Lecture at Voronezh State Univ.

Introduction to Automotive Embedded Systems

8-June-2012

Hiroaki TAKADA

Executive Director and Professor
Center for Embedded Computing Systems, Nagoya Univ.

Chairman, TOPPERS Project

Email: hiro@ertl.jp URL: http://www.ertl.jp/~hiro/

Introduction of Nagoya and Nagoya Univ.

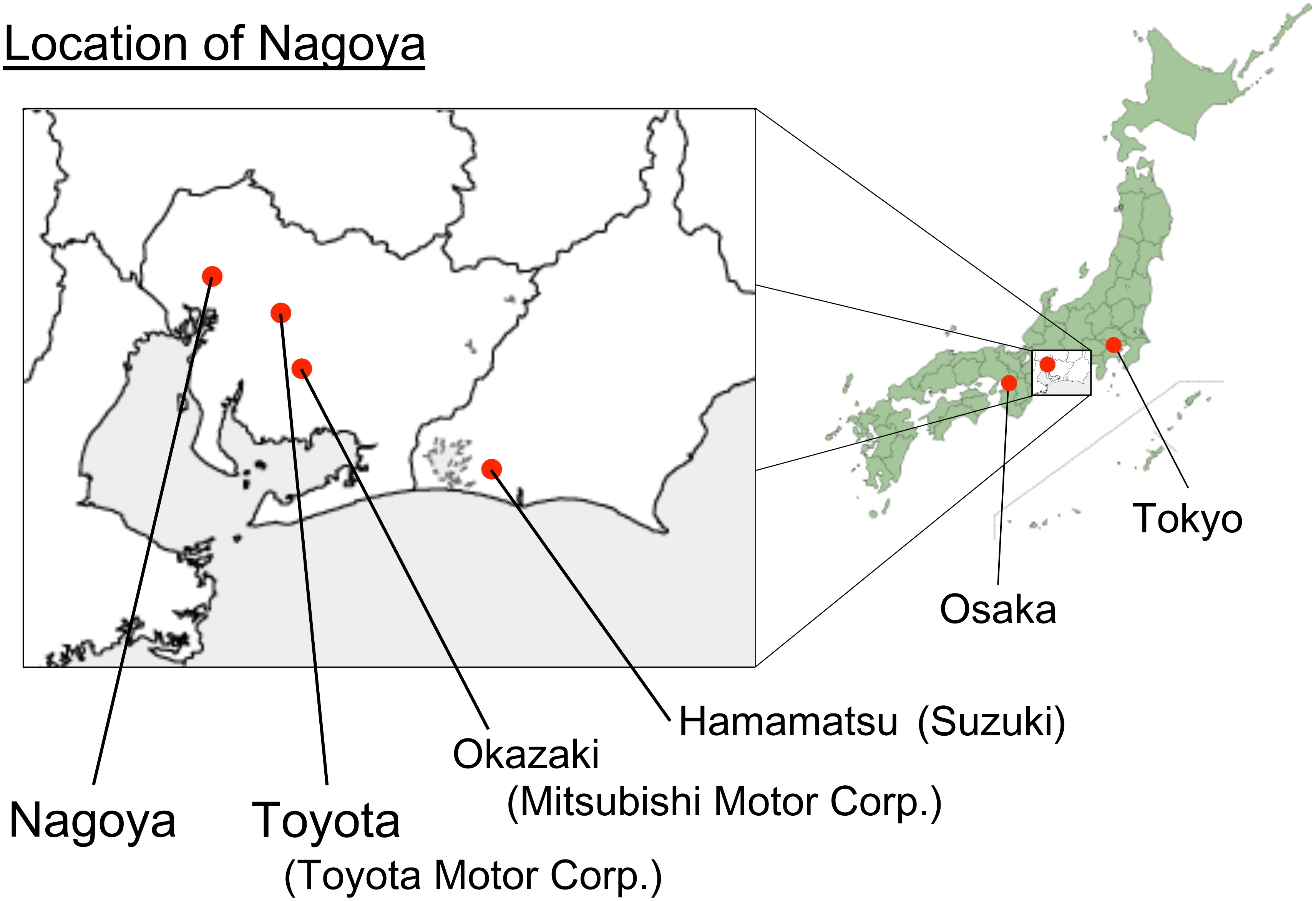
Nagoya

- Center city of third largest metropolitan area in Japan
  - Tokyo (incl. Yokohama), Osaka, Nagoya, …
- Located around the center of Japanese Main Island (between Tokyo and Osaka)
- Manufacturing industry center of Japan
- Automotive industries are concentrated, especially
  - The headquarters of Toyota Motor Corp. (located in Toyota City) is near to Nagoya.

Nagoya University

- National University located in Nagoya City
- Within top 10 (I hope top 5!) universities of Japan
- 4 Nobel Prize Winners

Location of Nagoya



Self Introduction – Hiroaki Takada

Current Positions

- Professor, Nagoya University
- Executive Director, Center for Embedded Computing Systems (NCES), Nagoya University
- Chairman, TOPPERS Project

and several others

Major Research Topics

- Real-time operating systems for embedded systems
- Real-time scheduling and analysis
- Electronic system-level design
- Automotive embedded systems

! *several joint projects with Toyota Motor Corp. and other Japanese automotive industries*

Table of Contents

INTRODUCTION TO AUTOMOTIVE EMBEDDED SYSTEMS

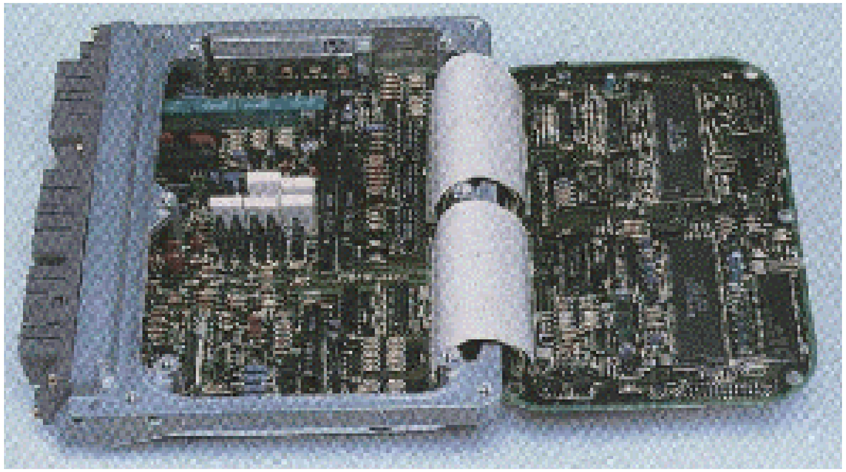
Automotive Embedded (Computing) Systems

Embedded (Computing) Systems

- A computer system that is embedded into an piece of equipment or a machine to control it.
- Embedded systems are applied to most electric/ electronic equipment, recently.

Automotive Embedded (Computing) System

- A computer system that is embedded into a car to control it.
- An embedded computer unit is called an ECU (Electronic Control Unit).



