



# Neural Network Architecture in Tesla Autopilot

by SE3010\_Y3S1\_WE\_22



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# Introduction

## System

Tesla Autopilot

## Architecture Style

Neural Network Architecture

## Key Qualities

- Safety First: Prioritizing your protection with state-of-the-art technology.
- Real-Time Decision Making: Lightning-fast responses for seamless driving.



# History and Most Significant Changes to the Architecture

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## Initial Design

Tesla's Autopilot began with a rule-based system using basic computer vision for lane detection and collision avoidance.

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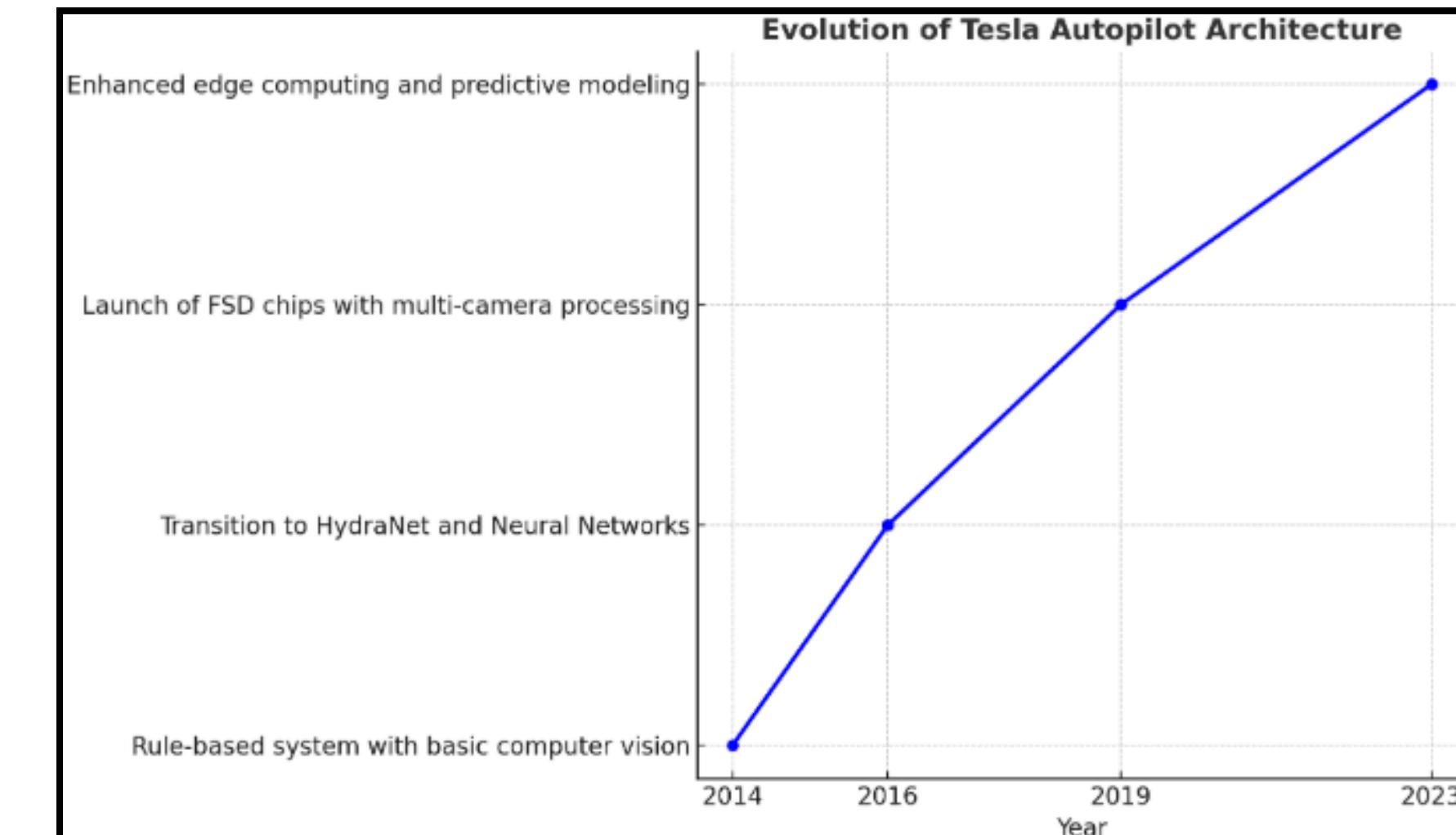
## Evolution to Neural Networks:

In 2016, Tesla adopted HydraNet, a neural network architecture enabling advanced pattern recognition and decision-making.

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## Significant Changes:

- Integration of HydraNet: A unified neural network that processes data from multiple cameras, sensors, and radars.
- Transition to multi-camera setup: 360° coverage with eight cameras for enhanced situational awareness.
- Adoption of FSD (Full Self-Driving) chips: Custom-designed hardware for real-time neural processing.



# Current Architecture

## HydraNet

Tesla's core architecture processes multi-camera video data simultaneously, incorporating spatial and temporal correlations.

## Sensor Fusion

Combines data from cameras, ultrasonics, and radar to provide a holistic environmental model.

## Decision-Making Algorithms

Implements reinforcement learning to refine control strategies.

## Safety Layers

Includes predictive modeling, redundancies, and real-time error correction to ensure safe navigation.

