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Real Time Systems in Automotive

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1

Overview

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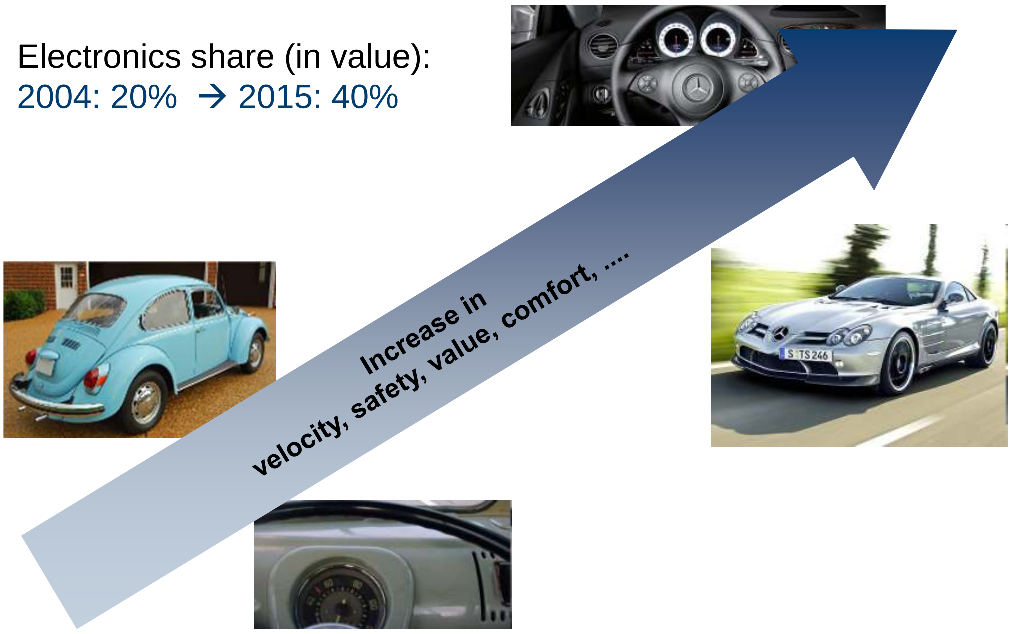
- **Automotive Domain**
- OSEK/VDX
- AUTOSAR
- Summary

2

Technology Changes

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



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

3

EU top 10 R&D Investing Companies

EU rank	Name	Country	Industrial sector (ICB-3D)	R&D 2012 (€million)
1	VOLKSWAGEN	Germany	Automobiles & Parts	9515.0
2	DAIMLER	Germany	Automobiles & Parts	5639,0
3	ROBERT BOSCH	Germany	Automobiles & Parts	4924,0
4	SANOFI-AVENTIS	France	Pharmaceuticals & Biotechnology	4909,0
5	SIEMENS	Germany	Electronic & Electrical Equipment	4572,0
6	GLAXOSMITHKLINE	UK	Pharmaceuticals & Biotechnology	4229,0
7	NOKIA	Finland	Technology Hardware & Equipment	4169,0
8	BMW	Germany	Automobiles & Parts	3952,0
9	ERICSSON	Sweden	Technology Hardware & Equipment	3862,7
10	EADS	The Netherlands	Aerospace & Defence	3630,0

Source: European Commission IRI; http://iri.jrc.ec.europa.eu/survey13.html

4

E/E Domains

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5

Cars Today

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- 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.)

6

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

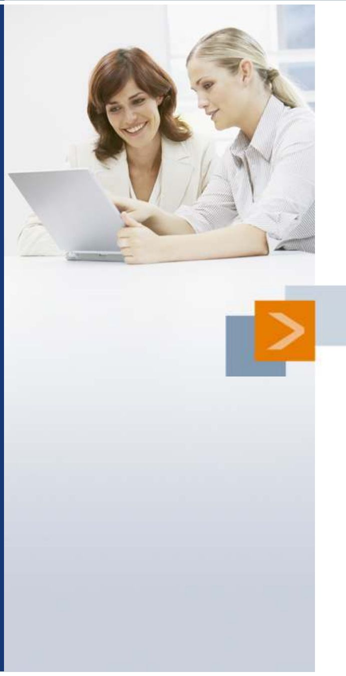
Today

- 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

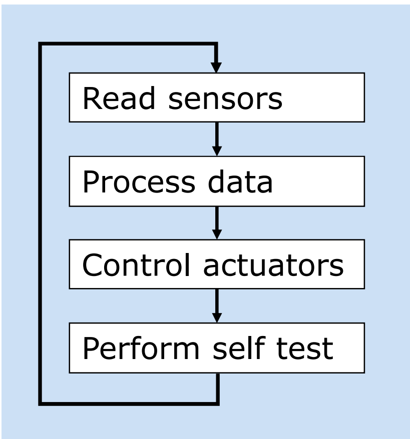
Which OS is used?

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

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

Infinite Loop

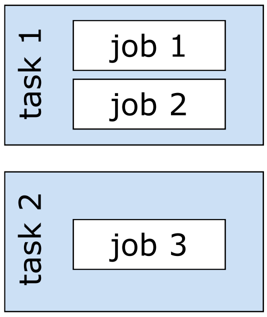
Within each loop cycle, a series of jobs is processed sequentially



