CUGS Course:
Real-Time and Dependable Ethernet (6 hp)

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What we'll discuss this week

- Introduction to distributed embedded real-time systems
- Overview of common real-time communication protocolos
- Ethernet, AVB, and TSN
- Clock synchronization
- Real-time packet scheduling
- Ethernet frame preemption
- Fault tolerance
- Security protocols
- Automotive case study

There will be a lot of acronyms

- IEEE Std 802.1Q: Defines behavior of switches and end stations in an Ethernet network
- IEEE Std 802.1BA: Audio/Video Bridging (AVB)
- IEEE Std 802.1AS: Clock synchronization
- IEEE Std 802.1Qbv-2015: Scheduled traffic (time-triggered). Also called TAS (Time Aware Shaper)
- IEEE Std 802.1Qbu-2016: Frame preemption. Allocation of queues to express vs. preemptable MACs
- IEEE Std 802.3br-2016: Companion standard to the above. Describes how preemption is done on Ethernet

More …

- IEEE Std 802.1Qci-2017: Ingress filtering and policing. Used to detect and isolate errors
- IEEE Std 802.1CB-2017: Redundancy. Replication and elimination of packets
- IEEE Std 802.1AS-2006 (+ various amendments): MACsec. Integrity and privacy on switched Ethernet with symmetric-key crypto
- IEEE Std 802.1X: Port authentication and key agreement protocol
- IEEE Std 802.1AR: Secure device identity with public-key crypto (elliptic curves)

Examination form

- Written term paper
- Presentation of term paper at final seminar in 2018
  - January 30, 2018
- Please think about topics that interest you while we go through the course content
  - We'll allocate time this week for discussions in smaller groups
  - It is fine to work together

Course literature

- To be provided on course web page
- I’ll also help you with specific literature suggestions and starting points for your term paper

Acknowledgments

Contributions to the slide decks from the following individuals:

- Dr. Helge Zinner, Continental Automotive
- Dr. Markus Jochim, General Motors
- Johannes Specht, Univ. Duisburg-Essen
- Dr. Gordon Bechtel, Bechtech
- Taeju Park, Univ. of Michigan, Ann Arbor

Introduction to Real-Time and Embedded Systems

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What is an Embedded System?

- There are many different definitions!
  - "A special-purpose computer system that is used for a particular task."
  - "A computer based systems embedded in real life machines. Though computer based, it dose not have the usual key-board and monitors."
- Some highlights what it is (not) used for:
  - "Any device which includes a programmable component but itself is not intended to be a general purpose computer."
- Some focus on what it is built from:
  - "A collection of programmable parts surrounded by ASICs and other standard components, that interact continuously with an environment through sensors and actuators."

What is a Real-Time System?

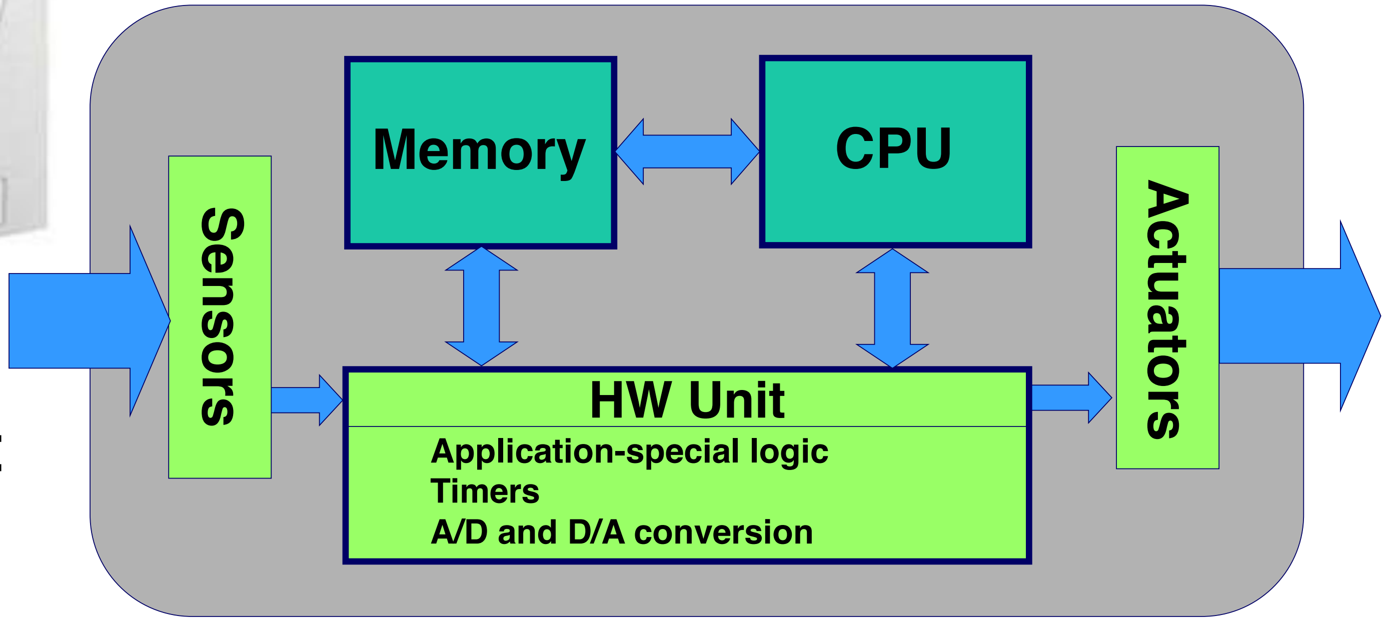
- "An information processing system that has to respond to input stimuli within a finite and specified time."
  - The correctness depends not only on the logical result but also the time it was delivered.
  - Failure to respond in time is as bad as the wrong response!