Engine Management ECU

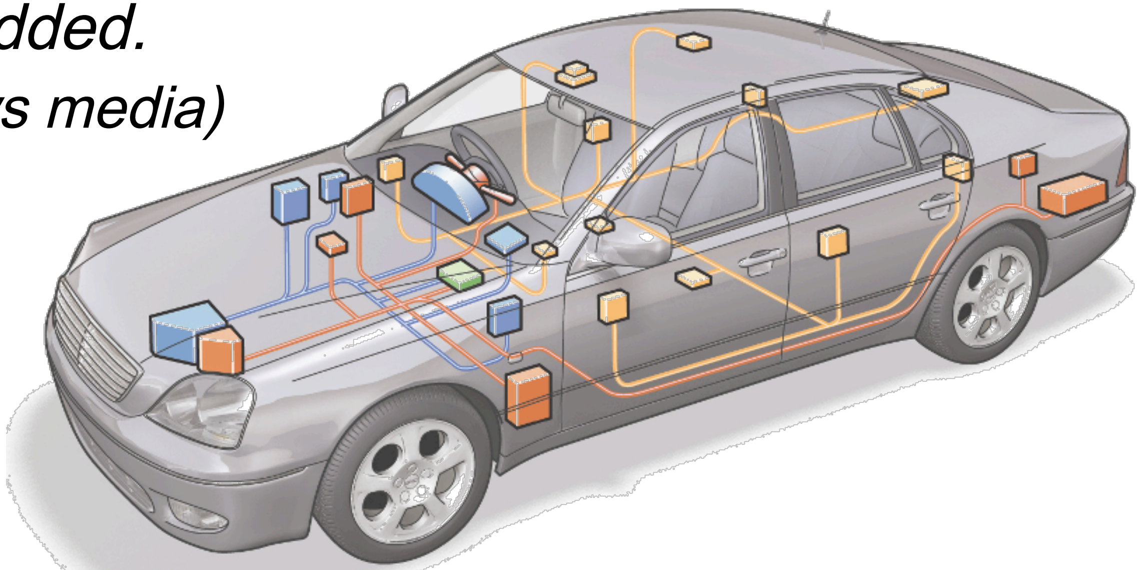
Courtesy: Toyota Motor Corp.

Example: LEXUS LS-460

- released in Sep., 2006.
- more than *100 ECUs embedded when all optional equipments are installed.*
- *about 7,000,000 lines of software embedded.*

(from different news media)

http://www.lexus.jp/



Automotive Embedded Systems and Networks

General Features of Automotive Embedded Systems

- Many (as many as 100) ECUs are used for the following purposes:
  - energy saving & low emission
  - safety (active & passive)
  - comfortableness, convenience, entertainment
  - cost & weight reduction
- ECUs are connected with several in-vehicle networks.
- *High reliability and safety requirements*
- *Strict real-time property required*
- Severe environmental conditions (temperature, EMC)
- *Severe production cost restriction*

! ECUs for different systems/services have different requirements and require different technologies.

Classification of Automotive Embedded Systems

Powertrain and Chassis Control

- engine, automatic transmission, hybrid control, ...
- steering, brake, suspension, ...

Body Electronics

- instrument panel, key, door, window, lighting, …
- air bag, seat belt, ...

Multimedia (Infortainment) Applications

- car audio, car navigation, traffic information, ...
- electronic toll collection (ETC), backguide monitor, ...

Integrated Systems/Services

- electronic stability control, pre-crash safety, …
- parking assistance, lane keeping assistance, ...

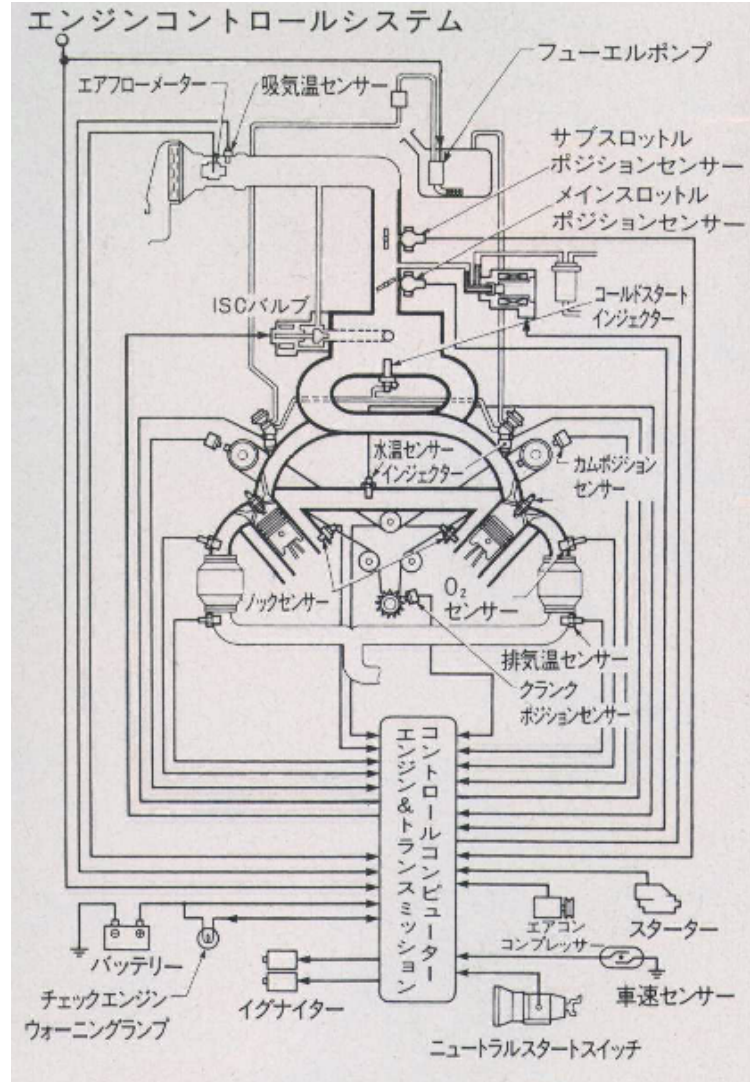
Example (1) – Engine Management System

System Components

- control computer (ECU)
- many sensors
  - crank position sensor
  - air flow meter
  - intake temperature sensor
  - throttle sensor
- some actuators

