving targets.



Waymo's Holistic Approach to Demonstrably Safe AI



The Waymo Foundation Model



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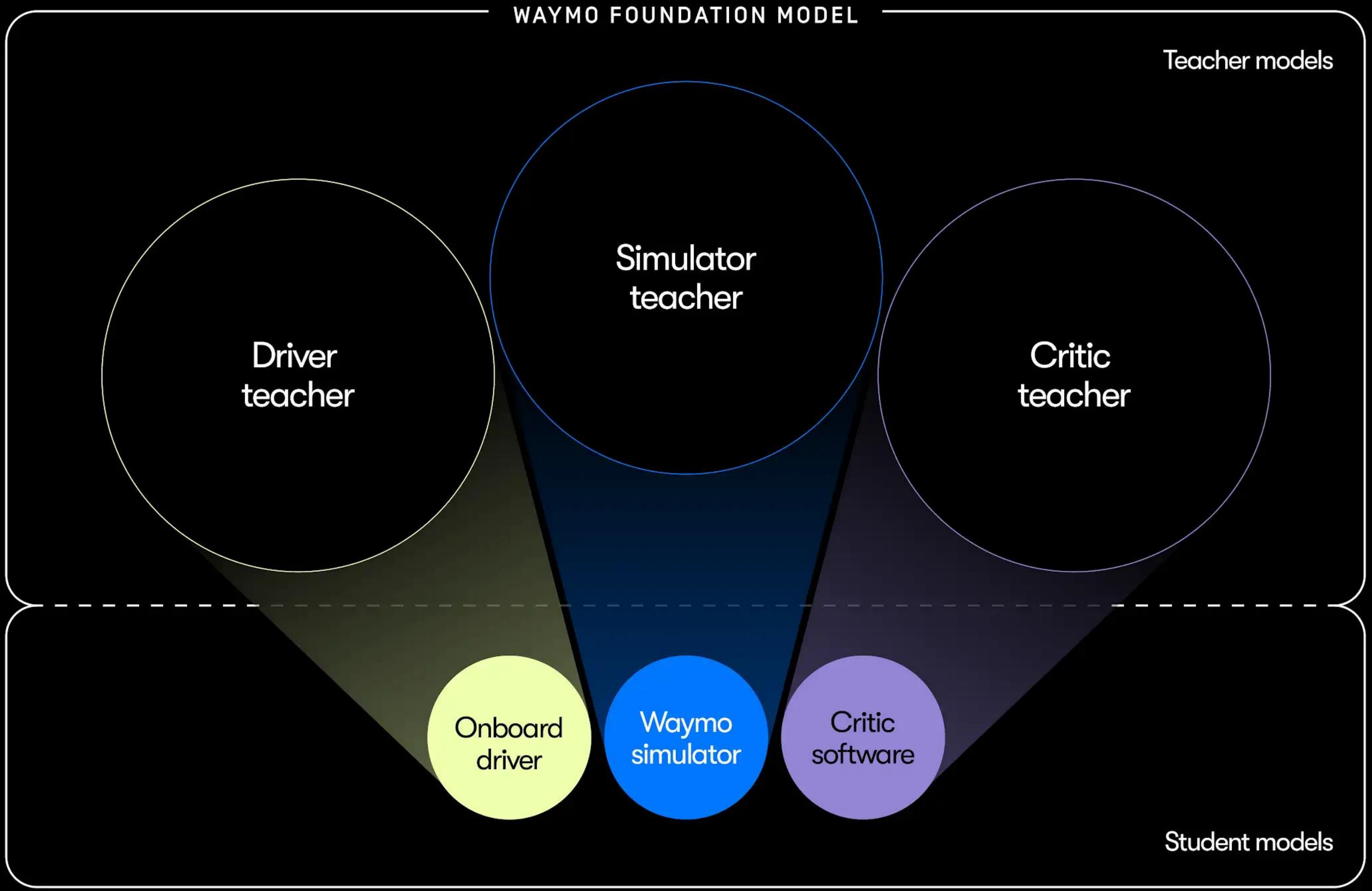
Waymo's AI ecosystem



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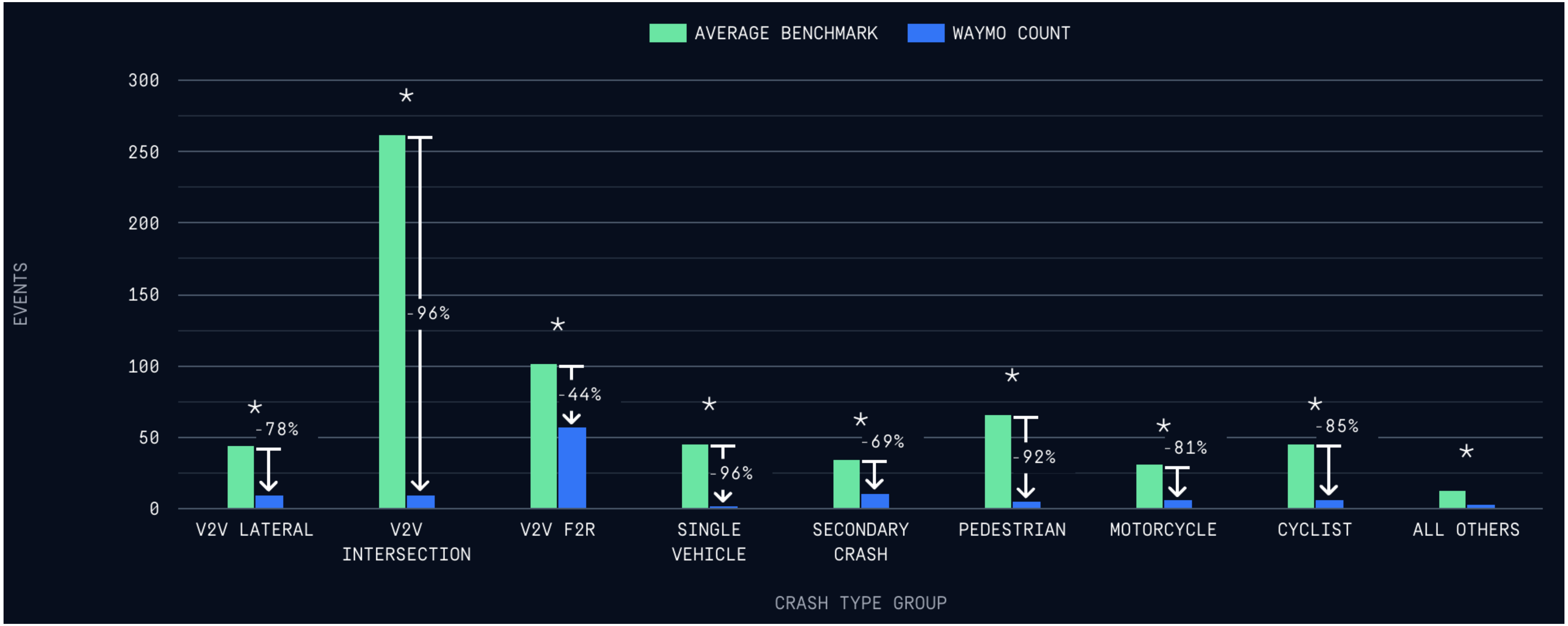
Accident Reduction