# Key Strengths, Weaknesses, and Areas to Improve

## Strengths:

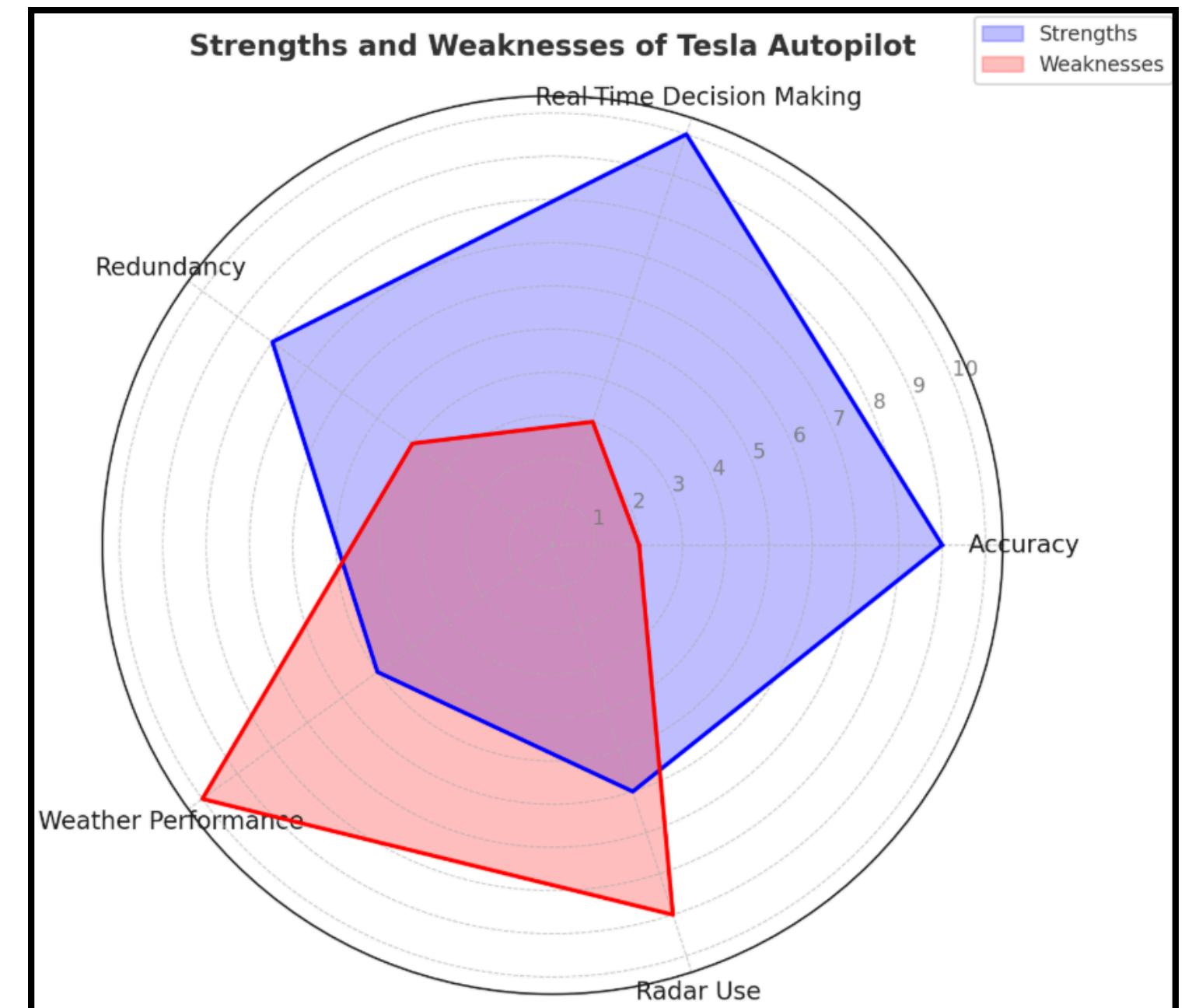
- High accuracy in detecting and classifying objects using HydraNet.
- Real-time decision-making enabled by FSD chips' superior processing speed.
- Redundancy mechanisms ensure safety even in partial system failures.

## Weaknesses:

- Limited capability in adverse weather conditions (rain, fog).
- Over-reliance on camera-based data while radar usage is minimized.

## Areas to Improve:

- Enhance performance in extreme weather through improved radar integration.
- Explore self-healing networks to adapt in real-time to unexpected scenarios.



# Key Findings and Observations

Tesla's architecture demonstrates a robust use of neural networks for real-time operations, yet faces challenges in scalability for global implementation.

Safety-critical redundancies have significantly reduced accident rates.

Comparative analysis with competitors shows Tesla's system excels in processing efficiency but lags in lidar integration.



# Other Architectural Styles in Consideration



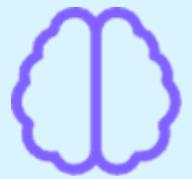
## Waymo's Approach

Leverages lidar and radar extensively for precise object mapping.



## NVIDIA Drive

Utilizes a GPU-intensive architecture for high-speed processing but requires higher power consumption.



## Why Neural Networks?

Tesla chose neural networks for their adaptability, self-learning capabilities, and ability to process unstructured data from real-world environments.

