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Challenges & Opportunities in the Automotive Sector

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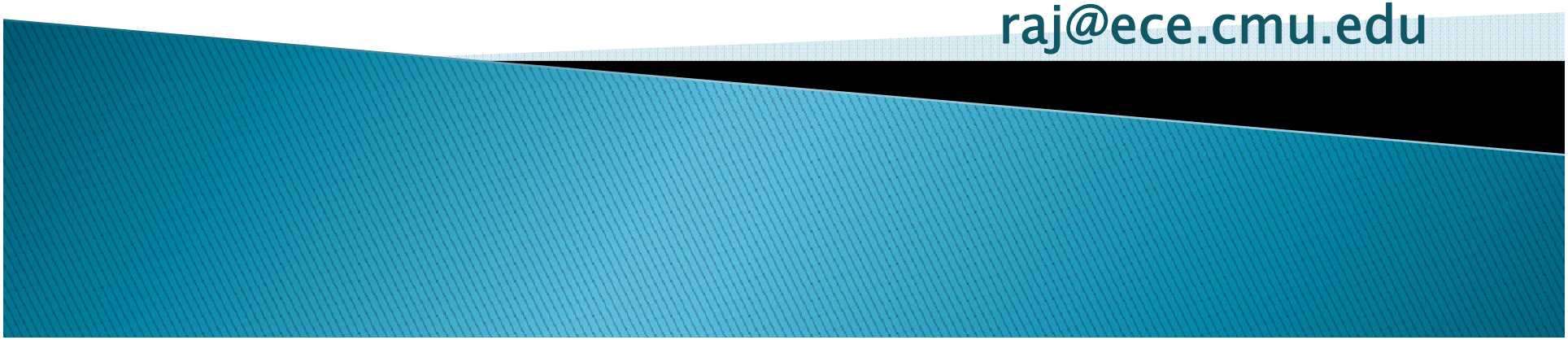


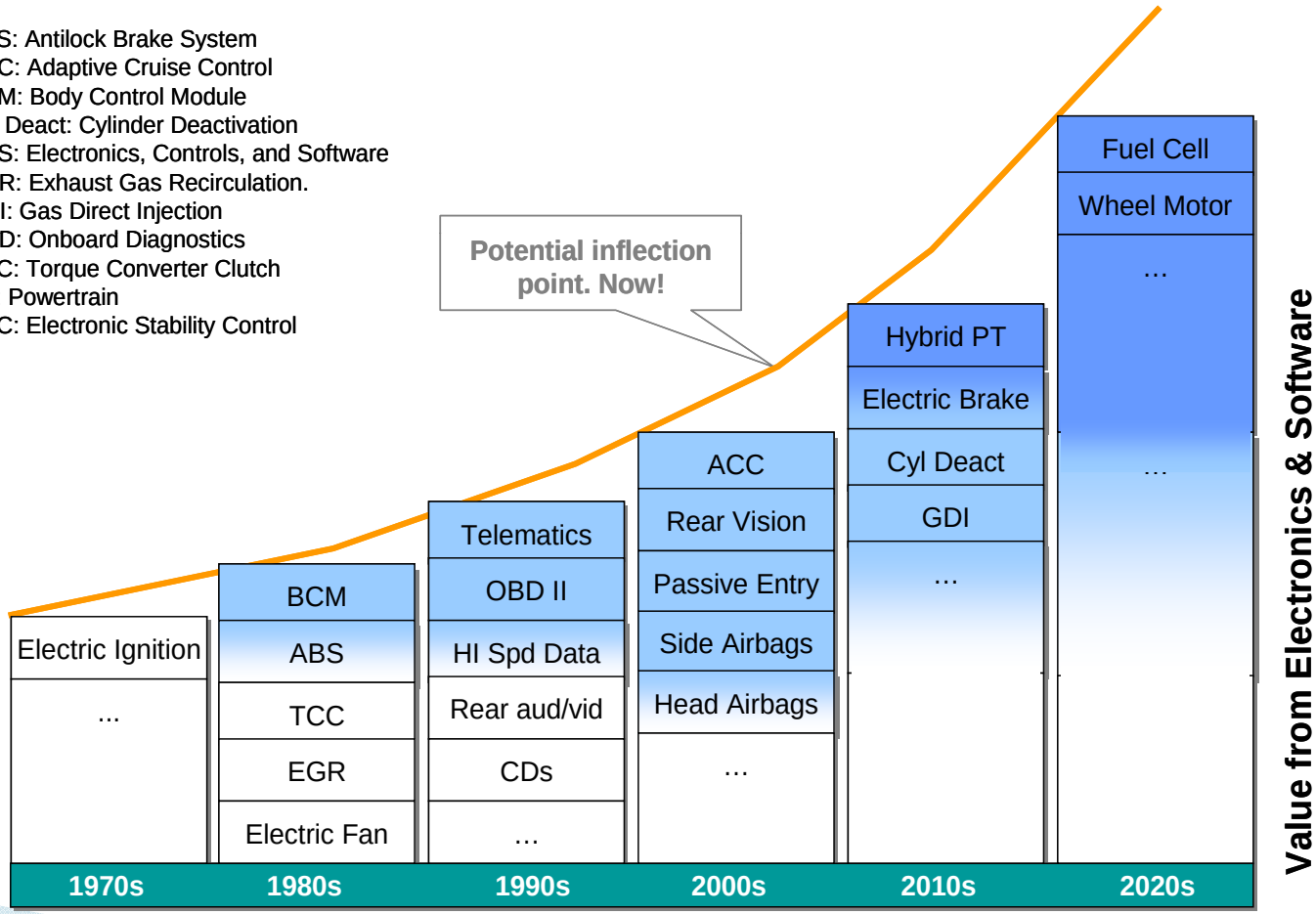
Growth

- In Global Volume Opportunity
  - 2007 70M Sales
  - 2016 94M Sales (projected)
- In Application Diversity
  - Autonomous Driving
  - Advance Entertainment (DVD +)
  - And every function in-between

Growth

- In Electronics Vehicle Content

ABS: Antilock Brake System
ACC: Adaptive Cruise Control
BCM: Body Control Module
Cyl Deact: Cylinder Deactivation
ECS: Electronics, Controls, and Software
EGR: Exhaust Gas Recirculation.
GDI: Gas Direct Injection
OBD: Onboard Diagnostics
TCC: Torque Converter Clutch
PT: Powertrain
ESC: Electronic Stability Control



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Globalization

- Global Markets
  - Environments are not homogeneous
    - Different Customer Expectations
    - Different Regulations & Laws
- Global Workforce
  - Collaborative Development
    - Requires daily interactions
    - Bridging of location constraints (time zones, etc…)
  - Different Footprints
    - For OEMs and for Suppliers, at every Tier

Changing Concept of Systems

- System Interaction Span
  - No longer isolated to a single ECU
    - ABS → ESC
    - IC engine → Hybrids
  - No longer isolated to a single Domain
    - Chassis, Navigation all interacting for performance
  - No longer isolated to a single Vehicle
    - V2V, and V2I changes the boundary of responsibility
- Migration to Open System (Standards)
  - Open Software Architectures
    - Enables Mixed Source Software IP
  - Open Intra-Vehicle Communication Standards
    - Enables Mixed Source Hardware Integration
  - Open Inter-Vehicle Communications
    - Enables Advanced Data Sharing

Fierce Competition

- Constant pressure to do more
  - For less
  - With less
- Constant pressure to do it faster
- Nobody can afford mistakes
  - Customer Dissatisfaction
  - Cost

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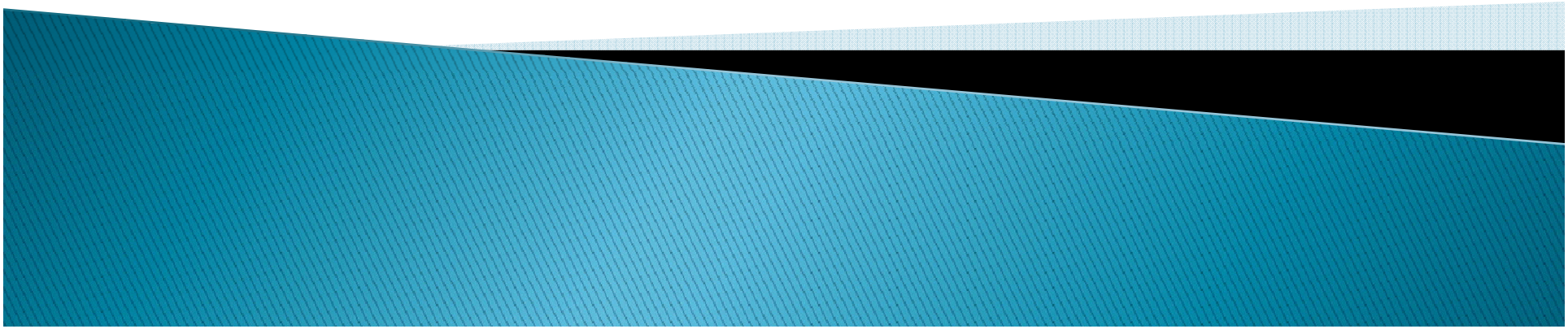
The Automobile: Re-Invented