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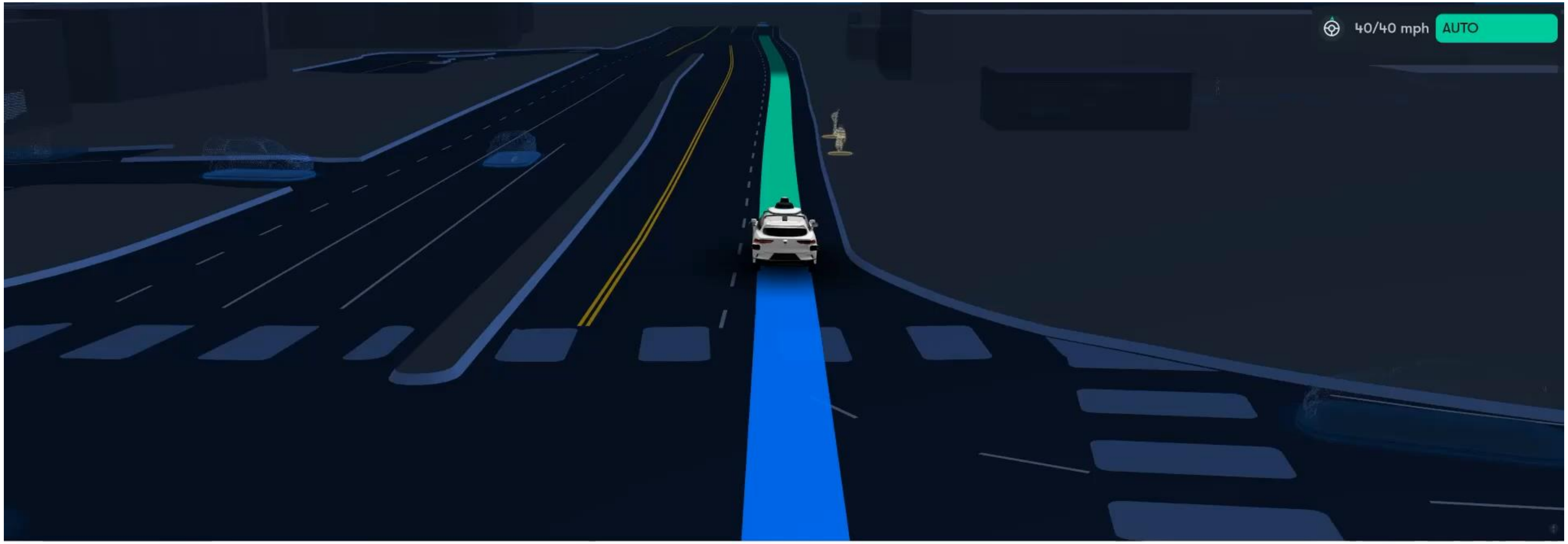
Accident Reduction



SCOPE FOR RESEARCH

SENSE
- Multi Sensor Fusion
- Information Embedding
- BVR Prediction
- Segmentation
- Detection
- Projection
- Missing Data

PLAN
- NN Design
- Rule based Systems
- AD Agents
- Safety Constraints
- Long-tailed Scenarios
- Unregulated Traffic
- Route Simulation

ACT
- Realtime Operations
- Response time
- Resource Optimization
- HCI Improvements
- Quality of Driving
- Emergency Response
- Conspicuous Driving

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GAPS

TECHNICAL

- Long-tailed Events
- Extreme weathers
- Entropy in Traffic
- Data Scarcity
- Reaction Time
- Communication

COGNITIVE

- Ability of Computer Vision
- Semantic Intelligence
- Social Norms
- Emotional Aspects of Traffic

INFRASTRUCTURE

- Road Qualities
- Infrastructure is built for Humans
- V2X communication
- VIoT infrastructure
- 5G anc connectivity
- Monitoring

REGULATORY

- AI Education
- New Policies
- Uniformity of Traffic Laws
- AI Certification

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OPPURTUNITIES

SERVICE

- Mobility as a Service
- From Ownership to Subscription on demand
- Ride Sharing - Reduced number of vehicles, parking spaces
- Better mobility solutions for physically impaired or elder individuals

LOGISTICS

- AV supply chains
- AV trucks can operate 20+ hours a day
- AV Platoons can operate more optimally and consume lesser fuel
- Personnel Costs will be lowered
- Reduced journey times due to V2X capabilities

SAFETY

- AVs will have lesser accident rates
- Avs have a more diverse set of sensors
- Avs are not emotional, always rational
- No loss of focus due to fatigue
- V2X communication can improve holistic traffic quality.

MARKET

- Biggest Consumer Market in Densest Areas
- Most complex traffic, most frustration, most loss of time and fuel in big cities
- Human drivers in dense traffic can cause chaos.
- Shift from personal cars to shared AVs.
- Optimized fuel usage, No Honking.

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THREATS

SECURITY

- Adversarial Attacks
- Denial of Service
- Hijacking
- Jamming

TRUST

- AI Mistakes won't be forgiven
- Public reactions
- Lack of AI knowledge will prevent trust building

LABOR

- AVs will eventually replace drivers one day.
- AVs will need personnel with new skill sets
- Labor Unions and Politics
- Transition will be messy

ETHICS

- Choosing the lesser evil
- Moral Frameworks (Human vs AI)
- Passenger vs Pedestrian
- Who will be accused / defended ?

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SOME EXISTING COMPUTATIONAL INFRASTRUCTURE

Category	Key Solutions & Technologies	Primary Functions & Features
Software Stacks & AI	*NVIDIA Alpamayo 1*	Open-source VLA model for reasoning-based autonomy without HD maps.
	Autoware	Open-source stack with native Internet of Cameras (NATIX) support.
	Wayve AI Driver	Mapless "Embodied AI" platform using generative world models (GAIA).
	Apollo (Baidu)	Mature open-source platform for L4 robotaxi and urban NOA fleets.
Hardware & Compute	*NVIDIA DRIVE Thor*	Centralized car computer delivering up to 2,000 TOPS for AI workloads.
	Qualcomm Dragonwing	SoC designed for Physical AI and cross-domain cockpit/ADAS integration.
	MediaTek Dimensity Auto	High-end AI processors (S1/P1 Ultra) with integrated NVIDIA GPUs.
	Horizon Robotics	Specialized SoCs for scaled highway and urban navigation (NOA).
Simulation & Infrastructure	*NVIDIA Omniverse*	High-fidelity world models for physics-based, closed-loop sensor testing.
	CARLA	Industry-standard simulator for autonomous driving research and RL training.
	IPG nxtAIM	Generative trajectory planning and synthetic dataset validation.
	C-V2X / Smart City	Cooperative perception and Roadside Units (RSUs) for edge intelligence.
Middleware & Dev-Ops	*ROS 2*	Standardized robotic communication layer and middleware.
	BlackBerry QNX	Safety-certified real-time operating system (RTOS) for automotive.
	NVIDIA Halos	Comprehensive safety architecture for ASIL-D compliant systems.
	Cloud Data Factories	Managed pipelines (AWS/Azure) for curating and training on massive datasets.