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



11

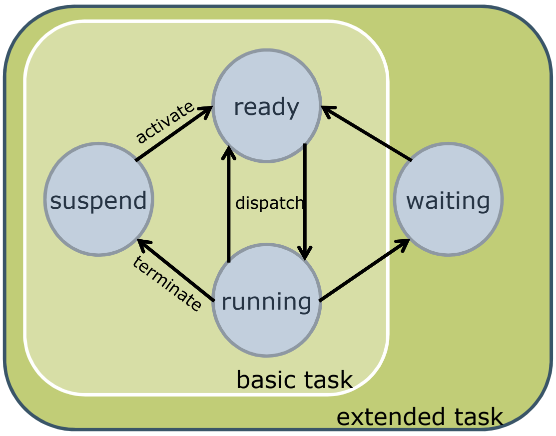
Tasks

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



OSEK Task Model

12

Flexible Preemption

Preemptable

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

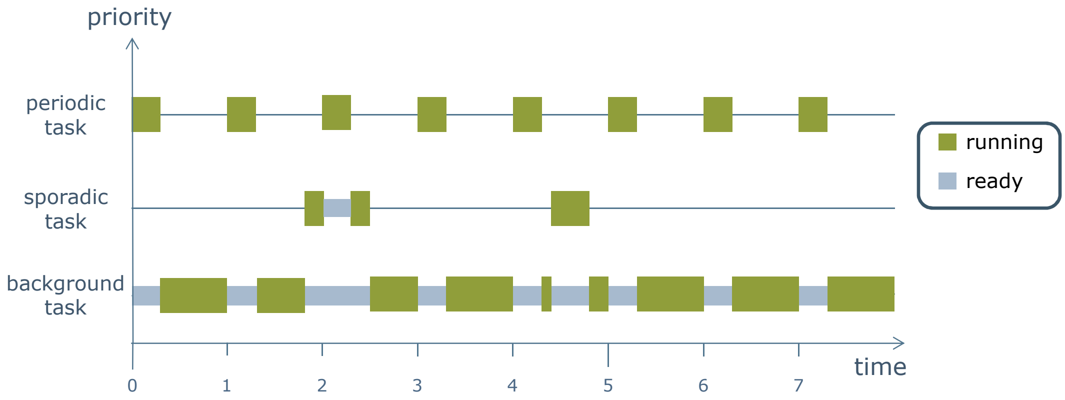
Non-preemptable

- 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



Priority Assignment Example

Rate Monotonic Scheduling

Variant of Fixed Priority Scheduling

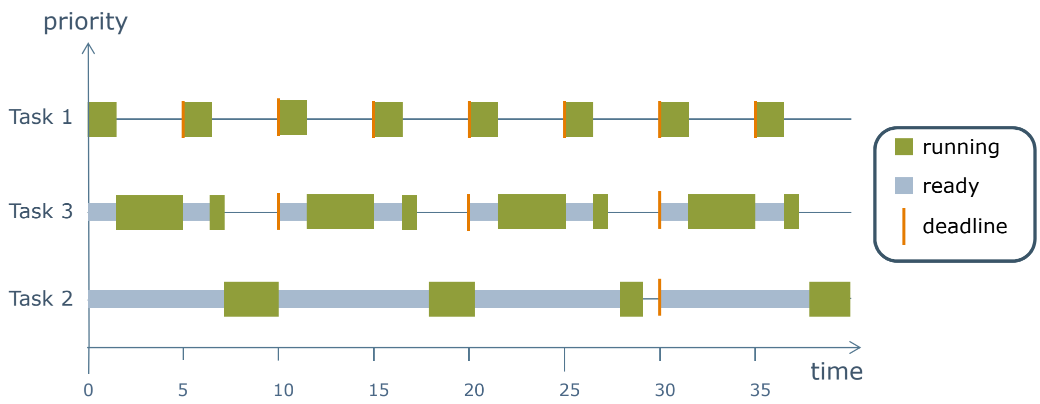
- Assumption: Deadline == Period
- Task priorities are inverse to the period

Example:

- Task 1: Period = 5 ms → Priority 1
- Task 2: Period = 30 ms → Priority 3
- Task 3: Period = 10 ms → Priority 2

Priority Assignment Example

Rate Monotonic Scheduling



17

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

18

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A critical section is a sequence of code that accesses a shared resource that must not be accessed concurrently.

Simple Example:

```
static volatile int counter = 0;

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

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

19

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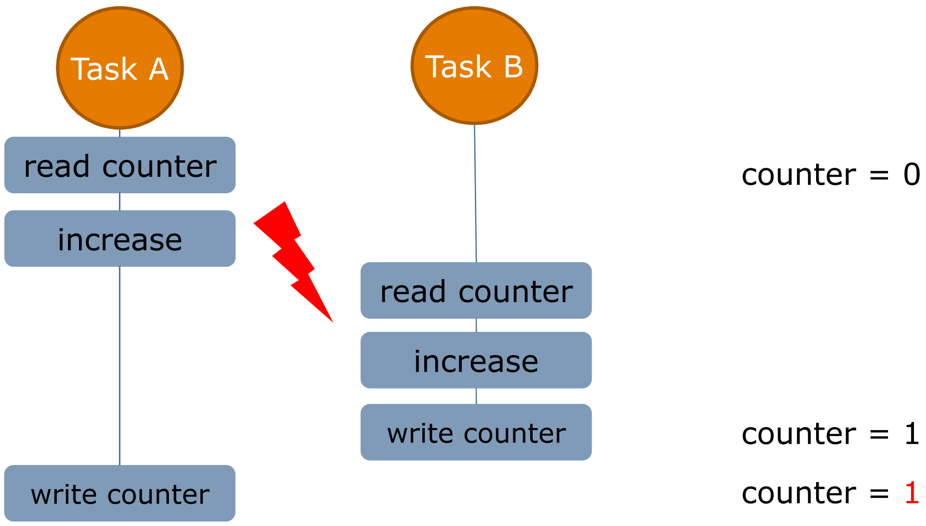

20

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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
- …

21

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Disable/Enable Interrupts

- Prevent task switching by disabling interrupts

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

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

22

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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

23

Concurrency

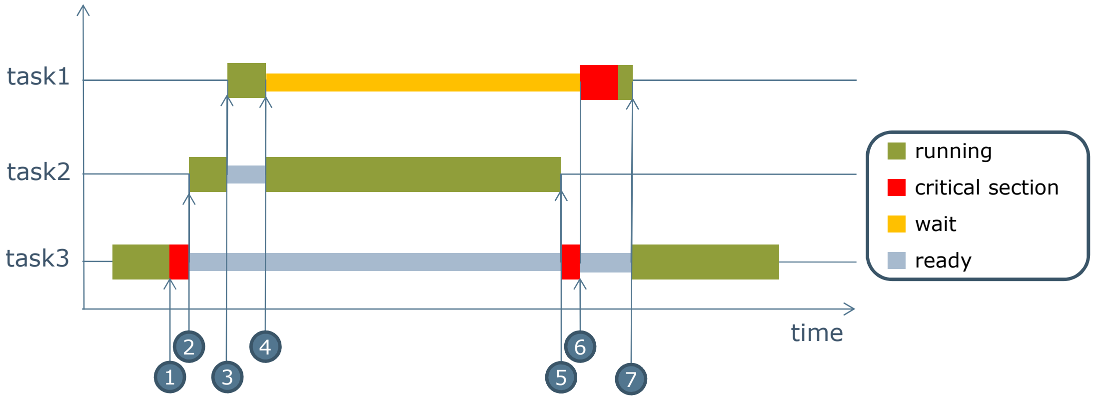
Synchronization Issues:

- 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

24

Concurrency

Priority inversion



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
   task1 enters critical section
7. task1 completes after task2

Concurrency

Priority inversion – solutions:

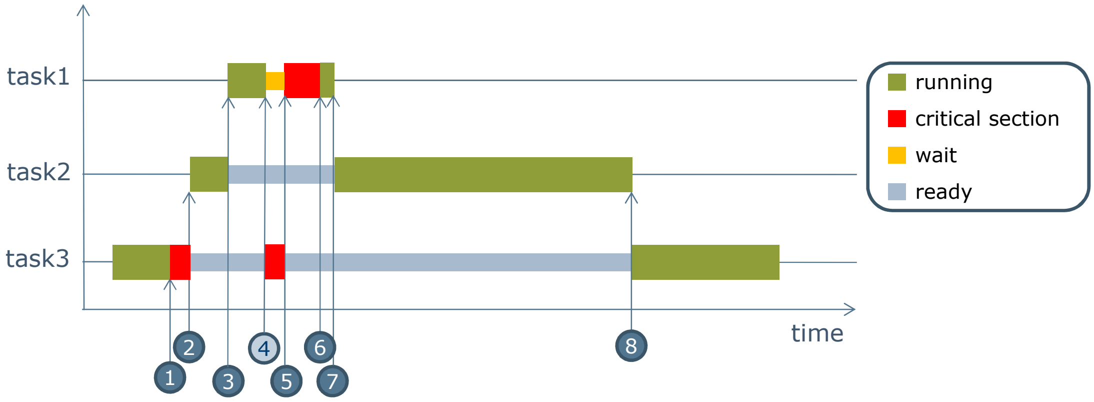
- Priority inheritance: If a task with a higher priority than the mutex owner attempts to lock a mutex, the effective priority of the current owner is temporarily increased to that of the higher-priority blocked task waiting for the mutex.

