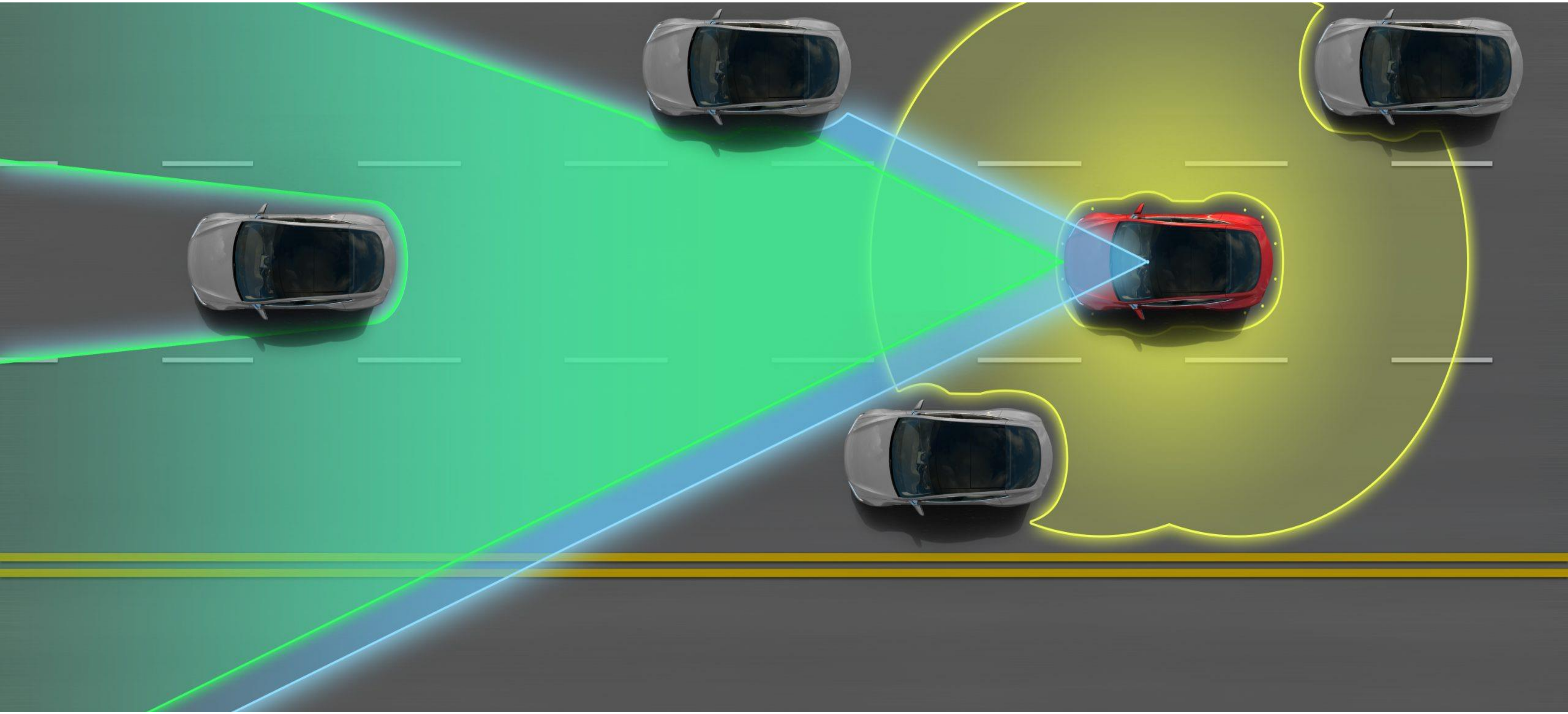


Autonomous Vehicles Simulation

Today's Agenda

1. Introduction
2. Current State
3. MC Simulation Explained
4. Hypothesis Results
5. Conclusion

Sensors – The Eyes and Ears of Autonomous Vehicles

C

Video cameras

Cameras identify traffic lights, road signs, and hazards.

B

Lidar sensors

These sensors read lights to determine distances, detect the edges of roads, and identify lane markings.