# Introduction to Safety in Tesla Autopilot

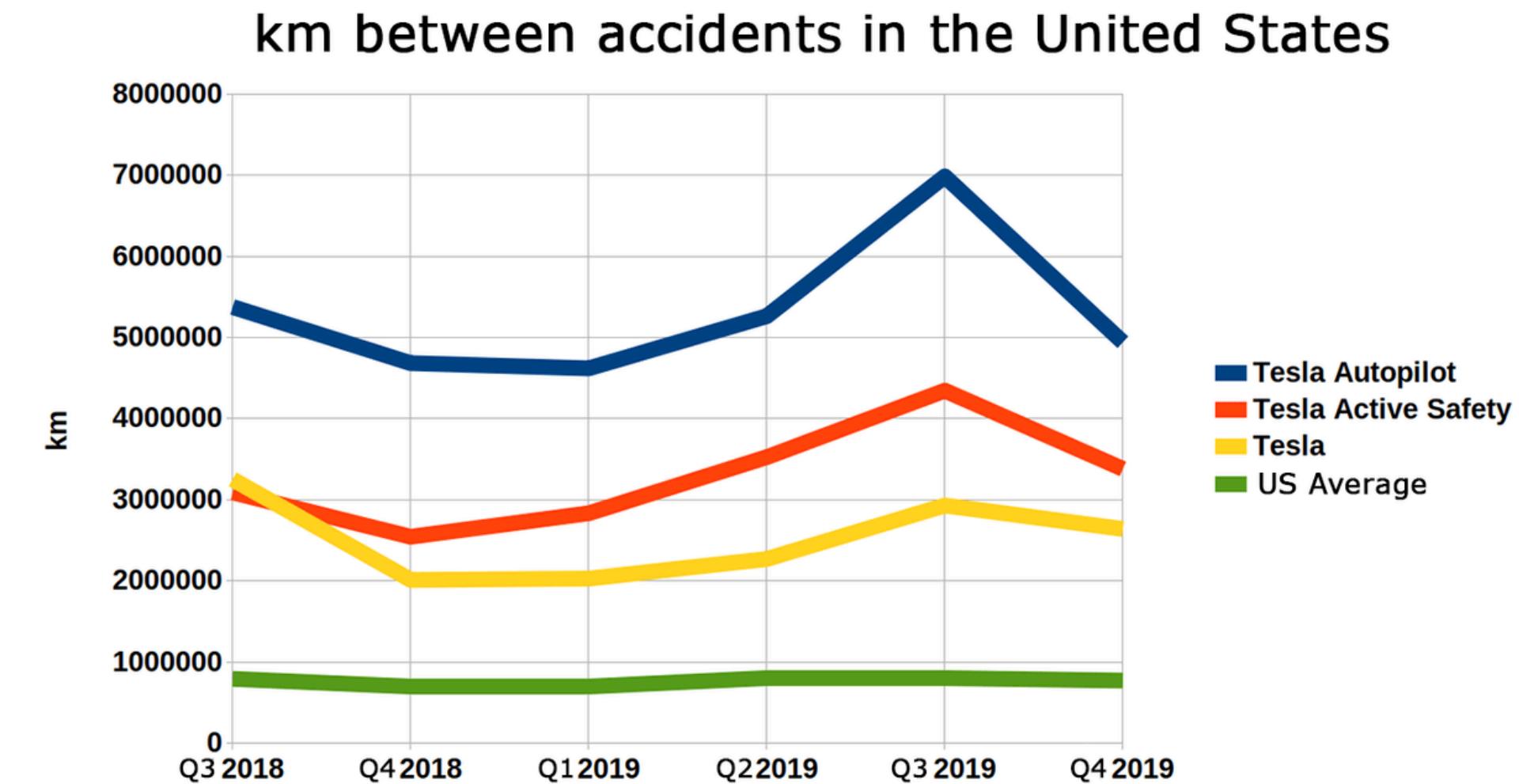
## Why Safety Is the Core of Tesla's Autopilot Design

### ◆ Making Fast, Smart Decisions

- Autopilot reacts in ~0.25 seconds – much faster than the human average of 1.5 seconds.
- Uses 8 external cameras to monitor surroundings constantly.

### ◆ Impressive Safety Numbers

- In early 2024, cars using Autopilot had 1 crash every 7.63 million miles.
- Tesla cars without Autopilot had 1 crash every 955,000 miles.
- The average U.S. driver had 1 crash every 670,000 miles.
- This shows that Autopilot is much safer, and it got 47% better than last year.



