Overview

- Automotive Domain
- OSEK/VDX
- AUTOSAR
- Summary
Technology Changes

Electronics share (in value):
2004: 20% → 2015: 40%

1) McKinsey, Automotive Electronics - Managing innovations on the road

---

EU top 10 R&D Investing Companies

<table>
<thead>
<tr>
<th>EU rank</th>
<th>Name</th>
<th>Country</th>
<th>Industrial sector [ICB 3D]</th>
<th>R&amp;D 2012 [€million]</th>
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<td>VOLKSWAGEN</td>
<td>Germany</td>
<td>Automobiles &amp; Parts</td>
<td>9515.0</td>
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<td>2</td>
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<td>Germany</td>
<td>Automobiles &amp; Parts</td>
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<tr>
<td>3</td>
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<td>Germany</td>
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<td>5</td>
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<td>Electronic &amp; Electrical Equipment</td>
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<td>9</td>
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<tr>
<td>10</td>
<td>EADS</td>
<td>The Netherlands</td>
<td>Aerospace &amp; Defence</td>
<td>3630.0</td>
</tr>
</tbody>
</table>

Cars Today

- Complex Network of Computer Systems (up to 40 ECUs per vehicle)
- Interaction of ECUs is relevant for “product experience”
- Hard real time requirements
  - injection
  - brake system (ABS, ESB, …)
  - torque vectoring
  - …
- Safety critical
  - traffic deaths:
    - 19.193 in 1970 (16.8 mil. vec.)
    - 3.606 in 2012 (51.7 mil. vec.)
**Typical ECU Resources**

In 2000
- Infotainment: 32-Bit MCU, 4 Mbyte RAM, 32 Mbyte ROM, MMU
- ECUs: 8 or 16-Bit MCU, 64 Kbyte RAM, 2 Mbyte ROM

Today
- Infotainment: 32-Bit MCU, 512 Mbyte RAM, Gbytes of Flash, MMU
- ECUs: 8/16/32-Bit MCU, 4 Mbyte RAM, 256 Mbyte Flash/ROM, MPU

Tomorrow
- Multi-Core, Lock-step

---

**Overview**

- Automotive Domain
- **OSEK/VDX**
- AUTOSAR
- Summary
Which OS is used?

Infotainment
- Linux (RT Linux, Android)
- VxWorks
- Windows CE

ECUs
- Infinite main loop (past)
- OSEK/VDX
- AUTOSAR (since 2005)

Infinite Loop

Within each loop cycle, a series of jobs is processed sequentially

- Read sensors
- Process data
- Control actuators
- Perform self test
OSEK: Tasks

**Multitasking** provides the possibility to execute jobs in parallel or pseudo parallel.

- Usually requires an operating system
- Jobs can be allocated to different tasks
- When an event occurs, the task that is responsible for processing the event is activated

Tasks

**Concepts**

Several Tasks are defined, where each task executes one or more jobs. The operating system scheduler determines which task should currently be executed.

Each Task has a state:

- **Suspend**: The task is not ready for execution
- **Ready**: The task is ready for execution, but not currently running
- **Running**: The task is executing
- **Waiting/Blocked**: The task is waiting for a resource or event and not ready for execution
Flexible Preemption

**Preemptable**
- A task can be preempted at any time by another task, e.g. because task with higher priority becomes ready

**Non-preemptable**
- A task always runs to completion

Fixed Priority Scheduling

- Each task has a unique priority
- Priorities are assigned at design time
- The operating system ensures that at each time, of all the "ready" tasks the one with the highest priority is executing.
Fixed Priority Scheduling Example

<table>
<thead>
<tr>
<th>priority</th>
<th>periodic task</th>
<th>sporadic task</th>
<th>background task</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>time</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
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<tr>
<td>running</td>
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<td></td>
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<td></td>
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<tr>
<td>ready</td>
<td></td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Priority Assignment Example

Rate Monotonic Scheduling

Variant of Fixed Priority Scheduling

- Assumption: Deadline == Period
- Task priorities are inverse to the period

Example:

- Task 1: Period = 5 ms \(\rightarrow\) Priority 1
- Task 2: Period = 30 ms \(\rightarrow\) Priority 3
- Task 3: Period = 10 ms \(\rightarrow\) Priority 2
Concurrency

Jobs are not independent of each other:

- A job depends on information produced by another job
- Jobs access shared data
- Problem: Inconsistencies or data lost when several tasks simultaneously accessing the same resource
  → Synchronization between jobs and / or tasks is required
A critical section is a sequence of code that accesses a shared resource that must not be accessed concurrently.

