Betriebssysteme für eingebettete Systeme und Echtzeitsysteme

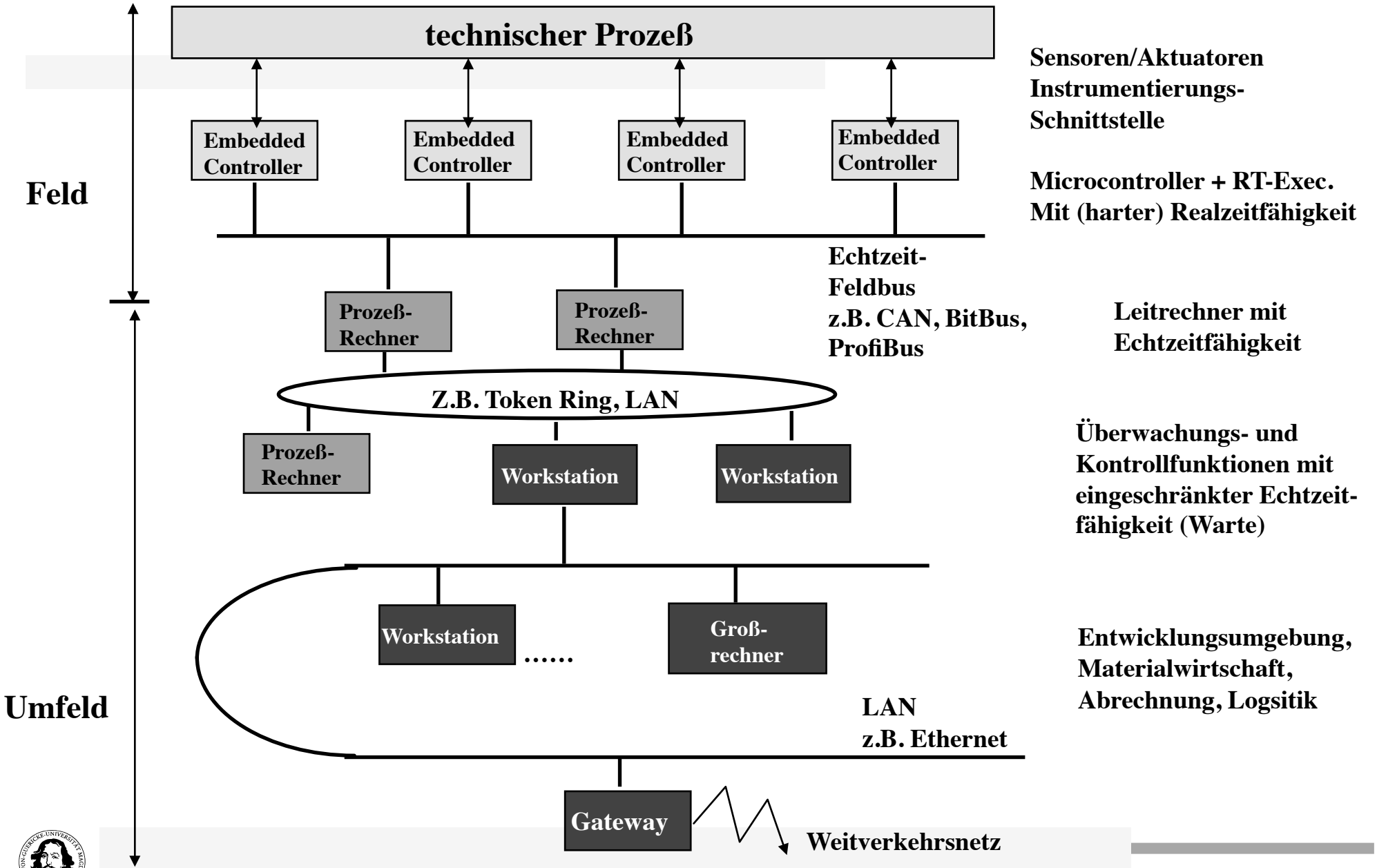
Betriebssystem-Kerne

Grundlegende Funktionalität:

High-Level:
- **Scheduling**
- **Zeitbehandlung**
- **Ein-Ausgabe, Ereignisbehandlung**
- **Kommunikation**
- **Ressourcenverwaltung**

Low-Level:
- **Task Management**
- **Task-Synchronisation**
- **Inter-Task-Kommunikation**
- **Zeitgeber und Uhren**
- **Unterbrechungsbehandlung**
- **Statische/Dynamische Speicherallokation**

Einbettung von Echtzeitsystemen in eine CIM-Umgebung



Anforderungen und Technologie

Ebene:	Charakteristische Anforderungen:	Technologien/Betriebssysteme:
Embedded Controller, einfache Steueraufgaben	Harte Echtzeitbedingungen, kurze Reaktionszeiten	Microcontroller, Echtzeitkerne mit eingeschränkter Funktionalität PXROS, RTkernel, VRTX, VXworks EUROS, iRMX, OSEK. . .
Leitrechnerebene	Harte Echtzeitbedingungen, kurze Reaktionszeiten, Realisierung konsistenter globaler Zustände, globales, verteiltes Scheduling, Erkennung globaler (kritischer) Zustände	Prozeßrechner oder Workstations, Echtzeitbetriebssysteme für komplexe verteilte Steuerungsaufgaben, Beisp.: OpenVMS, Posix IEEE 1003.13, LynxOS, QNX, RT-Linux, Maruti, SPRING, MARS, RT-Mach,
Warte	Eingeschränkte Echtzeitfähigkeit, graphische Bedienoberfläche	Workstationtechnologie, Touchscreen, GUI, Visualisierungs-werkzeuge (z.B. Matlab/Simulink, LabView)
Entwicklungsumgebung	Keine Echtzeitanforderungen, Leistungsfähige, Multi-User-Umgebung zur Programm-Entwicklung, Simulation, Verifikation, Test	High-End-Workstation, hoher Leistungsbedarf, Compiler: ADA, PEARL, C, C++, JAVA Off-line Scheduling Werkzeuge, Simulationsumgebung

Kategorien von eingebetteten Betriebssystemen

- Echtzeiterweiterungen für “Timesharing” Betriebssysteme
  Beispiele: RT-Mach, RT-Erweiterungen in POSIX, RED-Linux, RT-Linux, Xenomai, RTAI. . . . .