A

Radar sensors

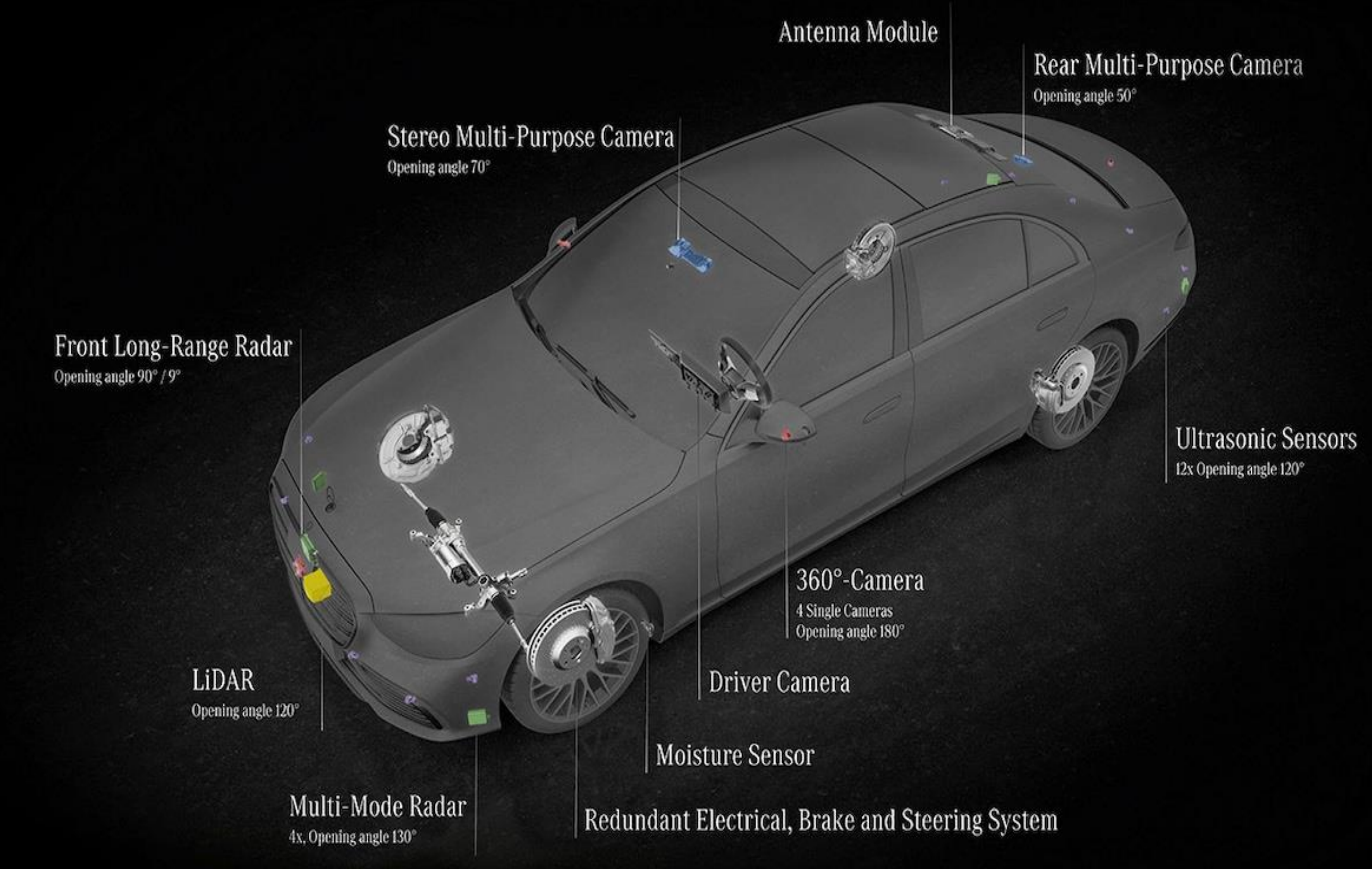
Radar sensors monitor the position of nearby vehicles.