Simple Example:

```c
static volatile int counter = 0;

TASK(A) {
    /* ... */
    counter++; /* ... */
}

TASK(B) {
    /* ... */
    counter++; /* ... */
}
```

Concurrent execution of `TASK(A)` and `TASK(B)` could result in:

- **Task A**: 
  - read counter
  - increase
  - write counter
  - counter = 0

- **Task B**: 
  - read counter
  - increase
  - read counter
  - increase
  - write counter
  - counter = 1

Result: `counter` may not be consistent.
Concurrency

Mutual Exclusion (Mutex) ensures that two tasks are not in their critical section at the same time.

There are several techniques used in embedded systems:

- Disable interrupts
- Lock
- Semaphore
- Atomic operations
- Spin-lock
- ...

Disable/Enable Interrupts

- Prevent task switching by disabling interrupts

```c
TASK(A) { 
/* ... */
DisableAllInterrupts();
counter++; 
EnableAllInterrupts();
/* ... */
}

TASK(B) { 
/* ... */
DisableAllInterrupts();
counter++; 
EnableAllInterrupts();
/* ... */
}
```
Concurrency

Disable/Enable Interrupts

Strengths:
- Low overhead on common MCUs

Limitations:
- Error-prone (e.g. missing enable interrupts)
- Increased interrupt latency
- Not suitable for multi-core systems

→ Critical section should be kept as short as possible

Concurrency

Synchronization Issues:

- **Priority Inversion**: A task with lower priority is superseding a task with higher priority, even if they do not share a resource

- **Deadlock**: No progress any more because all tasks are in the waiting state. e.g. two tasks are waiting on each other
1. task3 enters critical section
2. task2 is activated
3. task1 is activated
4. task1 reaches critical section
5. task2 completes before task1
6. task3 leaves critical section
7. task1 completes after task2

Priority inversion – solutions:

- **Priority inheritance**: If a task with a higher priority than the mutex owner attempts to lock a mutex, the effective priority of the current owner is temporarily increased to that of the higher-priority blocked task waiting for the mutex.

  ```
  pthread_mutexattr_setprotocol(attr, PTHREAD_PRIO_INHERIT);
  ```

- **Priority ceiling**: Each mutex has an attribute that is the highest priority of any task accessing that mutex. When locking that mutex, the priority of the task is increased to that priority.
Concurrency

Priority inheritance → no priority inversion

Resources

- Resources are data structures for the protection of critical regions
- Example: exclusive access to a port or a memory location
- Resources can be used by tasks and optionally by ISRs
- A resource allocated once cannot be allocated a second time
- After allocating a resource, a task must not
  - wait for events
  - terminate

Task or ISR

mutual exclusion

allocate and releases

Resource
TASK(A) {
    GetResource(ResX); /* access memory XY */
    ReleaseResource(ResX);
}

TASK(B) {
    GetResource(ResX); /* access memory XY */
    ReleaseResource(ResX);
}

Resources

Immediate priority ceiling → no priority inversion

1. task3 enters critical section
2. task2 is activated,
   task3 has ceiling priority
3. task3 leaves critical section,
   task2 has higher priority
4. task1 is activated
5. task1 enters critical section
6. task1 leaves critical section
7. task1 completes before task2
8. task2 completes after task1
Counter and Alarms

- Counters can be used to count events, e.g. timer ticks, movements, etc.
- Alarms are bound to a counter and expire when a certain counter value is reached.
- Expiration of an alarm results in one of four activities:
  - generation of an event
  - activation of a task
  - execution of a callback function*
  - Increment of software counter *
- More than one alarm can be bound to a single counter.
- Alarms can be activated and deactivated dynamically by tasks and ISRs.
- Alarms can be cyclic or one time.

Events

- Extended tasks can wait for the generation of an event.
- Events can be generated from inside tasks or ISRs.
- While waiting for an event, the task releases the CPU.
- A task can not determine the source of an event.
- ISRs can not wait for events, but have to activate a task for this purpose.
- There are some more ways to generate an event.