- Echtzeitbetriebssysteme in der Forschung
  Beispiele: MARS, CHAOS, Spring, ARTS, MARUTI, ...

- Prioritätsbasierte Betriebssystemkerne für eingebettete Anwendungen
  Beispiele: VRTX, VxWorks, QNX, OSEK, PXROS, RTkernel, OS9, RTEMS, u8os. . . . .

-Betriebssystemkerne für stark ressourcenbeschränkte Anwendungen
Beispiele: TinyOS, Contiki, Mantis, ...

VRTX
u8os

PXROS,
OSEK,

RTKernel,
EUROS, RTOS

Maruti, MARS,
Spring, PS/9

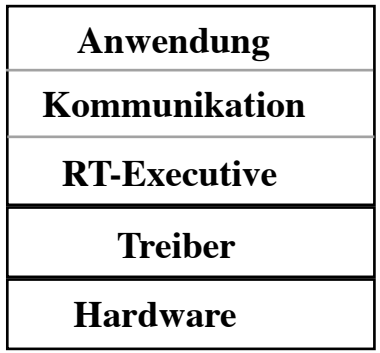
LynxOS, Mach, QNX,
Solaris, RTLinux, NT…

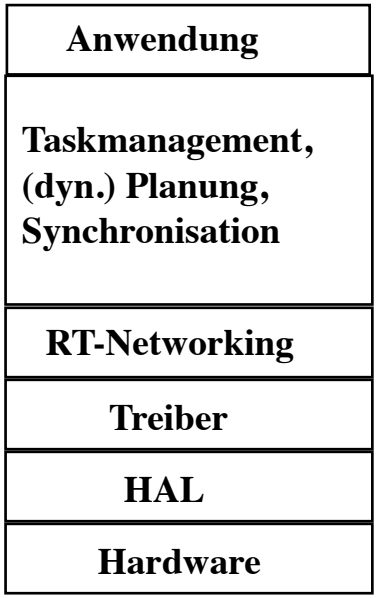
zunehmende
Systemkomplexität

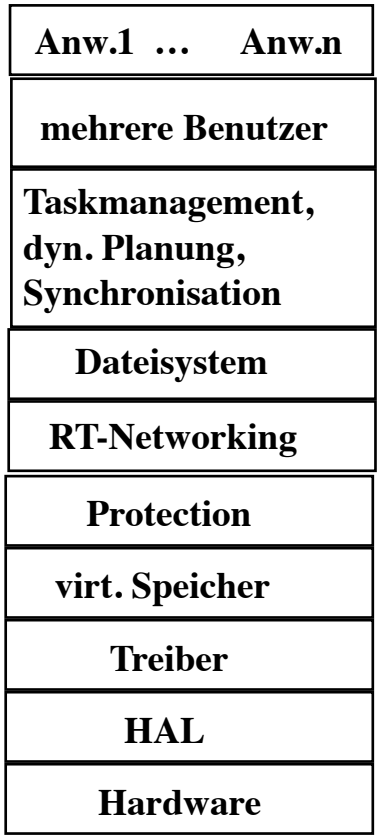
SimpleEmbedded Systems

+ Minimale System-Unterstützung
+ Minimaler Platzbedarf
+ Minimaler Overhead

- Aufwendige Off-line Analyse
- Statisches Systemverhalten
- kein Dateisystem
- kein HAL







Anpassen der Betriebssystemkerne an die Anwendungsanforderungen

Profile in POSIX (1003.13) :

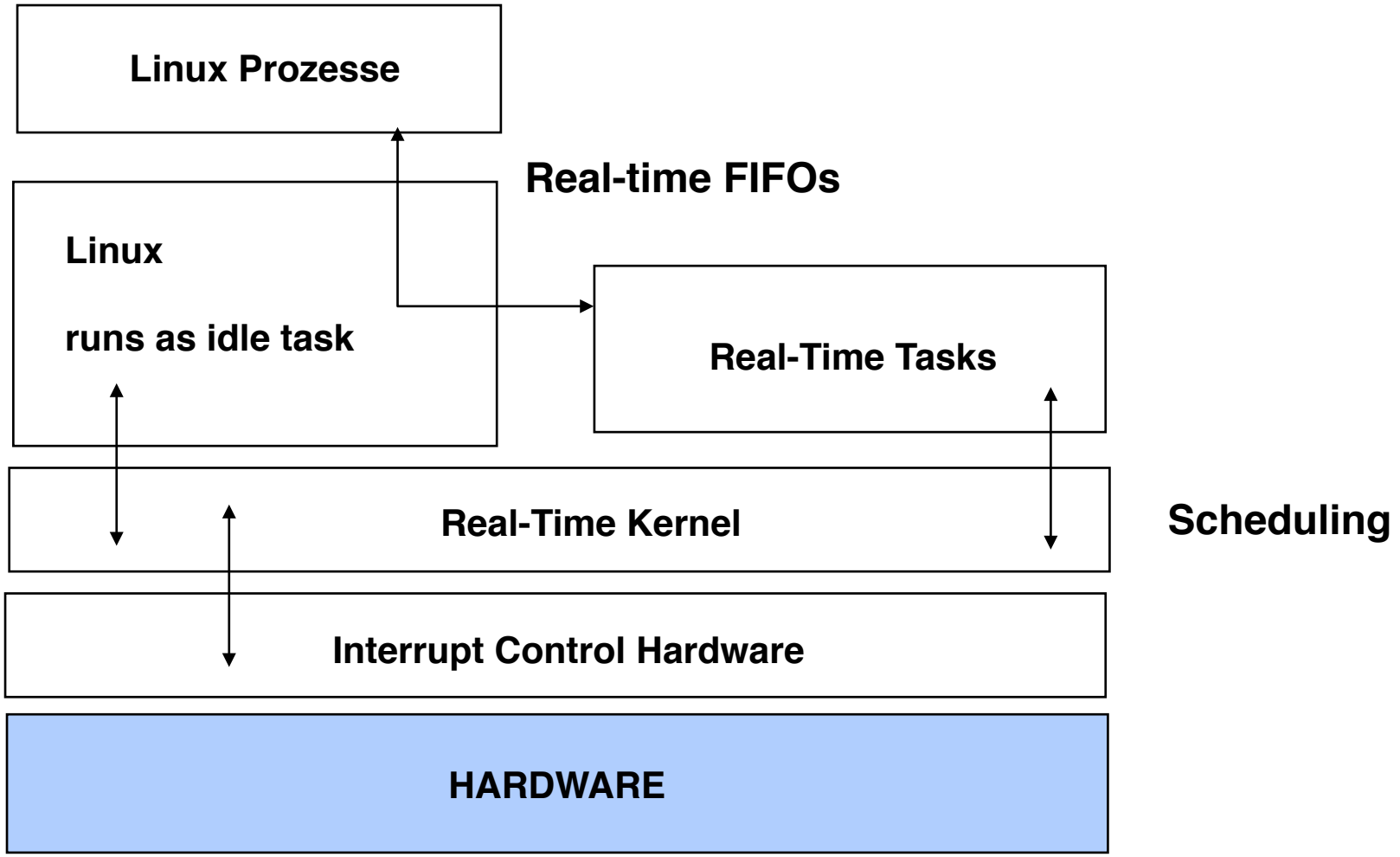
PSE50 - Minimales Realzeit System Profil:
Geeignet für eingebettete Ein- oder Mehrprozessorsysteme, die ein oder mehrere externe Geräte kontrollieren. Es wird nur ein einzelner Prozeß (nur 1 Adressraum!) mit mehreren Threads unterstützt. Kein Dateisystem, keine Operator-Schnittstelle.