# Neural Network Architecture for Safety in Tesla Autopilot

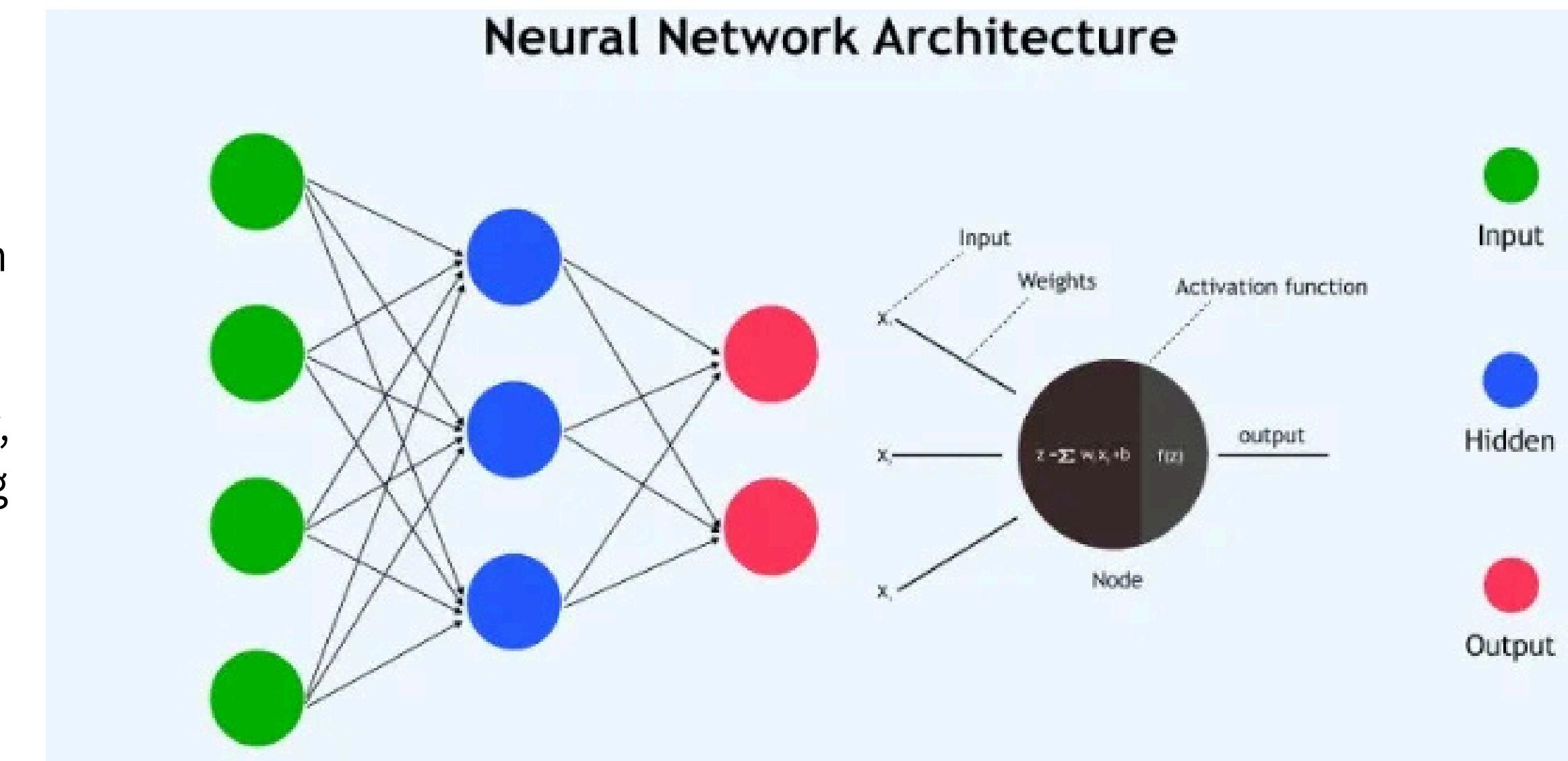
## 1. HydraNet Architecture (Modular Neural Network)

Central shared backbone processes raw input from all 8 cameras.

Multiple task-specific heads perform parallel perception tasks:

- Object Detection (vehicles, pedestrians)
- Lane Line Detection
- Traffic Light & Sign Recognition
- Depth & Distance Estimation

This modular design supports scalability, efficiency, and real-time decision making



# Methods Used to Improve Safety in Tesla Autopilot

## 1. Redundancy & Fail-Safe Mechanisms

- Tesla's system is built to detect and handle failures.
- Multiple neural networks verify each other's outputs (e.g., path prediction, object recognition).

## 2. Shadow Mode Testing

- New software updates are first run in shadow mode—they silently make predictions without controlling the car.
- Engineers compare shadow decisions vs. real driver actions.

## 3. Fleet Learning at Scale

- Every Tesla car contributes real-world driving data.
- Example: Thousands of videos of tricky intersections are used to train the system to handle them better.

## 4. Over-the-Air (OTA) Updates

- Tesla constantly improves the Autopilot via OTA updates.
- Improved neural network models
- Bug fixes
- New decision-making rules
- No need to visit a service center—cars update automatically.

# Autopilot's Safety: Key Challenges & Solutions

## 1. Cameras Seeing Everything? (The "Vision-Only" Challenge):

- Tesla mostly uses cameras to understand the world, like our eyes.
- The Challenge: Sometimes cameras can have trouble in tricky situations, like very bright sunlight, bad weather (rain/fog)
- Solutions: Sensor Fusion with Optional Radar or Ultrasonic Add-ons

## 2. "Phantom Braking" (Unexpected Stops):

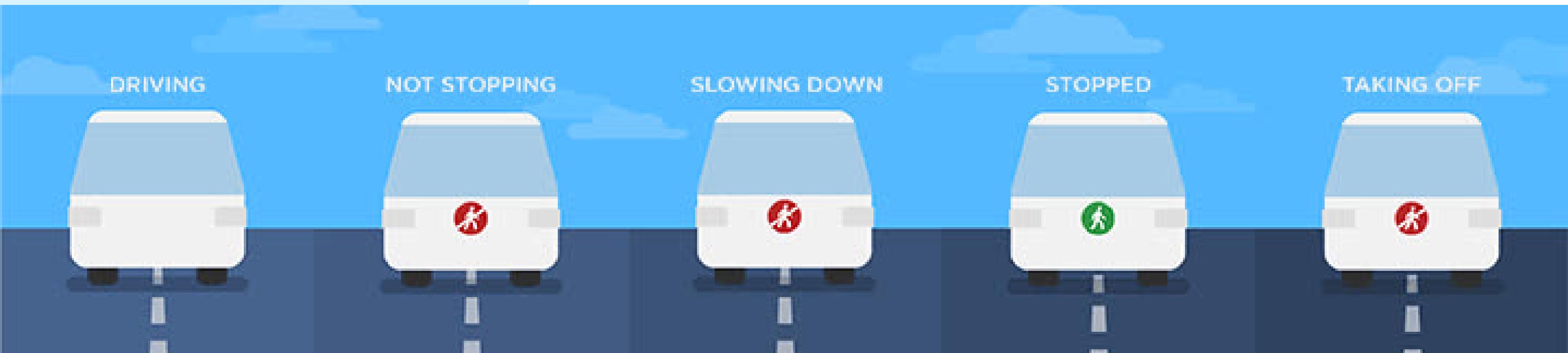
- Sometimes the car might brake suddenly when there's no real danger.
- The Challenge: This can be surprising and worrying for the driver, and potentially risky if there's a car close behind.
- Solution: Tesla constantly sends out software updates to try and fix this, making the system better at knowing when to brake and when not to.