*) not illustrated.
Events

```
TASK(A) {
    SetEvent(SimpleServer, My_Ev1);
    TerminateTask();
}

TASK(SimpleServer) {
    EventMaskType current;
    for (;;) {
        WaitEvent(My_Ev1 | My_Ev2);
        GetEvent(SimpleServer, &current);
        ClearEvent(current);
        if (current & My_Ev1) {
            /* work */
        }
        if (current & My_Ev2) {
            /* work */
        }
        TerminateTask();
    }
}
```

Interrupts

- ISR: Interrupt Service Routine
- ISRs are directly triggered by hardware interrupt requests
- ISRs have a higher priority than all tasks and will preempt task
- Calls to Autosar API functions are restricted inside ISRs
- ISRs should be small and fast
- ISRs can activate tasks or trigger events
- A blocking ISR will block the whole Autosar system
Interrupts

Interrupts can be used for jobs with high urgency

- An interrupt signals an event that must be handled immediately
  → Currently executing code is preempted with the interrupt handling code

The source of an interrupts can be in hardware or software:

- Hardware interrupts: e.g. hall sensor, data received...
- Software interrupts: e.g. division by zero, system call, ...

What is allowed within an interrupt handler?

- Which operating system calls?
- Floating point operations?

→ Check operating system documentation

Example: OSEK has two categories of interrupt handlers

- Category 1: no operating system services may be used
- Category 2: system services can be used
### Example: OSEK

<table>
<thead>
<tr>
<th>Service</th>
<th>Task</th>
<th>ISR Cat2</th>
<th>ISR Cat1</th>
</tr>
</thead>
<tbody>
<tr>
<td>ActivateTask</td>
<td>✓</td>
<td>✓</td>
<td>x</td>
</tr>
<tr>
<td>TerminateTask</td>
<td>✓</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Schedule</td>
<td>✓</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>GetTaskID</td>
<td>✓</td>
<td>✓</td>
<td>x</td>
</tr>
<tr>
<td>GetTaskState</td>
<td>✓</td>
<td>✓</td>
<td>x</td>
</tr>
<tr>
<td>Disable-/EnableAllInterrupts</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Suspend-/ResumeAllInterrupts</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Suspend-/ResumeOSInterrupts</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Get-/ReleaseResource</td>
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<td>✓</td>
<td>x</td>
</tr>
<tr>
<td>Set-/GetEvent</td>
<td>✓</td>
<td>✓</td>
<td>x</td>
</tr>
<tr>
<td>Wait-/ClearEvent</td>
<td>✓</td>
<td>x</td>
<td>x</td>
</tr>
</tbody>
</table>

### Cat1 Interrupts

![Diagram of Cat1 Interrupts](image-url)
Combining Approaches

Cyclic Executive / Multitasking + Interrupts:
- Most processing is done in cyclic executive or tasks
- Interrupts are used for high urgency jobs

Cyclic Executive + Multitasking:
- Different periodic tasks
- Within each task, jobs are executed in a cyclic executive
- e.g. used in AUTOSAR to schedule “runnables” within tasks
Concurrency – Interrupts

Problem: Concurrent access to data shared by tasks and interrupt handlers

→ Synchronization is necessary

Approaches:

- Disabling Interrupts
- Using operating system mechanisms
  - Queues, semaphores, mutexes
  - Needs to be non-blocking in ISR!

Overview

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Increasing number of ECUs

*) ECU = Electronic Control Unit = elektronische Steuergeräte

AUTOSAR Idea

- Decouple application software from hardware
- Standardize software interfaces
- Standardize configuration concepts
- Design the complete vehicle application software over all ECUs
**Main Working Topics**

**Architecture:**
Software architecture including a complete basic software stack for ECUs – the so called AUTOSAR Basic Software – as an integration platform for hardware independent software applications.

**Methodology:**
Exchange formats or description templates to enable a seamless configuration process and integration of application software. (e.g. SW component description)

**Application Interfaces:**
Specification of interfaces of typical automotive applications from all domains in terms of syntax and semantics, which should serve as a standard for application software.