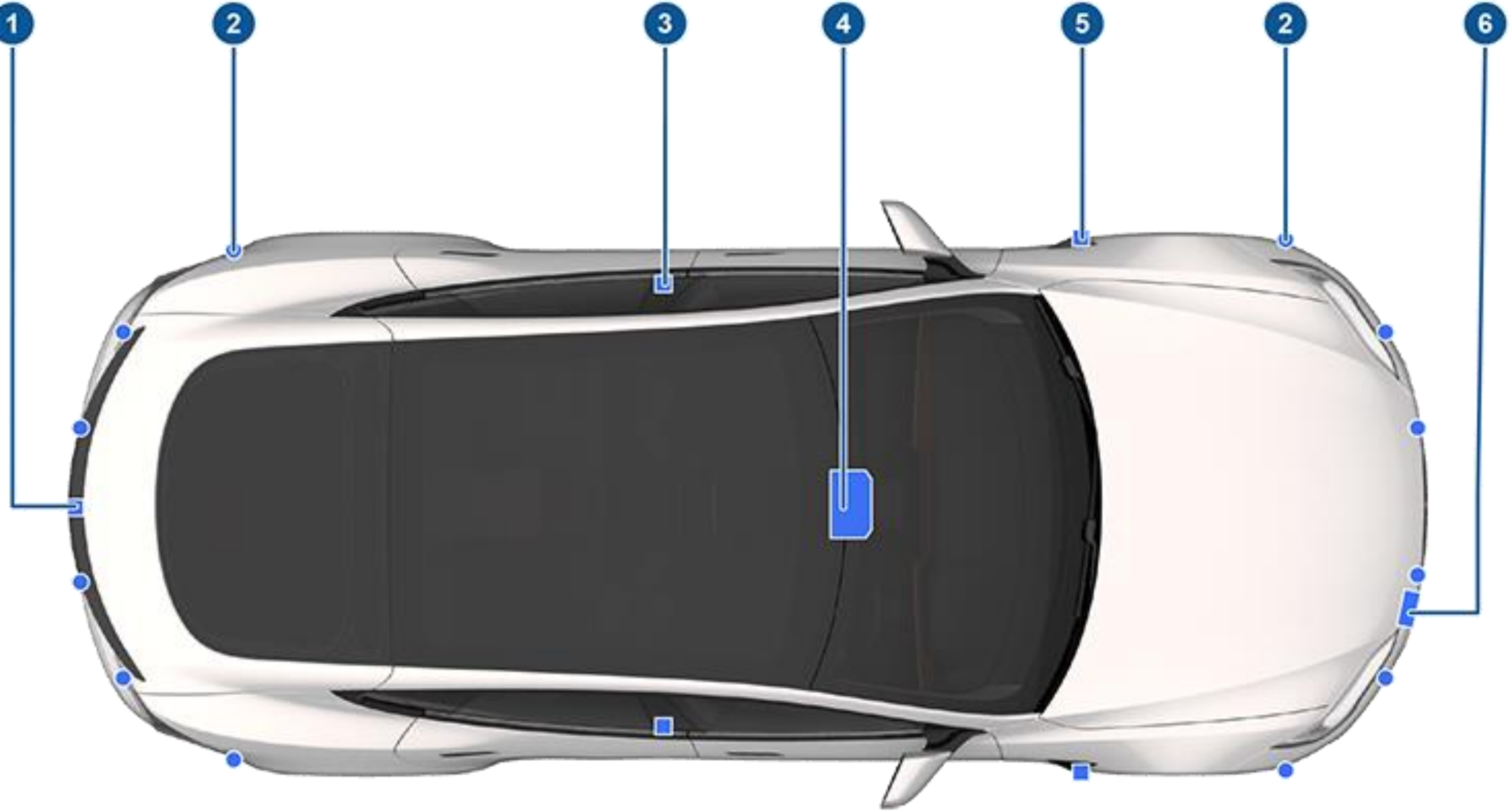
D

Ultrasonic sensors

Ultrasonic sensors detect curbs and other vehicles when parking.

DRIVE PILOT in the S-Class: Sensor Technology and Redundancy

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What are we trying to do ??

Hypothesis 1: A multi-sensor configuration will maintain higher detection rates in adverse weather conditions compared to a camera-only system.

Hypothesis 2: A hybrid configuration can achieve detection rates within 2% of the best-performing system while using fewer sensors.

Which approach is safer in adverse weather?
Can we optimize for cost-effectiveness without sacrificing safety?

Variables at Play

What We Fixed & What We Randomized ?