# Performance in Tesla Autopilot

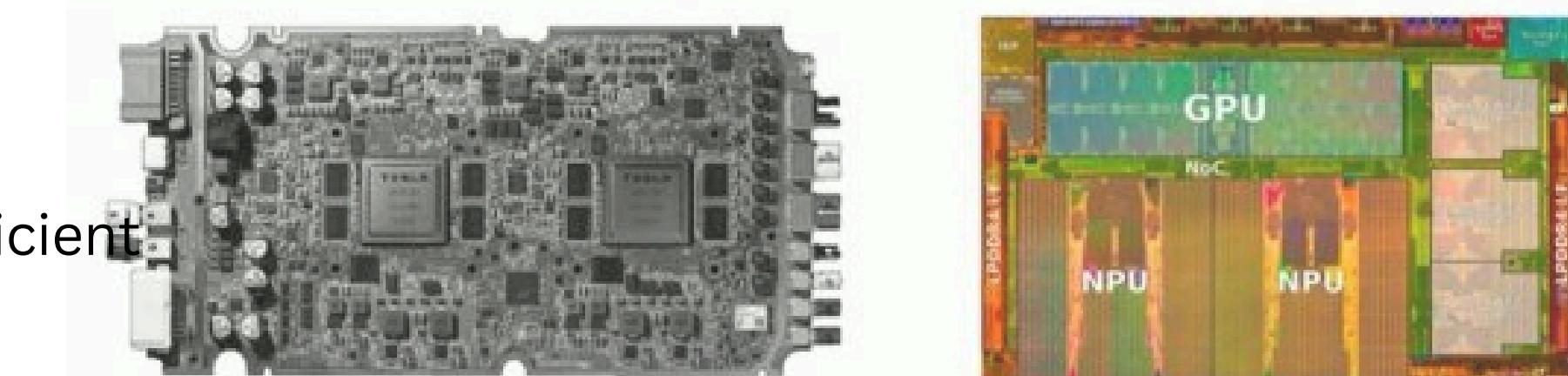
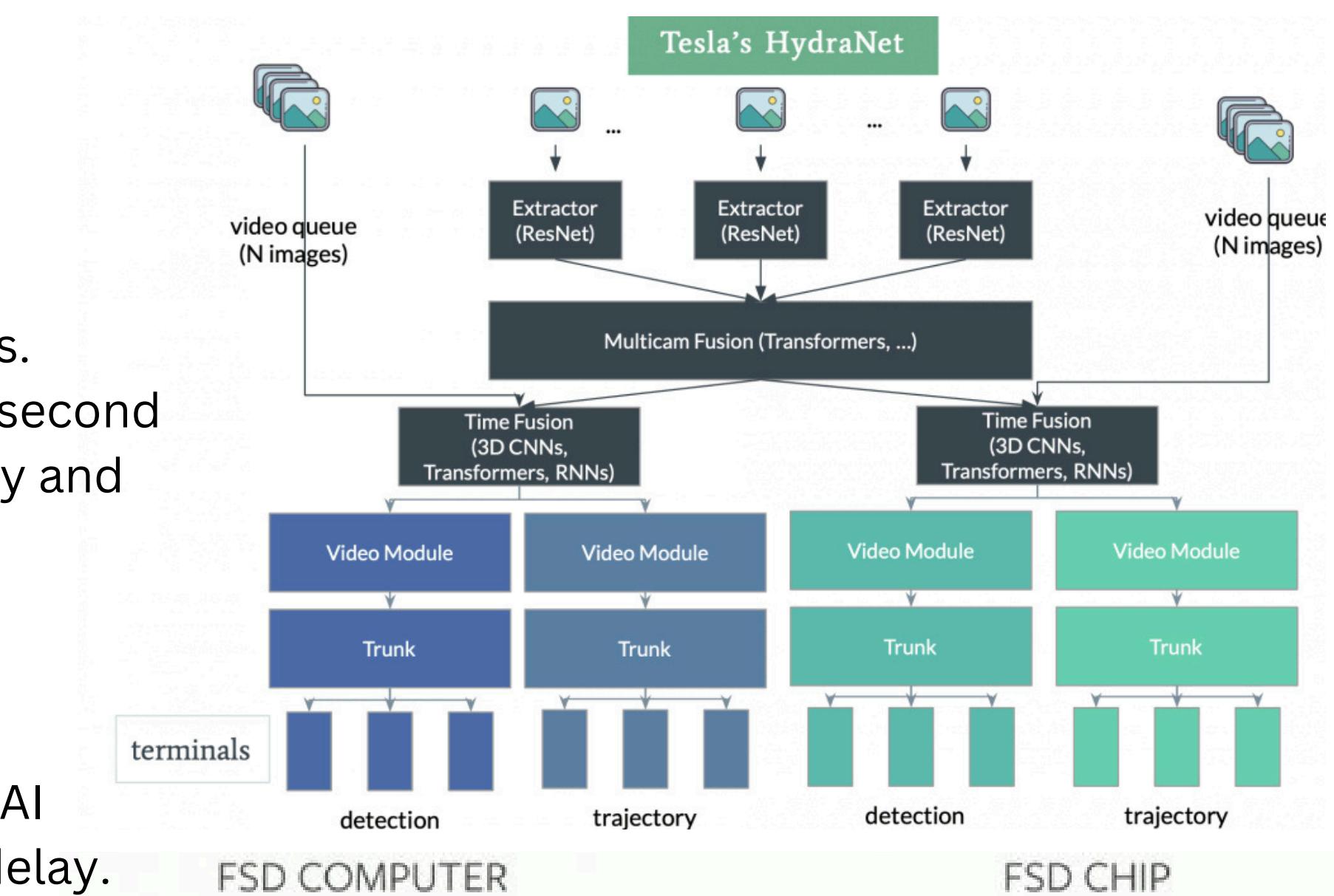
## Importance of Real-Time Decisions