SOME EXISTING PHYSICAL INFRASTRUCTURE

Facility	Location	Core Infrastructure & Capabilities
ZalaZone	Hungary	250-hectare site featuring a **Smart City zone**, high-speed handling, and specific V2X (Vehicle-to-Everything) communication testing modules. Integrated with AVL's simulation toolchain.
AstaZero	Sweden	World's first full-scale independent test environment. Features a unique **Multilane Road** and **Rural Road** setup designed for complex edge-case scenarios and 5G-enabled autonomous drone/vehicle coordination.
MIRA Technology Park	UK	A leading mobility R&D cluster with over 35 global OEMs. It offers dedicated **Cybersecurity testing** and a specialized human-centered design center for passenger trust in autonomy.
American Center for Mobility (ACM)	USA (Michigan)	A 500-acre campus with a **2.5-mile high-speed highway loop**, tunnels, and urban intersections. It acts as a primary node for the US National V2X Deployment Plan.
K-City / Gwangju City	South Korea	Beyond the K-City track, the government recently designated the **entire city of Gwangju** as a regulatory sandbox, deploying 200 software-centric vehicles for 24/7 real-road data collection.
Transpolis	France	A "living lab" that recreates a 1:1 scale urban environment with reconfigurable buildings, enabling testing of vehicle interaction with pedestrians and cyclists in a controlled setting.

SOME EXISTING PHYSICAL INFRASTRUCTURE






acility	Location	Core Infrastructure & Capabilities
ZalaZone	Hungary	250-hectare site featuring a **Smart City zone**, high-speed handling, and specific V2X (Vehicle-to-Everything) communication testing modules. Integrated with AVL's simulation toolchain.
AstaZero		e **Multilane** and 5G-
MIRA Technology Park		cated for
American Center for Mobility (ACN		and urban ment Plan.
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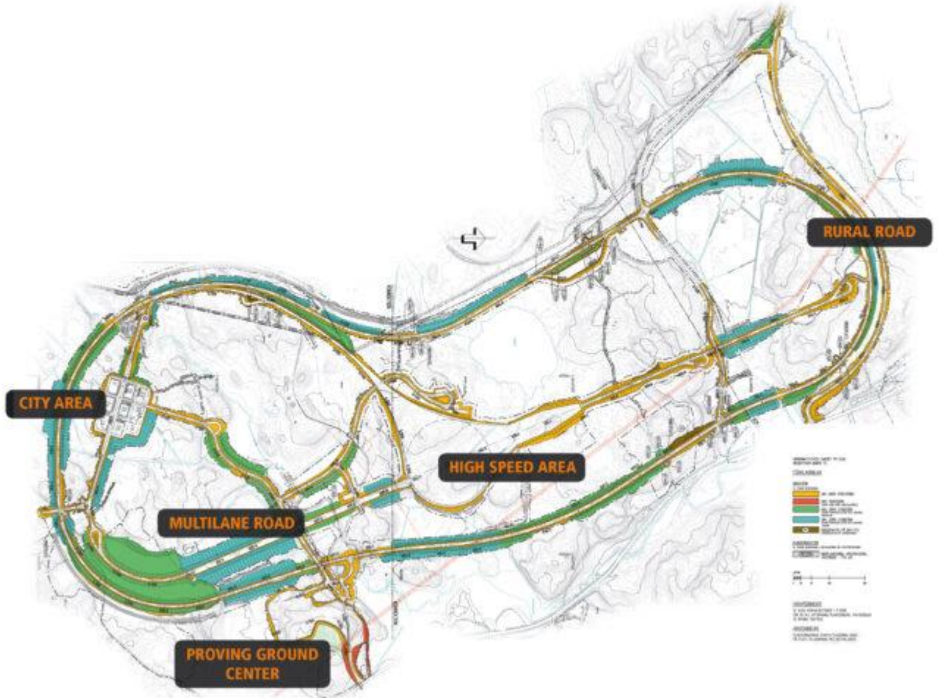

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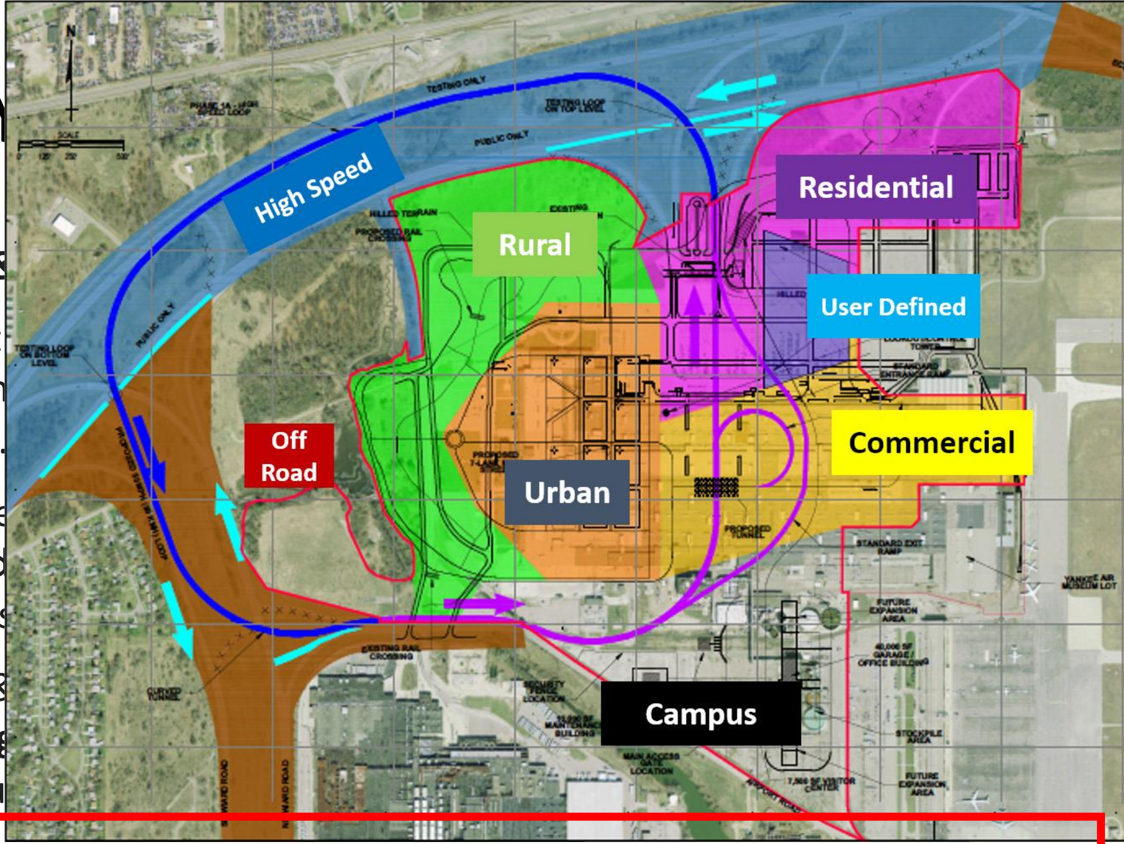