PSE51- Systemprofil für „Real-Time Controller“:
Erweiterung zu PSE50. Dateisystem und asynchrone Ein-/Ausgabe.

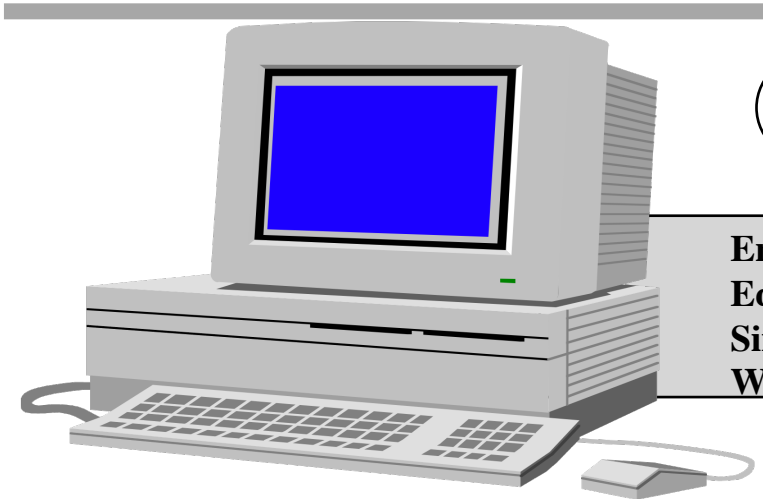
PSE52 – Spezielles Reazeit-Profil:
Erweiterung zu PSE50 um Systeme mit Speicherverwaltungseinheit. Unterstützt mehrere Prozesse aber kein Dateisystem.

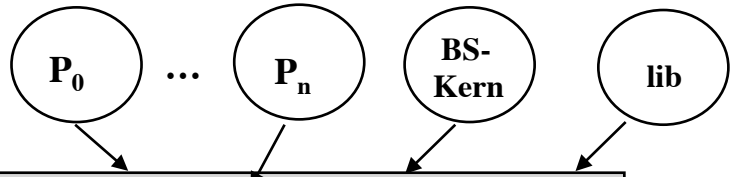
PSE53 – Multi-purpose Realzeit-Profil:
Unterstützt Koexistenz von Echtzeitsystemen und Nicht-Echtzeitsystemen. Für Ein-/ Mehrprozessorsysteme mit MMU, Massenspeicher, Netzwerk etc..

Architektur und Einbettung von RTLinux



Schema einer Cross-Entwickungsumgebung: Konfigurierbarer BS-Kern

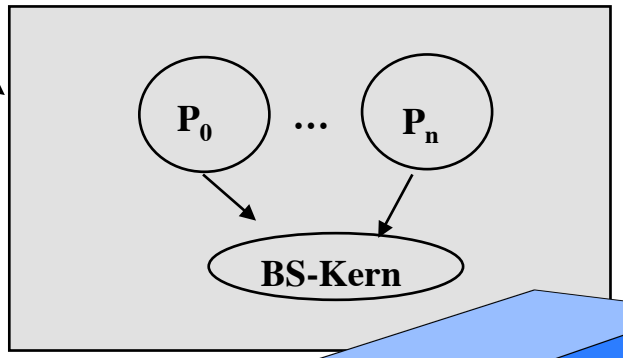


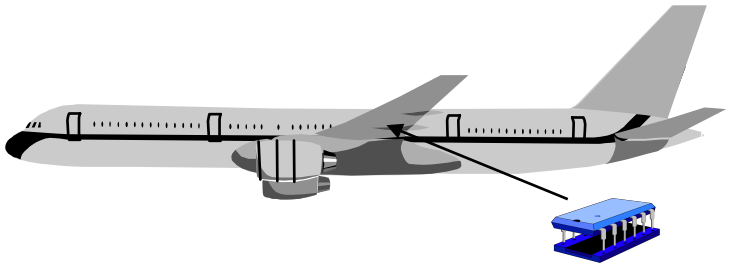


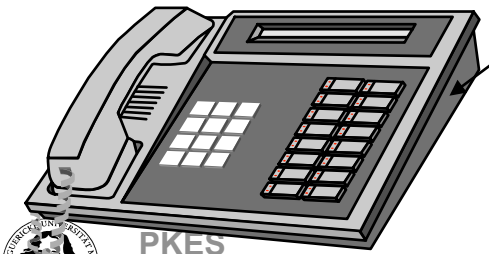
Entwicklungssystem
Editor, Compiler, Binder,Lader,
Simulator, Verifizierer, Scheduling-
Werkzeuge, etc...