- Instant Reaction for Safety: Autonomous vehicles must react immediately to avoid accidents
- Handling Dynamic Traffic: Driving environments are constantly changing, requiring swift responses.
- Minimizing Delays: Fast Processing help response without delay



# How Tesla Achieves Real-Time Performance

- Efficient HydraNet Architecture
  - Designed for quick processing of multiple tasks.
- Custom FSD Computer
  - Powerful onboard processing with dedicated AI chips.
  - hardware can handle up to 72 trillion operations per second (TOPS), allowing it to process complex models quickly and locally.
- Optimized Data Handling
  - Techniques like parallel processing for speed.
  - enables the system to process sensor data, perform AI inference, and make driving decisions with minimal delay.
- Local Processing
  - Optimizes the code and data flow to reduce delays.
  - Techniques like model pruning, quantization, and efficient memory management help reduce latency.



# Key Performance Indicators



## ➤ High Frame Rate

- Processing thousands of camera frames per second.
- Enables the system to analyze dynamic road conditions in real-time.

## ➤ Significant Computing Power

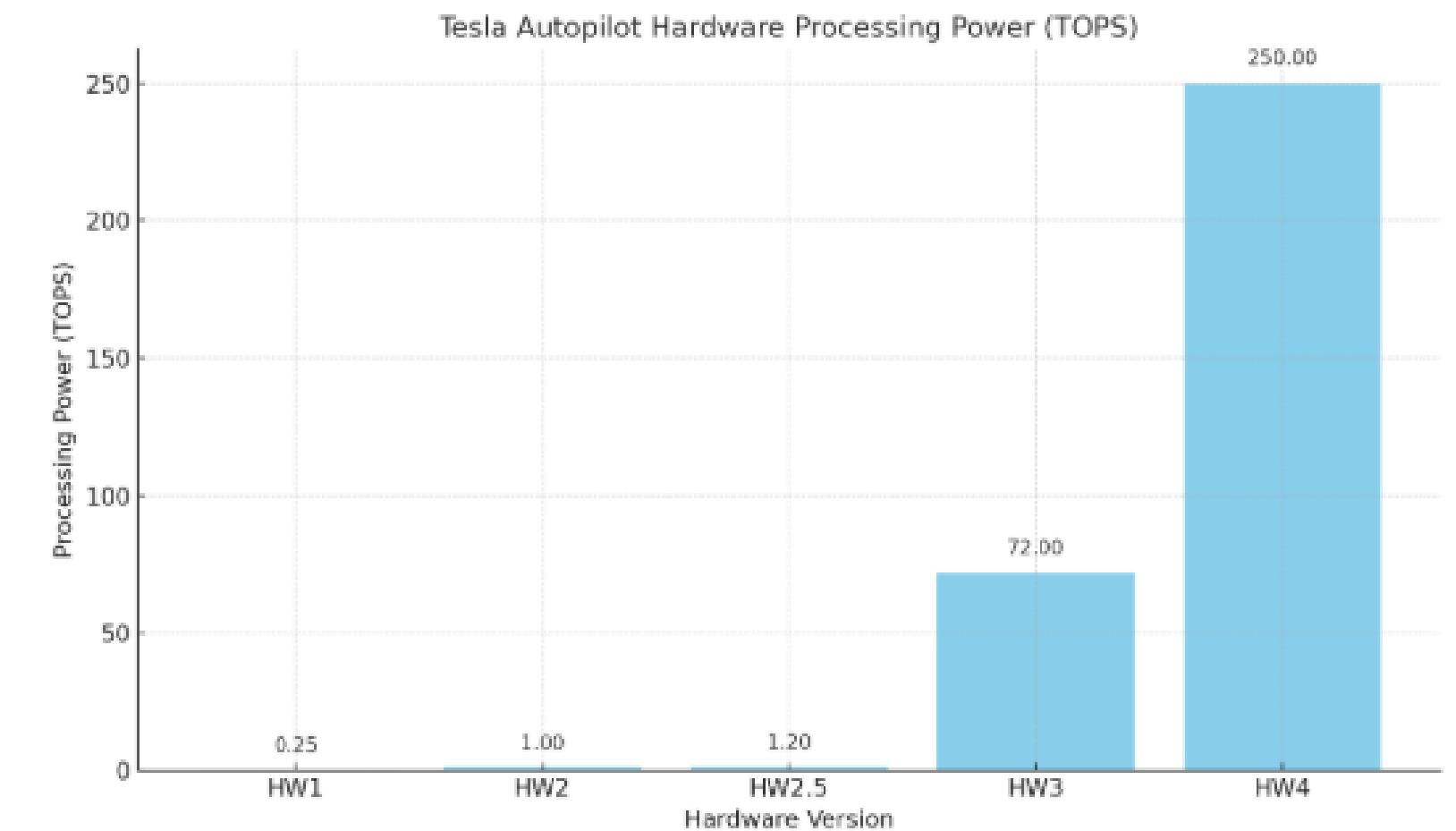
- Measured in Tera Operations Per Second (TOPS).
- High compute ensures smooth execution of deep neural networks and sensor fusion.