Embedded & Real-Time Systems




Embedded Controllers

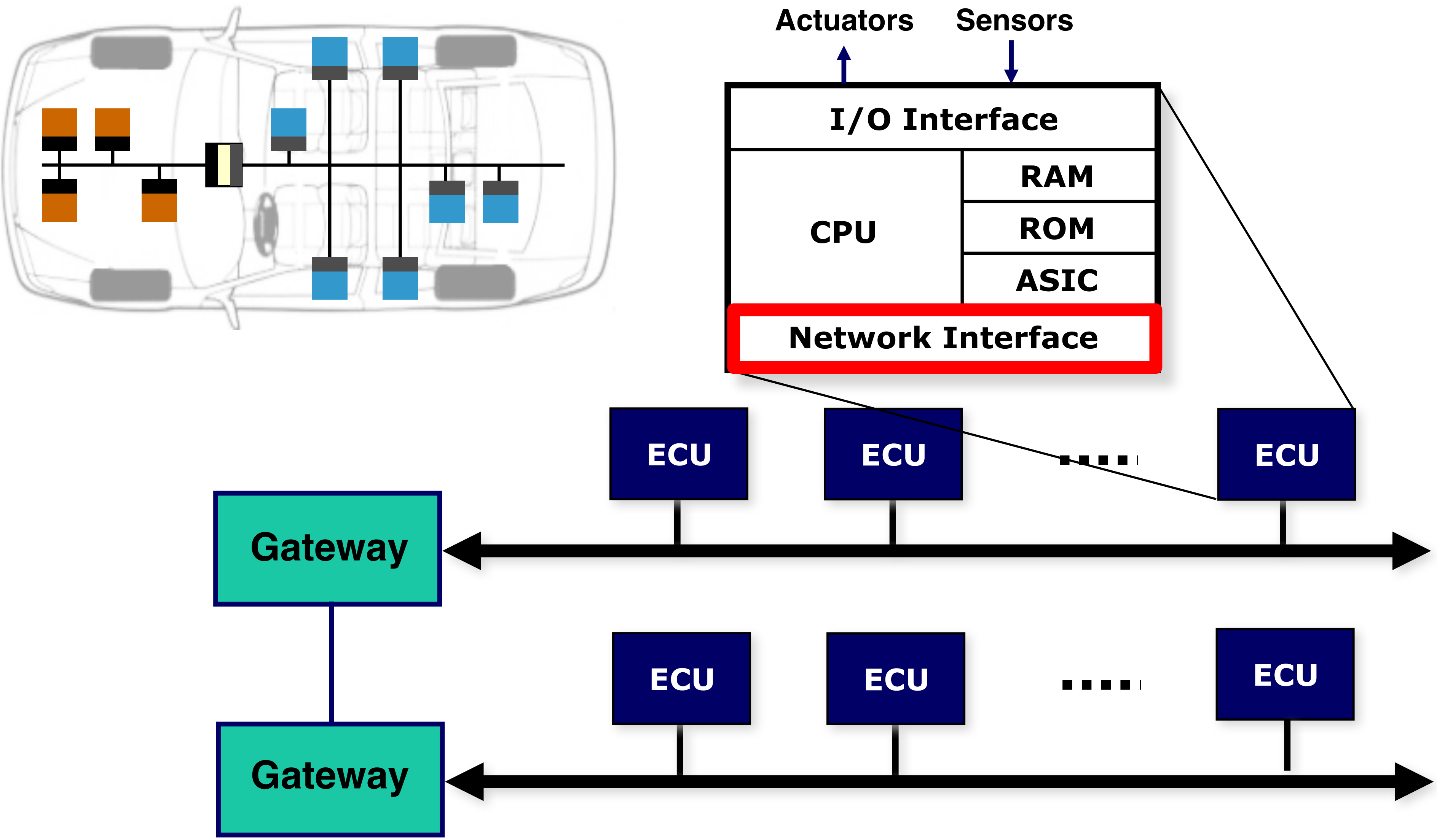
- Reactive systems.
  - The system never stops.
  - The system responds to signals produced by the environment.



Environment

Courtesy of Prof. Zebo Peng

Distributed Embedded Systems



Courtesy of Prof. Zebo Peng

Characteristics of Embedded RT Systems

- Dedicated computers (not general purpose).
  - One or several applications known at design-time.
- Contain a programmable component.
  - But usually not programmable by the end-user.
- Interact (continuously) with the environment:
  - Real-time behavior (faster ≠ better).
  - Predictable, safe and reliable.
- Usually very cost sensitive:
  - Products in competitive markets, demanding low cost.
- Low power/energy is often preferred.
  - Battery life: High energy consumption ⇒ short battery life time.
  - Cost issue: High power consumption ⇒ strong power supply and expensive cooling mechanism.

Many nonfunctional requirements

- Cost
- Real-time
- Dependability (fault tolerance, security)
- Maintainability (e.g., vehicle service)
- Extensibility (for future features)
- Scalability (across multiple product lines)
- Connectivity (V2V, V2I, cellular, Internet)
- Low footprint
- …

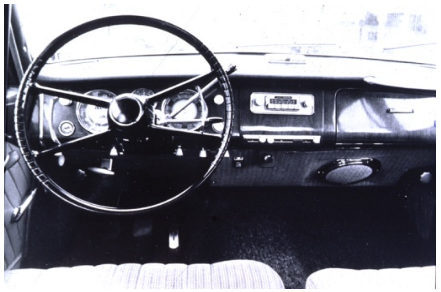
The ES Design Challenges

- Increasing application complexity (e.g., automotive)
- Heterogeneous architecture (HW, SW, network, mechatronics, etc.)
- Stringent time and power constraints
- Low cost requirement
- Short time to market
- Safety and reliability (e.g., very long life-time)
- Power consumption

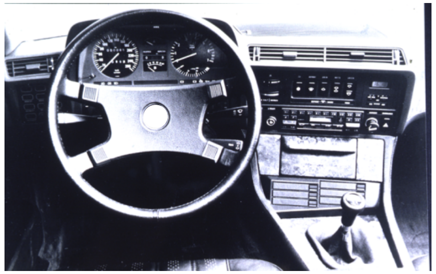
Some automotive examples

Innovation in automotive

- Increasing
  - Number of applications
  - Complexity
  - Bandwidth requirements
  - Reliability