📏 **Fixed Variables:**

- Sensor positions and orientations
- Field of view angles
- Detection ranges
- Number of objects (20 per simulation)

🎲 **Random Variables:**

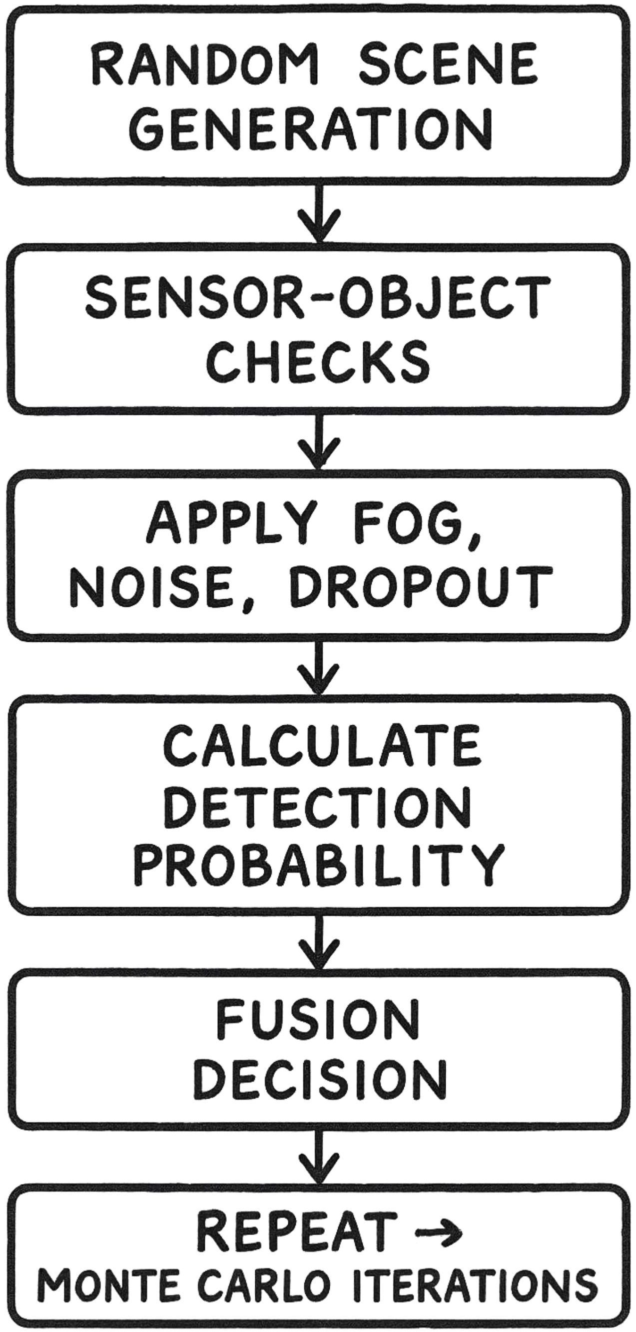
- **Object positions** → Uniform distribution
- **Object types** → Weighted distribution
- **Sensor noise** → Gaussian
- **Sensor dropout** → Bernoulli

Our Monte Carlo Engine

Object Simulation:
- Random placement of 20 objects per iteration
- Probabilistic object type assignment
- 5,000 iterations per configuration

Detection Modeling:
- FOV and range checks
- Distance-based probability decay
- Sensor-specific attenuation in fog
- Beer-Lambert law for fog effects

Sensor Fusion:
- Independent detection by each sensor
- Aggregate detection across all sensors



Assumptions & Simplifications

- Point-Based Objects
- No Occlusion
- Static Scenario
- Binary Detection in case of Camera
- No Material Properties
- Independent Sensors
- Homogeneous Fog and Single Weather Variable
- No Classification Errors
- Simple OR Fusion