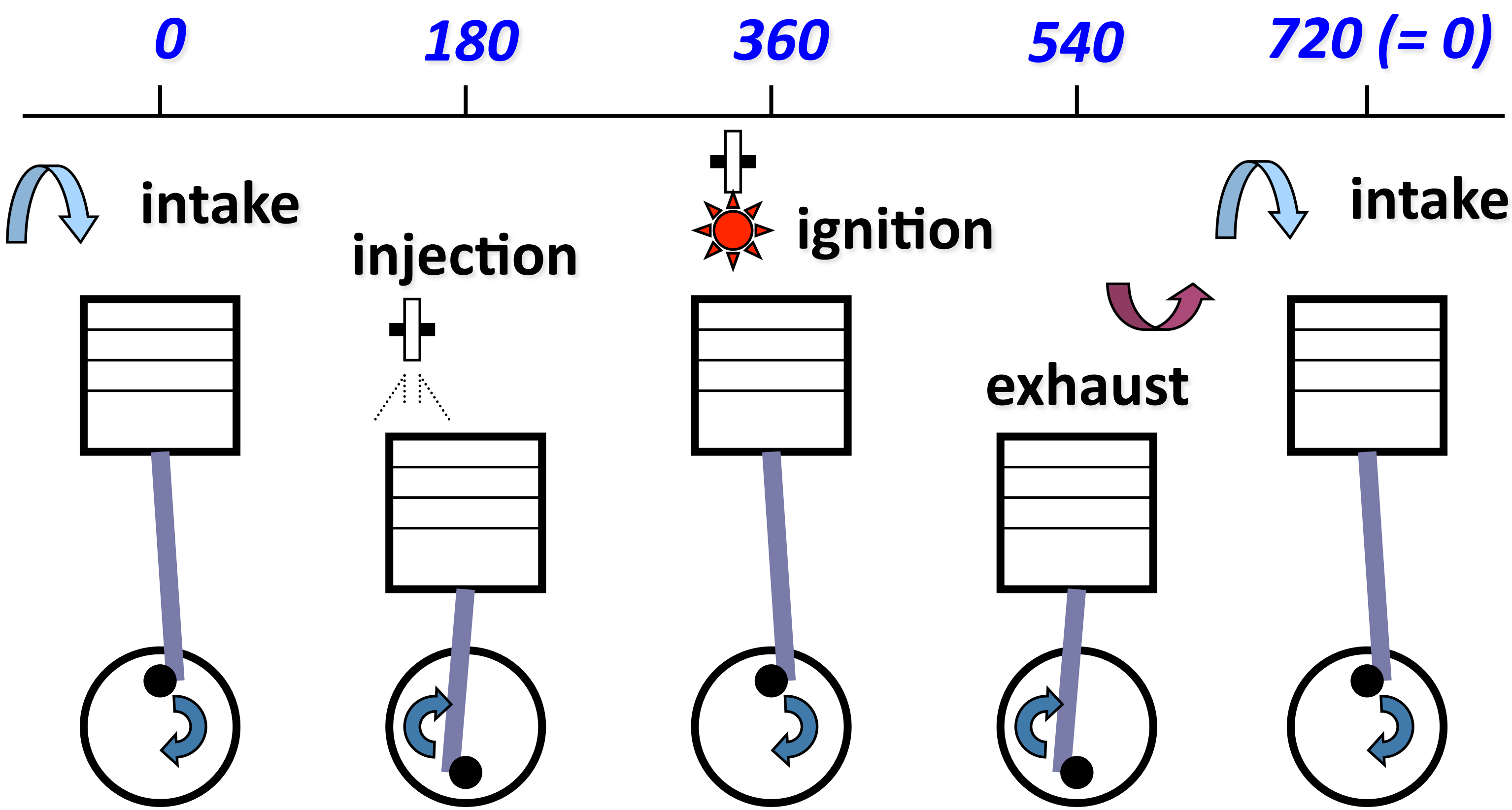
Basic Functions of the Control System

- to calculate fuel injection volume and ignition timing, and to control the actuators in every rotation cycle



Timing Behavior of Engine Management System

- When rotation speed is 6000*rpm*, one cycle is 20*msec.*
- Timing precision of the ignition is 10*μsec.* order.



Required Real-Time Property (Example)

- The calculation of the fuel injection volume *must be finished* before the injection timing.
- The calculation of the ignition timing *must be finished* before the ignition timing.
- Calculating too early has no additional value.

Safety Requirement (Example)

- Missing an ignition *must not happen*, because inflammable gas is emitted outside of the engine and can lead to a fire (because catalyst burns).
- If the ignition plug of a cylinder is broken, fuel *must not be injected* to the cylinder.

↓

- *The engine management system monitors the ignition plug and stops the injection if the plug is broken.*

Example (2) – ABS

Function of ABS ABS = Anti-lock Breaking System

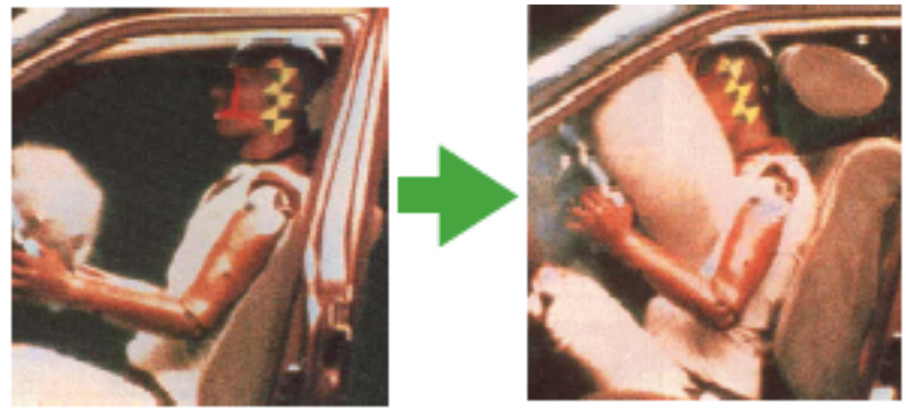
- The speed of the car and the rotational speed of the wheel are monitored, and a skid is detected.
- When a skid is detected, hydraulic pressure to the brake is reduced to stop the skid.
- The system is relatively simple, but is becoming more complex, recently.

Safety Requirement (Example) and Fail-Safe Design

- Continuous reduction of hydraulic pressure causes non-braking.
- If some fault is detected, ABS stops functioning. Then, the brake works though a skid cannot be avoided.

➔ *fail-safe design*

Example (3) – Airbag Control



Function of Airbag Control

- Airbag control system monitors various sensors including accelerometers and detects a collision.
- If a collision is detected, the ignition of a gas generator propellant is triggered to inflate a bag.

Real-Time Constraint

- The trigger must be within 10-20*msec*. after the collision.

Safety Requirements

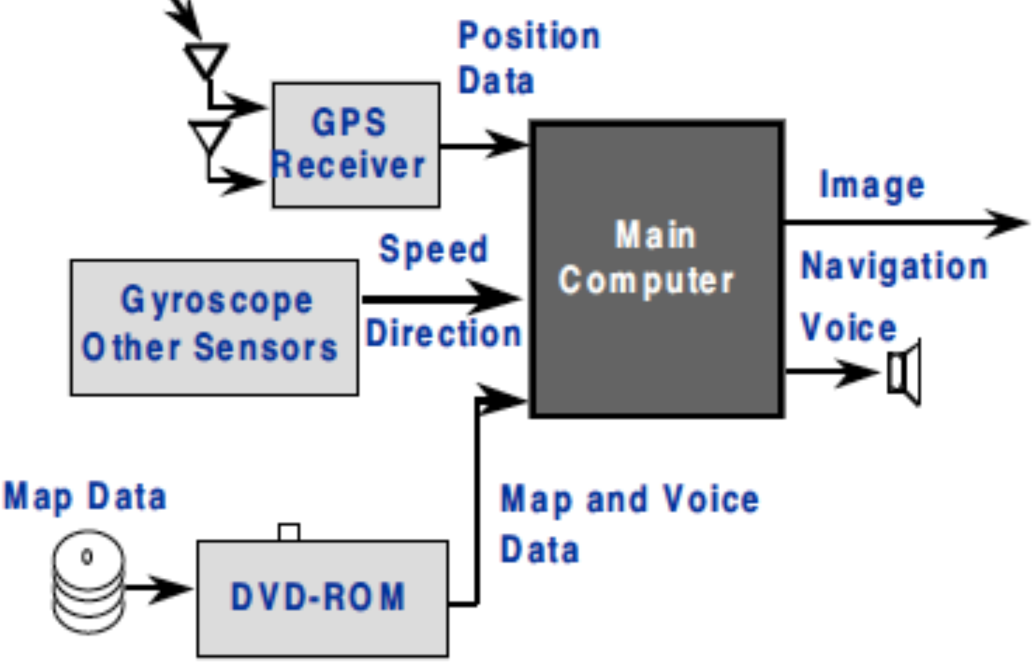
- Fail-safe design cannot be applied.