Electronic Injection
Check engine control
Cruise control
Central locking
…



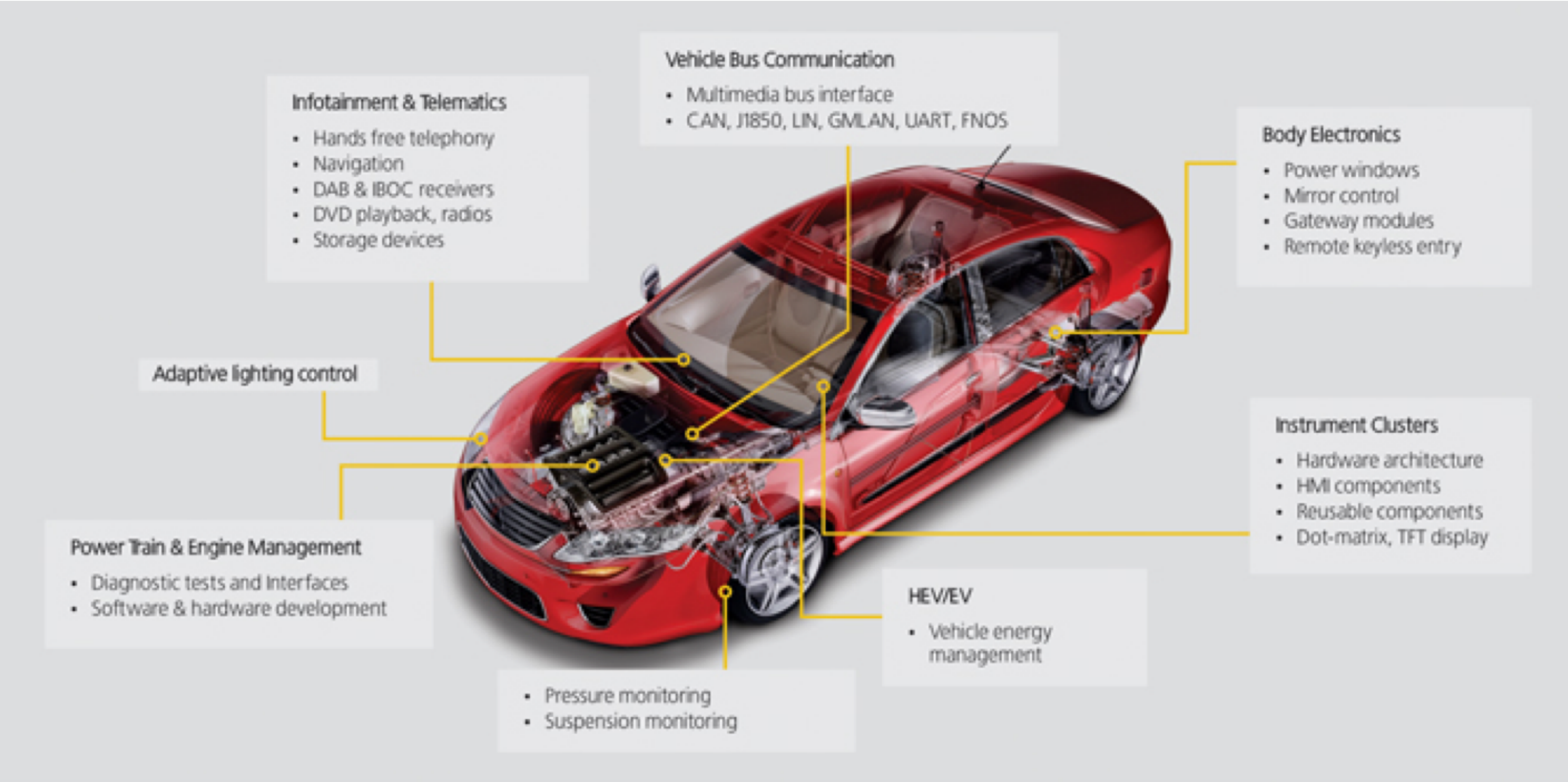
Gearbox control
Climate control
ASC Anti Slip Control
ABS Anti -lock Brake Sys.
Telephone
Seat heating control
Automatic mirrors

Navigation system
CD-changer
Active Cruise Control
Airbags
Dynamic Stability Control
Roll stabilization
Xenon lighting
Vehicle Assist
Voice input
Emergency call

ACC Stop&Go
Lane departure warning
Blind spot warning
Traffic sign recognition
Night vision
Active headlight system
Parking automation
Efficient dynamics
Hybrid engines
Internet access
Telematics
Online Services
Bluetooth integration
Local Hazard Warning
Personalization
SW Update
Smart Phone Apps

1970 1980 1990 > 2010

Car electronics



Automotive

Harsh environmental conditions:

- Body & cabin: -40°C to 85°C
- Chassis & powertrain: -40°C to 125°C or even 150°C
- Mechanical accelerations
- Not a data center: Dirt, water, salt, dust, ice, snow, mud, oil, grease, transmission fluid, brake fluid, engine coolant, ...
- Qualification of hardware is required (tight EMC requirements)
- Functional Safety/ASIL (ISO 26262) compliance

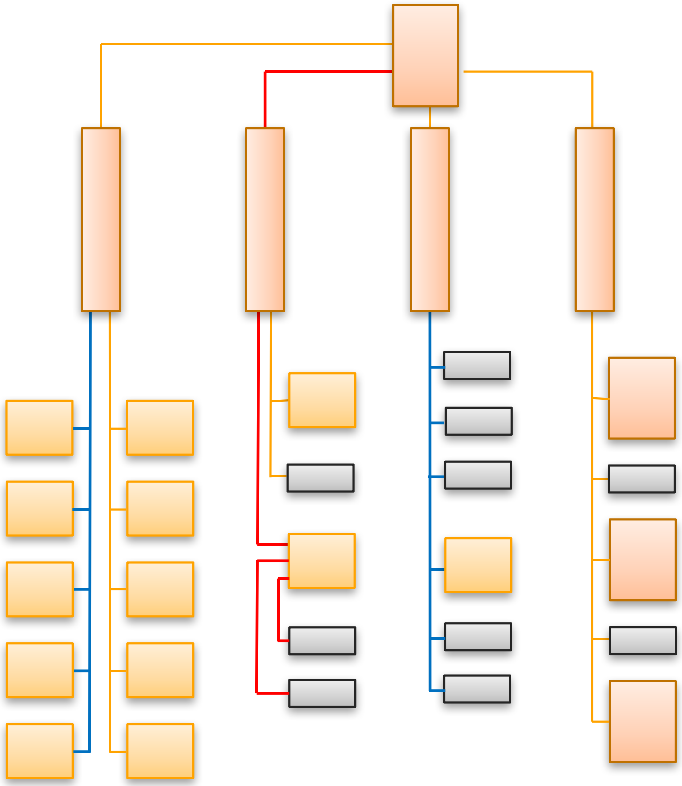
For additional information see:
http://www.ieee802.org/3/bw/public/buntz_tazebay_3bw_01_0914.pdf
http://www.ieee802.org/3/bw/public/Wienchowski_3bw_02_0914.pdf