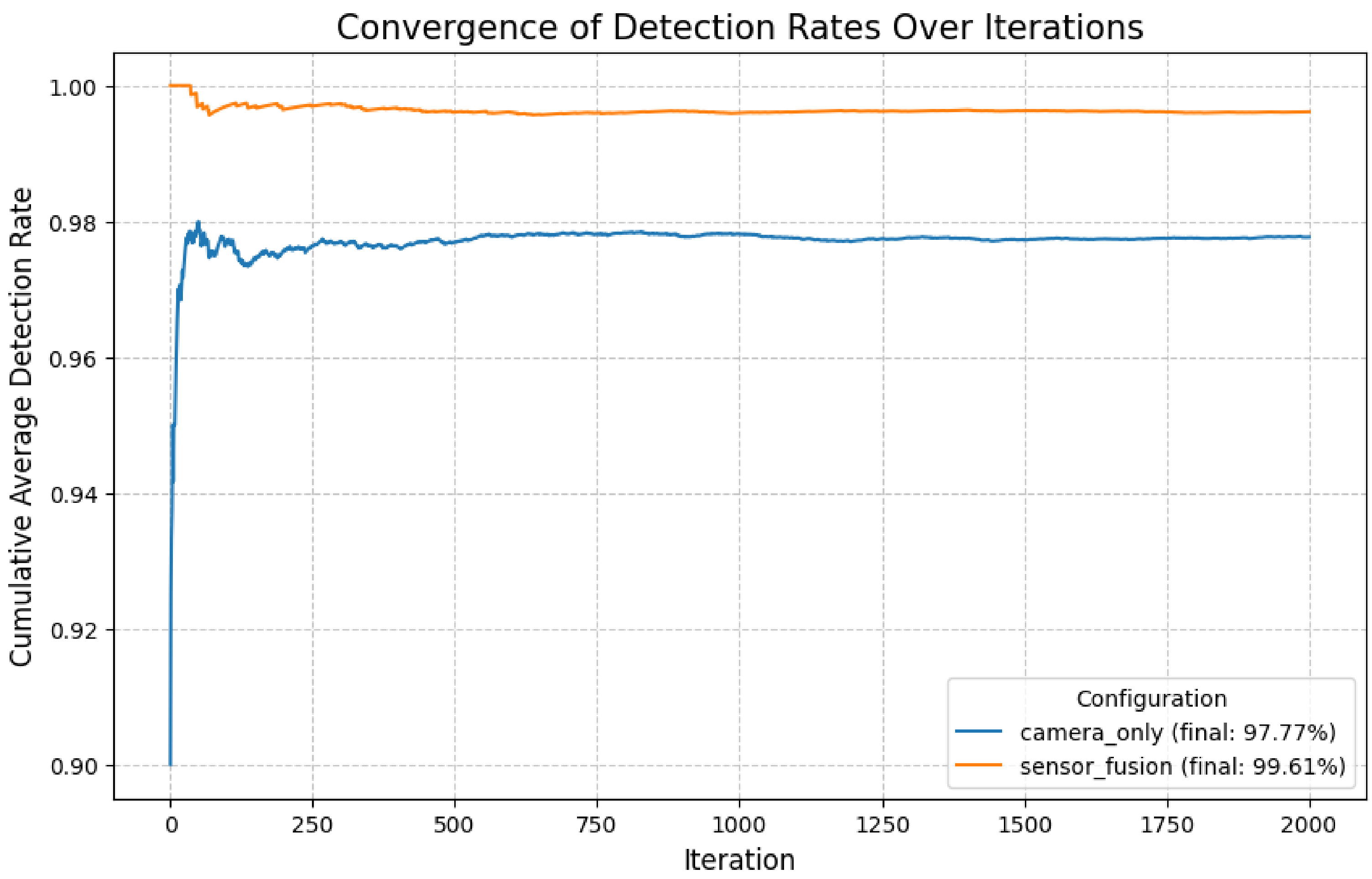
Validating Our Virtual World

Clear Weather Performance:

- All configurations converge to high detection rates
- Camera Only : 97.8%
- Sensor Fusion : 99.6%

Convergence Analysis:

- Stable results after ~1,000 iterations
- Consistent performance across multiple runs
- Validates simulation reliability



Hypothesis 1 Results

Fog Impact by Configuration:

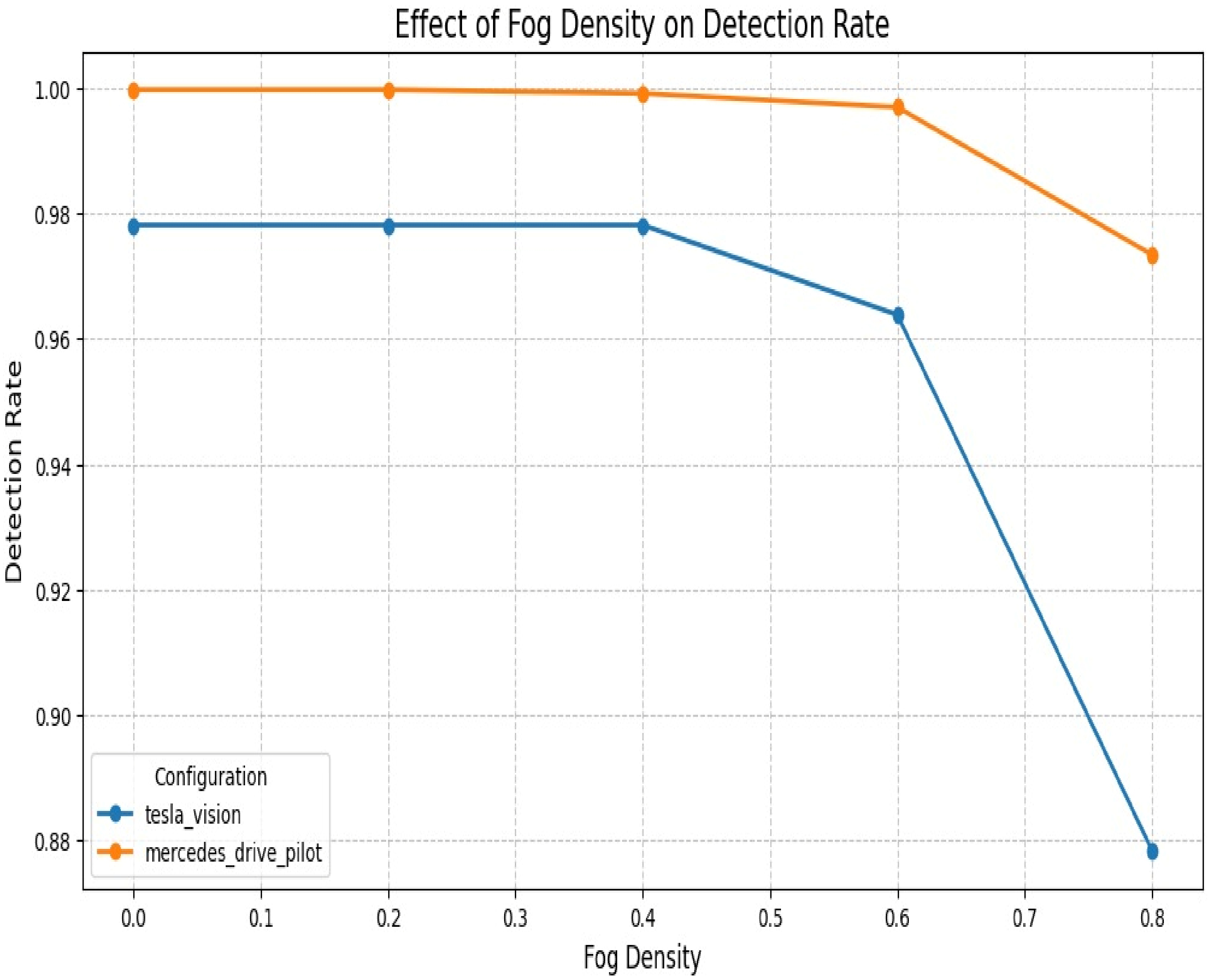
- Fusion : 99.98% → 97.35% (2.63% reduction)
- Camera Only : 97.81% → 87.85% (10.16% reduction)

Sensor Performance in Fog:

- Cameras: Severely affected (exp(-β·d) attenuation)
- Lidar: Moderately affected (70% of visual extinction)
- Radar: Minimally affected (5% of visual extinction)

Conclusion:

- Hypothesis confirmed: Multi-sensor configuration maintains significantly higher detection rates in fog.
- Camera-only systems experience substantial degradation in adverse weather.