Download,
EPROM,
Flash Memory

Embedded Controller

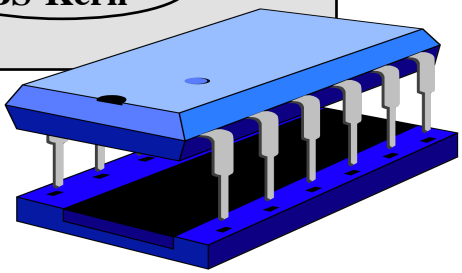




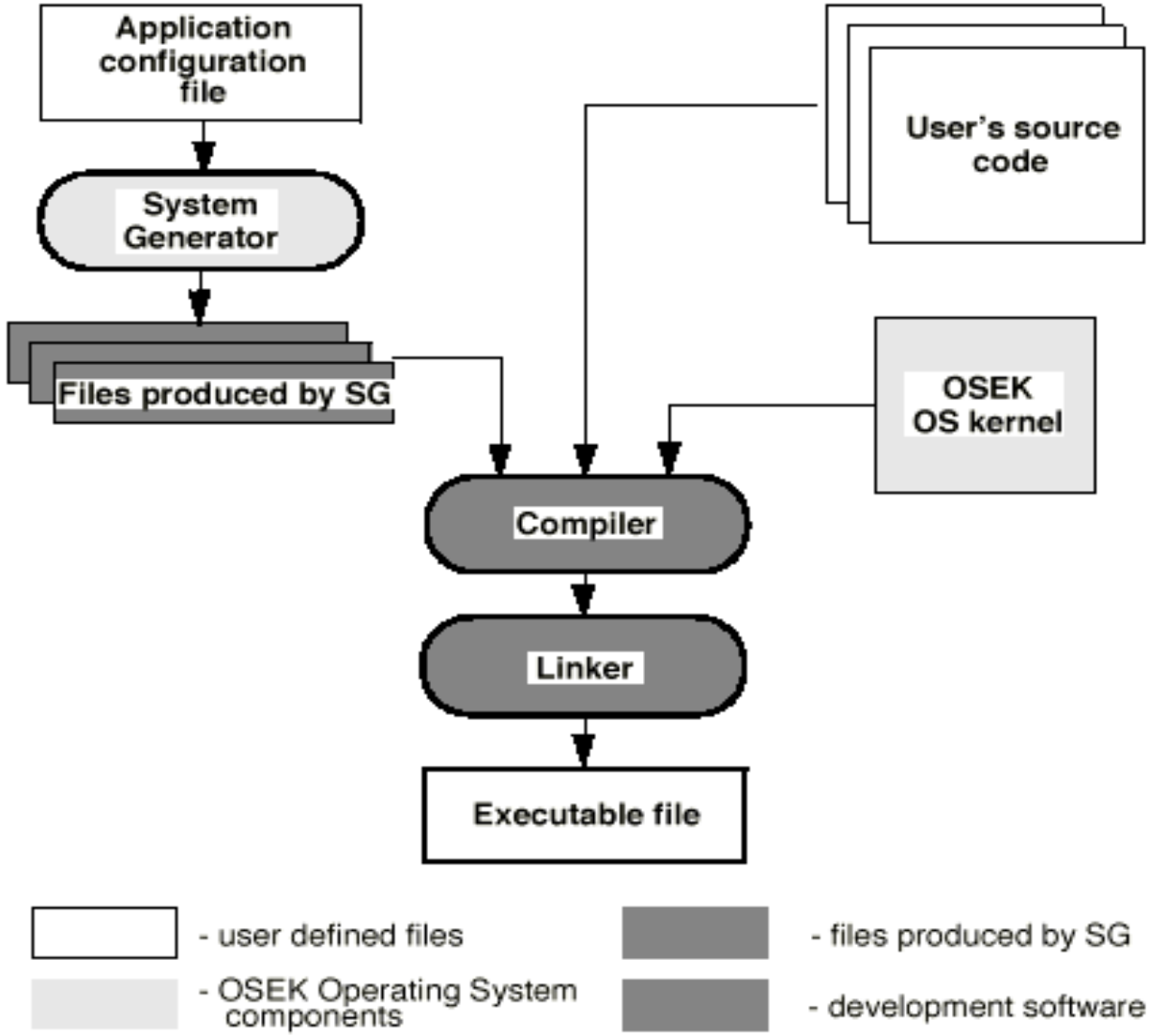


Embedded Controller:

- **spezifischer I/O**
- **spezifischer Befehlssatz**
- **spezifische Unterbrechungsbehandlung**
- **variable Zeitgeberfunktionen**



Application building process in OSEK



Beispiel: OSEK Konfigurationsdatei

```
[Property]
TargetMCU = HC08;
ConformanceClass =ECC1;
SimpleScheduler = OFF;
ExtendedStatus = ON;
HookRoutines = ON;
ErrorHandler = ON;
ContextSwitchRoutine = ON;
InterruptMaskControl = OFF;
TaskIndexMethod = OFF;
PersistentNode = OFF;
TaskOwnStack = ON;
TaskBasePage = ON;
StackPool = ON;
SchedulerPolicy = MIXPREEMPT;
CounterSize = 16;
Alarms = ON;
AlarmList = ON;
Resources = ON;
FastResource = OFF;
Events = ON;
StateMessage = ON;
StateMsgDefaultValue = ON;
StateMsgTimeStamp = ON;
EventMessage = ON;
EventMsgTimeStamp = ON;
EventMsgOneToN = OFF;
ActivateOnMsg = ON; /* Message signalling mechanism */
AlarmOnMsg = ON;
SetEventOnMsg = ON;
```

```
[Scheduler]
DefineScheduler( 4, 5, 128, , 64 ) ;
[Interrupt management]
DefineInterrupts( 0x8, 0, 0, 64 );
[User's hook]
DefineHooks ( OSError, OSPreTask, OSPostTask);
[Tasks]
DefineTask ( TASKSND, BASIC|PREEMPT|ACTIVATE, 3, TaskSND );
DefineTask ( TASKRCV, PREEMPT| BASIC|OWNSTACK, 1,
TaskRCV,,, TaskStack, TASKSTACKSIZE );
DefineTask ( TASKPROD, PREEMPT| EXTENDED|ACTIVATE|POOLSTACK, 2,
TaskProd,,, POOL );
DefineTask ( TASKCONS, NONPREEMPT|BASIC|POOLSTACK, 4,
TaskCons,,, POOL );
DefineStackPool( POOL, 70, 2 );
[Resources]
DefineResource( MSGACCESS, 1);
[Counters]
DefineSystemTimer( SYSTEMTIMER, -1, 10, 1000000 );
DefineCounter( MSGCOUNTER, 6, 1 );
[Alarms]
DefineAlarm( MSGALARM, SYSTEMTIMER, TASKSND );
DefineAlarm( PRODALARM, SYSTEMTIMER, TASKPROD, TIMEVENT );
DefineAlarm( EVMSGALARM, MSGCOUNTER, TASKCONS );
[State Messages]
DefineStateMessage( MsgA, MSGATYPE, sizeof(MSGATYPE),
WithoutTimeStamp );
ActivateOnMessage( MsgA, TASKRCV );
DefineMessageAlarm( MsgA, MSGALARM, 100 );
[Event Messages]
DefineEventMessage( MsgB, MSGBTYPE, sizeof( int), 5, 1,
WithOverwriteCheck, WithTimeStamp );
```