Many nonfunctional requirements

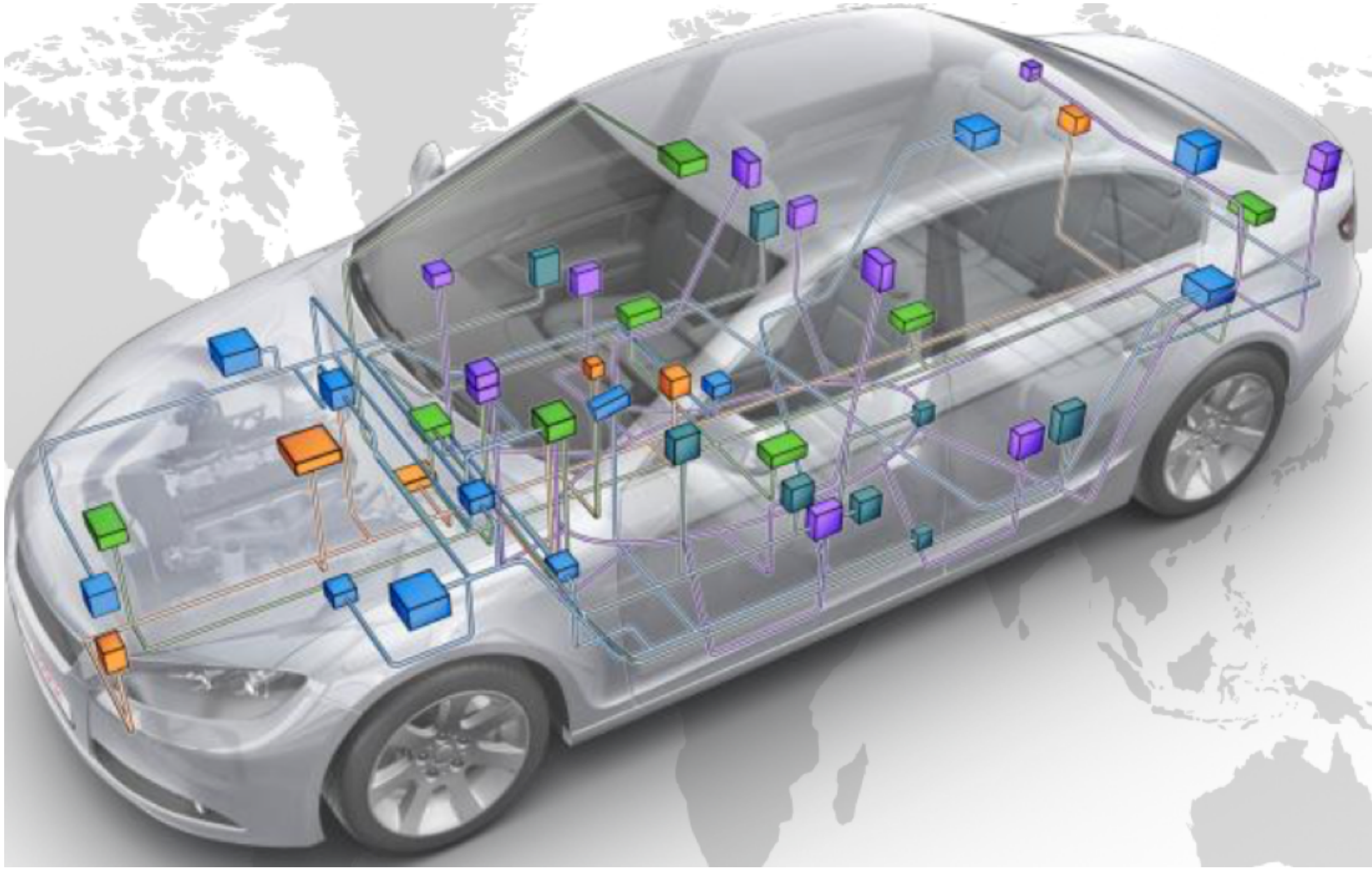
- Cost
- Real-time
  - Average/Worst case latency, jitter
  - Synchronization
- Dependability (fault tolerance, security)
- ISO 26262 Functional Safety standard
- Maintainability (e.g., vehicle service)
- Extensibility (for future features)
- Scalability (across multiple product lines)
- Connectivity (V2V, V2I, cellular, Internet)

Current E/E architectures

- Domain based
- Special-purpose ECUs with specialized I/O for the application
- Low-speed networks (1 Mbps is rare)
- Hardware and software tied together with direct I/O for the particular application
  - Brake control
  - Electric Power Steering
  - Body control electronics
- Leads to a lot of modules, a lot of wiring, and a lot of silos



Car electronics



Ethernet & IP @ Automotive TechDay 2013
Cost Efficient Gateway Architectures for Deterministic Automotive Networks
Thomas Hogenmüller (Bosch), Burkhard Triess (ETAS)

Wiring

- Cost and mass top 3
- 30-40% of warranty cost

Why Ethernet for automotive?

- Growing bandwidth requirements to push data around in and out of the vehicle
- Integration and fusion of sensor data
- New sensors for active safety & autonomous:
  - Camera, radar, lidar, HD maps
- Infotainment (audio, video, navigation, speech recognition, displays)
- V2V, V2I, and Internet connectivity
- Cloud computing and crowd-sourcing
- Up-integration of Electronic Control Units

Automotive Ethernet

- OEMs, Tier-1s, and semiconductor companies worked together to develop Ethernet PHYs for automotive environments
- 100BASE-T1 and 1000BASE-T1 completed
  - Full-duplex 100 Mbps and 1 Gbps, respectibely
  - Single unshielded twisted pair copper cable
  - 10 Mbps and multi-Gbps ongoing

Modern driver assistance systems

- "SuperCruise" (Cadillac CT6), hands-free semi-automated driving on controlled-access highways
- Technology
  - Driver monitoring camera
  - High-definition maps of US and Canada
  - Camera for lane detection
  - Multiple radar
- Increased bandwidth
- Increased dependability
- Fail-operational systems

Autonomous cars

Meet the VW ID electric car: 300-plus mile range in 2020, self-driving by 2025

By Bill Howard on September 30, 2016 at 9:22 am | 47 Comments

1 shares

Ford: We'll sell fully autonomous cars by 2021 with no steering wheels

By Bill Howard on August 17, 2016 at 11:30 am | 26 Comments

13 shares

Ford will build a fully autonomous vehicle by 2021 for the ride-hailing and ride-sharing markets.