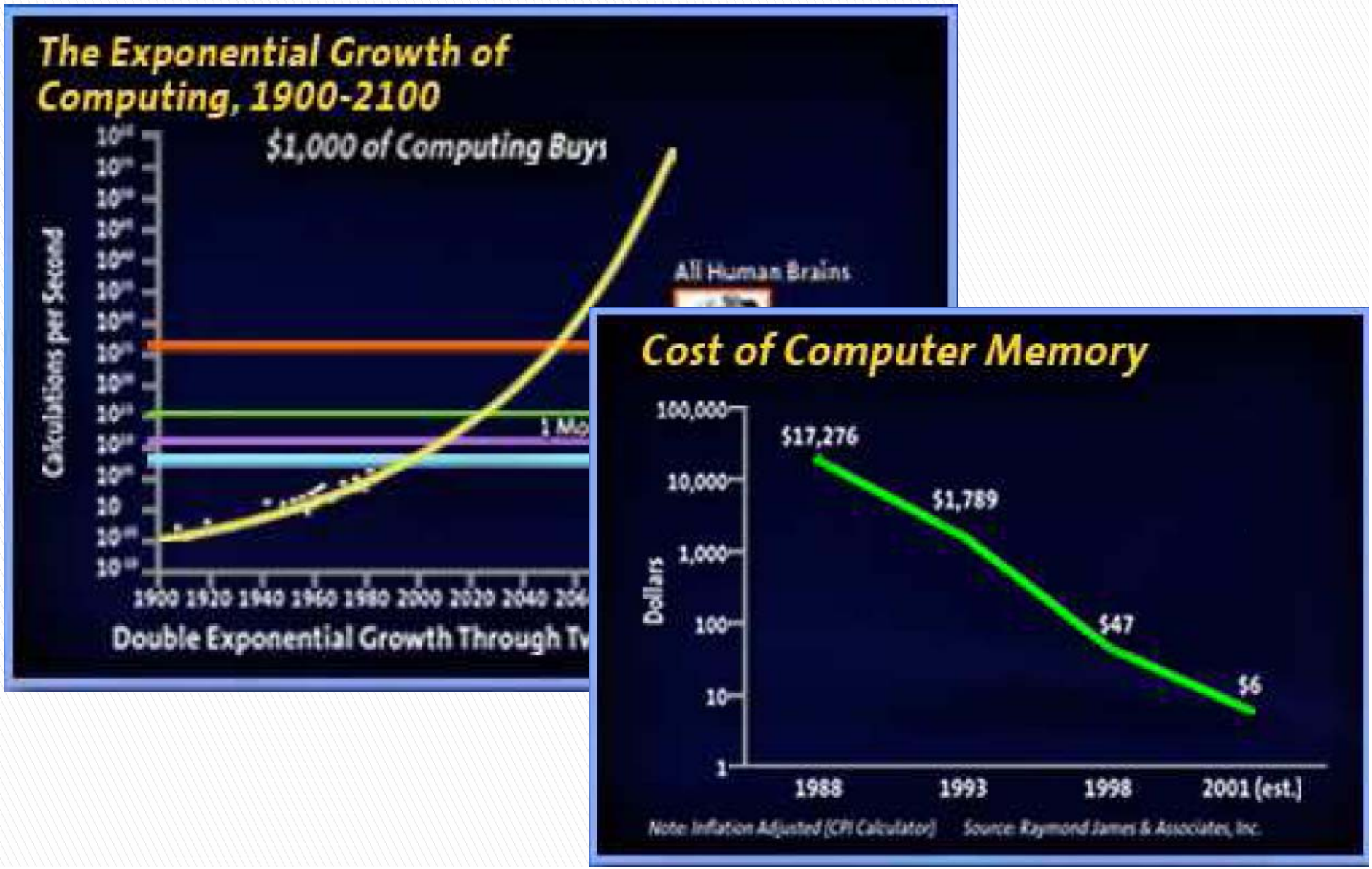
Current Basic Genetic Structure

- Mechanical drive
- Powered by oil
- Internal combustion engine
- Mechanical controls
- Independent operations
- Assembly-line manufacturing

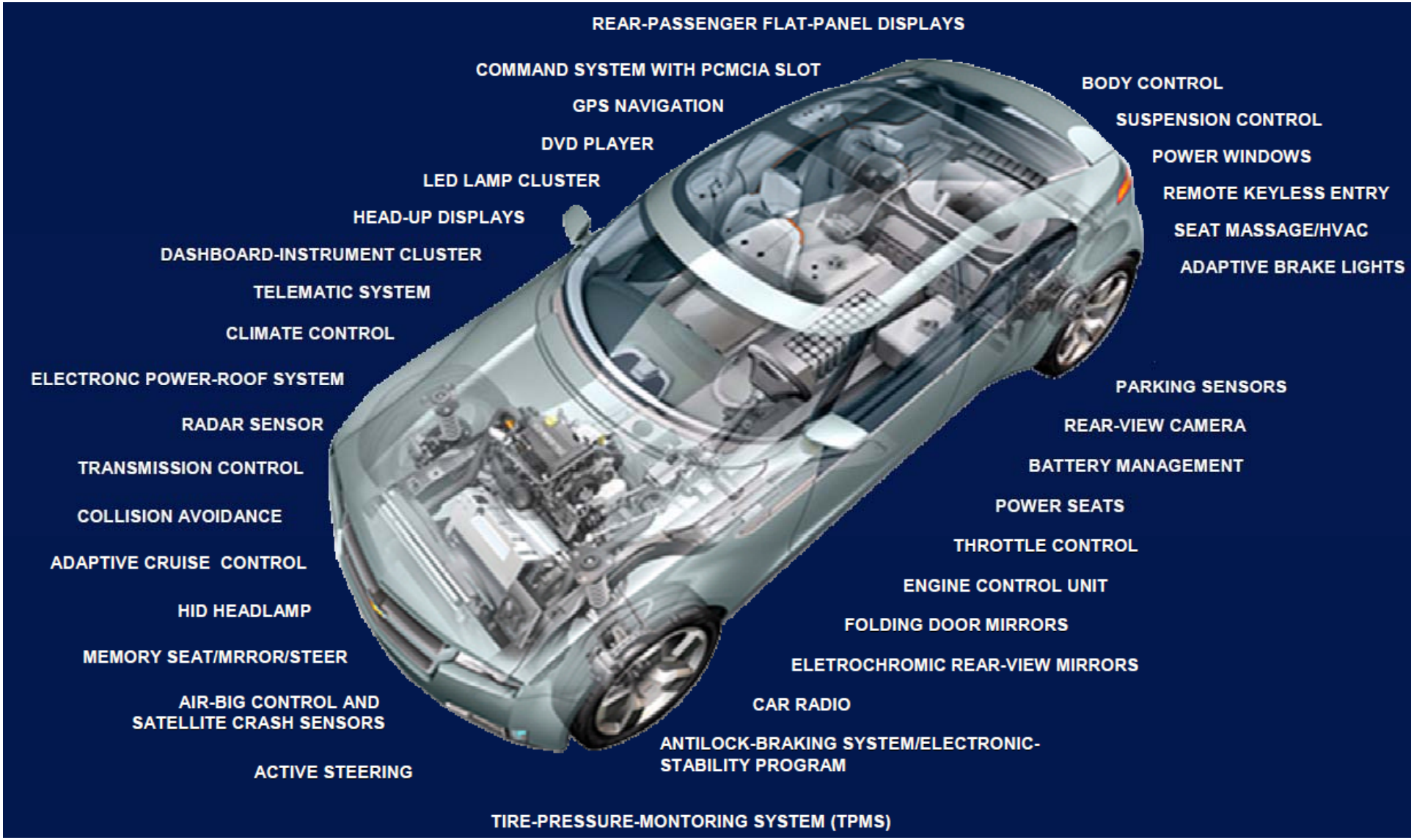
New Automotive Genetics

- Powered by electricity
- “By-wire” controls
- “Connected” vehicles
- Personalization

Basic Semiconductor Trends



Electronics in Automobiles



Vehicular Features

- Safety Features
  - Stability Control
  - Lane Departure Warning
  - Blind Zone Detection
  - Adaptive Cruise Control
  - “OnStar” monitoring and control
- Convenience Features
  - Keyless entry with push button start
  - Navigation with real-time traffic

Key Aspects of New Automotive Genetics

- Deep embedded electronics
  - Sensing
  - Computations and Communications
  - Actuation
- Rich communication capabilities
  - Smart phones with integrated navigation
  - V2V and V2I (V2*X*)
- Tight integration with driver and passenger behavior

Strategic Thrusts

- Environmentally friendly energy source
- “Connected” Vehicles
- Adaptive Vehicles
- By-wire controls
  - Steering, braking, throttling and gearing
- Active Safety → Autonomous Driving

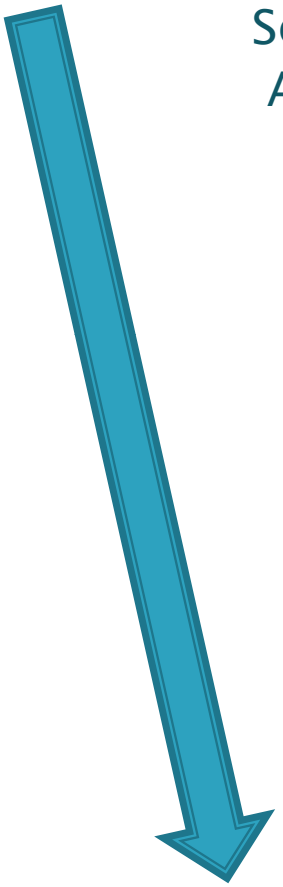
Energy Sources

- Oil → BioFuels → Electricity → Hydrogen
- IC Engine Enhancements → (Plug-in) Hybrd Electric Vehicles
  - → Battery-Electric Vehicles →Electric & Hydrogen Fuel Cell
- Plug-in hybrids
  - can achieve better than double the fuel efficiency of existing vehicles

By-Wire Controls

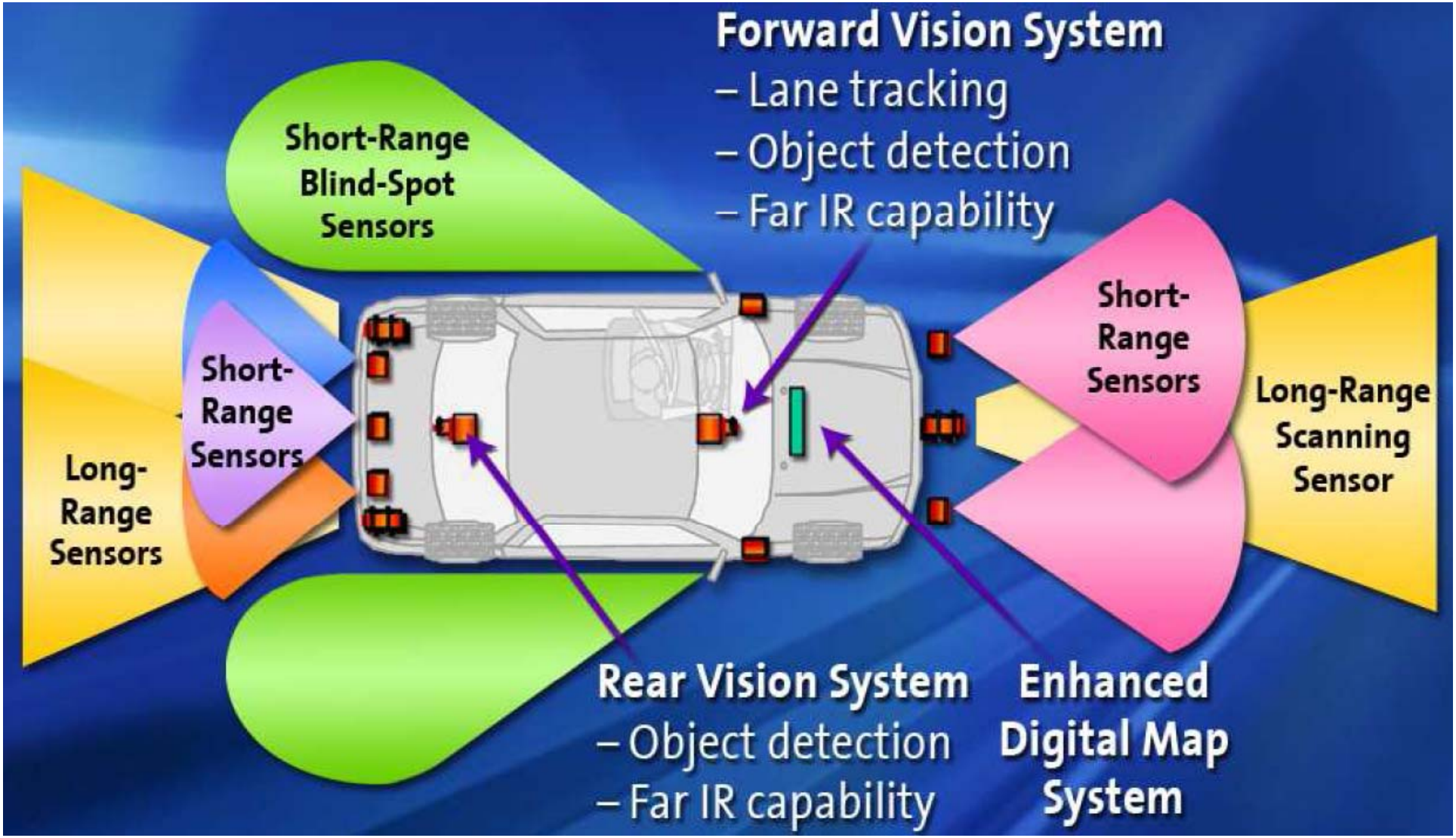
- Increased System Complexity
  - Hybrid power-train
  - Controlled Steering and chassis systems
  - Semi-autonomous and autonomous driving
- Safety-Criticality
  - Active safety
  - Passive safety
- Interactions
  - Different subsystems built by different suppliers