Hypothesis 2 Results

Hybrid Configuration Testing:

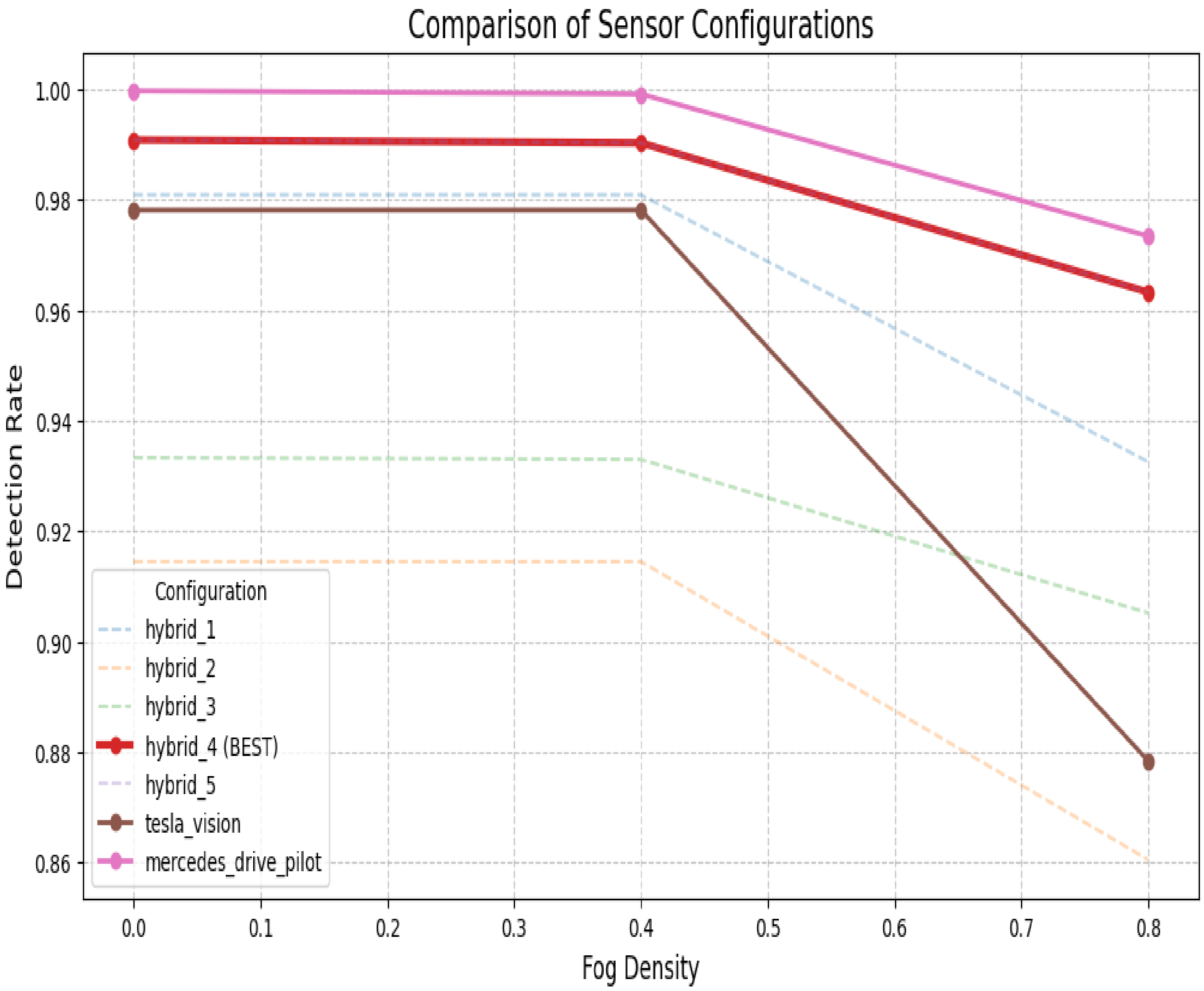
- 5 different hybrid configurations tested
- Best hybrid: 7 cameras, 3 radars, 1 lidar

Performance Comparison:

- Fusion : 99.08% average detection rate (13 sensors)
- Best Hybrid: 98.15% average detection rate (11 sensors)
- Camera : 94.49% average detection rate (8 sensors)

Key Finding:

- Hypothesis confirmed: Hybrid configuration achieved 99.06% of Mercedes performance with 15% fewer sensors
- Optimal balance between sensor types provides resilience with reduced complexity



Current Limitations:

- Objects modeled as points (no dimensions or occlusion)
- Limited to fog simulation only
- Static vehicle and objects
- Simplified detection probability models

Future Enhancements:

- Include object dimensions and occlusion effects
- Add rain and snow weather models
- Validate against real-world datasets (Waymo, nuScenes)
- Test dynamic scenarios with moving vehicle
- Cost-benefit analysis

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Thank
you !!
Questions ?