```
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

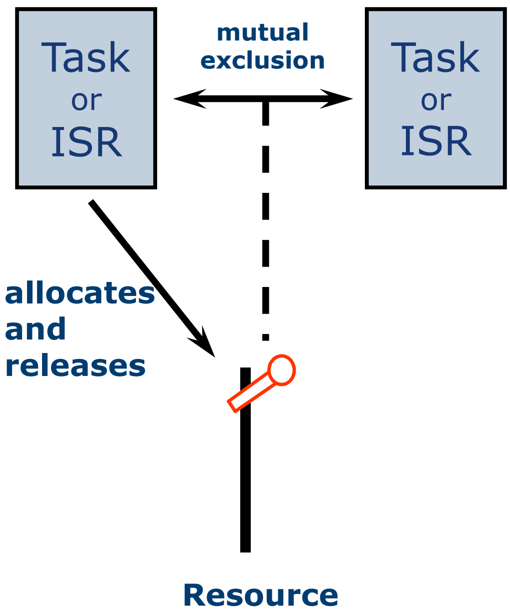


1. task3 enters critical section
2. task2 is activated
3. task1 is activated
4. task1 reaches critical section, task3 inherits priority
5. task3 leaves critical section
6. task1 leaves critical section
7. task1 completes before task2
8. task2 completes after task1

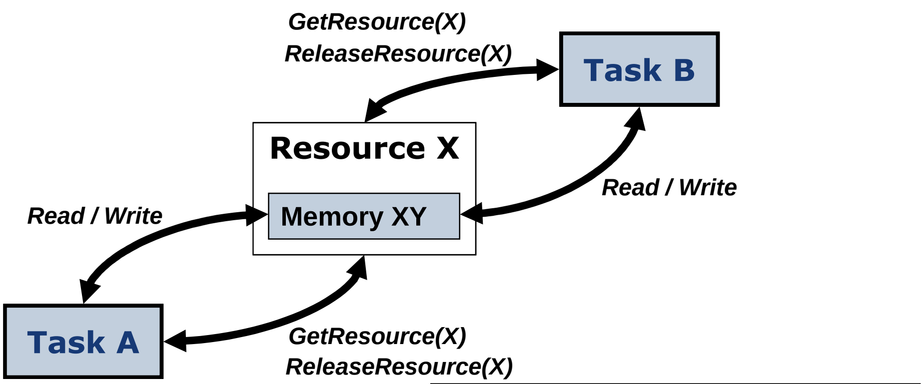
27

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 can not be allocated a second time
- After allocating a resource, a task must not
  - wait for events
  - terminate



Resources

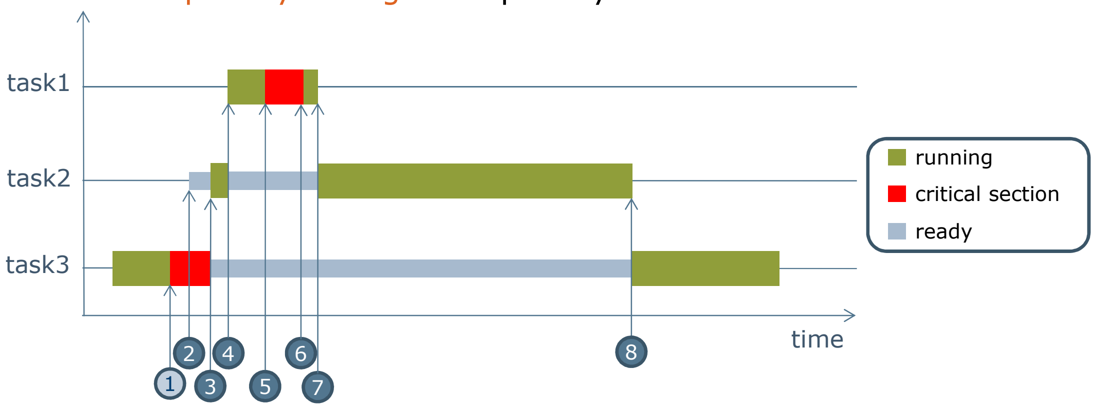



```
TASK(A)
{
  GetResource(ResX);
  /* access memory XY */
  ReleaseResource(ResX);
}
```

```
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

30

Counter and Alarms

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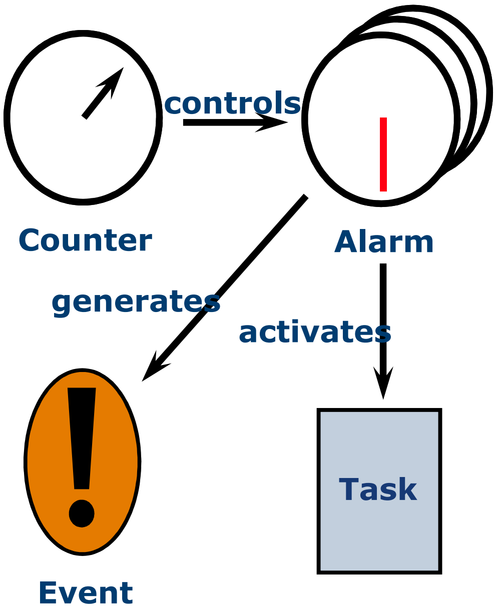
- Counters can be used to count events, e.g. timer ticks, movements, etc.
- Alarms are bound to a counter and expire when a certain counter value is reached
- Expiration of an alarm results in one of four activities
  - generation of an event
  - activation of a task
  - execution of a callback function*
  - 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



*) not illustrated

Events

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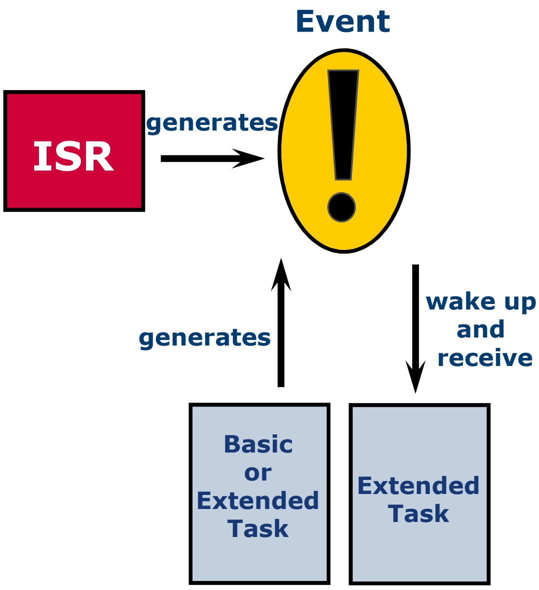
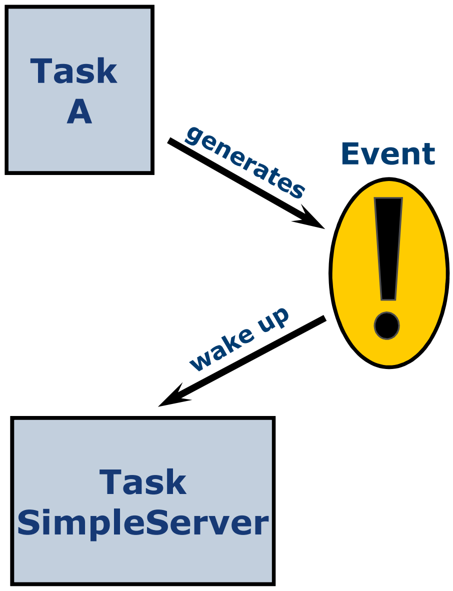
- Extended tasks can wait for the generation of an event
- Events can be generated from inside tasks or ISRs
- While waiting for an event, the task releases the CPU
- A task can not determine the source of an event
- ISRs can not wait for events, but have to activate a task for this purpose
- There are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



Events

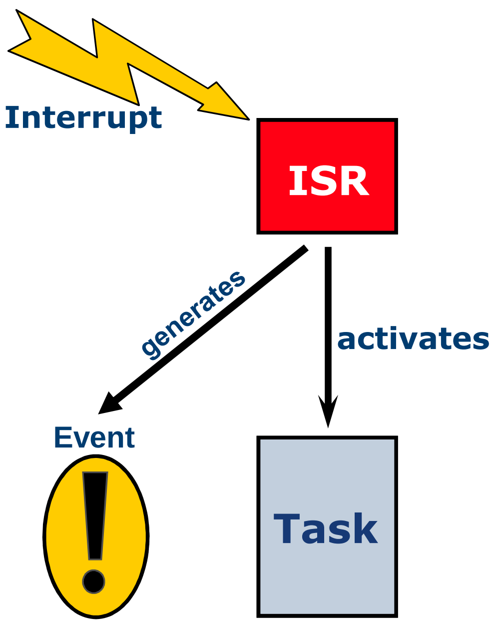
```
TASK(A)
{
  SetEvent(SimpleServer, My_Ev1);
  TerminateTask();
}
```