How autonomous? It will be built with no steering wheel, no gas pedal, and no brake pedal.

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GM Executive Credits Silicon Valley for Accelerating Development of Self-Driving Cars

Head of GM's foresight and trends unit says timetable for autonomous vehicles likely moved from 2035 to 2020, if not sooner

By JOHN D. STOLL

Updated May 10, 2016 5:48 p.m. ET

AUGUST 11, 2016

33 Corporations Working On Autonomous Vehicles

CBINSIGHTS

www.cbinsights.com

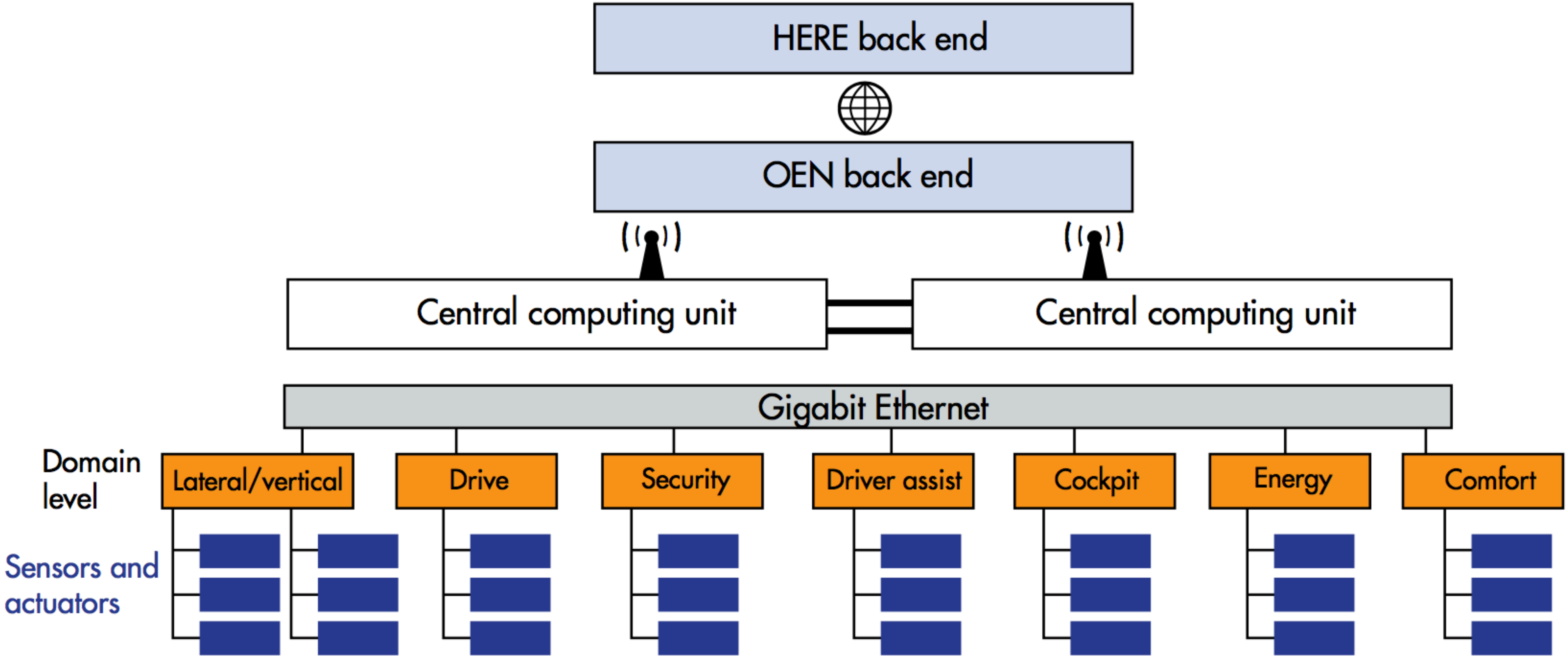
Growing amount of sensor data

- Long range radars in front and back
- Short/mid range radars around the car
- Cameras with different fields-of-view and angle around the car
- Lidar (laser) in front and back
- Precise GPS and HD maps
- Connectivity (V2V, V2I, cellular, ...)

Typical functions

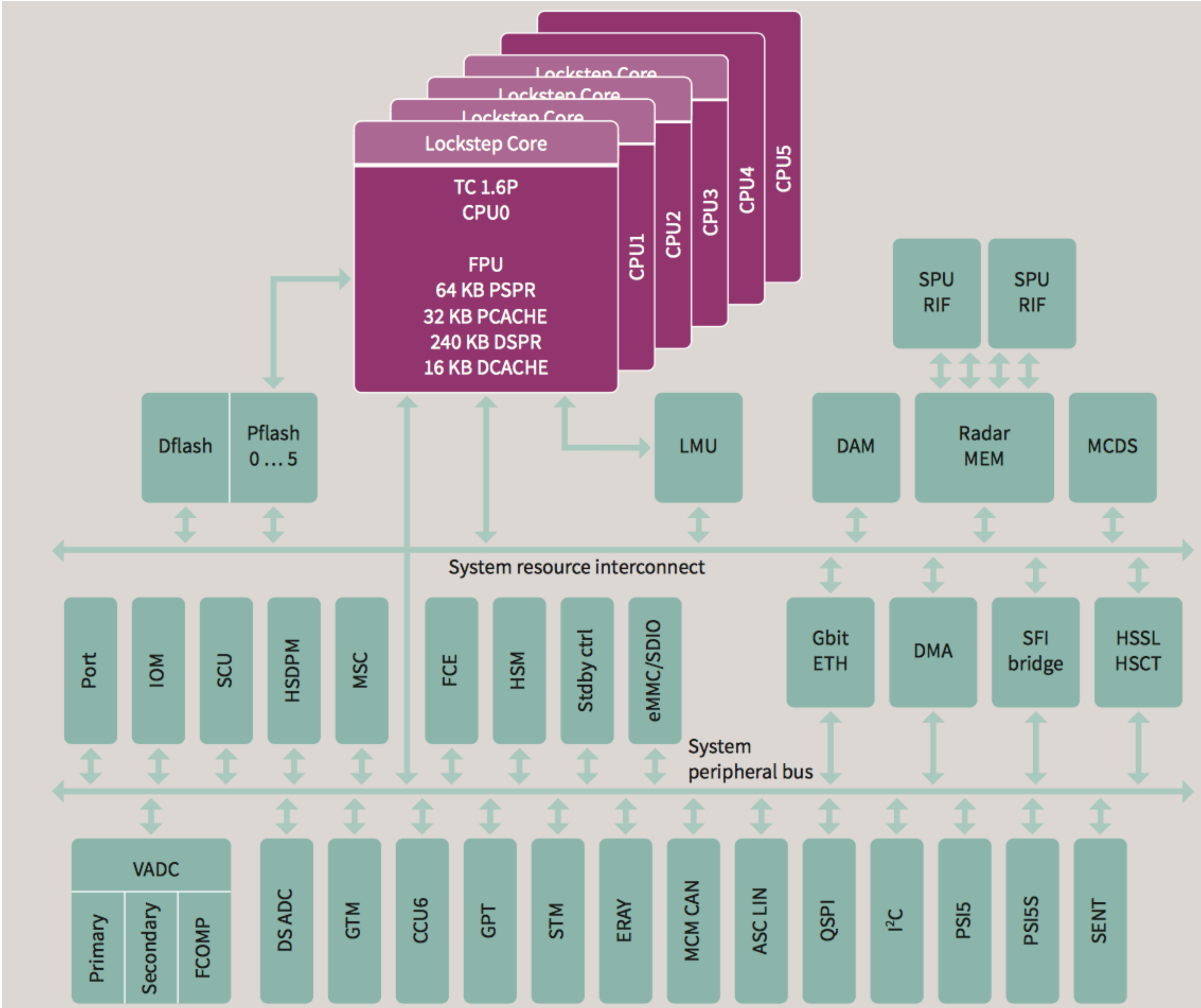
- Sensing
- Perception (360 degree, short and long range)
- HD maps
- Precise localization (GPS with corrections, visual odometry, vehicle sensors)
- Behaviors
- Planning
- Trajectory
- Control
- Actuation