Advanced Safety Technologies



Anti-lock Braking
Traction Control
Semi-Active Suspension
Adaptive Variable-Effort Steering
Electronic Stability Control
Near-Obstacle Detection
Vision Enhancement
Adaptive Cruise Control
Forward Collision Warning
Active Roll Control
Lane Sensing/Warning
Driver Performance Monitor
Forward Collision Avoidance (Braking)
Lane Keeping
V2I Communication
Steer-by-Wire
V2V Communications
Collision Avoidance (Steering)
…

360º Sensing



Autonomous Driving Roadmap

- Driver Assist / Warning
  - Lane Departure Warning
  - Side Blind-Zone Alert
- Semi-Autonomous Driving
  - Cooperative Control between Vehicle and Driver
  - Lane Centering
- On-Demand Automomous Driving
  - On-demand autonomous driving for limited travel
  - Highway-Only Autonomy
  - Virtual Valet parking
- Autonomous Driving
  - Virtual Chauffeur

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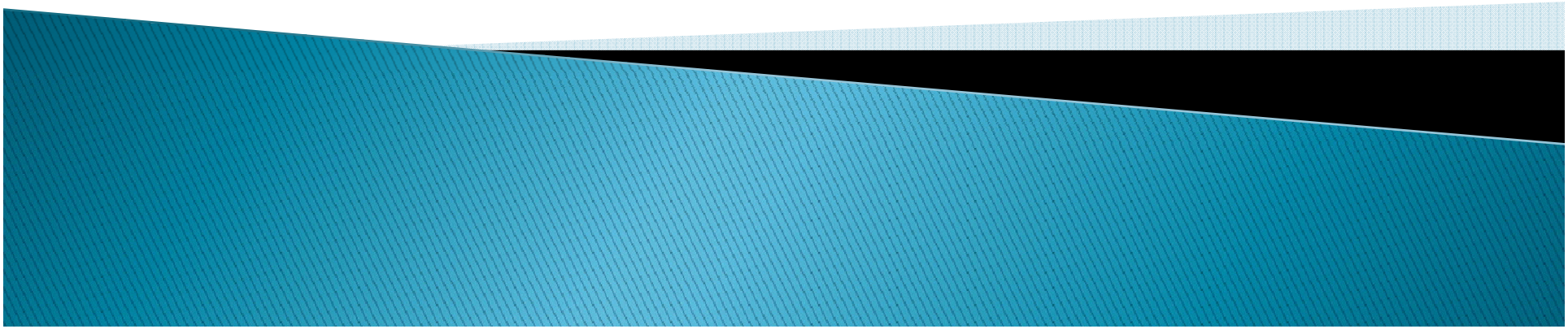
DARPA Urban Challenge

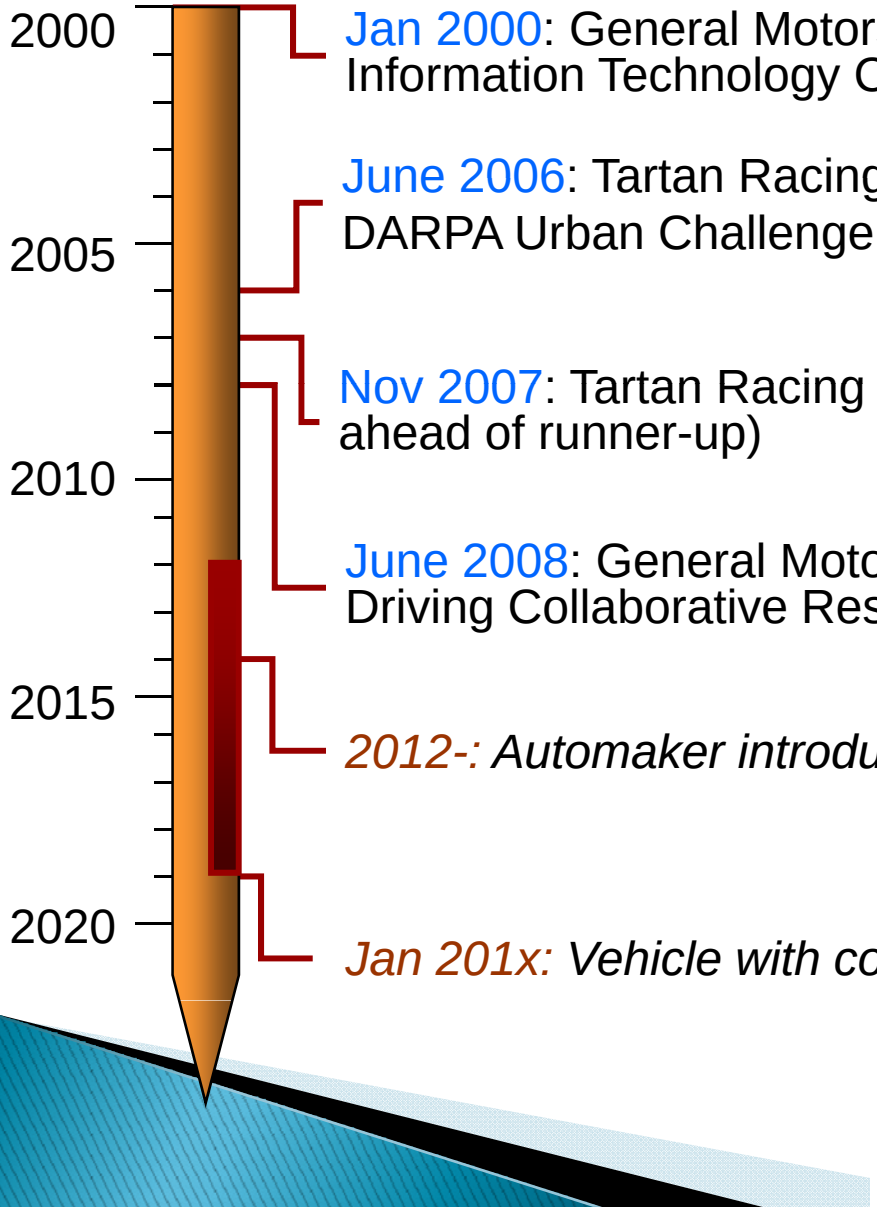
Carnegie Mellon's Tartan Racing win



Society and Automobiles

- More than 1 million people die every year in automotive accidents globally
  - Largest global killer of aged 10-24
  - Tens of millions of injuries
  - Global annual cost of road injuries in medical care, disability and property damage is $518 billion.
- Traffic delays are expensive.
  - The average US driver spends a week stuck in traffic per year.
  - In the EU, 80 billion euros wasted per year due to traffic congestion.
- Loss of independence and self-esteem of senior and disabled citizens

Timeline



Jan 2000: General Motors-Carnegie Mellon Vehicular Information Technology Collaborative Research Lab launched

June 2006: Tartan Racing Consortium launched to compete in DARPA Urban Challenge at Carnegie Mellon

Nov 2007: Tartan Racing wins Urban Challenge (20 minutes ahead of runner-up)

June 2008: General Motors-Carnegie Mellon Autonomous Driving Collaborative Research Lab launched

2012-: Automaker introduces active features year after year

Jan 201x: Vehicle with complete autonomy.

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The DARPA Urban Challenge

- Urban Autonomous Vehicle Race
  - November 3rd, 2007
- 60 miles in less than 6 hours
  - Multiple autonomous vehicles competing with each other on a simulated urban course
  - Other traffic vehicles driven by humans
  - Qualifiers determines the finalists
  - 30 mph max speed limit

Urban Driving Skills

- Safe and Defensive Driving
  - California DMV rules of the road
- Negotiate
  - Stationary and Moving Vehicles
  - Blocked Roadways
  - Intersections and Roundabouts
- Capable of turns, stops, passing, merging, following
- Reasoning about traffic
- Roads included curves, paved/unpaved roads
- Parking (in unstructured environments)
- Progressing safely in the face of adversity