! even harder than ABS

Courtesy: Toyota Motor Corp.

Example (4) – Car Navigation System

- The current position of the car obtained from GPS, gyroscope, and others is displayed with the map.
  - Route navigation service
  - Traffic information is also displayed.



Specific Requirements on Example Systems

Engine Management

- very short response time (10 or 100*μsec*. order)
- large software and high computing power required
- high reliability

Air Bag

- a kind of signal processing application
- short response time (10*msec*. order)
- very high reliability

Car Navigation System

- largest and most complicated software in a car
- large computing power required
- moderate reliability, real-time property still required

Requirements on In-Vehicle Networks

Chassis Network ➔ *high-speed CAN, FlexRay*

- short and guaranteed response time
- small data size
- high reliability

Body Electronics Network ➔ *low-speed CAN, LIN*

- a large number of network nodes and data
- moderate reliability, low power consumption

Multimedia Network ➔ *MOST, IDB-1394*

- high bandwidth for multimedia data
- moderate reliability

(True) By-Wire Network ... **in future** ➔ ***FlexRay?, TTP?***

- **very high reliability**

Evolution Steps of Automotive Control Systems

- Evolution of automotive control systems and networks is well understood with the following 4 stages.

Stage 1

- Computer control (ECU) is applied to various component (engine, brake, steering, and so on), independently.
- In-vehicle network is not used.

Stage 2

- Each control system (ECU) exchanges useful data for improving the quality of the control system.
- Each system operates almost independently, and timing constraints on networks are loose.

Stage 3 (Current) *integrated systems/services*

- Each system still operates autonomously, and some services are provided with multiple ECUs connected with in-vehicle networks.
- Mechanical backup system still exists, thus the basic functions of a car are preserved even if an electronic system fails.

Stage 4.A (Future)

- Networks with outside of the car (communication with another car and the road) are intensively used.

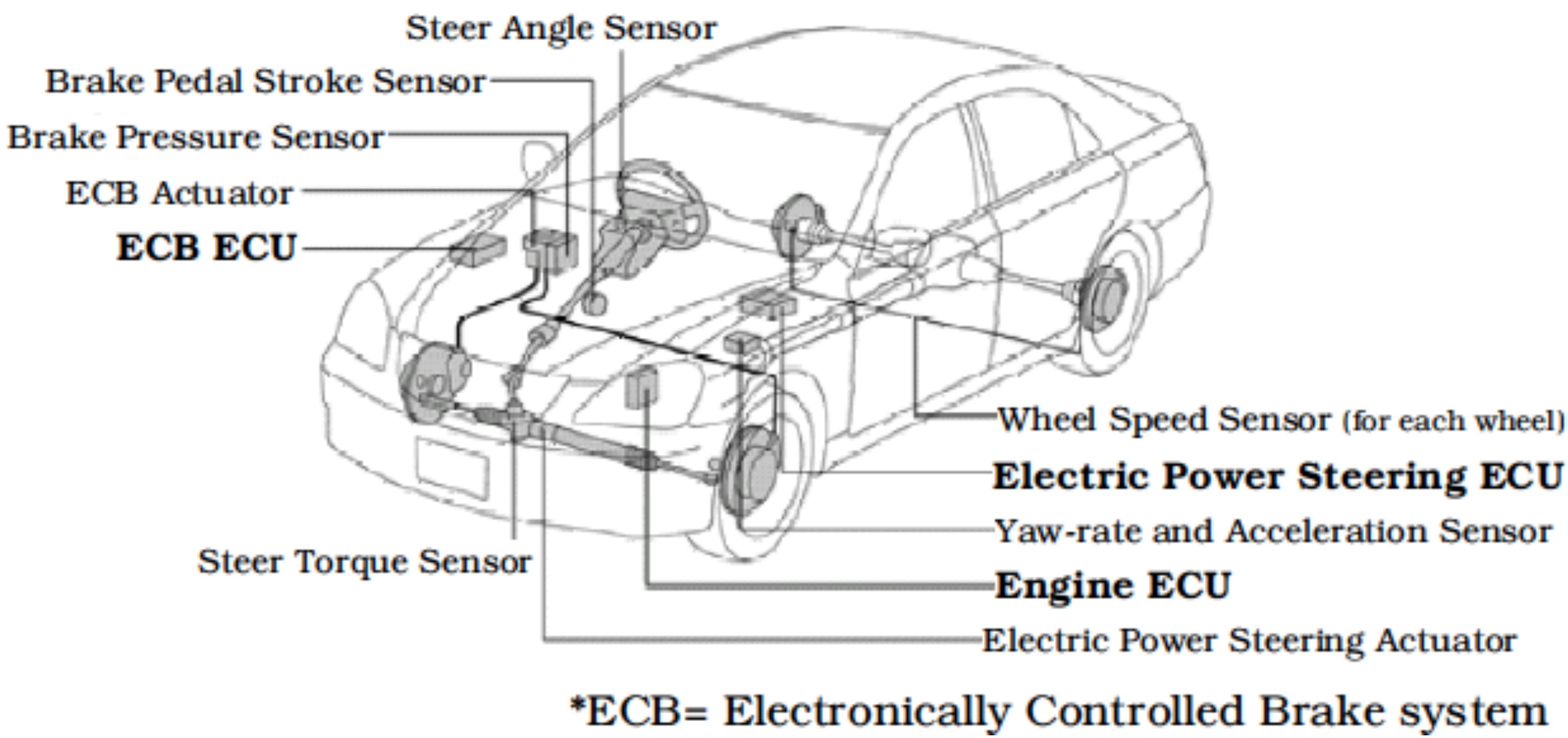
Stage 4.B (Future) *(true) by-wire systems*

- Mechanical systems (incl. backups) are replaced with ECUs and networks.
- A failure of electronic systems is life-critical.