Trends in automotive E/E architectures



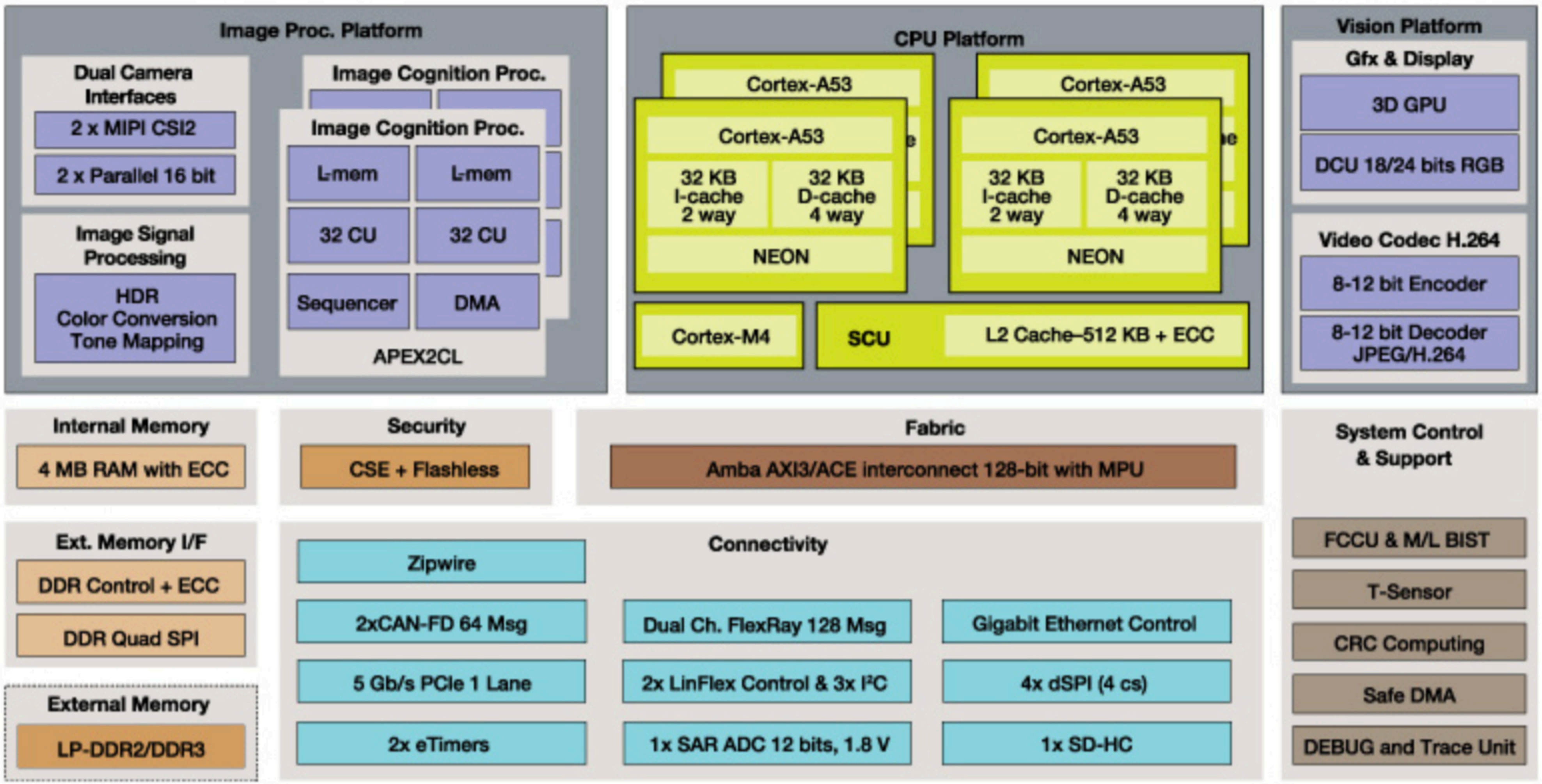
Hansen Report on Automotive Electronics, May 2017