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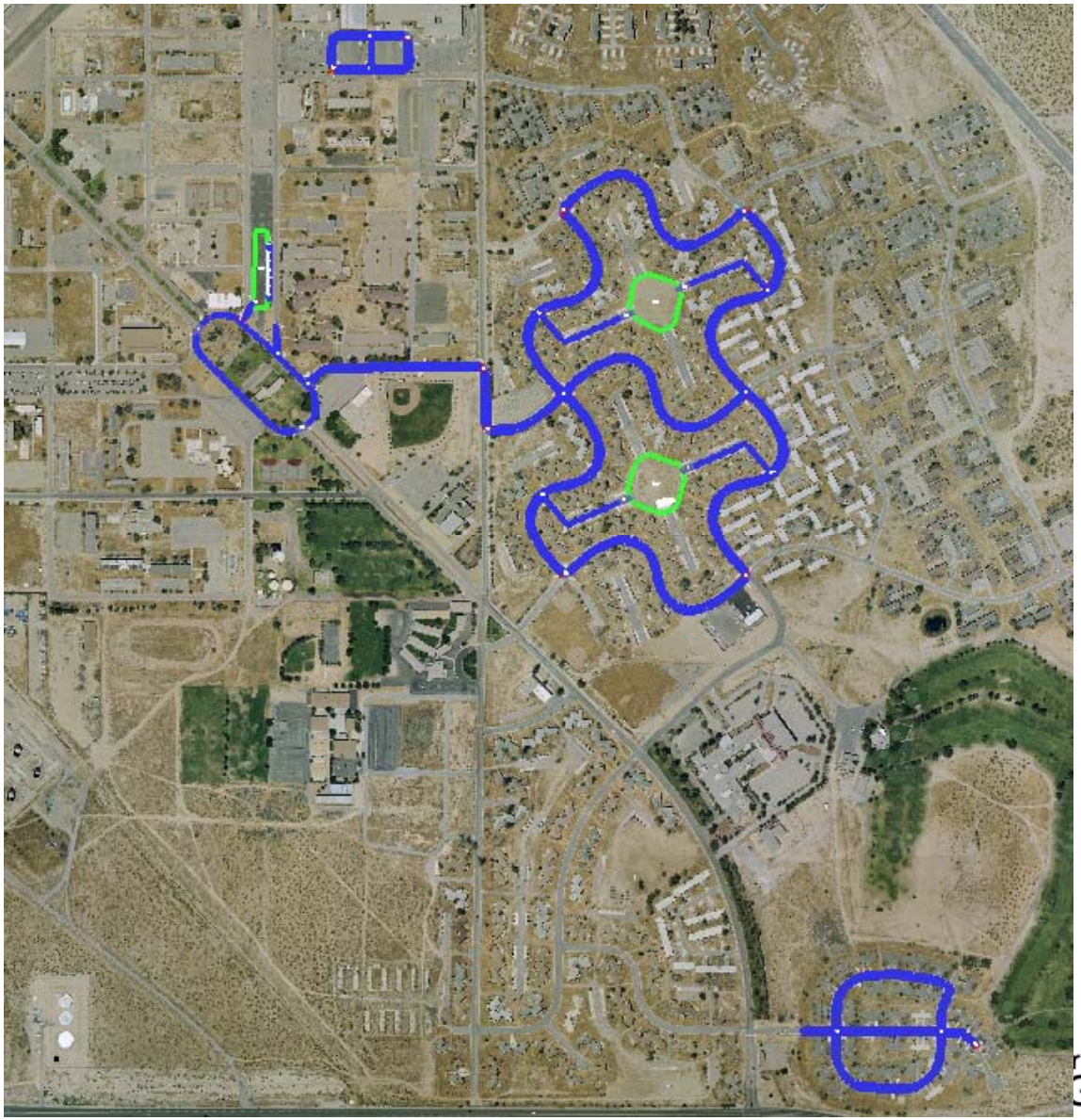
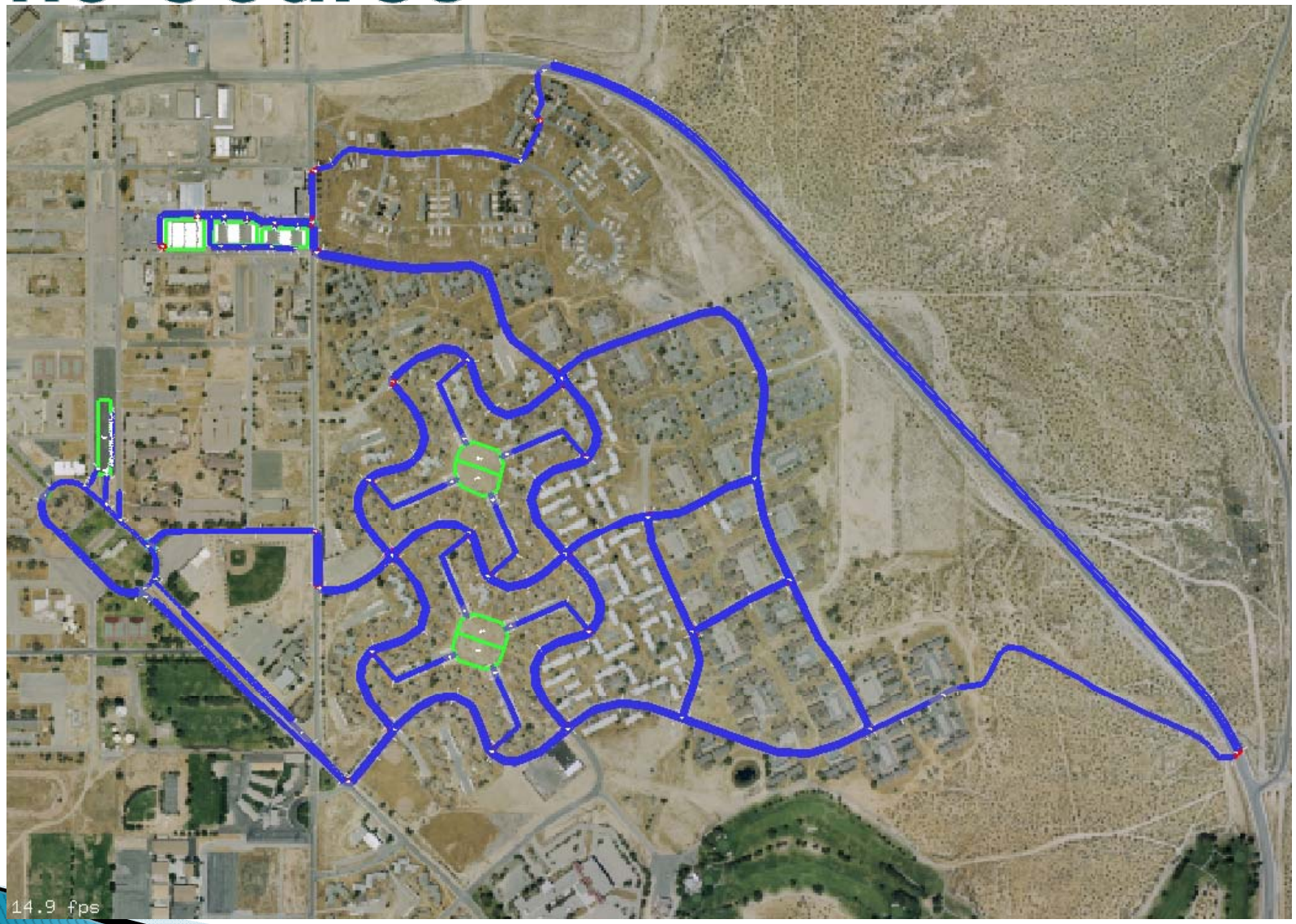
National Qualifying Events



The Course



Urban Challenge Excerpts

The Course

Improvising

Passing

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Sensors

Velodyne
multi-plane lidar
360°x26° FOV, 60m

Applanix
GPS/INS

Continental
ISF 172 lidar
14°, 150m

High dynamic
range camera
90° FOV

Ma/Com
proximity radar
80°, 27m

SICK Scanning Lidar
90/180° FOV, 40m

IBEO
180° FOV,
multi-plane, multi-echo

Continental
ARS 300 radar
60/17°, 60/200m

Vehicle Tracking

Vehicle Tracking

- Raw Data

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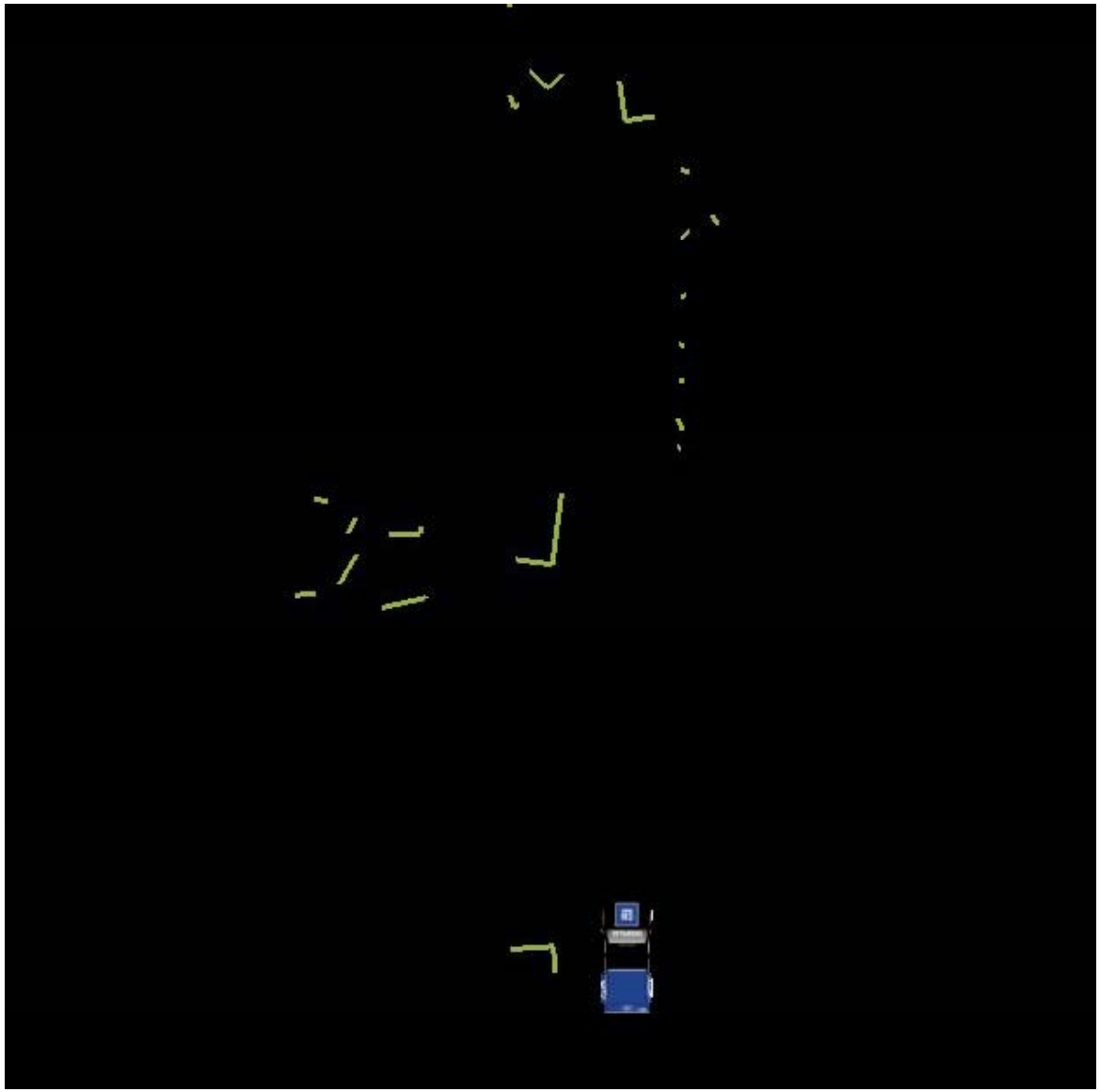
Vehicle Tracking