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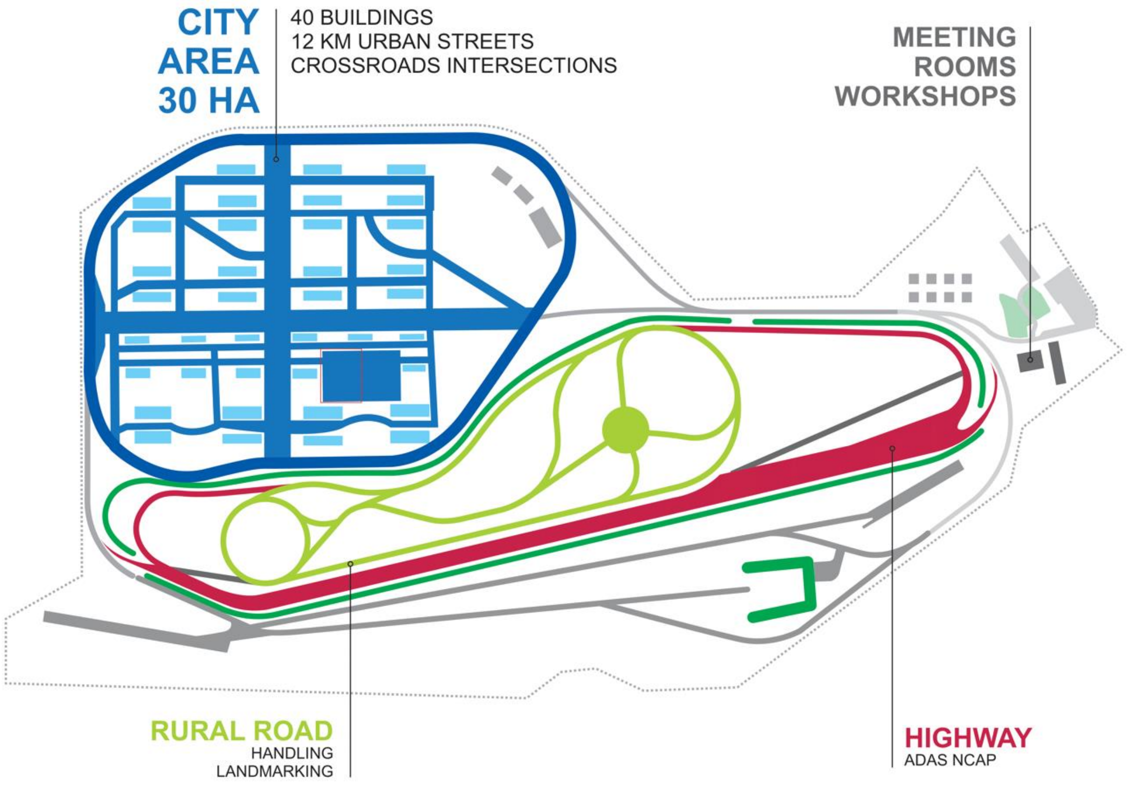
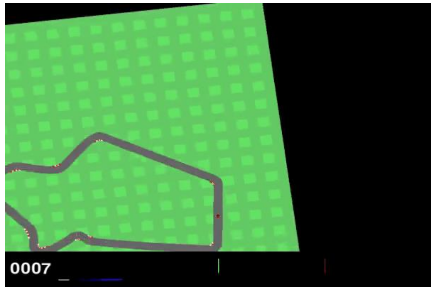
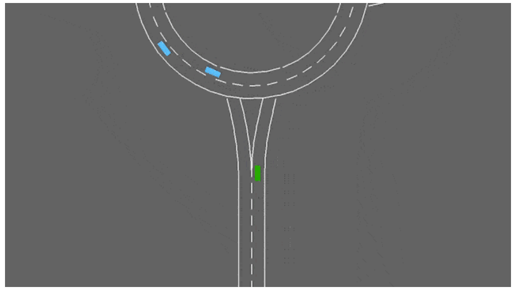
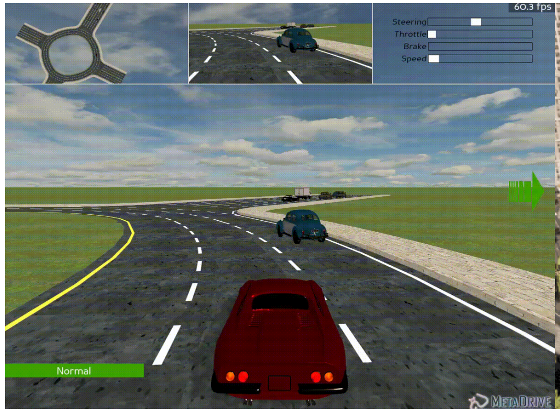
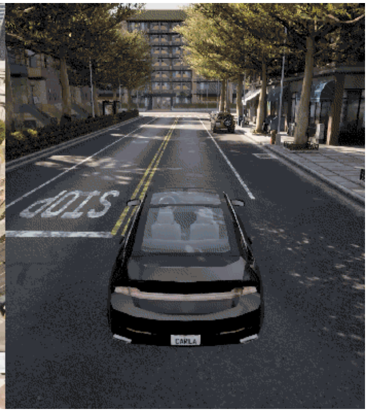