Integrated System/Service Examples

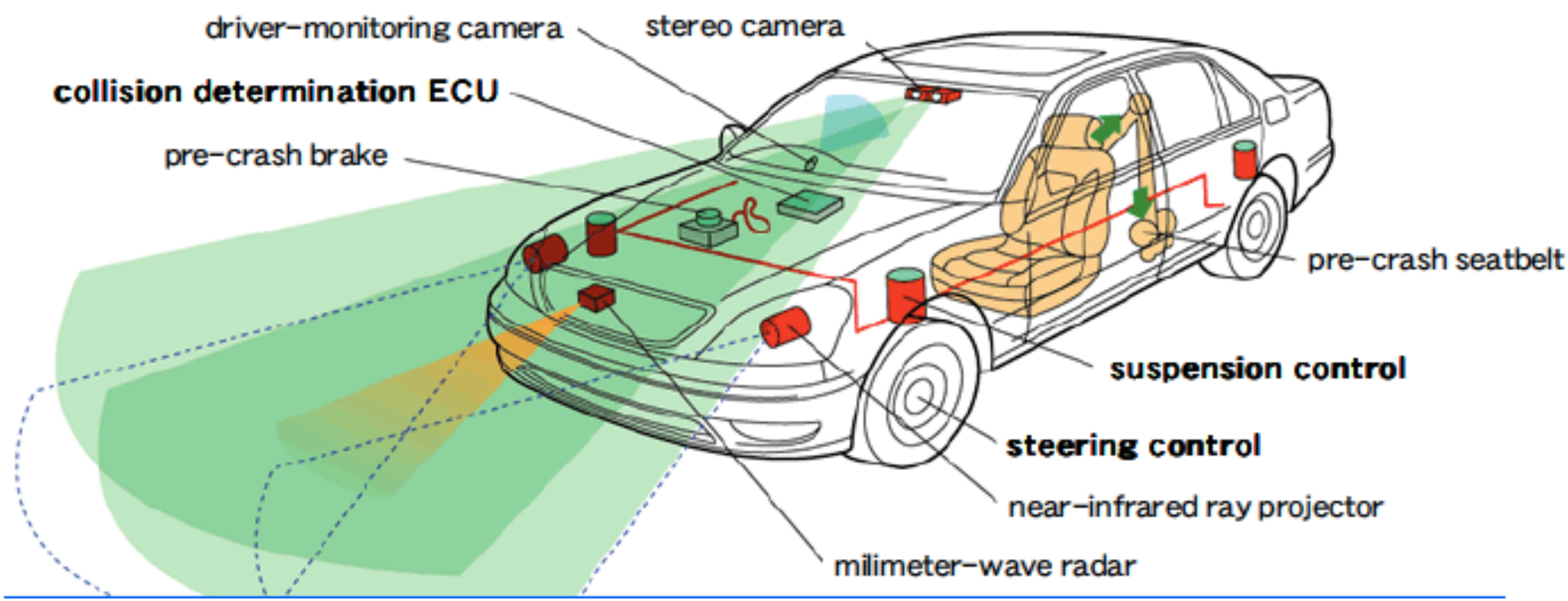
Vehicle Dynamics Integrated Management (VDIM)

- Control brake, steering, and engine for avoiding slip and spin.



Pre-crash Safety System (PCS)

- When an obstacle is detected with stereo camera and milimeter-wave radar, the system retracts the seatbelts, warns the driver, and applies the brake.
- Driver's condition (eg. face direction) is monitored.



Courtesy: Toyota Motor Corp.

Current Problems of Automotive Embedded Systems

Complicated system design

- Increasing development cost and time
- How to achieve high reliability and safety?

Large-scale and complicated software

- How to achieve high reliability and safety?
- How to effectively reuse existing software?

Too large number of ECUs

- Increasing cost
- Insufficient space (in a car) for ECUs

Complicated network architecture

- Increasing design complexity

Platform-base Development

Conventional Component-base Development

- Each ECU (component) is developed (usually independently) at first.
  - An automotive component supplier develops both of the hardware and software of ECU.
- Car (system) is designed by integrating the ECUs developed by different suppliers.

Platform-base Development

- Platform (PF) should be developed at first.
  - PF = Hardware PF + Software PF + Network
  - Software PF = OS + middleware
- Application software should be developed on the PF.

AUTOSAR (Automotive Open System Architecture)

- A global partnership of carmakers, car component, electronics, semiconductor, and software industries founded in 2003.
  - defines a methodology that supports a distributed, function-driven development process.
  - standardizes the software-architecture for ECU.

Core partners:

- BMW
- Bosch
- Continental
- Daimler
- Ford
- GM
- PSA Peugeot Citroen
- Toyota Motor
- Volkswagen

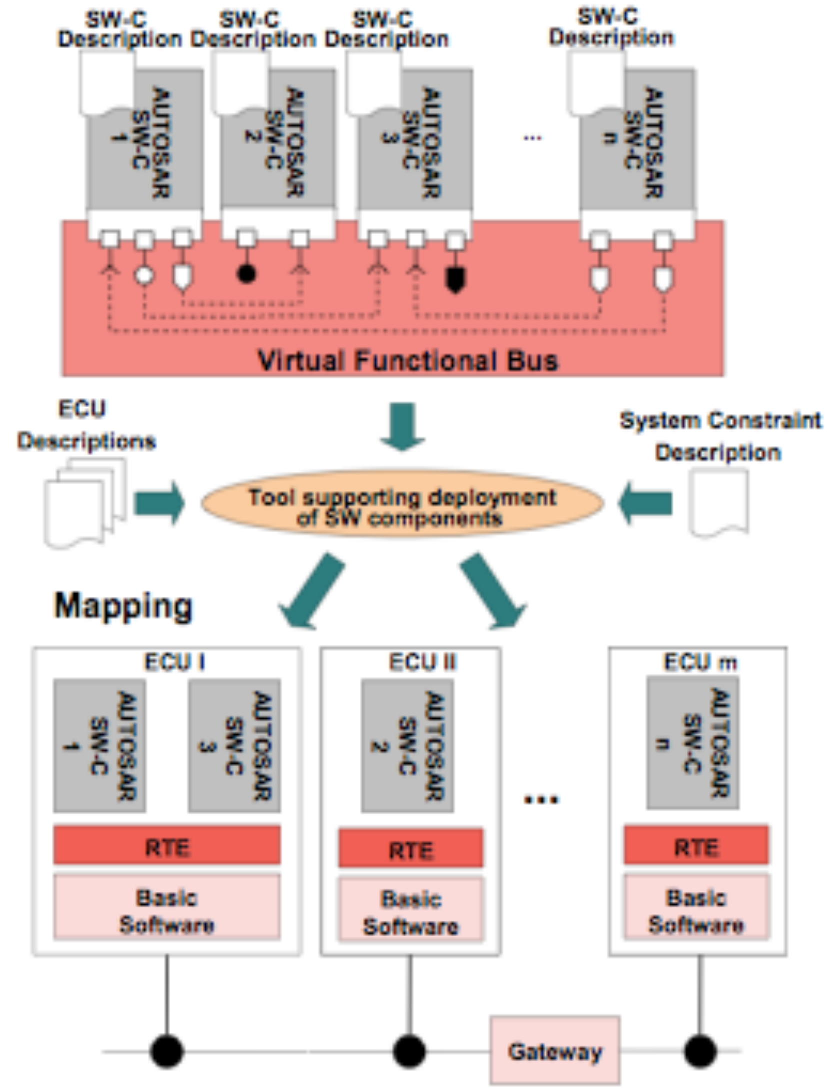
Results and Current Status

- Recent version (Release 4.0-REV 3) consists of about 100 specifications and 80 related documents.
- Phase III activity was started in 2010.

Overview of AUTOSAR Framework

AUTOSAR Approach

- Describe a system as a set of software components (SW-C) connected with virtual function bus, logically.
- Map the system to ECUs connected with in-vehicle network by a tool.
- ECU and system constraint descriptions are inputs to the tool.
- The software platform consists of RTE and BSW.