- Raw Data
- Feature Extraction



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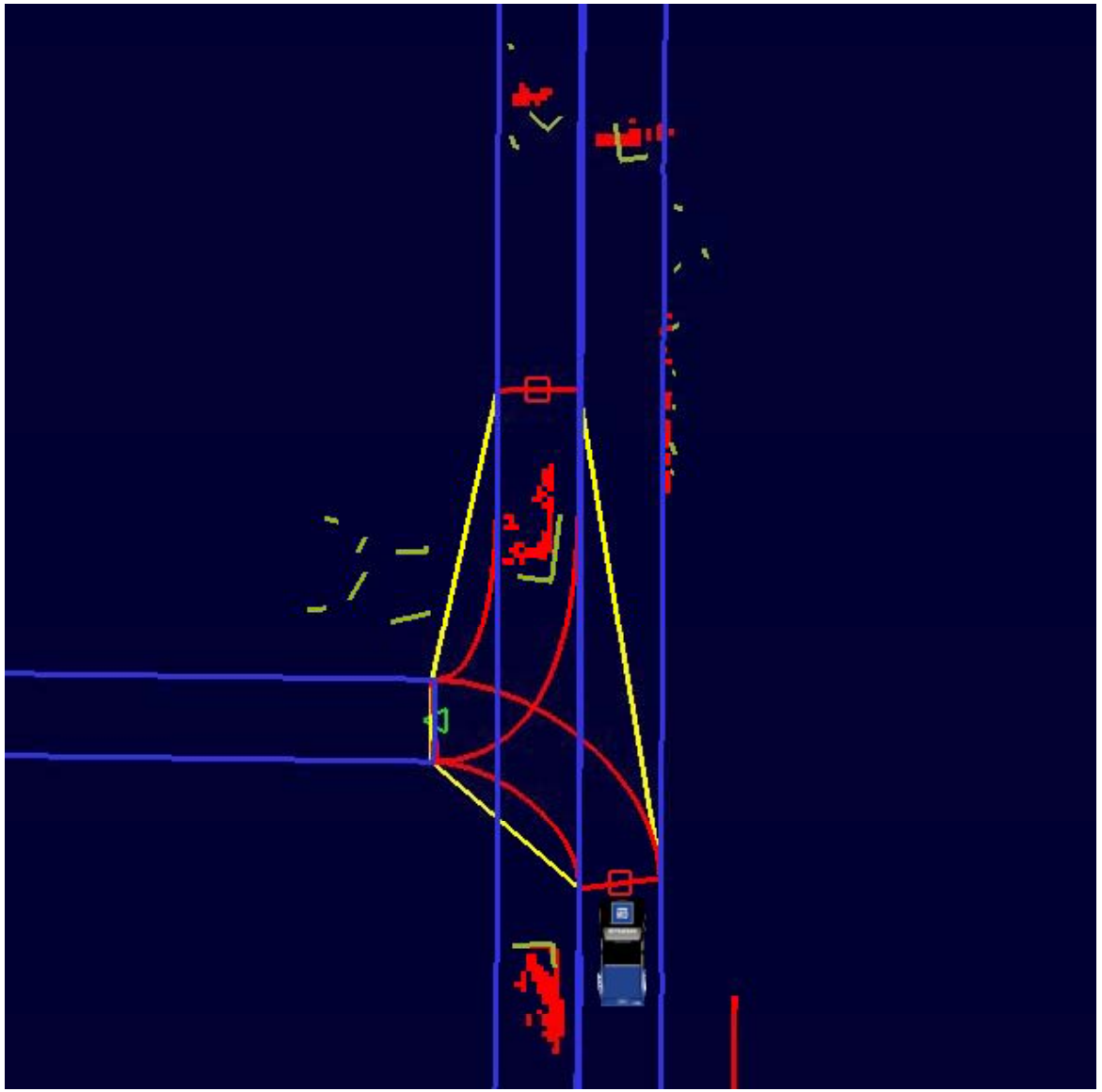
Vehicle Tracking

- Raw Data
- Feature Extraction
- Measurement Validation



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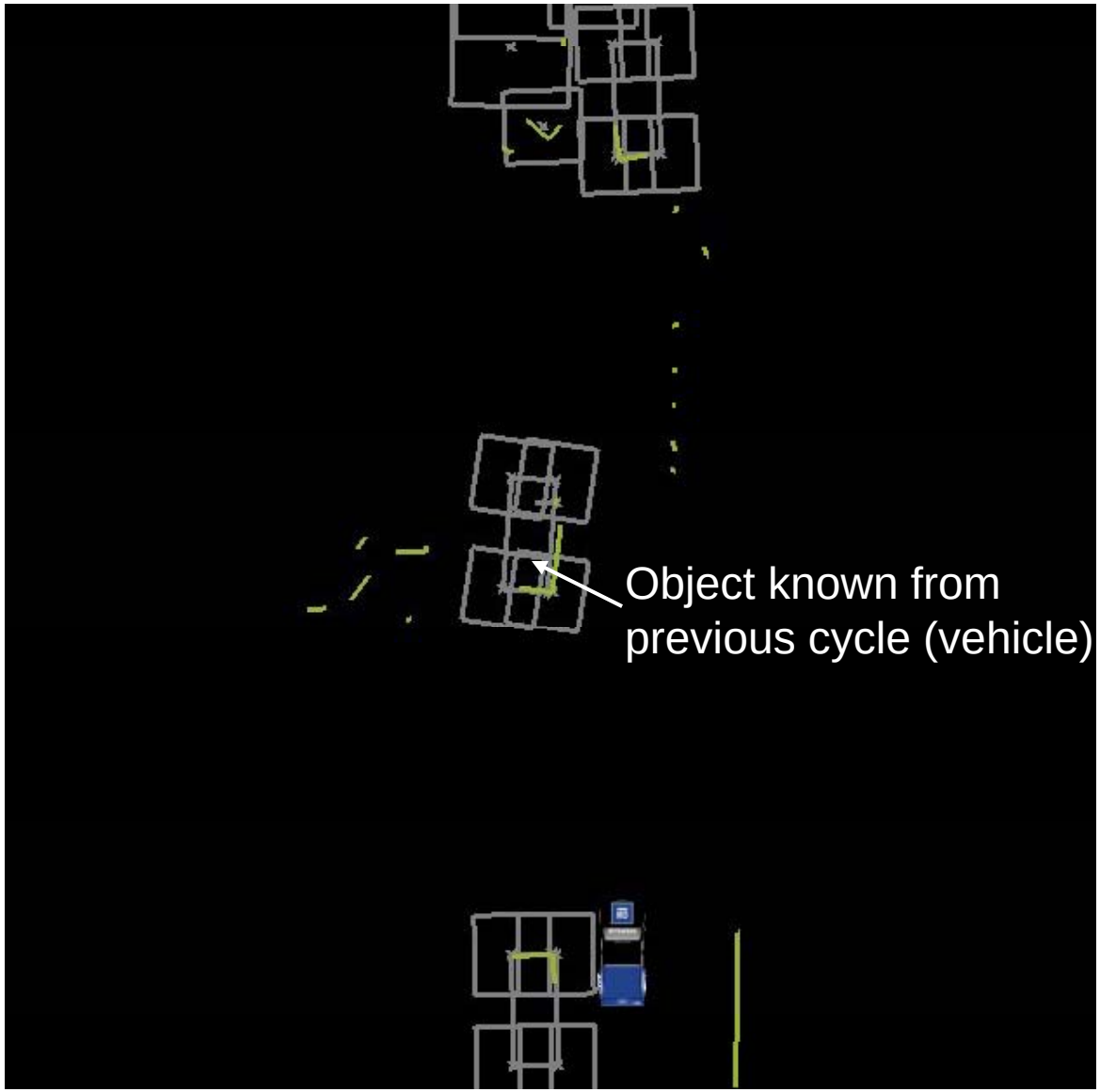
Vehicle Tracking

- Raw Data
- Feature Extraction
- Measurement Validation
- Data Association



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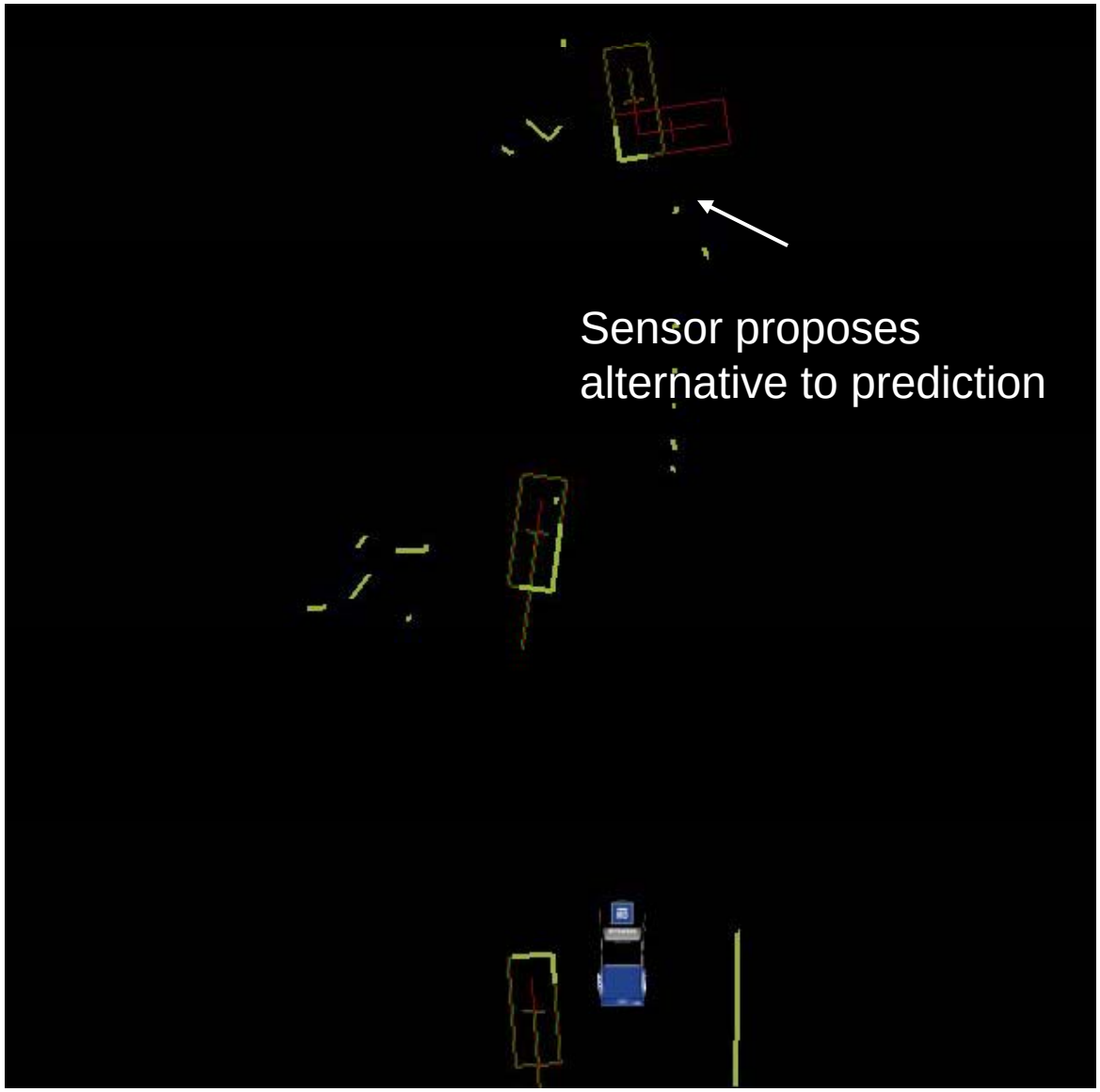
Vehicle Tracking