Fallbeispiel:
OSEK/VDX

OSEK
Offene Systeme und deren Schnittstellen für die Elektronik im Kraft-fahrzeug

VDX
Vehicle Distributed eXecutive

What is OSEK/VDX?

OSEK/VDX is a joint project of the automotive industry. It aims at an industry standard for an open-ended architecture for distributed control units in vehicles.

A real-time operating system, software interfaces and functions for communication and network management tasks are thus jointly specified.

The term OSEK means:

”Offene Systeme und deren Schnittstellen für die Elektronik im Kraft-fahrzeug”
(Open systems and the corresponding interfaces for automotive electronics).

The term VDX means
„Vehicle Distributed eXecutive“.
The functionality of OSEK operating system was harmonised with VDX. For simplicity OSEK will be used instead of OSEK/VDX in the document.

Special support for automotive requirements

Specific requirements for an OSEK operating system arise in the application context of software development for automotive control units. Requirements such as reliability, real-time capability, and cost sensitivity are addressed by the following features:

- **The OSEK operating system is configured and scaled statically. The number of tasks, resources, and services required is statically specified by the user.**
- **The specification of the OSEK operating system supports implementations capable of running on ROM, i.e. the code could be executed from Read-Only-Memory.**
- **The OSEK operating system supports portability of application tasks.**
- **The specification of the OSEK operating system provides a predictable and documented behaviour to enable operating system implementations, which meet automotive real-time requirements.**
- **For each operating system implementation performance parameters must be known.**

Services

Task management

•Activation and termination of tasks
• Management of task states, task switch

Synchronisation

The operating system supports two means of synchronisation effective on tasks:

- Resource management
  Access control for inseparable operations to jointly used (logic) resources or devices, or for control of a program flow.
- Event control
  Event management for task synchronisation.

Inter-Task Kommunikation

Interrupt management

- Services for interrupt processing

Alarms

• Relative and absolute alarms
• Static (defined at compile-time) and dynamic (defined at run-time) alarms

Error treatment

• Mechanisms supporting the user in case of various errors

OSEK OS - Conformance Classes (CC)

•Generell zwei Gruppen von CC

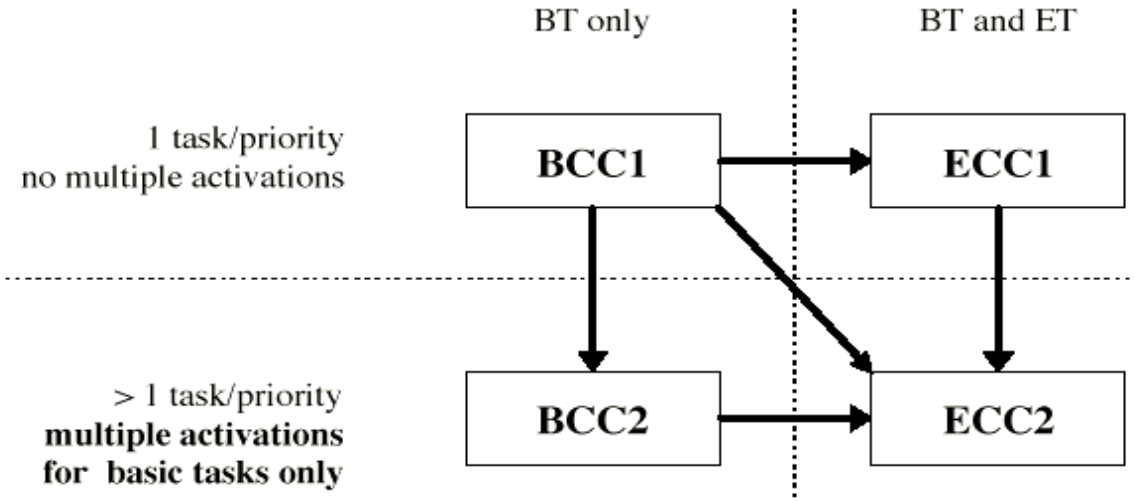
–Basic (BCC) erlaubt nur Basic Tasks

(Basic Tasks haben keinen *waiting*-Zustand, sie können unterbrechbar oder nicht unterbrechbar sein)

–Extended (ECC) erlaubt auch extended Tasks

(Extended Tasks können im Wait-Zustand auf Events warten)

•Aufwärts-kompatible CC's



Minimal parameters of implementations

	BCC1	BCC2	BCC3	ECC1	ECC2
Multiple activation of tasks	no		yes	BT: yes, ET: no	YES
Number of tasks which are not in the *suspended* state	≥8			≥ 16, any combination of BT/ET	
Number of tasks per priority	1	>1		BT: >1, ET: 1	>1
Number of events per task	-			BT: no ET: ≥ 8	
Number of priority classes	≥8				
Resources	only Scheduler		≥ 8 resources (including Scheduler)		
Alarm	≥ 1 single or cyclic alarm				
Messages	possible				