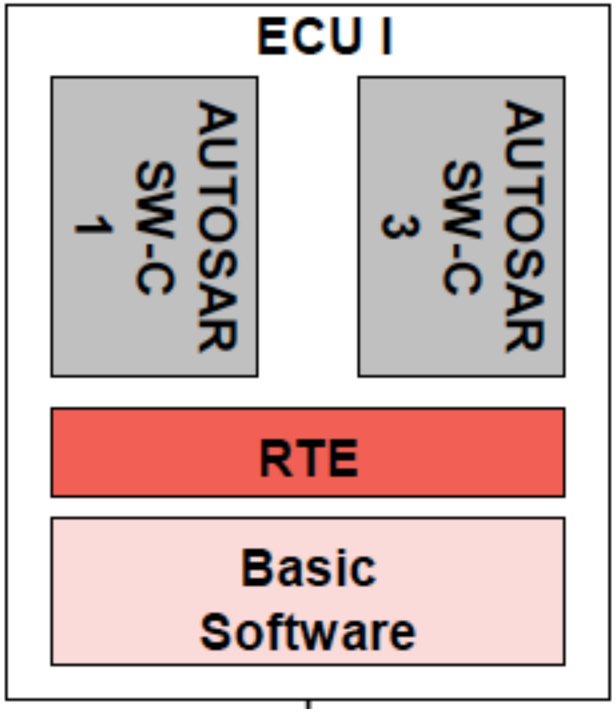


Structure of AUTOSAR Software Platform

Run-Time Environment (RTE)

- Provides interfaces between SW-Cs and between SW-C and BSW.
- Provides the BSW services to SW-C (API abstraction)
- Source code of RTE is generated by a tool from the description of communication interfaces

  ! the most distinctive feature of AUTOSAR platform

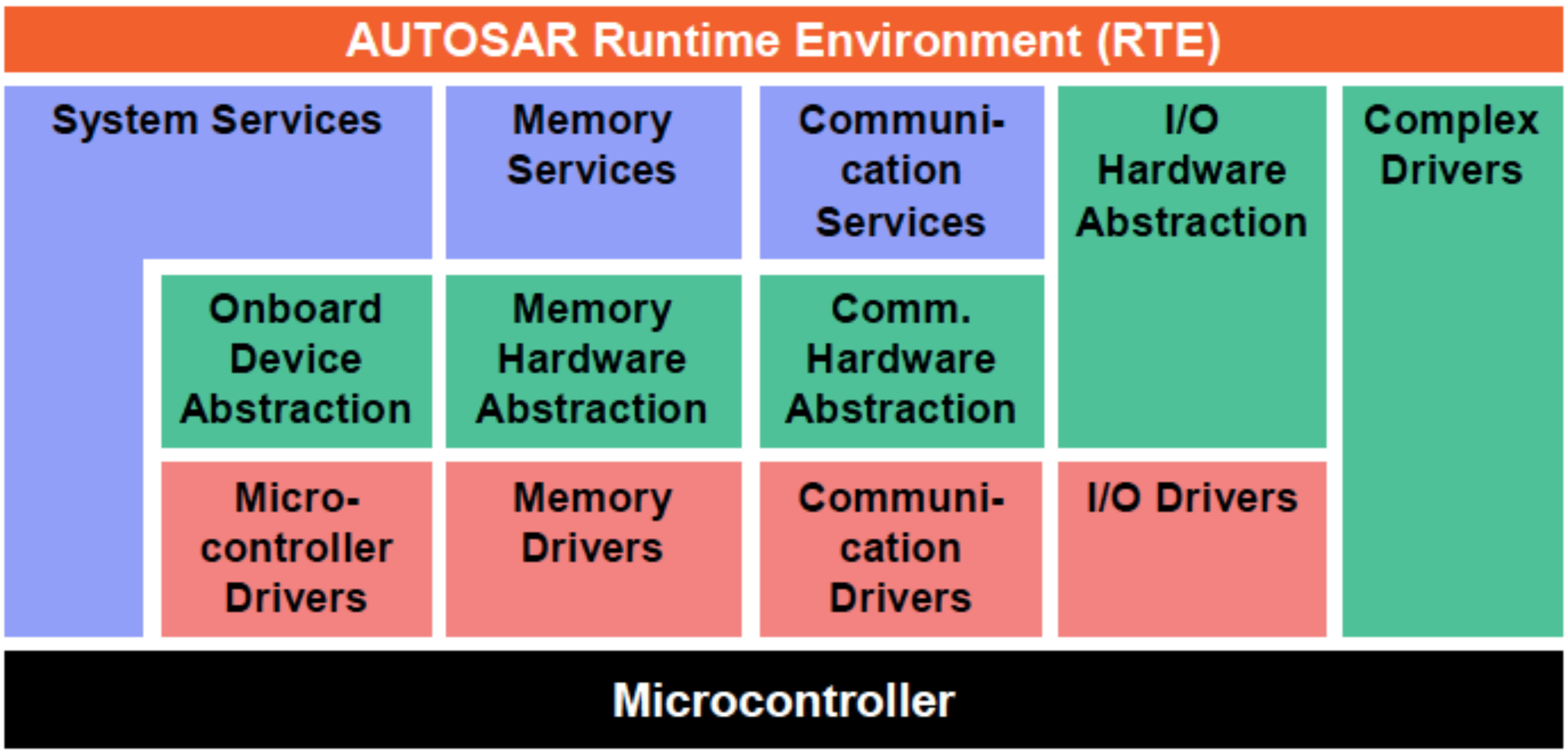


Basic Software (BSW)

- operating system (OS)
- device drivers
- middleware

Structure of Basic Software (BSW)

- 4 function groups (system, memory, communication, I/O) are organized in 3 layers (service, ECU abstraction, microcontroller abstraction)
- complex drivers (to shortcut the layers)



JasPar (Japan Automotive Software Platform Architecture)

- Car makers and other companies jointly develop network technology, middleware, software platform for automotive control systems (founded in 2004).

Board Members

- Toyota Motor
- Honda
- DENSO
- Nissan
- Toyota Tsusho Electronics

Members

- about 100 carmakers, car component suppliers, semiconductor companies, and software companies

Major Activities and Results

- Standardization related to FlexRay (wiring rule, ...)
- Development of software platform based on AUTOSAR Standard.
- Development of design guidelines for ISO 26262.

ISO 26262 – Functional Safety Standard

What is Safety?

- Safety : "freedom from those conditions that can cause death, injury, occupational illness, or damage to or loss of equipment or property, or damage to the environment"
- Reliability : "the ability of a system or component to per- form its required functions under stated conditions for a specified period of time"
- A safe system is not necessarily reliable and vice versa.

What is Functional Safety?

- Original meaning: safety achieved by functions
- "absence of unreasonable risk due to hazards caused by malfunctioning behavior of E/E systems" (ISO 26262-1)

What is ISO 26262?