- Raw Data
- Feature Extraction
- Measurement Validation
- Data Association
- Proposals & Observation



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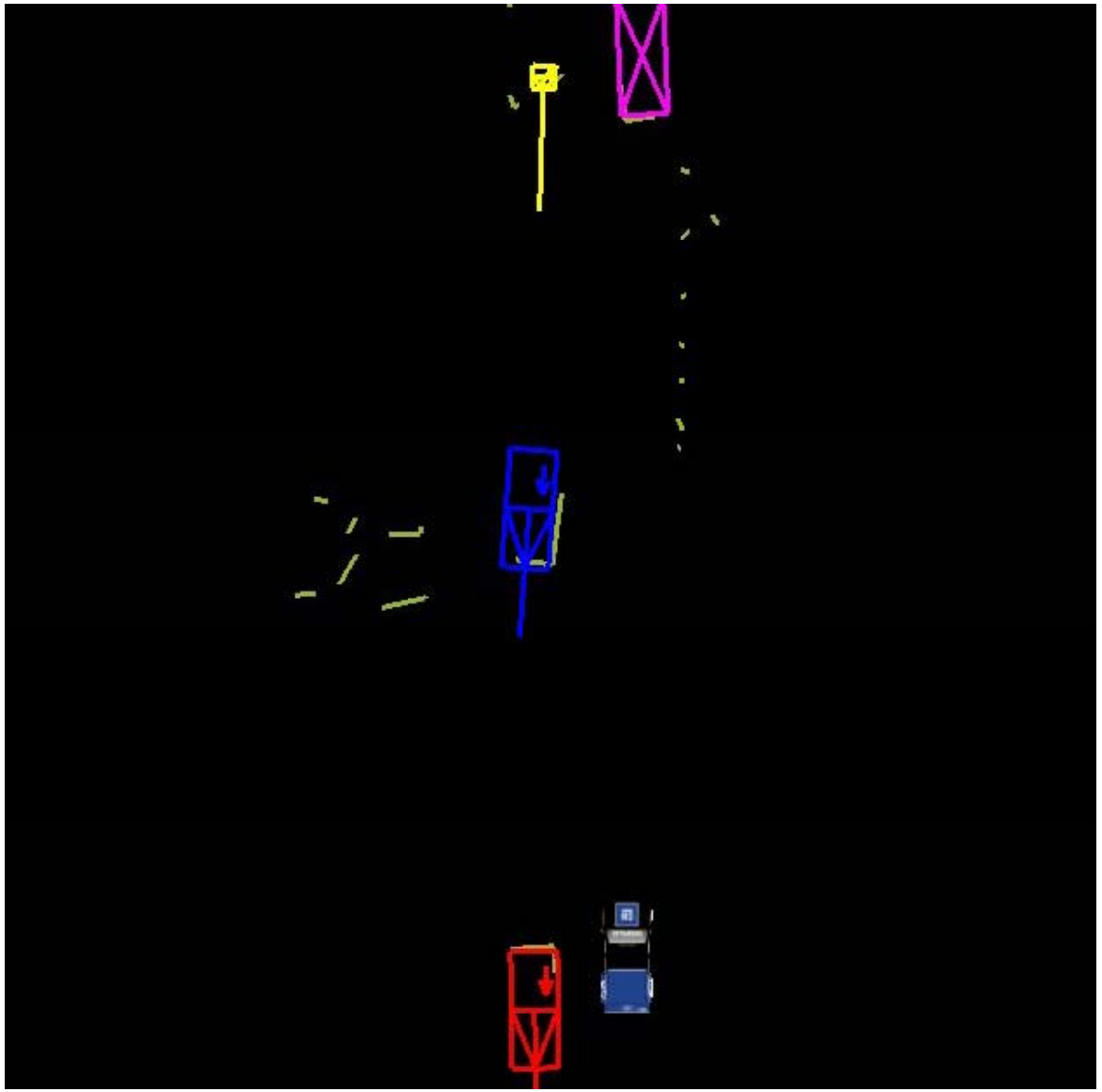
Vehicle Tracking

- Raw Data
- Feature Extraction
- Measurement Validation
- Data Association
- Proposals & Observation
- Model Voting
- Estimation
- Statistics



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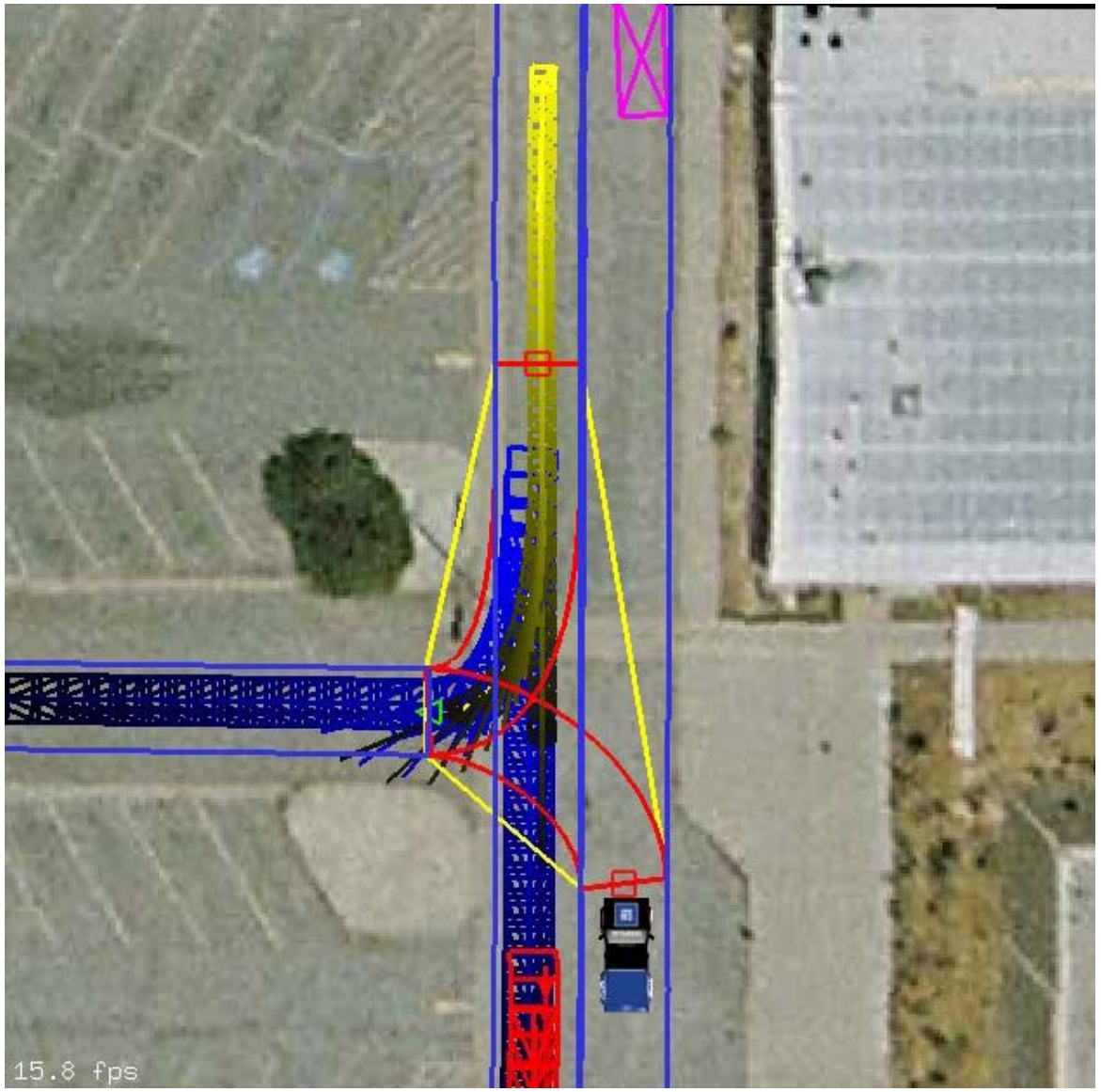
Vehicle Tracking

- Raw Data
- Feature Extraction
- Measurement Validation
- Data Association
- Proposals & Observation
- Model Voting
- Estimation
- Statistics
- Prediction



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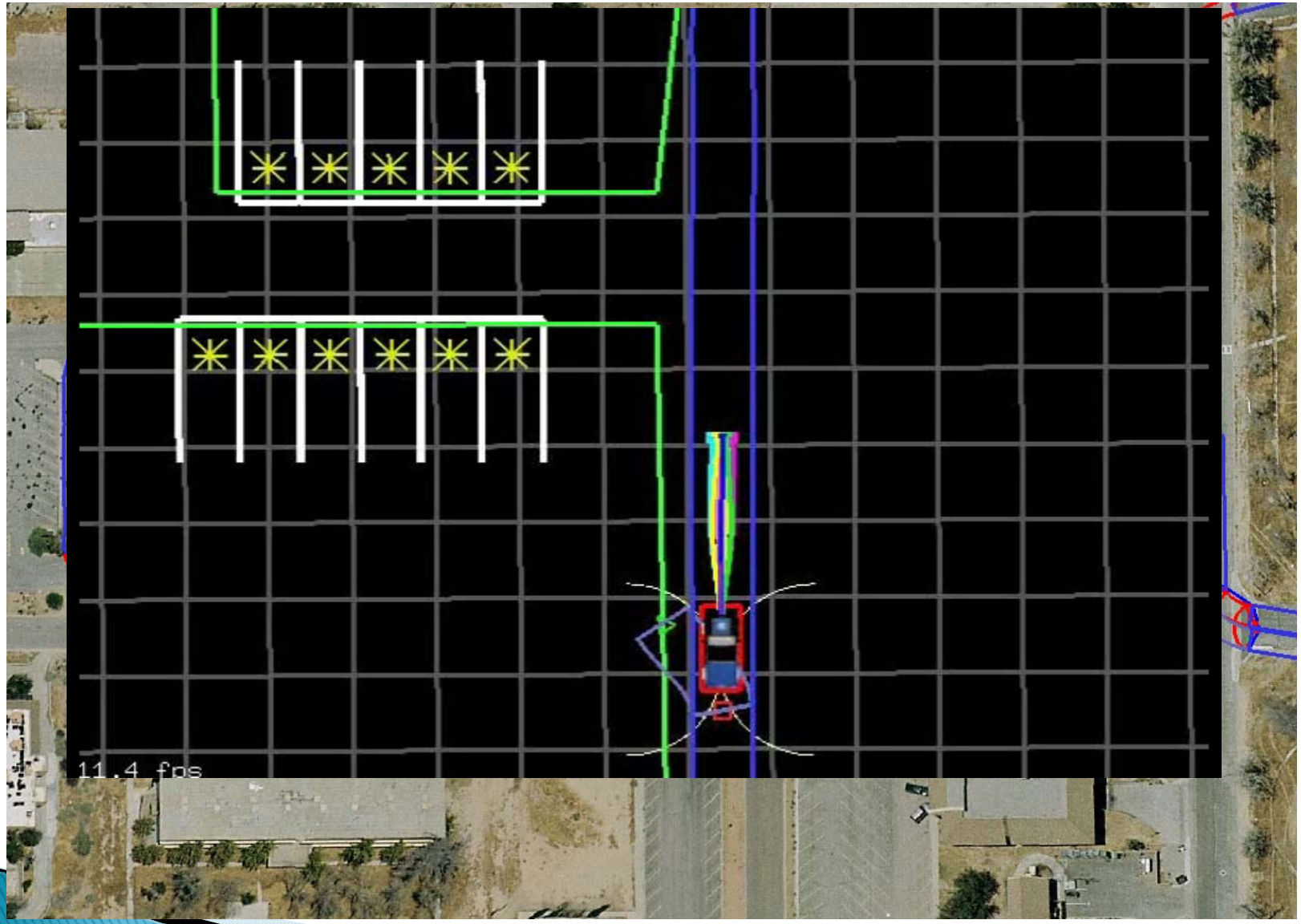
Motion Planning (and Parking)