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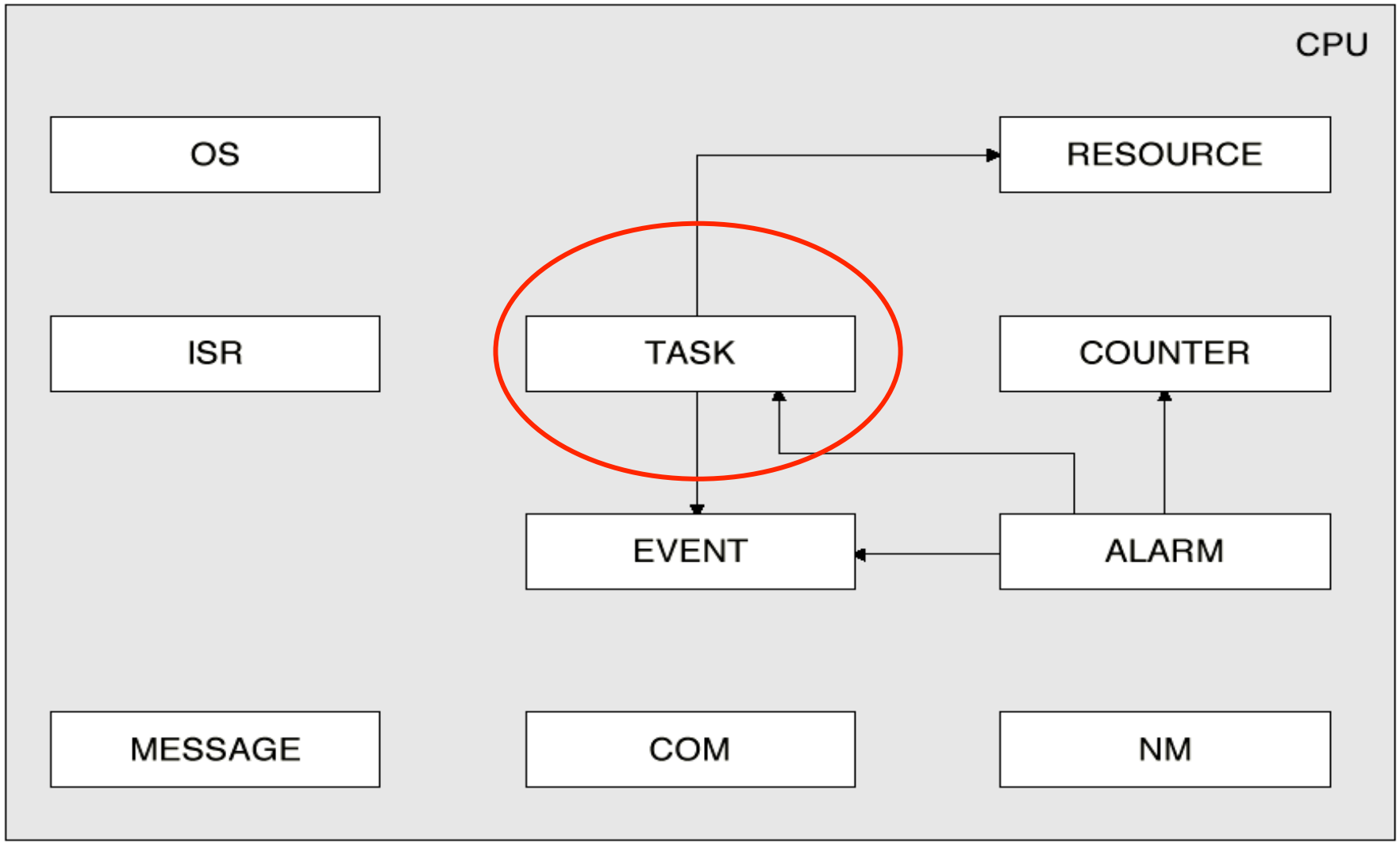
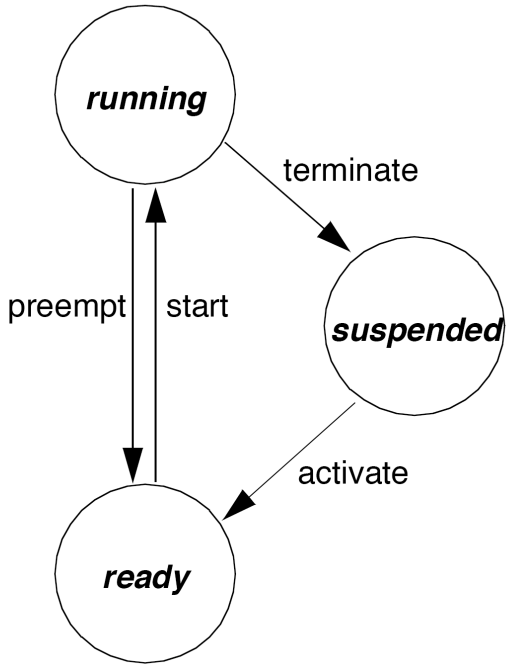
```

OSEK Komponenten



Basic Tasks



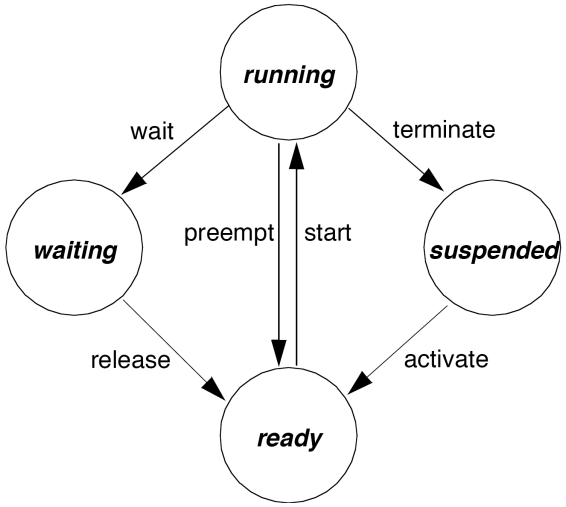
- **running**
  In the running state, the CPU is assigned to the task, so that its instructions can be executed. Only one task can be in this state at any point in time, while all the other states can be adopted simultaneously by several tasks.

- **ready**
  All functional prerequisites for a transition into the running state exist, and the task only waits for allocation of the processor. The scheduler decides which ready task is executed next.

- **suspended**
  In the suspended state the task is passive and can be activated.

Transition	Former state	New state	Description
activate	suspended	ready	A new task is entered into the *ready* list by a system service.
start	ready	running	A *ready* task selected by the scheduler is executed.
preempt	running	ready	The scheduler decides to start another task. The *running* task is put into the *ready* state.
terminate	running	suspended	The *running* task causes its transition into the *suspended* state by a system service.

Extended Tasks



- **running**

In the running state, the CPU is assigned to the task, so that its instructions can be executed. Only one task can be in this state at any point in time, while all the other states can be adopted simultaneously by several tasks.

- **ready**

All functional prerequisites for a transition into the running state exist, and the task only waits for allocation of the processor. The scheduler decides which ready task is executed next.

- **waiting**