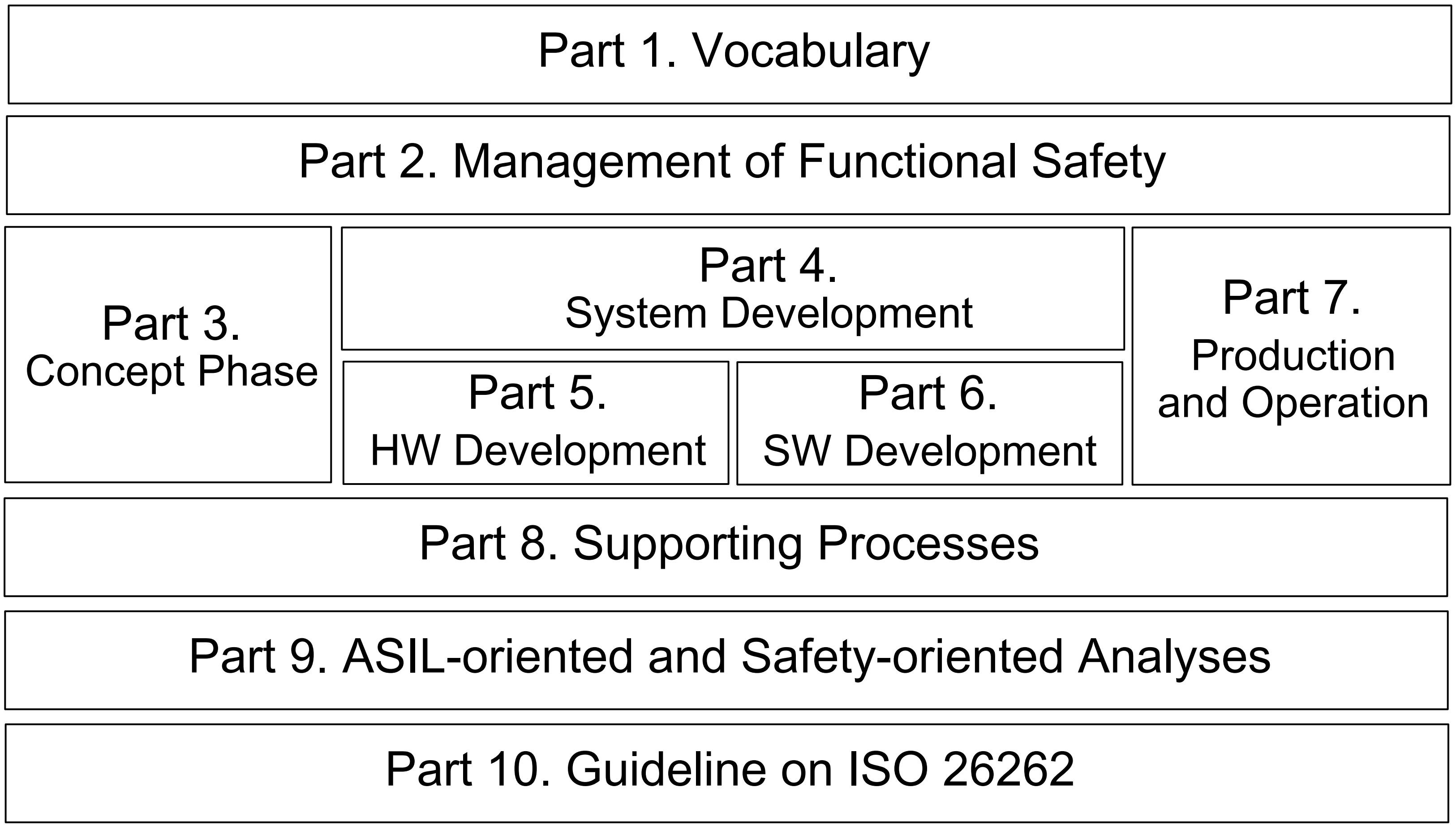
- "Road vehicles – Functional safety –"
- published in Nov. 2011.

Characteristics of ISO 26262

- A compilation of best practice for developing a safety-related system.
  - In the standard, many development techniques of safe systems are listed and required depending on the safety level (ASIL).
- Reliability of hardware is calculated from the failure rate of each component consisting the system.
- Reliability of software is achieved with software development process.
  - *A software that is developed with a process satisfying the requirements of the standard is considered to be enough reliable.*

Overall Structure of ISO 26262

- ISO 26262 consists of 10 parts (Part 10 has not been published yet).



ASIL (Automotive Safety Integrity Level)

- requirement level of safety measures to be applied for avoiding an unreasonable residual risk
- four (+ one) levels
  - ASIL D … most stringent level
  - ASIL C
  - ASIL B
  - ASIL A … least stringent level
  - QM (quality management) … non-safety-related
- ASIL is determined for each hazardous event based on its severity, exposure, and controllability.

Future Trends of Automotive Embedded Systems

Advancement of Integrated Systems/Services

- communication with another car and the road
- using various information (surrounding situation and map information) for controlling a car
- emergence of true by-wire systems*??*

Changes in System Architecture

- ECU integration (or reduction)
- platform-base development
- separation into two types of ECUs

Changes in Software Development

- model-base design
- component-base software development
- virtual platform for software development

Brief Introduction to Our Activities – NCES and TOPPERS –

Overview of Our Activities

ERTL (Embedded and Real-Time Systems Laboratory)

- Takada Laboratory
- several joint projects with car makers, semi-conductor makers, and software companies

NCES (Center for Embedded Computing Systems)

- several (relatively) large-scale joint projects with car makers and car component suppliers
- projects for educating embedded system engineers

TOPPERS ... independent non-profit organization

- development of open-source real-time operating system (RTOS) and middleware for embedded systems
- cooperation of academia, industry, public research institutes, and individual engineers

Introduction to NCES

NCES (Center for Embedded Computing Systems)

- a research center focused on embedded computing systems
  - automotive application is the main focus
  - several (relatively) large-scale joint projects with car makers and car component suppliers
- established in 2006 to form a hub for collaborative research and education of embedded systems technologies

Scope of NCES

- research aiming at practical use in industry
- development of prototype system/software
- education and human resource development

Major Research Projects of NCES

Projects funded by Industries

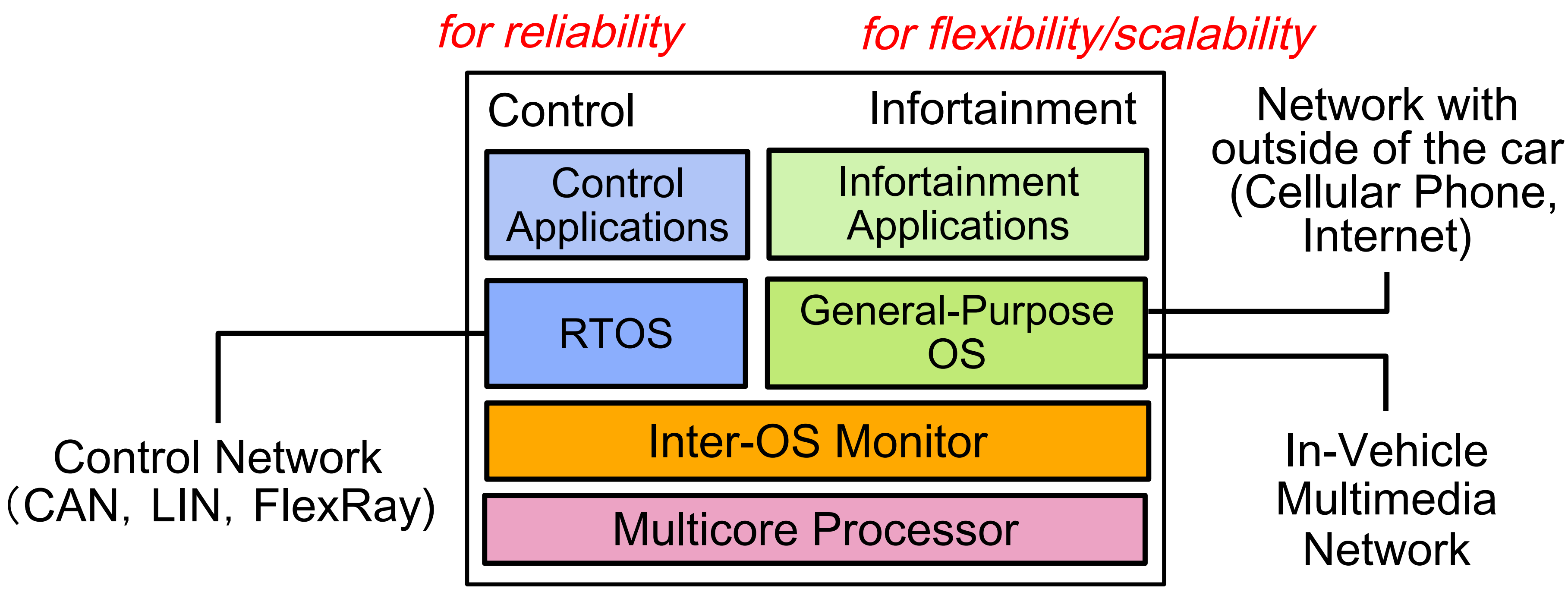
- OS for in-vehicle multimedia systems (TMC)
- Next-generation automotive network (AutoNetworks Technologies, Ltd.)
- Next-generation real-time operating system for automotive control systems (consortium type)
- Automotive data integration platform (consortium type)
- Studies on functional safety standard (JarPar)
- Software PF for Space Application (JAXA)