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Boss Improvises

Accidents Galore

How did it turn out?

- **11 vehicles qualified** for the final event
- **6 completed** the course
- 3 did so within the allotted time and without interventions
  - Nobody was perfect, all were great
  - Carnegie Mellon finished ~20 minutes quicker than Stanford over the ~4 hour run

Challenges

- Exogenous: The complexity & uncertainty of the real world
  - Weather, lighting, and road conditions; construction; accidents; obsolete information, loss of GPS.
- Endogenous: Online and safe recovery from failures of sensors, actuators, computing or communications.
  - Sensors
    - Calibration, wear and tear, failures.
    - Occasional loss of GPS
- Inter-acting: Vehicular Networks
  - communicate securely and coordinate carefully
- Consumer Acceptance
  - Reliability, cost and maintenance
- Legal implications
- Incremental deployment

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Intermediate Milestones

- Active safety and convenience features
- Pedestrian, child, bicyclist, animal warnings
- Virtual Valet
- Highway Chauffeur
- Traffic Jam Chauffeur

- *Dependable/safe embedded computing and communications*

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Autonomous Vehicle Needs

- Localization – Where is it?
  - Accurate GPS
  - Accurate maps
- Awareness – What's around?
  - 360º Sensing
  - V2V
- Controls – Drive to destination safely
  - Vision and signal processing algorithms, route planning, decision-making
  - Reliable controls and actuators

Fail-Silent / Fail-Operational Architectural Components

- Redundant power supplies
- Fail-Silent nodes/boards
- Fail-Operational nodes
- Redundant communication backbones
- Fail-silent nodes for non-critical domains

Fail-Silent / Fail-Operational Software

- Error detection and program flow monitoring
- Dependability and health monitoring services
- Event loggers for Diagnostics and Prognostics
- Reconfigurable for graceful degradation
- Fault isolation
- Standards-compliant interfaces (both hardware and software)

Operational Demands

- Limited inspection and maintenance by end-users
- Wide temperature range (-50°C to 175° C)
- Mechanical stress (vibration, pressure, temperature cycles)
- High voltage/current for power semiconductors and switches
- Long-term reliability requirement
- Long-term (10 years or more) data stability
- "Zero defects"

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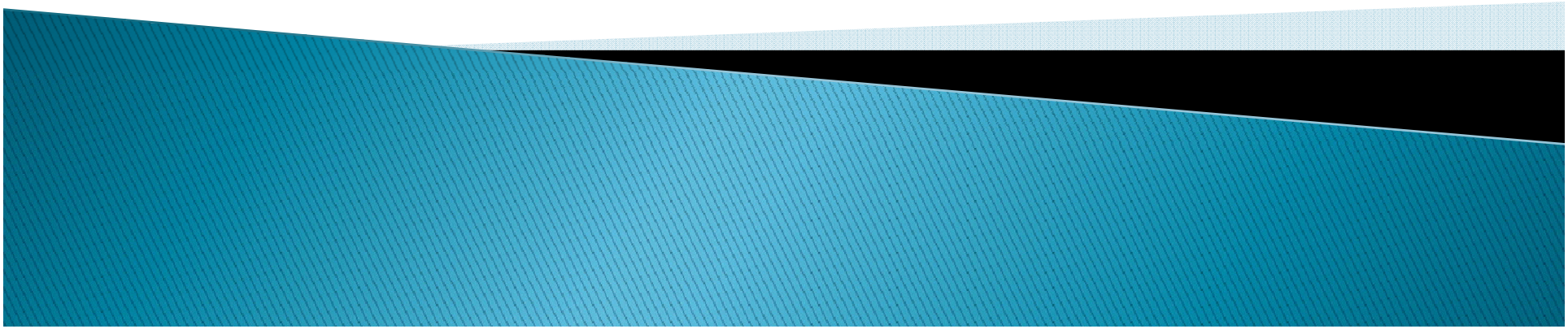
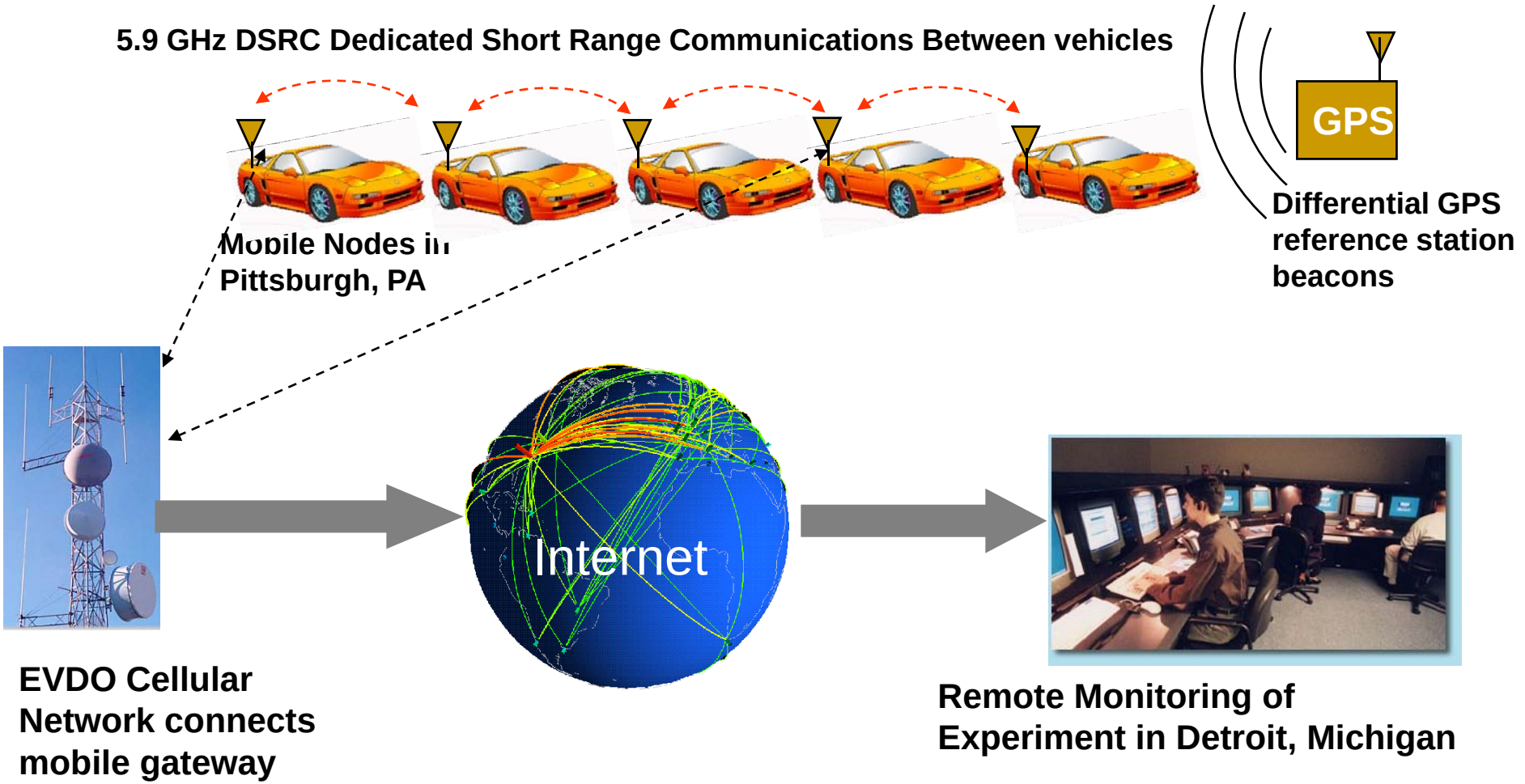
Connected Vehicles