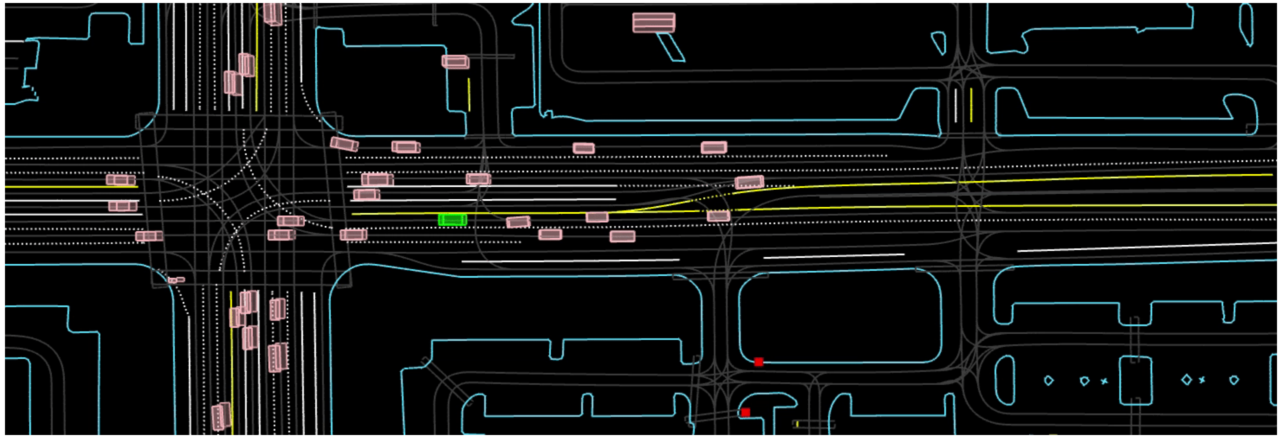
SOME EXISTING SIMULATION PLATFORMS



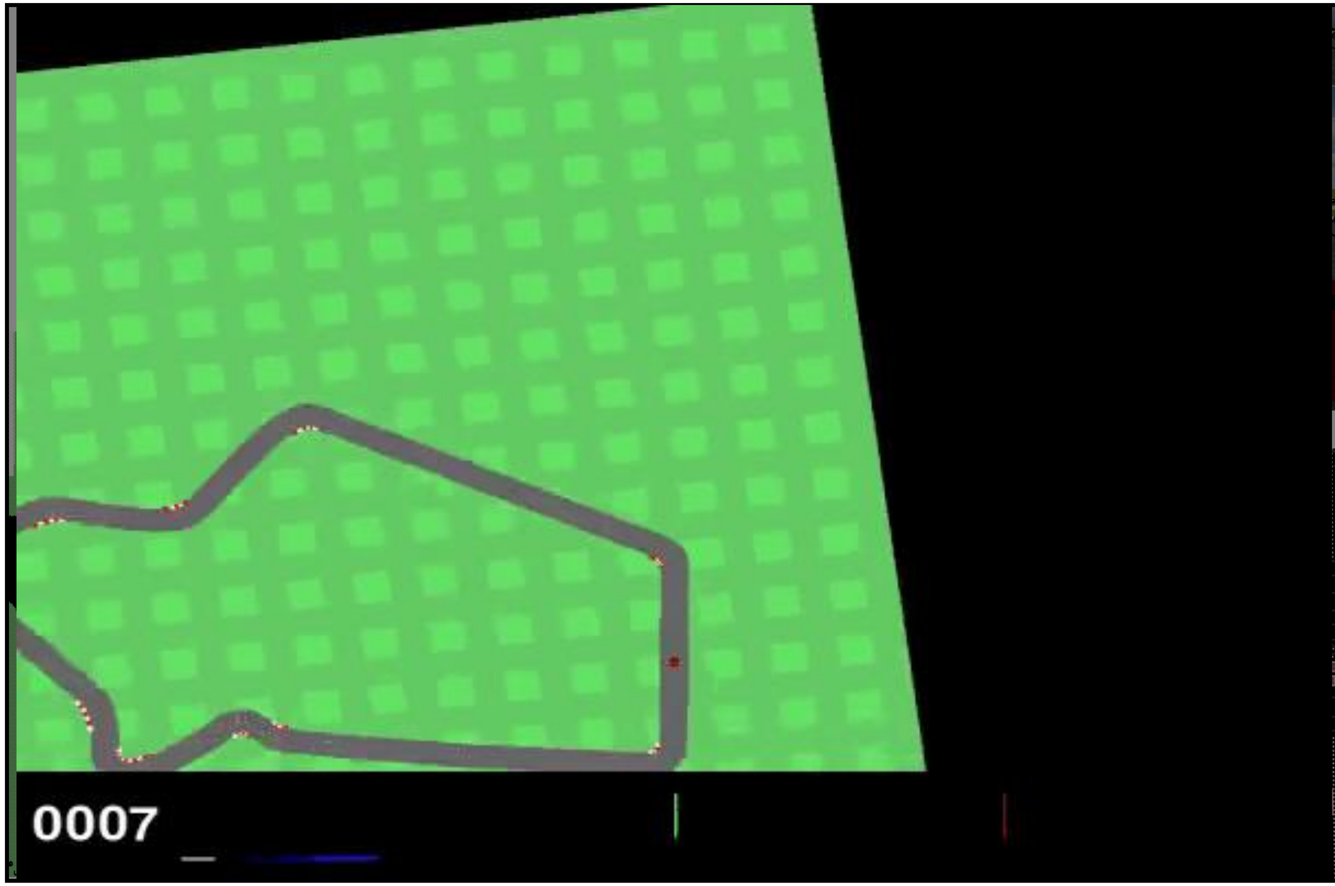


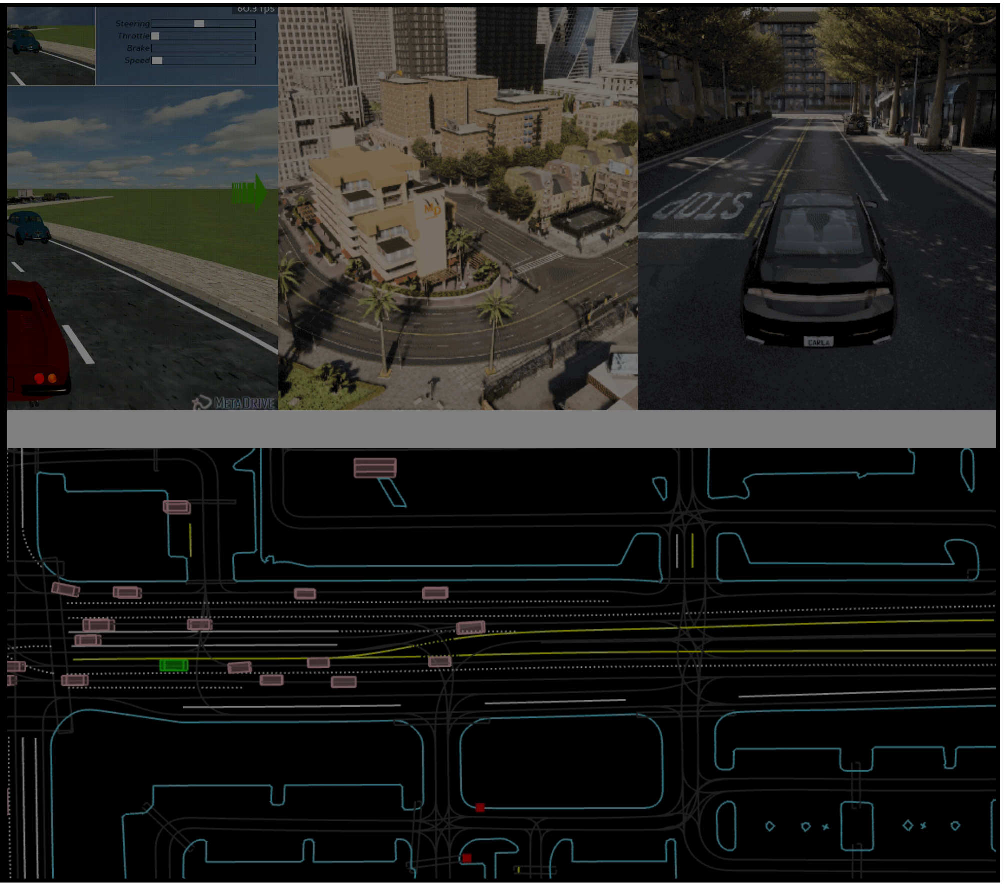




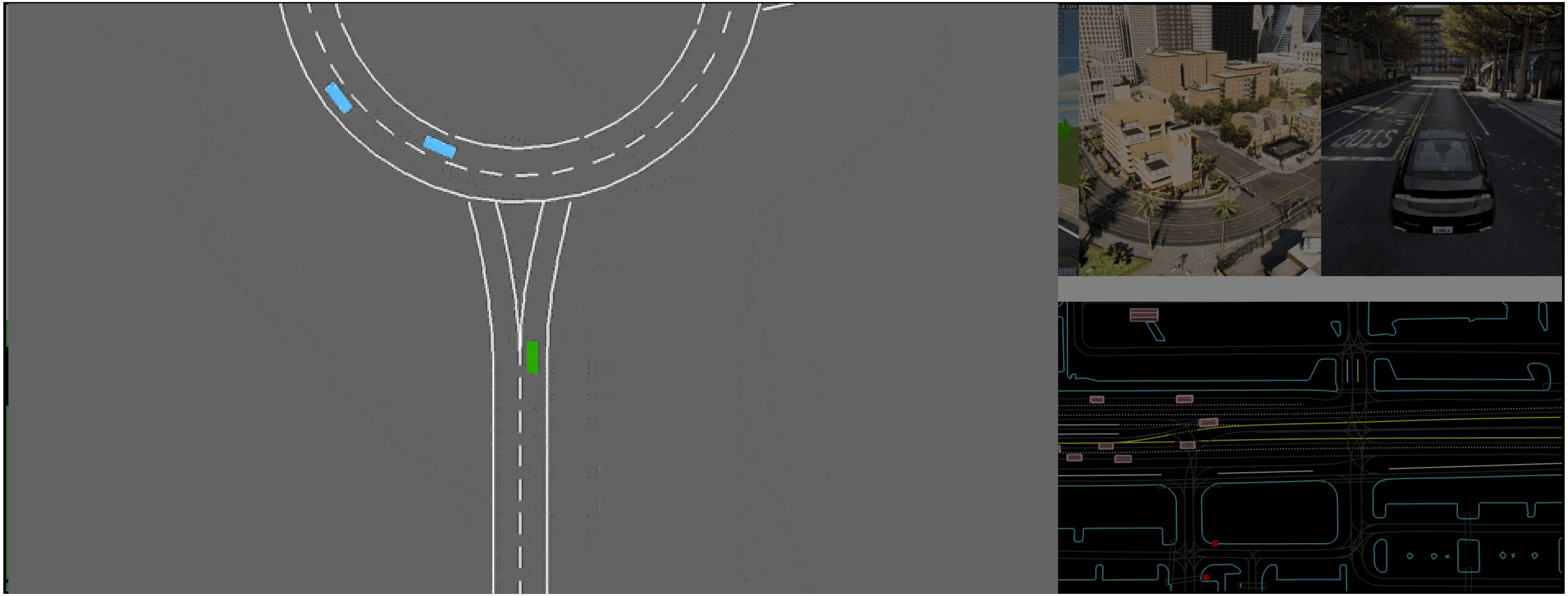


GYMNASIUM – CAR RACING

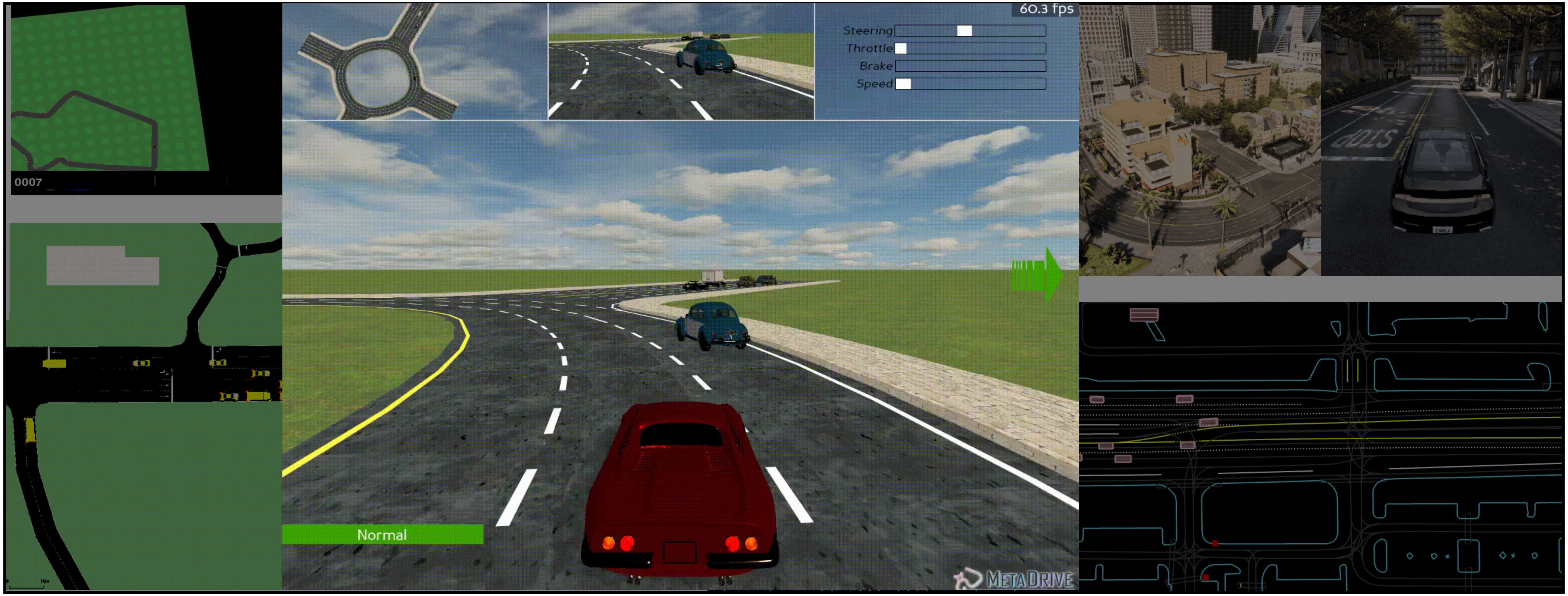




GYMNASIUM - HIGHWAY



METADRIVERSE



CARLA

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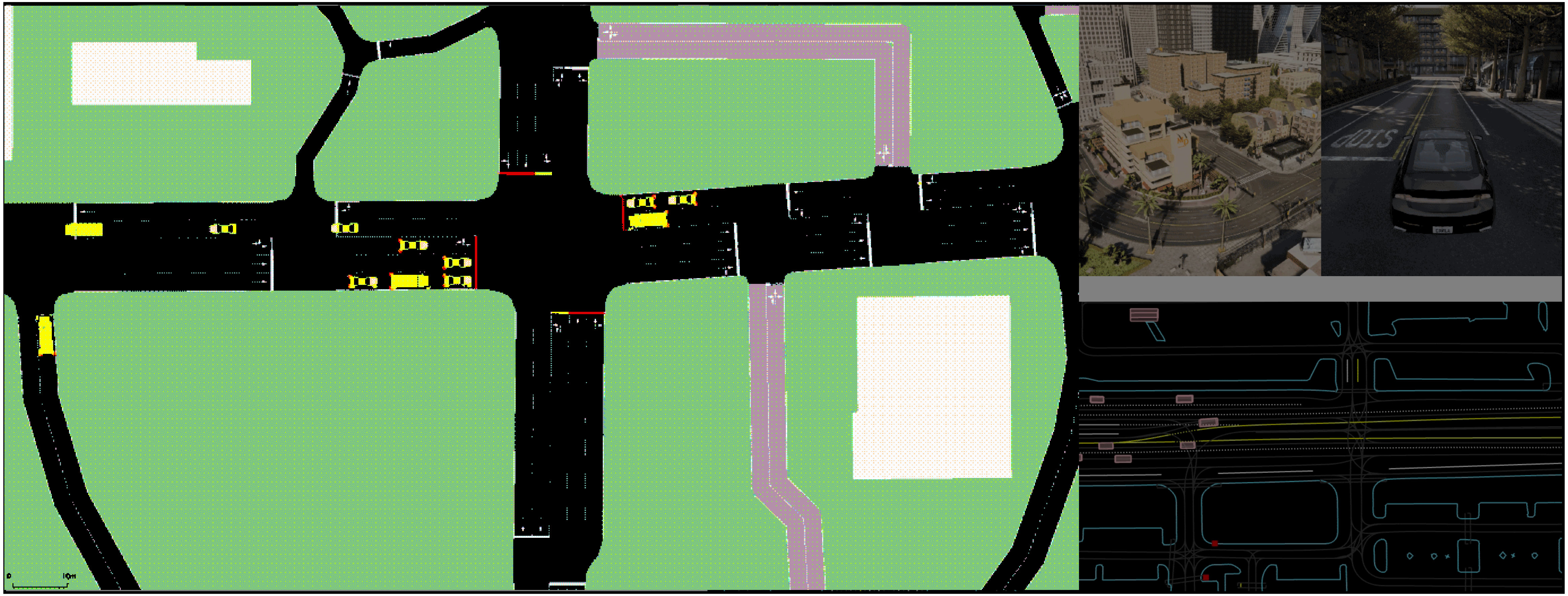
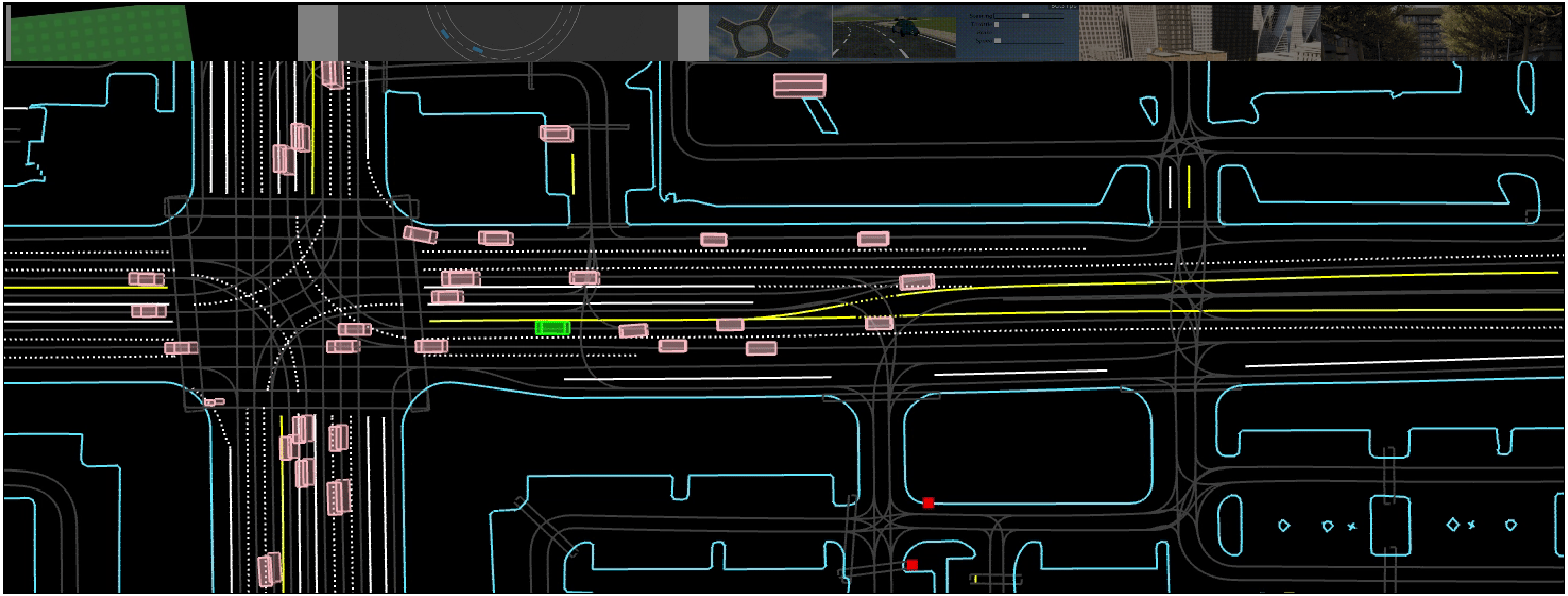
SUMO



WAYMAX



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LANCER : LEARNING AUTONOMOUS NAVIGATION IN COMPLEX ENVIRONMET USING REINFORCEMENT

- Develop reinforcement learning systems for training autonomous driving agents
- Particularly focusing on complex environments with high entropy
- Variable environment conditions, secondary agents, and dynamics of traffic.

Why RL for Autonomous Driving

Traditional robotics relies on **explicit programming**, but driving is an **implicit negotiation**.

- **Handling the "Long Tail" of Edge Cases:**