Infineon Aurix TC3xx microcontroller family

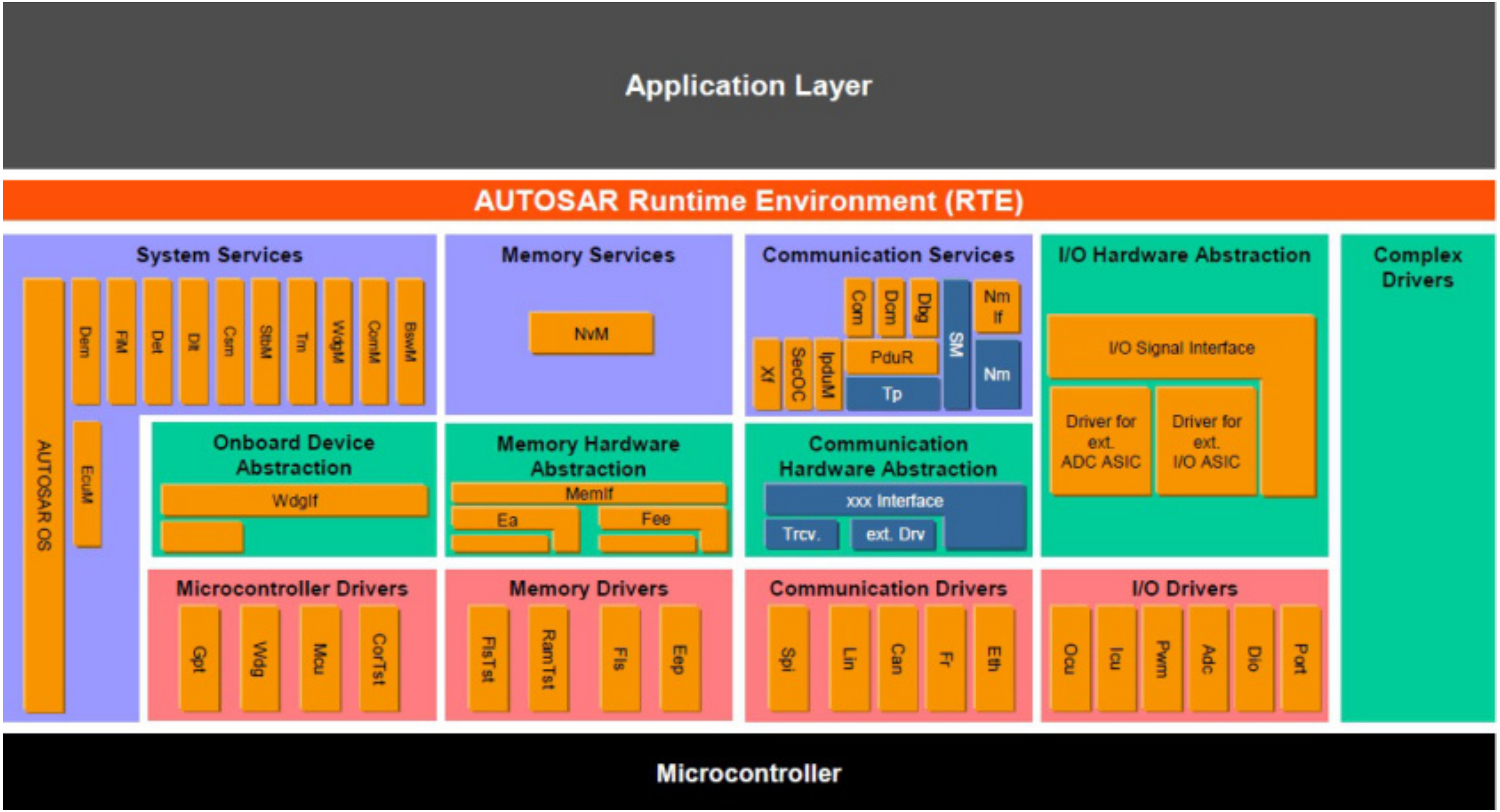


NXP Treerunner

S32V234 Block Diagram



AUTOSAR SW Stack



Summary

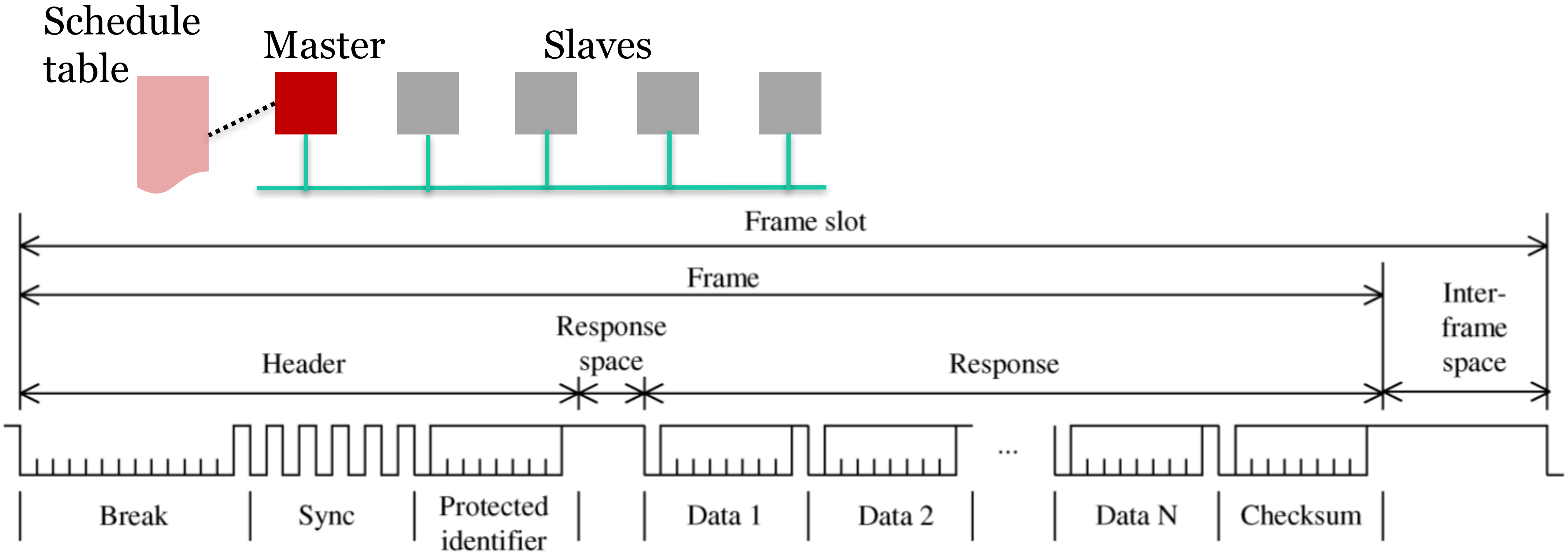
- Embedded real-time systems are found in most products we use in our lives
- Automotive industry is in a transformation
  - Autonomous driving and MaaS
  - Connectivity
- Ethernet is one of the foundational technologies to support this transformation
- Other drivers are centralization and integration
- Bandwidth is not the only solution; also need solutions for real-time and dependability