```
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, …

35

Interrupts

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

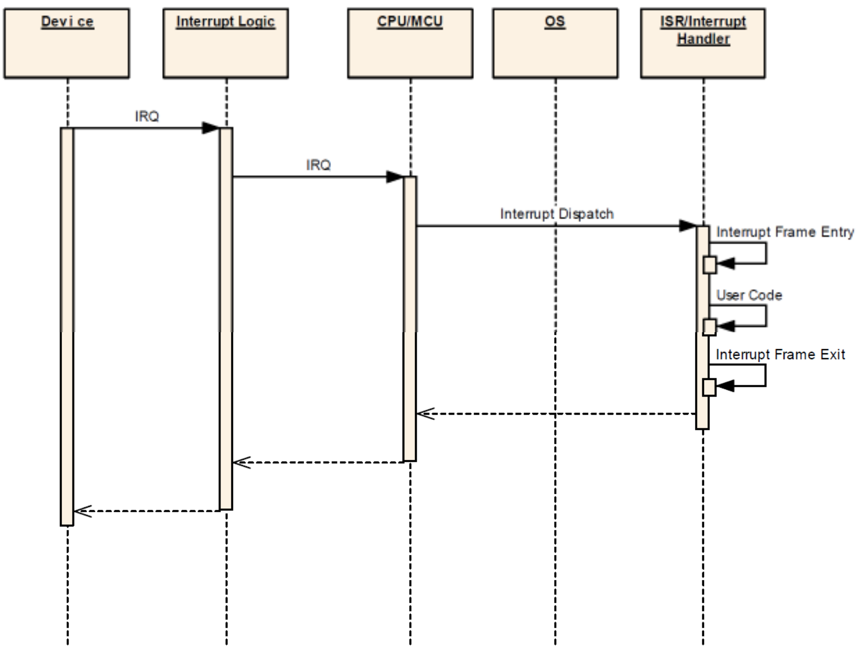
- Category 1: no operating system services may be used
- Category 2: system services can be used

36

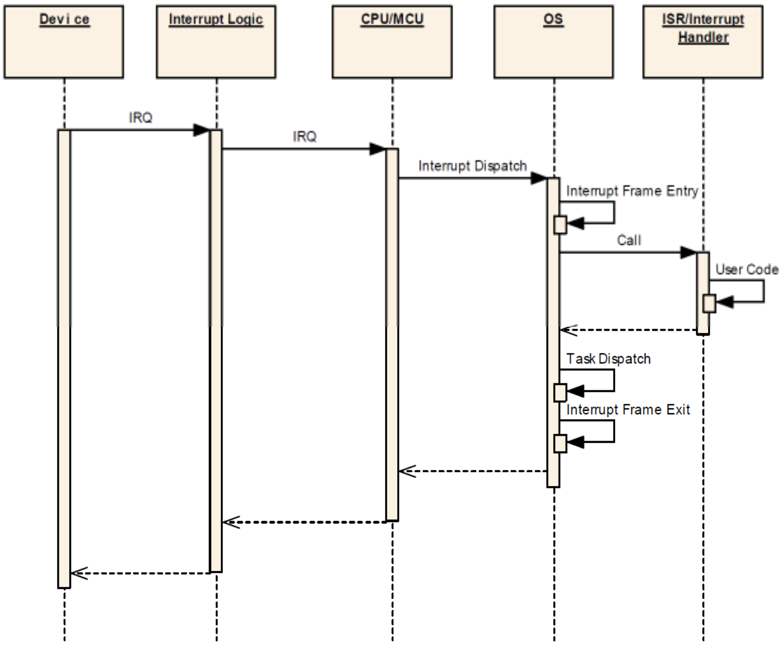
Example: OSEK

Service	Task	ISR Cat2	ISR Cat1
ActivateTask	✓	✓	×
TerminateTask	✓	×	×
Schedule	✓	×	×
GetTaskID	✓	✓	×
GetTaskState	✓	✓	×
Disable-/EnableAllInterrupts	✓	✓	✓
Suspend-/ResumeAllInterrupts	✓	✓	✓
Suspend-/ResumeOSInterrupts	✓	✓	✓
Get-/ReleaseResource	✓	✓	×
Set-/GetEvent	✓	✓	×
Wait-/ClearEvent	✓	×	×

Cat1 Interrupts



Cat2 Interrupts



39

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

40

Concurrency – Interrupts

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

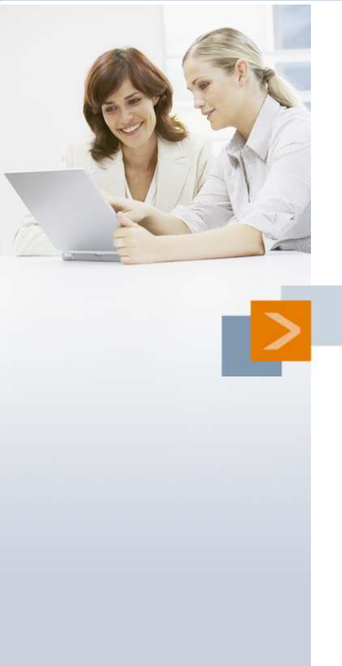
→ Synchronization is necessary

Approaches:

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

41

Overview



- Automotive Domain
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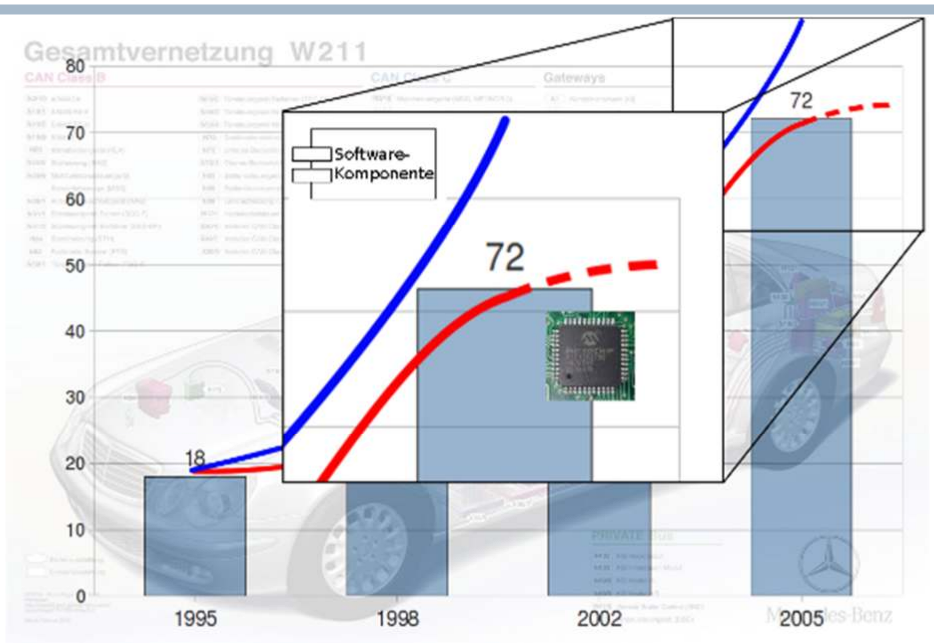
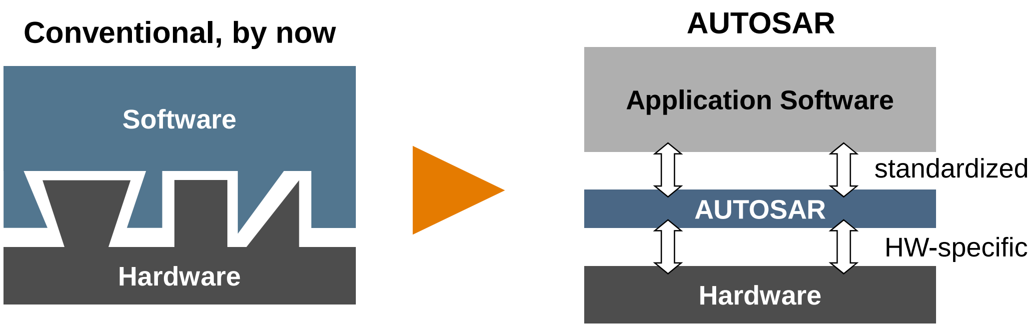
42

Increasing number of ECUs*)



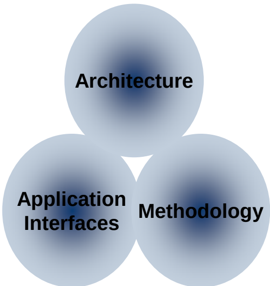
*) ECU = Electronic Control Unit = elektronische Steuergerät

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

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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

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9 Core Partners

11 Development Members

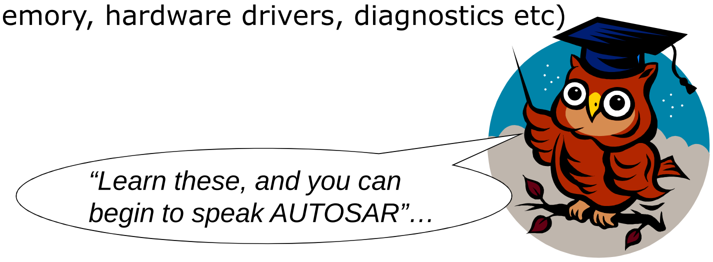
57 Premium Member

88 Associate Members
17 Attendees

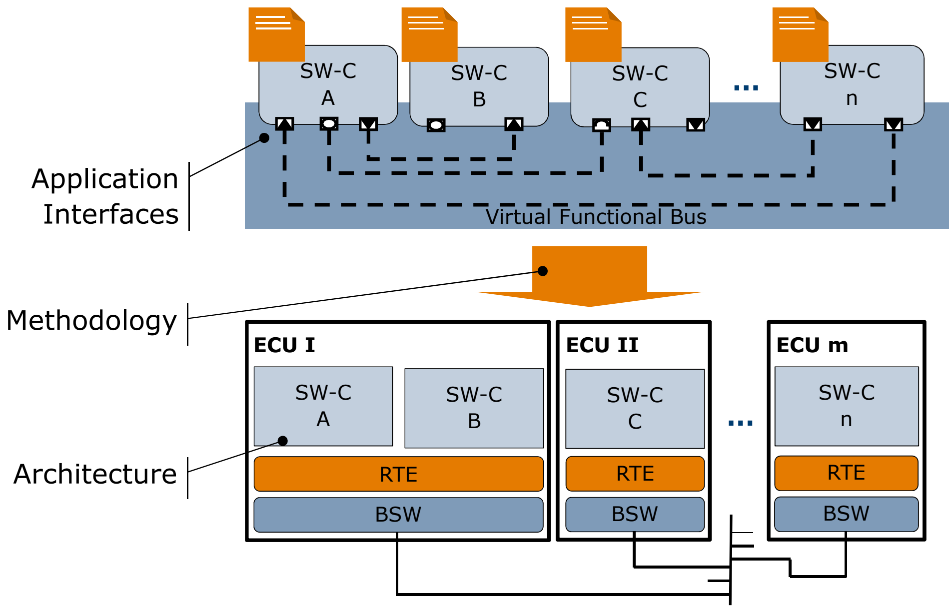
BASIC AUTOSAR CONCEPTS

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)

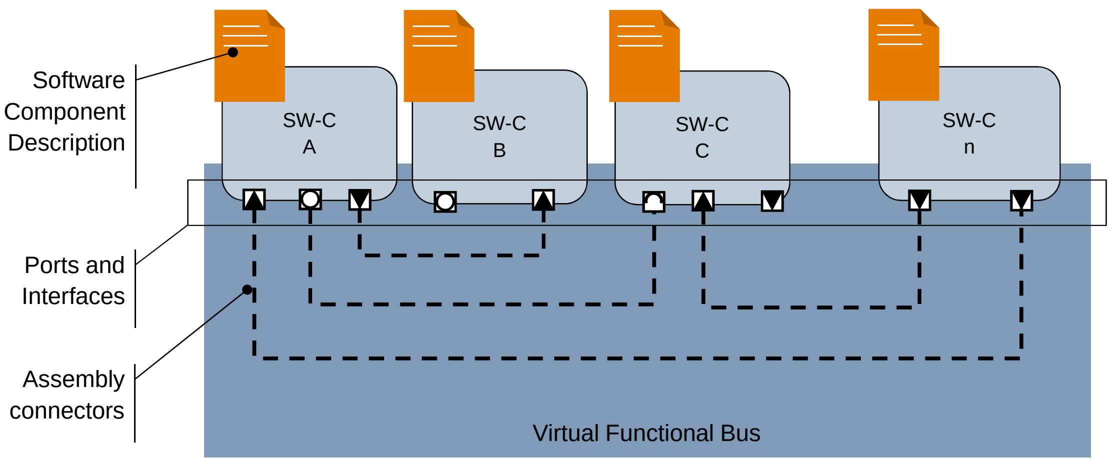


Introduction
Basic AUTOSAR Approach



- 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***

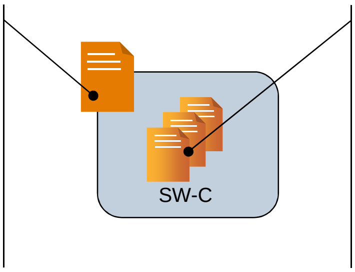


Introduction
Basic AUTOSAR Approach

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>
```



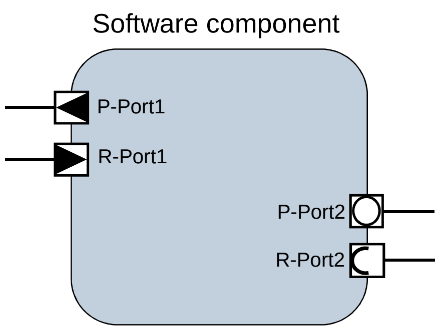