  - Classic algorithms struggle with rare, unpredictable scenarios (e.g., a distracted pedestrian, erratic lane changes).
  - RL generalizes better by learning *policies* rather than hard-coded rules.
- **Adaptive Decision Making in Dynamic Traffic:**
  - Driving isn't just about lane keeping; it’s about interacting with other "agents."
  - RL is naturally suited for multi-agent environments where the ego-vehicle must predict and react to the intent of others.
- **Optimization of Conflicting Objectives:**
  - Drivers constantly balance **Safety**, **Efficiency**, and **Comfort**.
  - Through the **Reward Function**, RL can find a mathematical "sweet spot" between these trade-offs that is difficult to tune manually.
- **Reduction of Engineering Complexity:**
  - Replaces thousands of "if-else" statements with a unified learning framework.
  - Reduces the need for hand-engineered heuristics in motion planning

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Why RL for Autonomous Driving

We don't want to tell the car *how* to drive

↓

We want to tell it what a *good* driving looks like

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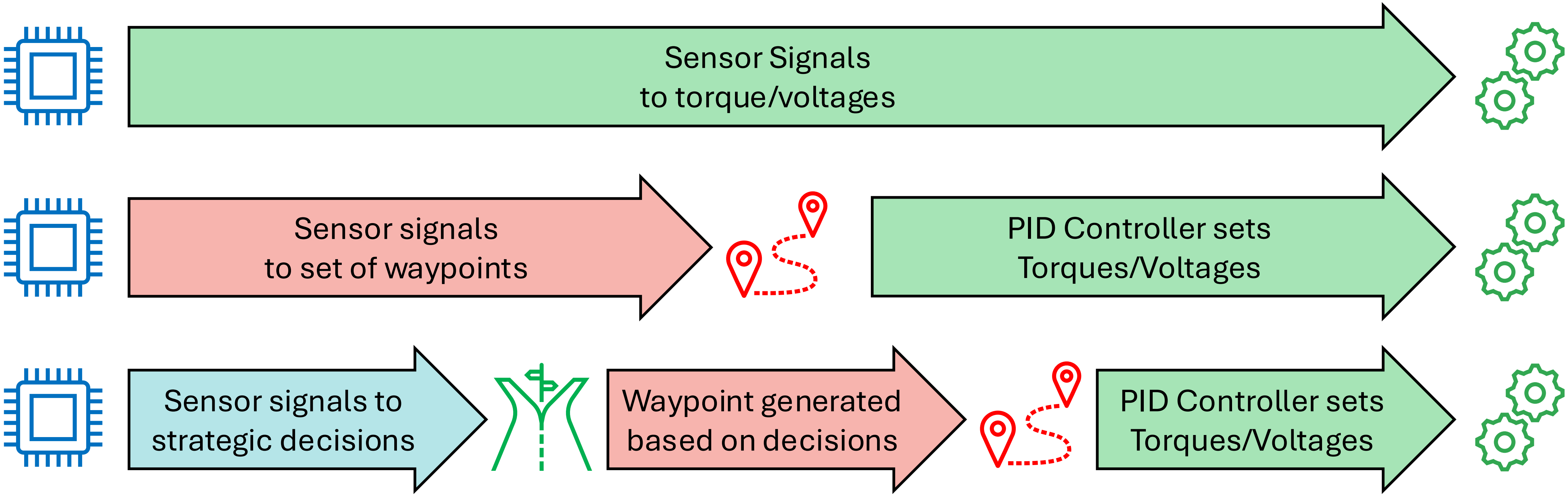
Control Hierarchies in RL for Driving



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OBSERVATION SPACE

Raw Sensor Information

- RGB Sensors
- LIDARs
- RADARs
- IMU/GNSS/GPS etc

Derived Information

- Road Markings
- Pedestrian Position & Vectors
- Vehicle Position & Vectors
- Self Position & Vectors
- Anticipated Future Positions
- Drivable vs Non-Drivable Area
- Traffic Signals and Signs

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ACTION SPACE

The Control Hierarchy
The action space determines how the agent interacts with the environment. In AV research, we generally categorize these into two levels:

Continuous Action Space (The Standard)

- **Actions:** Throttle $[0, 1]$, Brake $[0, 1]$, and Steering $[-1, 1]$.
- **Pros:** Allows for high-precision, smooth driving maneuvres.
- **Cons:** Harder to explore during training; the agent might "vibrate" the steering wheel initially as it learns.