## ➤ Low Latency Design

- Engineered for minimal delay in reaction time.
- Achieves faster decision-making critical for safety and responsiveness.

## ➤ Regular Hardware Upgrades

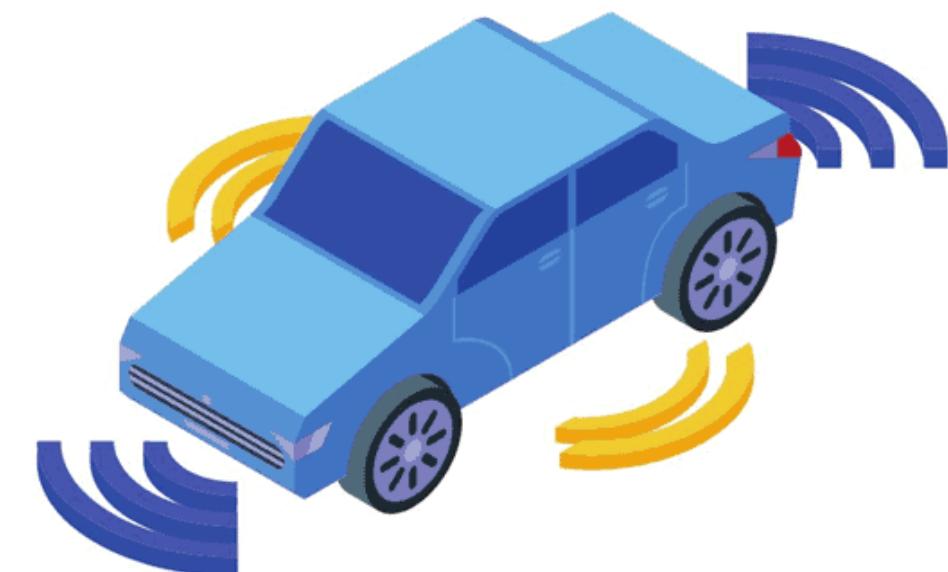
- Newer versions like HW4 offer even more power.



# Trade-offs in Real-Time Decision Making

Achieving both timely and accurate decision-making in autonomous driving involves balancing several key factors:

- Model Complexity vs. Speed
  - Use a very smart (complex) AI model, it usually takes more time and power to process decisions.
  - Trade-off: Use HydraNet architectures to maintain accuracy while keeping times low.
- Data Volume vs. Responsiveness
  - The more sensor data (camera, radar, etc.), can get more accurate the decisions. but might slow things down.
  - Trade-off: prioritize and fuse data streams to balance completeness and speed.
- Hardware Limits
  - Cost and power consumption need to be balanced with performance needs
  - Trade-off: Maximize compute highest processing power possible with the lowest energy use.



# Market Needs: Current & Future of Autonomous Driving

- **Current Needs**

Enhanced safety, driver assistance, and driving convenience.

- **Future Needs**

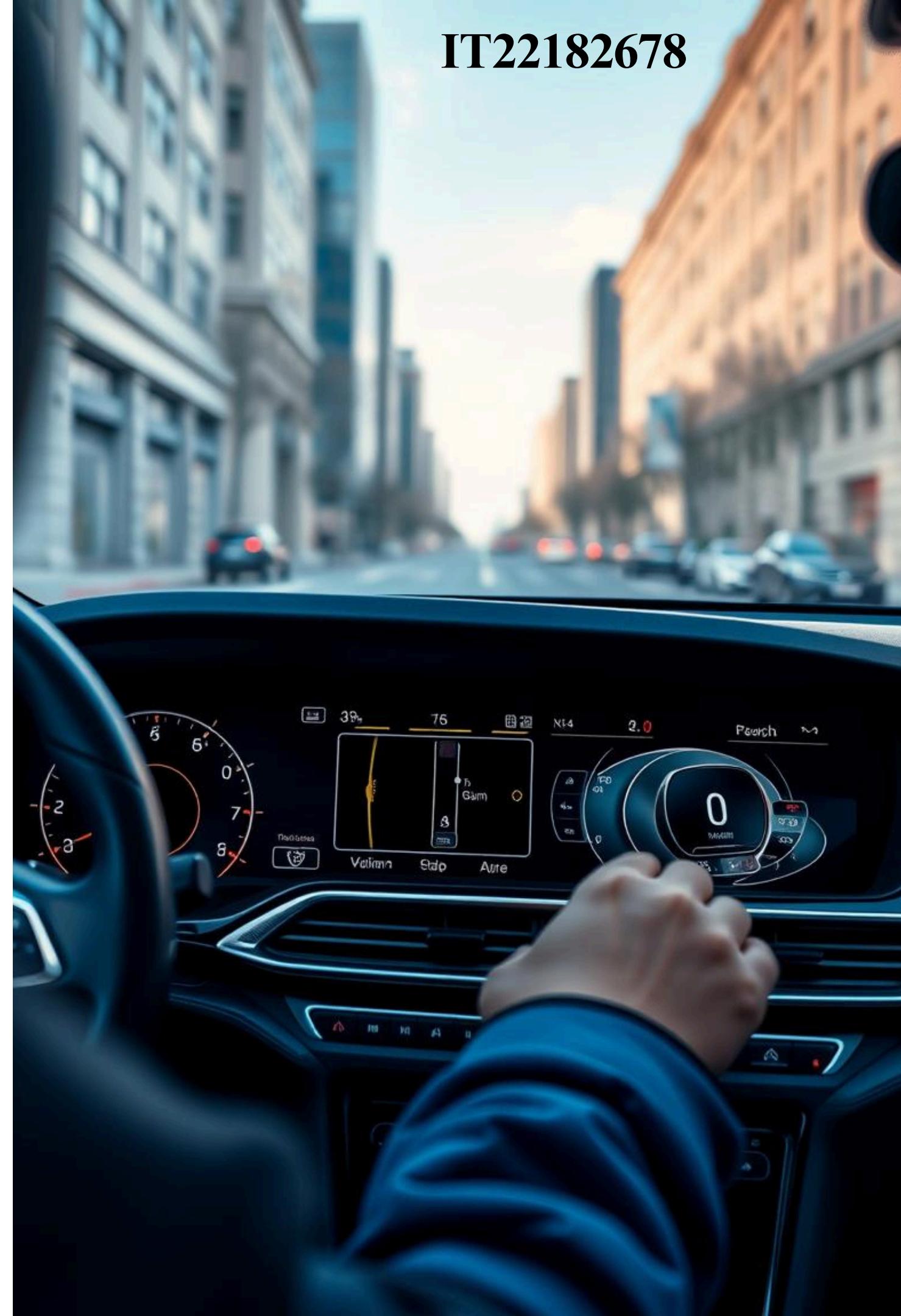
Full autonomy Level 5, accident reduction, and efficient transport.