Today’s real-time communication protocols

- LIN and CAN are two common real-time communication protocols (e.g., in cars)
- For some time, nobody thought we would need more than CAN
- FlexRay was developed by an automotive consortium
  - Was widely anticipated to become a de facto standard
  - Eventually to be replaced by Ethernet (already happening)

LIN

- Master has a schedule with ordered list of message identifiers (64 identifiers are available)
- An identifier is assigned to the master or a slave
- Determinism by schedule table (determined offline)



Controller Area Network (CAN)

- Developed by Bosch
- Now ISO standard
- CSMA/CA, shared, half-duplex, broadcast media
- Typically 500 kbps today, some 1 Mbps
- CAN with Flexible Data-rate (2-5 Mbps, depending on number of nodes and length of cables)
- Common serial data communication technology among Electronic Control Units in cars and trucks

CAN-FD frame format

- 11-bit frame identifier encodes priority of communication (priority is inversely proportional to identifier value)
- Nodes that want to transmit first send the identifier
- Highest priority wins arbitration
- Other nodes start receiving the frame

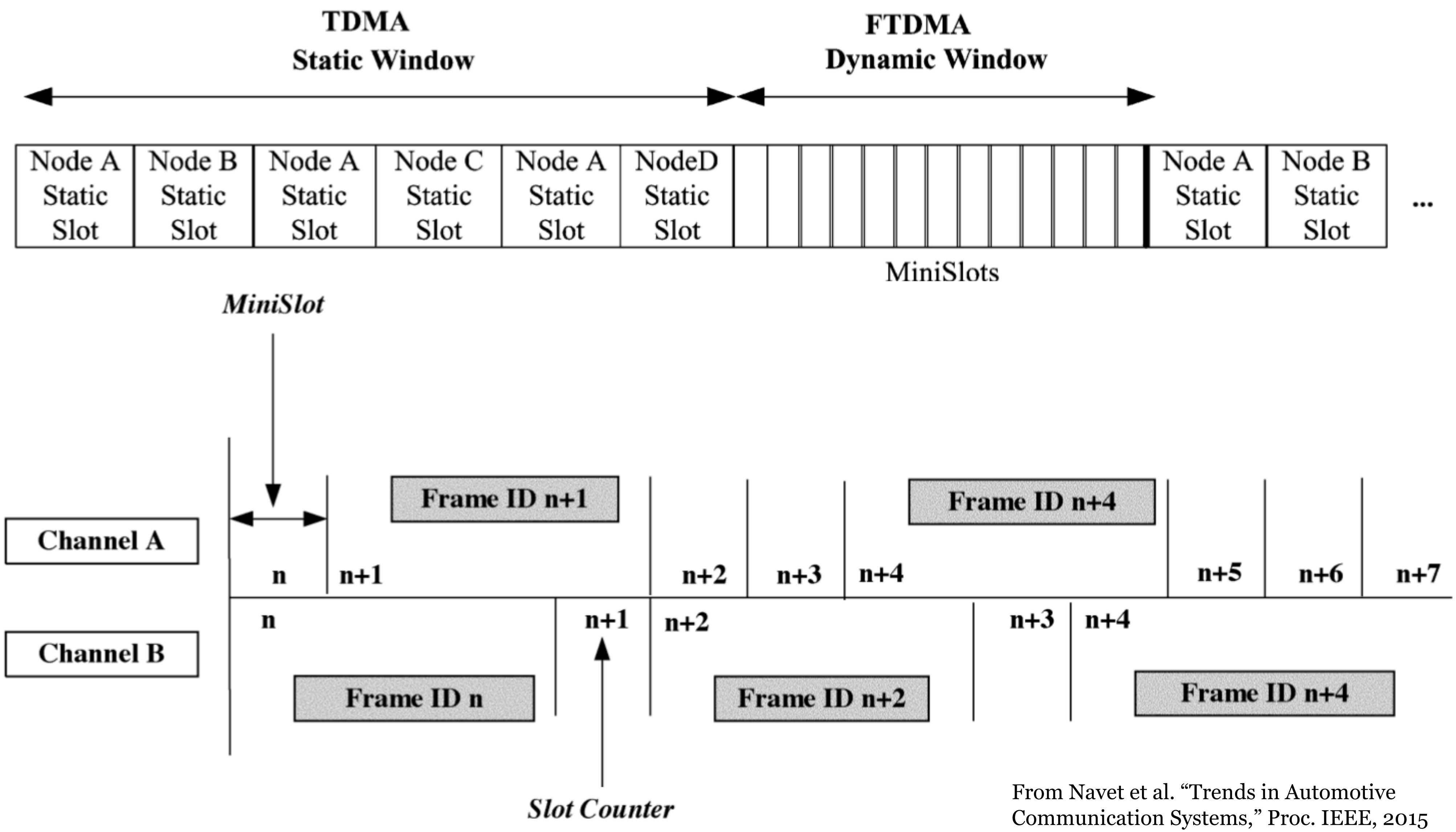
FlexRay

- Developed by consortium of automotive OEMs, Tier-1 suppliers, and semiconductor companies
- Focusing on safety-critical applications with real-time and fault-tolerance requirements
- 10 Mbps with dual channels with 254 bytes payload
- Fault-tolerant clock synchronization
- Dual channels provides two (conflicting) values: 2x bandwidth and redundancy
- Shared, half-duplex, broadcast media

FlexRay

- Periodically alternating static and dynamic segment
- Static segment is TDMA with equal-sized time slots
  - A node is assigned 0, 1, or more slots
- Dynamic segment is "Flexible TDMA" with minislots
  - Nodes are assigned frame identifiers
  - Lower frame identifiers imply higher chance of getting time to transmit in the dynamic segment

FlexRay



From Navet et al. "Trends in Automotive Communication Systems," Proc. IEEE, 2015

Summary

- 20 kbps: LIN is a low speed, low cost communication bus with a bus master initiates all communication
- 0.125-1 Mbps: CAN has an arbitration mechanism to prioritize real-time traffic on the bus
- 10 Mbps: FlexRay is a combination of TDMA (time-triggered) and FTDMA (event-based, flexible) with dual channels for bandwidth and redundancy
- 10 Mbps – 1 Gbps and beyond provides a scalable, homogeneous network for future real-time networking applications with high bandwidth, real-time and dependability requirements