A task cannot continue execution because it has to wait for at least one event (see chapter 6, Event mechanism).

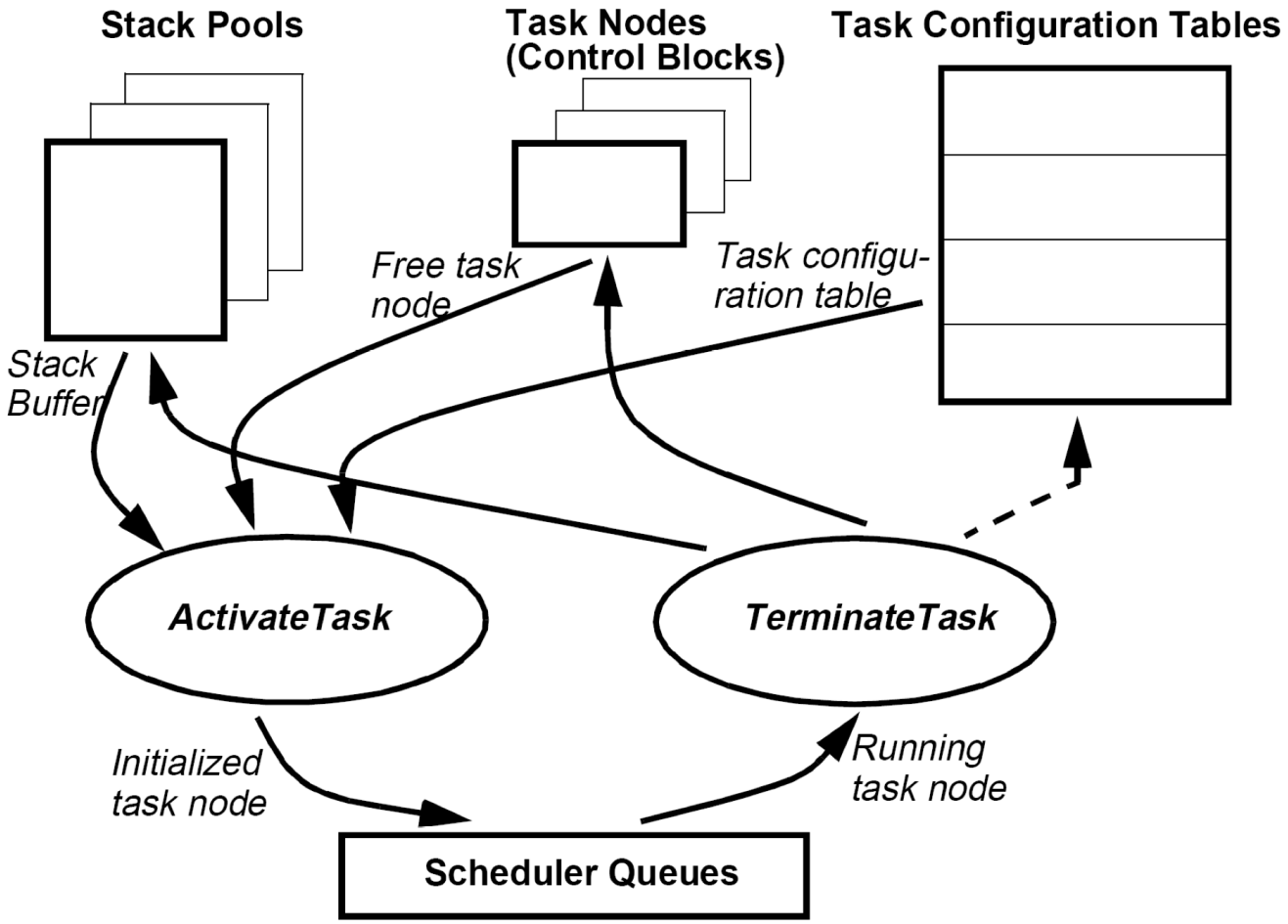
- **suspended**

In the suspended state the task is passive and can be activated.

Transition	Former state	New state	Description
activate	suspended	ready	A new task is entered into the *ready* list by a system service.
start	ready	running	A *ready* task selected by the scheduler is executed.
wait	running	waiting	To be able to continue operation, the *running* task requires an event. It causes its transition into the *waiting* state by using a system service.
release	waiting	ready	Events have occurred which a task has waited on.
preempt	running	ready	The scheduler decides to start another task. The *running* task is put into the *ready* state.
terminate	running	suspended	The *running* task causes its transition into the *suspended* state by a system service.

Task Properties

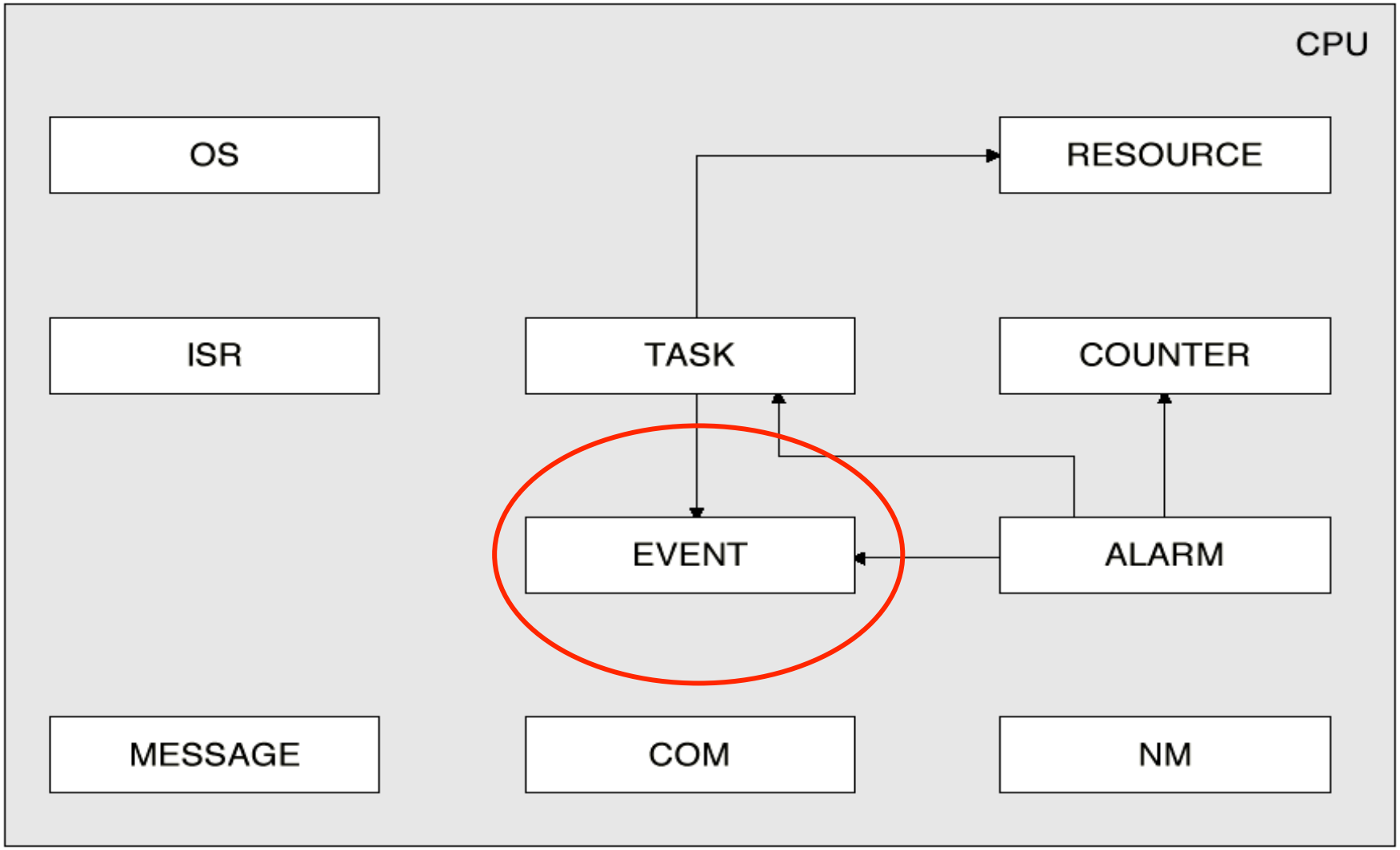
Property Name	Description
BASIC	Basic task
EXTENDED	Extended task
NONPREEMPT	Non-preemptive task
PREEMPT	Preemptive task
ACTIVATE	Activate the task at system start-up
ASSIGNNODE	A persistent task control block is assigned (linked with the task configuration tables)
POOLSTACK	A stack should be allocated to the task during task activation - dynamic stack allocation from the stack pool
OWNSTACK	A stack is explicitly assigned to the task (address of the top of the stack is included into the task configuration table)
NODESTACK	A task node stack is implicitly assigned to be used by the task (during the task activation)
ASSIGNSTK	A persistent stack from the stack pool (the pool identifier is included into the task configuration table)