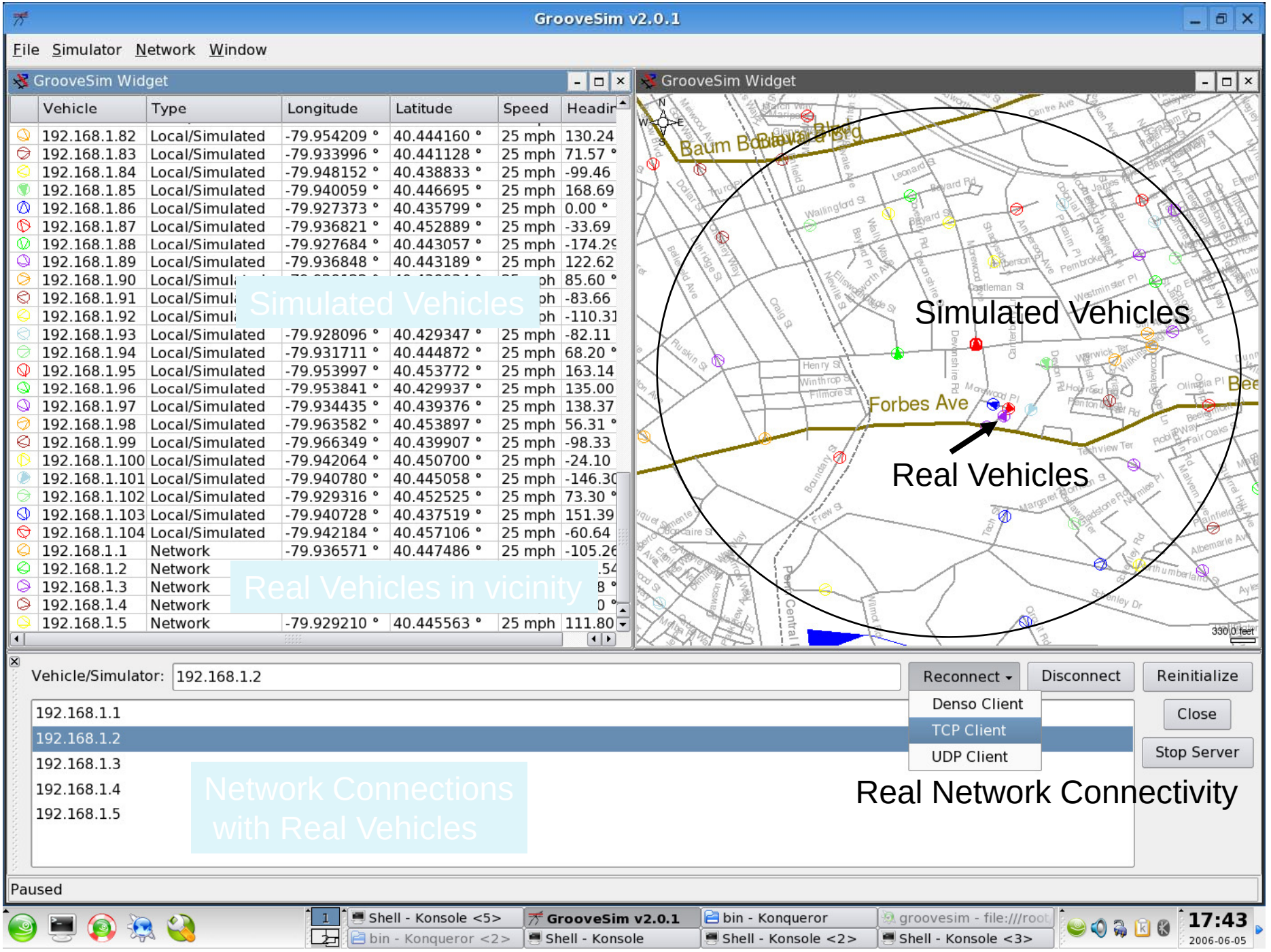
OnStar (for example)

- Safety
  - Airbag deployment warning
  - Automatic dispatch of help
- Maintenance
  - Vehicle diagnostics
  - Regular reports
- Convenience
  - Remote door lock/unlock
  - Stolen vehicle tracking and disabling
- Concierge
  - Locations
  - Directions

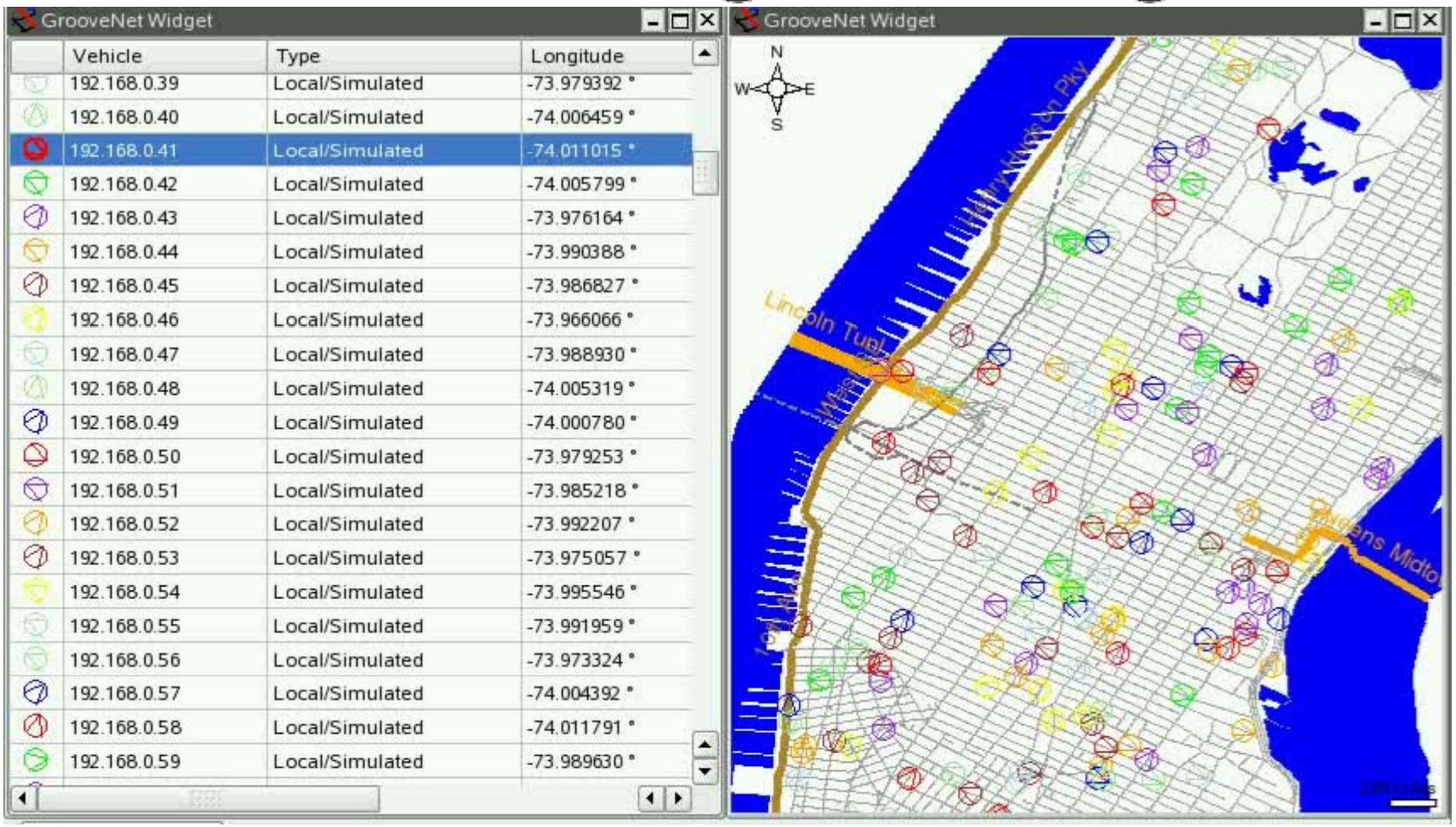
Multi-hop Vehicular Network Test-bed



1. Vehicle-to-Vehicle Multi-hop
2. Vehicle-to-Infrastructure


GrooveSim v2.0.1
File Simulator Network Window
GrooveSim Widget
Vehicle Type Longitude Latitude Speed Headir
192.168.1.82 Local/Simulated -79.954209 ° 40.444160 ° 25 mph 130.24
192.168.1.83 Local/Simulated -79.933996 ° 40.441128 ° 25 mph 71.57 °
192.168.1.84 Local/Simulated -79.948152 ° 40.438833 ° 25 mph -99.46
192.168.1.85 Local/Simulated -79.940059 ° 40.446695 ° 25 mph 168.69
192.168.1.86 Local/Simulated -79.927373 ° 40.435799 ° 25 mph 0.00 °
192.168.1.87 Local/Simulated -79.936821 ° 40.452889 ° 25 mph -33.69
192.168.1.88 Local/Simulated -79.927684 ° 40.443057 ° 25 mph -174.2
192.168.1.89 Local/Simulated -79.936848 ° 40.443189 ° 25 mph 122.62
192.168.1.90 Local/Simul ph 85.60 °
192.168.1.91 Local/Simul ph -83.66
192.168.1.92 Local/Simul ph -110.31
192.168.1.93 Local/Simulated -79.928096 ° 40.429347 ° 25 mph -82.11
192.168.1.94 Local/Simulated -79.931711 ° 40.444872 ° 25 mph 68.20 °
192.168.1.95 Local/Simulated -79.953997 ° 40.453772 ° 25 mph 163.14
192.168.1.96 Local/Simulated -79.953841 ° 40.429937 ° 25 mph 135.00
192.168.1.97 Local/Simulated -79.934435 ° 40.439376 ° 25 mph 138.37
192.168.1.98 Local/Simulated -79.963582 ° 40.453897 ° 25 mph 56.31 °
192.168.1.99 Local/Simulated -79.966349 ° 40.439907 ° 25 mph -98.33
192.168.1.100 Local/Simulated -79.942064 ° 40.450700 ° 25 mph -24.10
192.168.1.101 Local/Simulated -79.940780 ° 40.445058 ° 25 mph -146.3
192.168.1.102 Local/Simulated -79.929316 ° 40.452525 ° 25 mph 73.30 °
192.168.1.103 Local/Simulated -79.940728 ° 40.437519 ° 25 mph 151.39
192.168.1.104 Local/Simulated -79.942184 ° 40.457106 ° 25 mph -60.64
192.168.1.1 Network -79.936571 ° 40.447486 ° 25 mph -105.26
192.168.1.2 Network .54
192.168.1.3 Network 8 °
192.168.1.4 Network 0 °
192.168.1.5 Network -79.929210 ° 40.445563 ° 25 mph 111.80
Simulated Vehicles
Real Vehicles in vicinity
GrooveSim Widget
Baum Blvd
Forbes Ave
Simulated Vehicles
Real Vehicles
330.0 feet
Vehicle/Simulator: 192.168.1.2
Reconnect
Disconnect
Reinitialize
Denso Client
TCP Client
UDP Client
Close
Stop Server
192.168.1.1
192.168.1.2
192.168.1.3
192.168.1.4
192.168.1.5
Network Connections with Real Vehicles
Real Network Connectivity
Paused
Shell - Konsole <5>
GrooveSim v2.0.1
bin - Konqueror
groovesim - file:///root
bin - Konqueror <2>
Shell - Konsole
Shell - Konsole <2>
Shell - Konsole <3>
17:43
2006-06-05

New York – Message Flooding



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Health Monitoring

- Exploit real-time information streams
- Cross-functional coordination
- Collaboration with partners and competitors

Challenges

- Sensor Fusion and Data Mining
- Methods for designing reliable software systems
- Reliable sensors, communications, actuators and computations
- Information and controls security
- Fail-soft technologies
- Diagnostics and Prognostics
- Energy storage and recovery
- Complexity management

Personalization

Education and Training

- Need to bring “cyber-physical systems” (CPS) knowledge into the undergraduate engineering curriculum
- Need to bring technology advances to practicing automotive engineers

Conclusions

- An automobile is the most complex consumer appliance (and mobile device)
- Biggest challenges:
  - Electronics: tighter integration for less complexity
    - Computing, communications, sensors and actuators
    - Cost, cost and cost
  - Reliabilty: Dependable, safe and secure operations in real-time
    - Cost vs functionality tradeoffs
- V2X: V2V and V2I Connectivity