Discrete Action Space (The Simplified)

- **Actions:** Preset modes: [Stay in Lane, Lane Change Left, Lane Change Right, Accelerate, Brake].
- **Pros:** Simplifies the learning problem significantly; great for high-level tactical decision-making.
- **Cons:** Results in "jerky" movements; cannot handle fine-grained emergency steering.

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ACTION SPACE

Low-Level vs. Mid-Level Control

- **Direct Control (Low - Level):** The RL agent outputs raw torque/voltage commands. This requires the agent to learn basic physics (like friction) alongside traffic rules.
- **Waypoint Tracking (Mid - Level):** The RL agent outputs a **Target Waypoint** or a **Target Speed**, which is then fed into a traditional controller (like a **PID** or **MPC**).
- **Strategic Decision Making (High - Level):** Agent chooses from a set of commands [Stay in Lane, Lane Change Left, Lane Change Right, Accelerate, Brake]

Safety Constraints

- **Action Clipping:** Ensuring the agent doesn't "snap" the steering wheel 90 degrees at 100 km/h.
- **Temporal Consistency:** Penalizing the agent for rapid, oscillating changes in action to ensure passenger comfort.

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Reward Modelling

Episodic Rewards	Episodic Penalties
Reach Destination	Collision

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Reward Modelling

Episodic Rewards	**Episodic Penalties**
Reach Destination	Collision
Immediate Rewards	**Immediate Penalties**
Progress to Destination Compliance with Rules Withing Contraints Good Behaviour Smooth Driving	Missing Waypoints Breaking Rules Overspeeding Unnecessary Behaviours Rough Jerky Movements

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Reward Shaping – Positive Rewards

Reward Category	Specific Signal	Description	Example Reward Calculation
Mission Success	**Reaching Destination**	The primary goal; delivered only upon completing the entire planned route.	$R_{final} = +1000$
Progress	**Reaching Waypoints**	Interim bonuses for staying on the intended path.	$R_{waypoint} = +50\ (upon\ passing\ a\ waypoint)$
Progress	**Reduced Distance to Target**	A continuous signal based on Euclidean or road distance reduction.	$R_{distance} = \alpha \times (d_{t-1} - d_t)\ (if\ d_t < d_{t-1})$
Compliance	**Responding to Signals**	Correct behavioral response to dynamic traffic elements.	$R_{compliance} = +10\ (for\ each\ step\ stopped\ at\ a\ red\ light)$
Constraint	**Maintaining Target Speed**	Rewards keeping pace with the flow of traffic within legal limits.	$R_{speed} = \beta \times e^{-(v_{target} - v_{current})^2}$
Behavioral	**Maintaining Lane Center**	Promotes stable, predictable, and safe lateral positioning.	$R_{lane} = +1.0\ \ if\ (\lvert car_{center} - lane_{center} \rvert < t)$
Comfort	**Lower G-Forces**	Encourages smooth, non-aggressive acceleration, braking, and steering.	$R_{comfort} = \gamma \times (G_{safe} - G_{current})$

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Reward Shaping – Negative Rewards or Penalties

Penalty Category	Specific Signal	Description	Example Penalty Calculation
Efficiency	**Time Consumed**	A continuous penalty to encourage the agent to find the quickest route.	$P_{time} = -0.1\ (per\ unit\ time)$
Safety	**Collision**	A high negative reward for if vehicle collides with another object	$P_{collission} = -1000$
Navigation	**Missing Waypoints**	A major penalty for straying off the designated route or missing a turn.	$P_{route} = -500$
Navigation	**Increased Distance from Target**	A continuous penalty when the agent moves away from its goal.	$P_{distance} = \delta \times (d_t - d_{t-1})$
Compliance	**Failing Traffic Signals or Crossing Speed Limit**	A significant safety penalty for running red lights, ignoring stop signs, overspeeding etc.	$P_{violation} = -200\ or$ $P_{overspeed} = \epsilon \times (speed_{limit} - speed_{current})$
Behavioral	**Non-mandatory Lane-Changing**	Minimizes unnecessary lane-weaving, which increases collision risk.	$P_{lane\_change} = -50\ (per\ illegal\ lane\ change)$ or $= -2\ (legal\ but\ non-mandatory)$
Comfort	**Higher G-Forces or Jerks**	Penalizes aggressive inputs that degrade passenger comfort.	$R_{comfort} = \gamma \times (G_{safe} - G_{current})$

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The Role of High-Fidelity Simulation

- **Safety (Zero-Risk Training):** Training an RL agent involves thousands of crashes. In a simulator, a "collision" is just a reset button; in reality, it is a catastrophic liability.
- **Cost Efficiency:** Maintaining a fleet of sensor-heavy vehicles is expensive. Running 100 parallel instances of a simulator on a server cluster costs a fraction of the price.
- **Time Scaling:** Simulators can run **faster than real-time**. While a human driver is limited by the 24-hour day, an agent can "experience" years of driving data in a matter of weeks.
- **Edge Case Generation:** It is nearly impossible to find a specific triple-lane-change accident in the real world on demand. In simulation, you can script "The Long Tail" of rare, dangerous events repeatedly until the agent masters them.
- **Curriculum Learning:** Start the agent in a very simple environment (e.g., a straight, empty road with the goal only 5 meters away). As the agent masters the simple task, gradually increase the distance and complexity (traffic, curves, intersections). This ensures the agent "hits" the reward frequently enough to start learning.

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Core Requirements for High Fidelity

To ensure **Sim-to-Real Transfer**, where a model trained in simulation actually works on a real car, the environment must meet three criteria:

Requirement	Description
Realistic Physics	Must accurately model tire-road friction, mass distribution, aerodynamics, and inertia. If the "math" of the car is wrong, the RL agent will learn "cheats" that don't work in reality.
Photorealistic Rendering	Crucial for agents using **Camera/Vision sensors**. The lighting, shadows, and textures must mimic the real-world so the Neural Network generalizes to actual sunlight and rain.
Programmable Traffic	The environment cannot be static. It requires dynamic "Actors" (pedestrians, cyclists, and other cars) with varied behaviours to test the agent's tactical decision-making.

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OUR GOAL

SIMULATION

- A customizable traffic simulation platform
- Variable entropy
- Edge Case Events

INTEGRATION

- Multi-agent Interactions
- Competition and Cooperation
- Adversarial Agents

SAFETY

- Safe reinforcement learning agents
- Parameterized safety in reward models
- Threat Prediction

INCLUSIVITY

- Static to Adaptive Agents
- Entropy Modelling
- Entropy guided parameter estimation

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I would love some spicy discussions

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THANK YOU FOR THE OPPURTUNITY

DHONYOBAD - SHUKRIYA - OBRIGADO - HVALA

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