- **Market Demand**

\$60 autonomous vehicle market expected by 2030.

- **Consumer Interest**

70% of consumers seek advanced safety features.



# Competitive Landscape: Autopilot Alternatives

## ↳ Waymo

- Geofenced robotaxis focus
- \$5 R&D investment

## ↳ Cruise

- GM-backed autonomous expansion
- Major city operations growing

## ↳ Mercedes-Benz DRIVE PILOT

- \$14,000 Level 3 option
- Available in EQS and S-Class

## ↳ Market Share

- Tesla leads in ADAS
- Waymo leads full autonomy testing

# System Challenges: Gaining Market Control



## Safety

Handling rare and unpredictable edge cases.



## Sensor Limits

Challenges in poor weather and lighting conditions.



## Regulation

Varying state and country laws to navigate.



## Ethics & Privacy

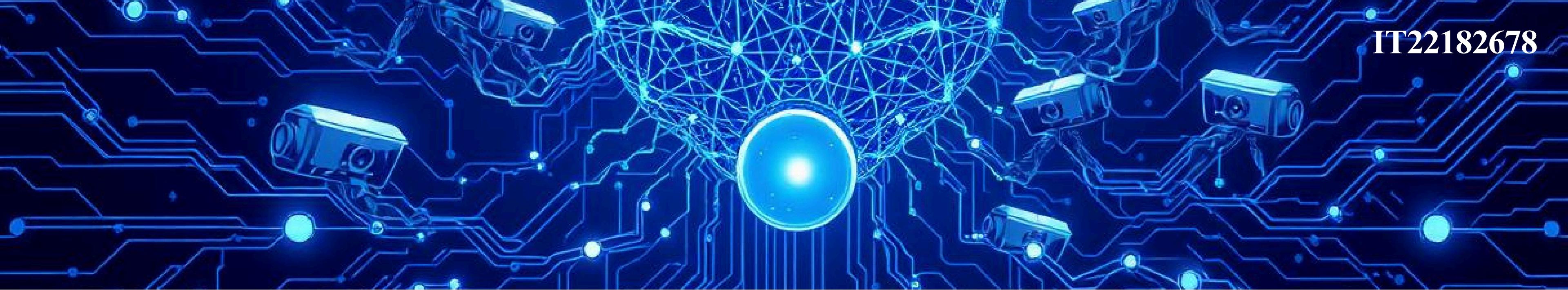
Accident liability and data privacy concerns.





## Benchmarking : Autopilot vs Competitors

Attribute	Tesla Autopilot	Waymo
Safety (Miles per Disengagement)	~7.3 million	~25,000+
Reliability	High uptime, low errors	Industry leader in stability
Performance	Advanced object detection	Optimized response times
Adaptability	Learning across diverse scenarios	Strong geofenced adaptability



# Neural Network Architecture: Key Components



## Vision Transformer

Enables spatial reasoning from multi-camera input.



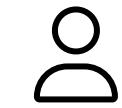
## Multi-camera Setup

Eight cameras capture a 360-degree environment.



## Data Engine

\$1+ invested in data collection & labeling for training.



## Custom Hardware

Dojo chips optimize neural network training speeds.

# Recommendations: Achieving Market Dominance

- **Data Collection**

Increase sensor coverage and scenario diversity.

- **Testing & Validation**

Rigorous simulation plus extensive real-world tests.

- **User Experience**

Smooth integration and clear driver communication.

- **Regulatory Collaboration**

Transparent processes and active authority engagement.





# Conclusion

Tesla Autopilot exhibits significant promise driven by advanced neural networks. To secure long-term success, continuous system refinement is vital. Future efforts should prioritize data accuracy, user safety, and regulatory alignment. As competition grows in autonomous driving, maintaining technological leadership requires relentless innovation.

Building public trust will be essential, demanding transparency, accountability, and real-world performance.