**AUTOSAR Advantages**

- Standard based
  - „cooperation in standardization and competition in implementation“
- Automotive software becomes a product
  - Stable or decreasing development cost
  - Common widely used software
  - Well tested also field-tested
- Exchangeable and reusable software
- Standardized interfaces to applications
AUTOSAR – Cooperation Structure

**Core Partner**
- Organizational control
- Administrative control
- Definition of external Information (web-release, clearance, etc.)
- Leadership of Working Groups
- Involvement in Working Groups
- Technical contributions
- Access to current information
- Royalty free utilization of the AUTOSAR standard

**Premium Partner**
- Leadership of Working Groups
- Involvement in Working Groups
- Technical contributions
- Access to current information
- Royalty free utilization of the AUTOSAR standard

**Development Partner**
- Involvement in Working Groups
- Expertise contributions
- Access to current information
- Royalty free utilization of the AUTOSAR standard

**Associate Partner**
- Access to finalized documents
- Royalty free utilization of the AUTOSAR standard

**Attendees**
- Participation and cooperation in Working Groups
- Access to current information

AUTOSAR Members

**9 Core Partners**
- BMW Group
- Continental
- Daimler
- Ford
- PSA Peugeot Citroën
- Toyota
- Volkswagen AG

**57 Premium Member**
- Bosch
- Intel
- Infineon
- Johnson Controls
- Magna
- Nissan
- Renesas
- Siemens
- Texas Instruments

**11 Development Members**
- ATRACOM
- Autoliv
- Continental
- Denso
- Hitachi
- Hyundai Kia Motors
- ITM
- Magna
- MAN
- Mitsubishi
- NXP

**88 Associate Members**
- 17 Attendees

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AUTOSAR defines four key concepts:

- **Software components (SW-C)**
  - A piece of software to be run in an AUTOSAR system

- **Virtual Functional Bus (VFB)**
  - High level communication abstraction

- **Run Time Environment (RTE)**
  - Implements the VFB on one ECU

- **Basic Software (BSW)**
  - Standard software for standard ECU functionality (OS, communication, memory, hardware drivers, diagnostics etc)

“Learn these, and you can begin to speak AUTOSAR”…

Introduction: Basic AUTOSAR Approach

Application Interfaces

Methodology

Architecture

Virtual Functional Bus

ECU I

SW-C A

RTE

BSW

ECU II

SW-C B

RTE

BSW

ECU m

SW-C C

RTE

BSW

SW-C

A

B

n

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An **AUTOSAR application** consists of one or more (interconnected) Software components (SW-C)

- **Virtual Functional Bus (VFB)** is a concept that allows for strict separation between software components and infrastructure.

- **Run Time Environment (RTE)** is a communication centre for inter- and intra-ECU information exchange.

- The **Basic Software (BSW)** is a standardized software layer that provides standard ECU functionality (OS, low level drivers, bus-communication, diagnostics, memory management etc.)

SW-C communicates through well defined **Ports** and **Interfaces**

Ports and Interfaces are specified in **Software Component Descriptions**
The **Software Component Description** (SWCD) is an XML file that completely define the SW-C (e.g. ports, interfaces and behavior).

The SW-C contains an SWCD and the SW-C implementation:

```xml
<?xml version="1.0" encoding="UTF-8"?>
<AUTOSAR xmlns="http://autosar.org/3.1.2">
  <TOP-LEVEL-PACKAGES>
    <AR-PACKAGE>
      <SHORT-NAME>MySwcDescription</SHORT-NAME>
      <ELEMENTS>...
      </ELEMENTS>
    </AR-PACKAGE>
  </TOP-LEVEL-PACKAGES>
</AUTOSAR>
```

```c
#include "MySWC.h"

Std_ReturnType fun1() {
  /* Implementation */
  return E_OK;
}

Std_ReturnType fun2() {
  /* Implementation */ ...
}
```

**Introduction Ports**

An **SW-C** uses **Ports** to communicate with other components or with the ECU hardware.

Two types of ports depending on signal direction or semantics:

- **Require Port** (R-Port)
- **Provide Port** (P-Port)
An **Interface** is a contract between a **P-port** and an **R-port**

The **Interface** defines the data or operations that can be handled by the Port.

There are different kinds of **Interfaces**
- Sender-Receiver (S/R)
- Client-Server (C/S)

**DataElements** (signals) always have a data type
- Primitive data types (Integer, Enumeration, Boolean...)
- Complex data types (Arrays and Record)
A C/S interface may contain one or more **Operations** (functions)

Each operation contains zero or more **Arguments** (type “IN”, “OUT” or “IN/OUT”)

Each operation contains zero or more **Error Return Codes**

A Server provides a service via a P-Port

The clients may invoke the server by connecting their R-Ports to the server port (the client requires a service)

**Synchronous** call
- Rte_Call will not return until result is available (blocking)

**Asynchronous** call
- Rte_Call will initiate operation but will return immediately (non-blocking)
- Rte_Result will provide the result (non-blocking or blocking)
A **Software Component** (SW-C) is an application module that implements an AUTOSAR application. An SW-C is a high level abstraction which is unaware of where in the system (in which ECU) it is situated. The **Virtual Functional Bus** (VFB) is a high level abstraction of the available communication paths between the SW-Cs.