Projects funded by Government

- Energy Consumption optimization of embedded systems (JST CREST)
- Automotive software platform conforming to the functional safety standard (METI)

OS for In-vehicle Multimedia Systems

- joint project with Toyota Motor Corp. started in 2006
- a hybrid OS for in-vehicle multimedia systems to achieve both reliability and flexibility/scalability
- SafeG, the most important result, is distributed as an open-source software from TOPPERS Project.



Next-Generation Automotive Network

- joint project with AutoNetworks Technologies, Ltd. (a subsidiary of Sumitomo Electric Industries) started in April, 2006

Concept of Scalable CAN

- Scalable CAN is compatible with conventional CAN from software point of view and achieves higher bandwidth.
- Scalable CAN and conventional CAN can be connected with a gateway.

10Mbit/s CAN

- star topology, in which each node is connected to a central hub (gateway).

5Mbit/s CAN

- bus topology with limited number of nodes on a bus.

Next-Generation RTOS for Automotive Systems

- consortium-type project with NCES and 12 companies started in Apr. 2011
- 12 engineers from these companies are staying at NCES and engaged in the development.

What is to be developed

- specification of next-generation RTOS for automotive control systems based on AUTOSAR OS
- RTOS implementation based on the specification
- test suite for the RTOS

Release plan of the developed software

- Developed RTOS will be released as an open source software from TOPPERS Project.
- Test suite is shared only by the consortium members.

Introduction to TOPPERS Project

TOPPERS = Toyohashi Open Platform for Embedded and Real-Time Systems

TOPPERS

Objectives of the Project

- To develop various open-source software for embedded systems including RTOS and to promote their use.

Building a widely used open-source OS as Linux in the area of embedded systems!

Main Activities of the Project

- Building a definitive μITRON-conformant RTOS
- Developing a next generation RTOS technology
- Developing software development technology and tools for embedded systems
- Fostering Embedded System Engineers

Major Products (Software) of TOPPERS

! *All SW listed below can be downloaded from the TOPPERS website at http://www.toppers.jp/.*

TOPPERS/JSP Kernel (JSP = Just Standard Profile)

- RTOS conformant to the standard profile of μITRON4.0 specification

TOPPERS/ATK1 (ATK = Automotive Kernel)

- RTOS conformant to OSEK/VDX OS specification

TOPPER/ASP Kernel (ASP = Advanced Standard Profile)

- Improvement of JSP kernel
- Basis of TOPPERS new generation kernels

TOPPERS/FMP Kernel (FMP = Flexible Multiprocessing)

- Extension of ASP kernel to various types of multiprocessor systems

<u>TECS (TOPPERS Embedded Component System)</u>

- Specification and tools for component-based development of embedded software.

<u>TINET</u>

- Compact TCP/IP protocol stack conformant to ITRON TCP/IP API specification.
- Both IPv4 and IPv6 are supported.

<u>TLV (TraceLogVisualizer)</u>

- Customizable tool to visualize various trace logs, including the trace log of RTOS

<u>Several Open Educational Materials</u>

- Educational materials including presentation slides, software, and so on.

Application Example of TOPPERS OS

Consumer Applications

PM-A970 (EPSON)

DO!KARAOKE
(PANASONIC)

IPSiO GX e3300 (Ricoh)

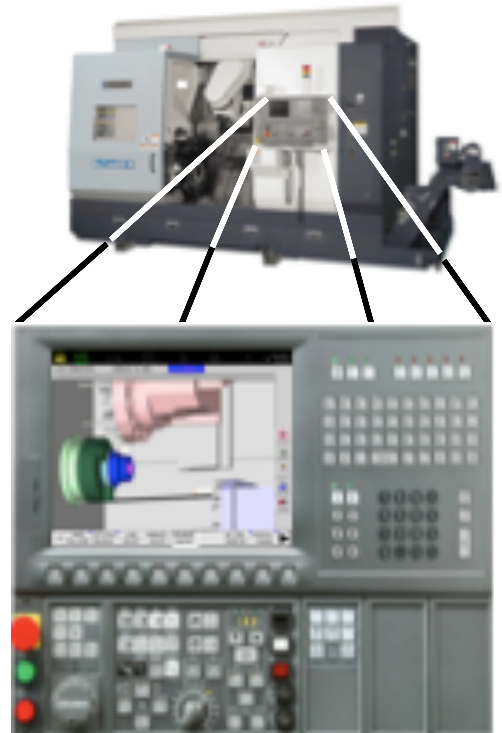
UA-101 (Roland)

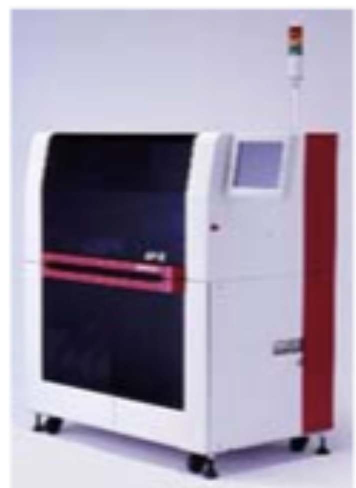
GT-541 (Brother)

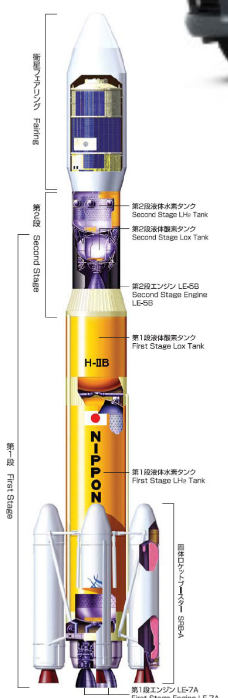
Industrial and Other Applications

DP-350 (Daihen)

Kizashi (SUZUKI)







H−IIB（JAXA)
under development

ASTRO-H (JAXA)
under development

AP-X (Kyowa MEDIX)

OSP-P200 (Okuma)