```c
#include "MySWC.h"

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)

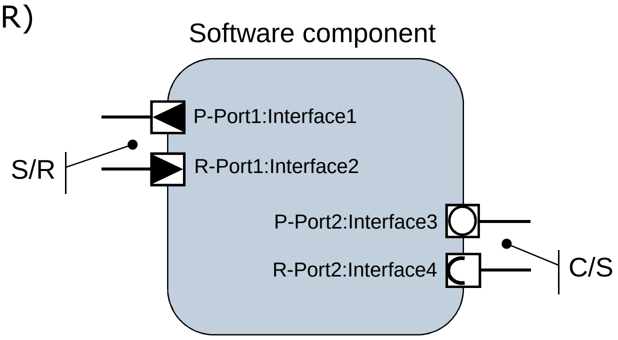


An ***Interface*** is a contract between a ***P-port*** and an ***R-port***

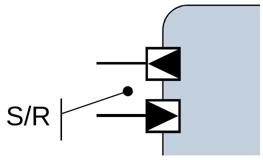
The ***Interface*** defines the data or operations that can be handled by the Port

There are different kind of ***Interfaces***

- Sender-Receiver (S/R)
- Client-Server (C/S)



Broadcast of signals

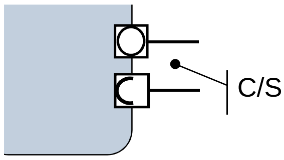


An S/R interface may contain one or more ***DataElements*** (signals)

A ***DataElement*** always has a data type

- Primitive data types (Integer, Enumeration, Boolean…)
- Complex data types (Arrays and Record)

Introduction
Client-Server Communication



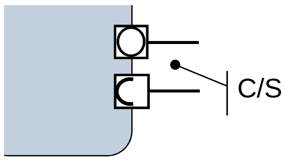
A C/S interface may contain one or more ***Operations*** (functions)

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

Introduction
Client-Server Communication



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

Synchronous call

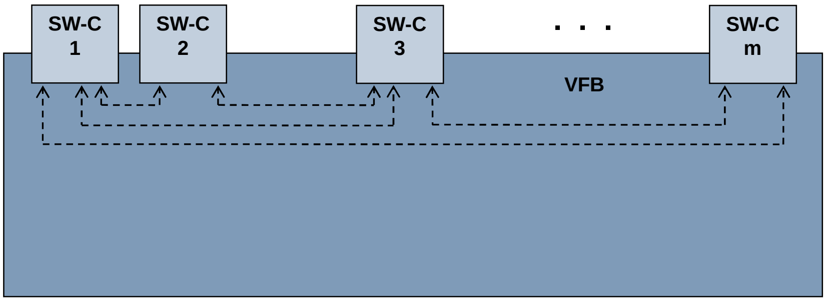
- Rte_Call will not return until result is available (blocking)

Asynchronous call

- Rte_Call will initiate operation but will return immediately (non-blocking)
- Rte_Result will provide the result (non-blocking or blocking)

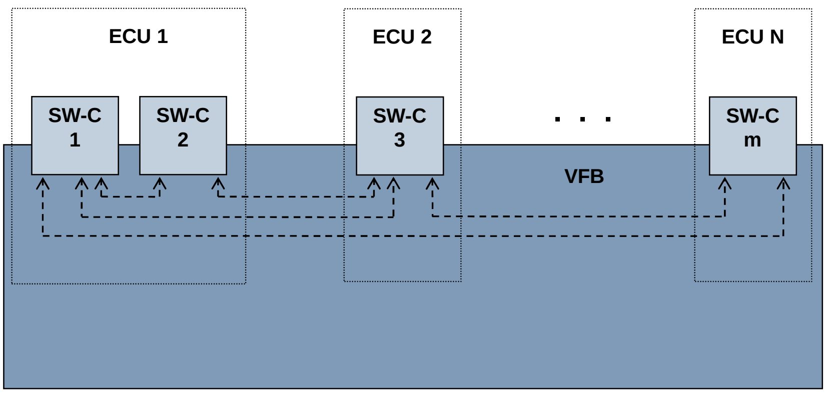
VIRTUAL FUNCTIONAL BUS (VFB)

- 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



VIRTUAL FUNCTIONAL BUS (VFB)

- 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)

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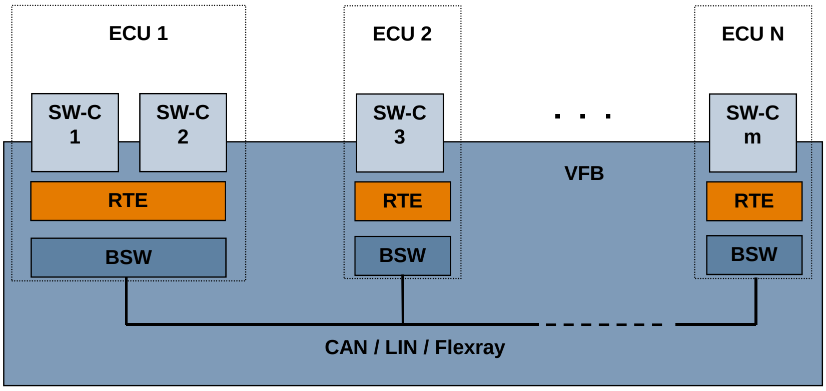
- The ***Runtime Environment*** (RTE) is the only interface to the SW-Cs
- The RTE implements the VFB
- The RTE uses CAN/LIN/FlexRay buses for inter-ECU communication via the ***Basic Software Layer*** (BSW)



AUTOSAR BENEFITS

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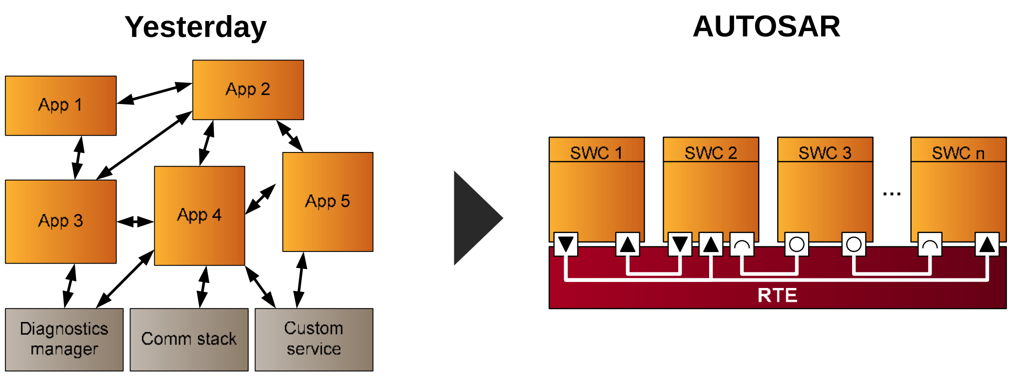

- AUTOSAR is a standardized platform
- Well defined APIs for communication
- No difference between internal communication and bus communication