During system design, the SW-Cs are partitioned onto ECUs. There are two different types of communication paths in the VFB:
- **Intra-ECU** (inside one ECU)
- **Inter-ECU** (between different ECUs)
**RUNTIME ENVIRONMENT (RTE)**

- The **Runtime Environment** (RTE) is the only interface to the SW-Cs
- The RTE implements the VFB
- The RTE uses CAN/LIN/FlexRay buses for inter-ECU communication via the **Basic Software Layer** (BSW)

---

**AUTOSAR BENEFITS**

- AUTOSAR is a standardized platform
- Well defined APIs for communication
- No difference between internal communication and bus communication

→ **Relocatability and reuse!**
The implementations of the RTE and BSW modules are specified by AUTOSAR.

Their behavior must be configured by the integrator.

Examples:
- Number of CAN channels
- CAN frames
- ECU power states
- Flash memory blocks
- OS tick time

Exception: The HW I/O abstraction module is project specific and has to be implemented from scratch (more about this later).
SW-C CONFIGURATION

- SW-Cs are also configured to some extent
- Examples:
  - Data Types
  - Communication signals
  - Scheduling
  - Inter task communication
- Based on this configuration, the RTE will provide the necessary APIs
- The source code in the SW-Cs can either be implemented manually (coding C or C++) or modeled using e.g. Simulink or Targetlink

ECU CONFIGURATION DESCRIPTION

- The entire configuration (SW-C + RTE + BSW) for one ECU is called the ECU Configuration Description
- The ECU configuration description can be stored and exchanged in a standardized XML format called AUTOSAR XML (ARXML)
The ECU configuration description is translated into compilable C source code using Source Code Generators (SCG).

Typically there is one SCG per module in the BSW layer. The RTE is also generated using an SCG.

The generated configuration files will together with the static BSW module implementation files form a complete compilable module.
AUTOSAR BSW CONFIGURATION EDITOR

- To edit the BSW configuration a **Generic Configuration Editor** (GCE) may be used
  
  - The GCE loads **BSW module description** (BSW-MD) files which contain rules for creating the BSW configurations
  
  - The user can browse the **BSW module configurations** and edit their contents
  
  - Example of GCEs:
    - EB tresos Studio
    - Mecel Picea Workbench
    - Geensoft GCE
    - Vector DaVinci Configurator Pro
    - ...

AUTOSAR SW-C CONFIGURATION EDITOR

- To edit the SW-C configurations an **AUTOSAR Authoring Tool** (AAT) is used
  
  - The authoring tool allows you to specify SW-Cs, connect them and integrate them with the BSW layer
  
  - Example of AATs:
    - dSpace SystemDesk
    - Geensoft AUTOSAR Builder
    - Vector DaVinci Developer
    - Mecel Picea Workbench
OSEK/VDX with new features

- Memory protection
- Timing protection
- Service protection
- Schedule tables
- Inter-OS-Application Communicator (IOC)

Schedule Table

- A Schedule Table is a predefined sequence of actions (expiry points)
- Os iterates over the Schedule Table and processes each expiry point in turn
- Actions on a expiry point
  - ActivateTask()
  - SetEvent()
- Schedule Table is attached to a counter which provides the underlying interval measurement
- ScheduleTable can be started relatively or absolutely to the current counter value
- Schedule Table modes
  - One shot
  - Periodic
<table>
<thead>
<tr>
<th>Summary</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Automotive Domain</strong></td>
</tr>
<tr>
<td>- Biggest R&amp;D Sector in Europe</td>
</tr>
<tr>
<td>- Network of ECUs</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td><strong>OSEK/VDX</strong></td>
</tr>
<tr>
<td>- The most popular OS?</td>
</tr>
<tr>
<td>- Keep It Small and Simple</td>
</tr>
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<tr>
<td><strong>AUTOSAR</strong></td>
</tr>
<tr>
<td>- Software as a Component</td>
</tr>
<tr>
<td>- The ECU Middleware</td>
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