→ ***Relocatability and reuse!***

BASIC SOFTWARE MODULES

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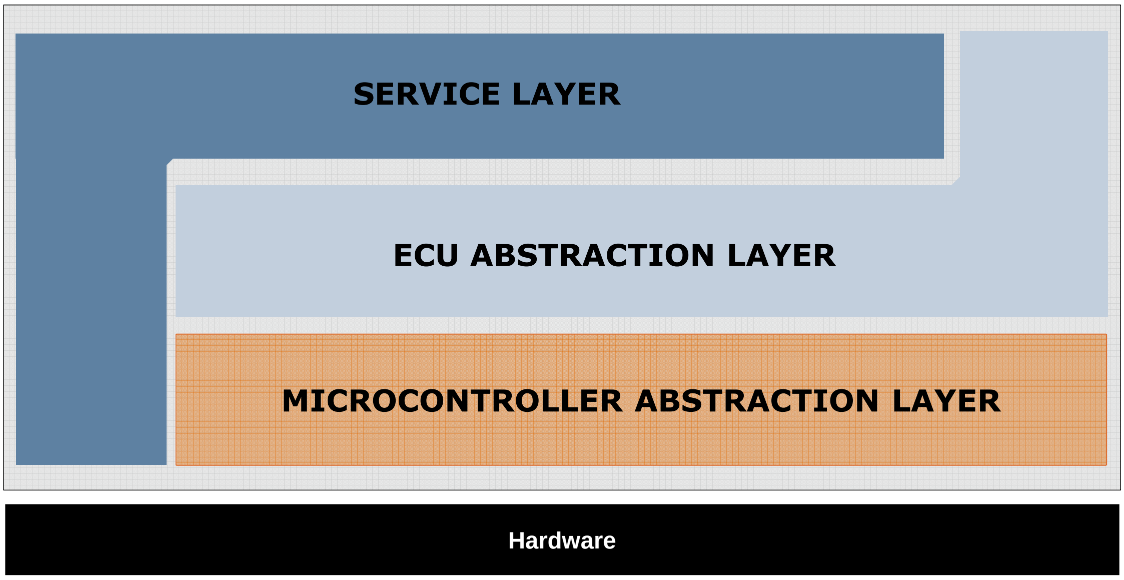

BASIC SOFTWARE MODULES

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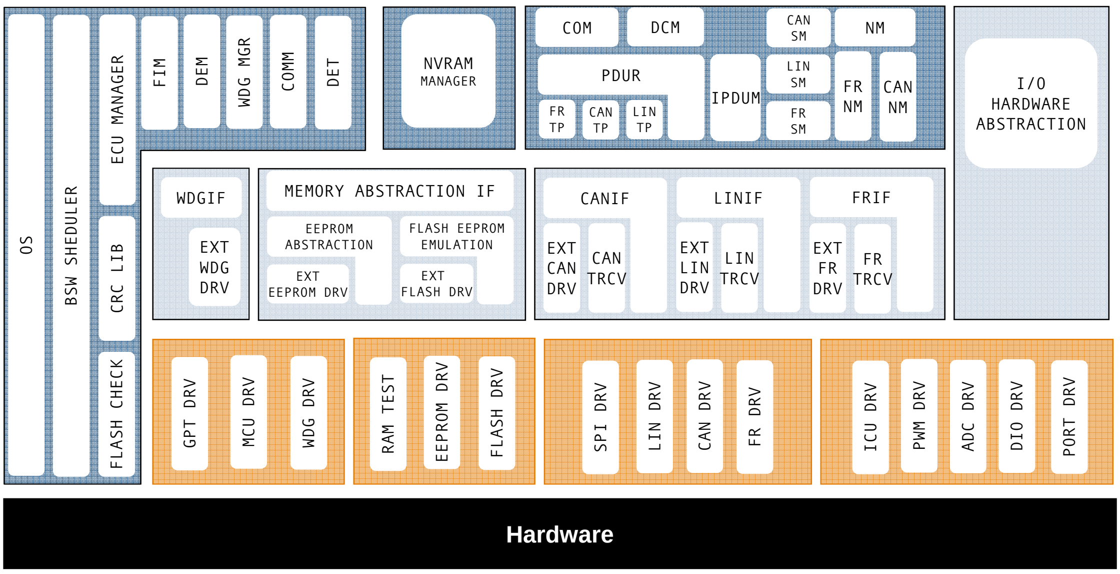

BASIC AUTOSAR APPROACH

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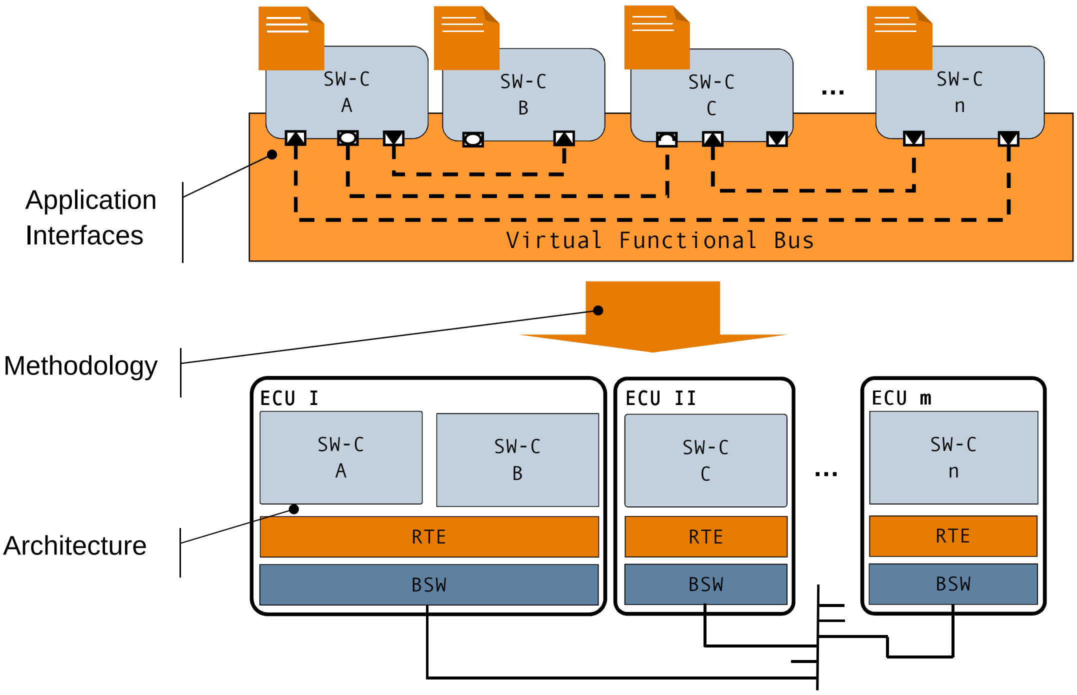

RTE/BSW CONFIGURATION

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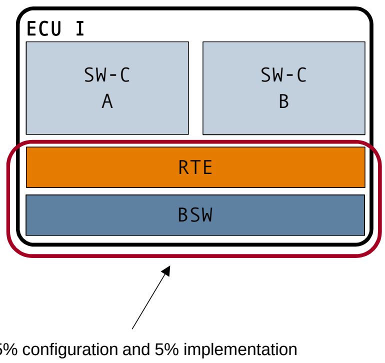
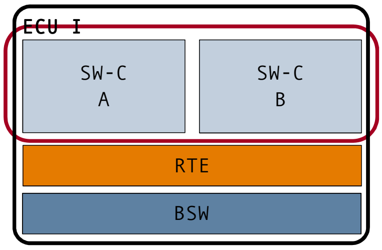
- The implementations of the RTE and BSW modules are specified by AUTOSAR
- Their behavior must be ***configured*** by the integrator
- Examples:
  - Number of CAN channels
  - CAN frames
  - ECU power states
  - Flash memory blocks
  - OS tick time
- Exception: The ***HW I/O abstraction*** module is project specific and has to be implemented from scratch (more about this later)



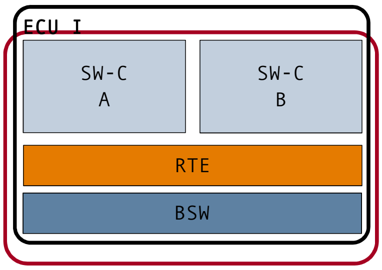
SW-C CONFIGURATION

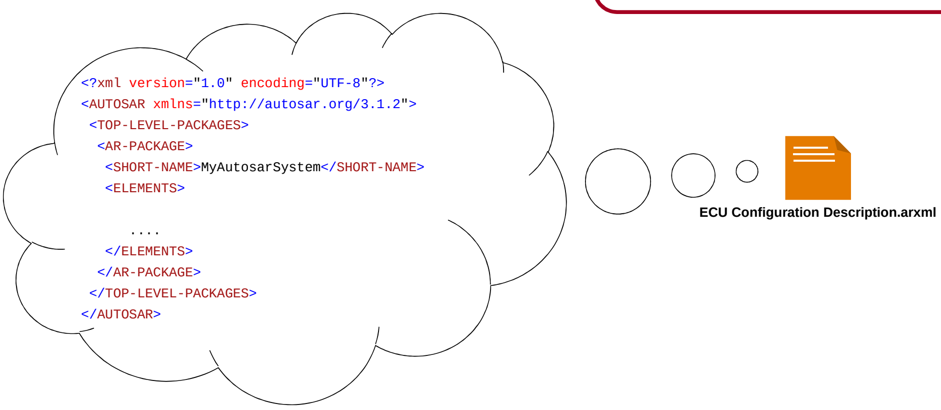
- SW-Cs are also configured to some extent
- Examples:
  - Data Types
  - Communication signals
  - Scheduling
  - Inter task communication
- Based on this configuration, the RTE will provide the necessary APIs
- The source code in the SW-Cs can either be implemented manually (coding C or C++) or modeled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



ECU CONFIGURATION DESCRIPTION

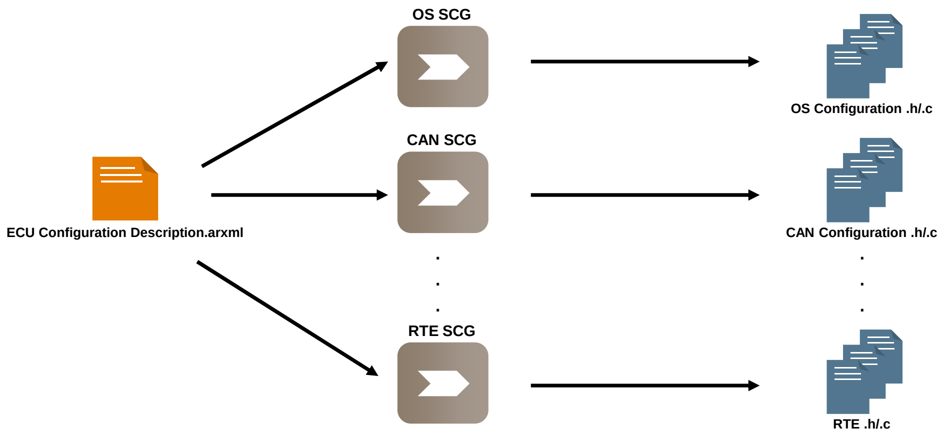
- The entire configuration (SW-C + RTE + BSW) for one ECU is called the ***ECU Configuration Description***
- The ECU configuration description can be stored and exchanged in a standardized XML format called ***AUTOSAR XML*** (ARXML)





BASIC SOFTWARE CONFIGURATION

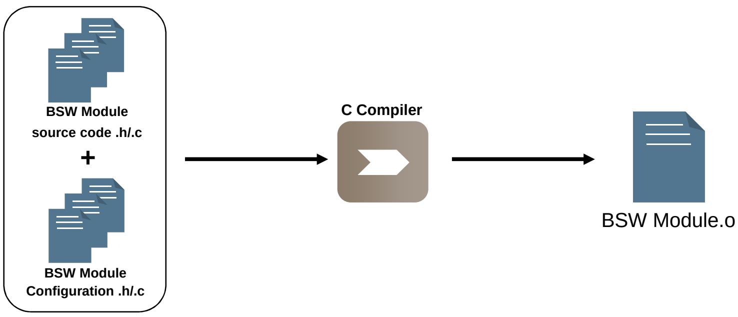
- The ECU configuration description is translated into compilable ***C source code*** using ***Source Code Generators*** (SCG)



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

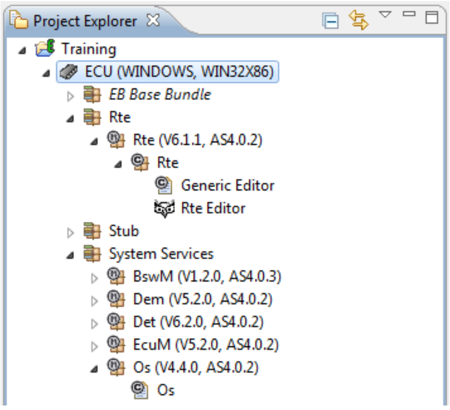
BASIC SOFTWARE CONFIGURATION

- 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

AUTOSAR OS

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OSEK/VDX with new features

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

73

Schedule Table

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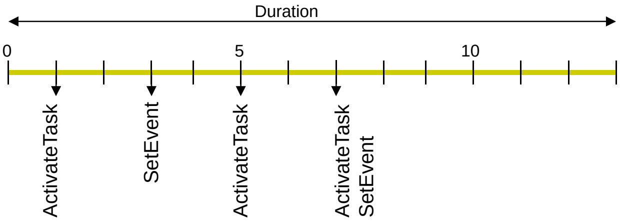
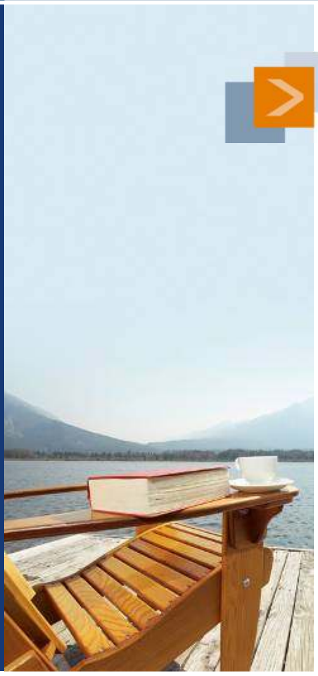
- A Schedule Table is a predefined sequence of actions (expiry points)
- Os iterates over the Schedule Table and processes each expiry point in turn
- Actions on a expiry point
  - `ActivateTask()`
  - `SetEvent()`
- Schedule Table is attached to a counter which provides the underlying interval measurement
- ScheduleTable can be started relatively or absolutely to the current counter value
- Schedule Table modes
  - One shot
  - Periodic



Summary



- Automotive Domain
  - Biggest R&D Sector in Europe
  - Network of ECUs
- OSEK/VDX
  - The most popular OS?
  - Keep It Small and Simple
- AUTOSAR
  - Software as a Component
  - The ECU Middleware