```
DefineTask( <TaskName>, <TaskProperties>, <TaskPriority>,
<EntryPoint> [,<TaskBank>] [,<InterruptMask>]
[,<TaskStack>] [,<TaskStackSize] );
```

System services related to tasks:

Service Name	Description
ActivateTask	Activates the task, i.e. put it from the *suspended* into the *ready* state
TerminateTask	Terminates the task, i.e. put it from the *ready* into the *suspended* state
ChainTask	Terminates the task and activates a new one immediately
Schedule	Yields control to a higher-priority ready task (if any exists)
GetTaskId	Gets the identifier of the running task
GetTaskState	Gets the status of the specified task



OSEK Komponenten

The Event mechanism

- **is a means of synchronisation**

  in conjunction with the wait-state of an extended task

- **is only provided for extended tasks**

  Each extended task has a specified number of events

- **initiates state transitions of tasks to and from the waiting state.**

No. of events/task ≤ 8

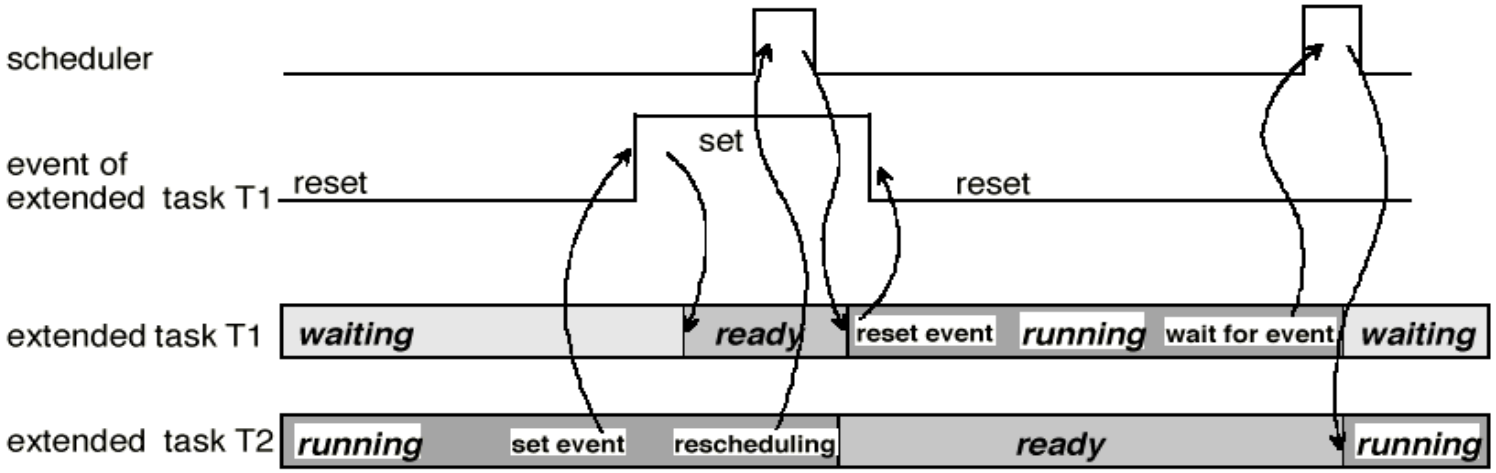
Each task has two event masks in its control block:
1. 8-Bit-Vector contains events the task is waiting for
2. 8-Bit-Vector contains events set for the task

System services related to Event Processing:

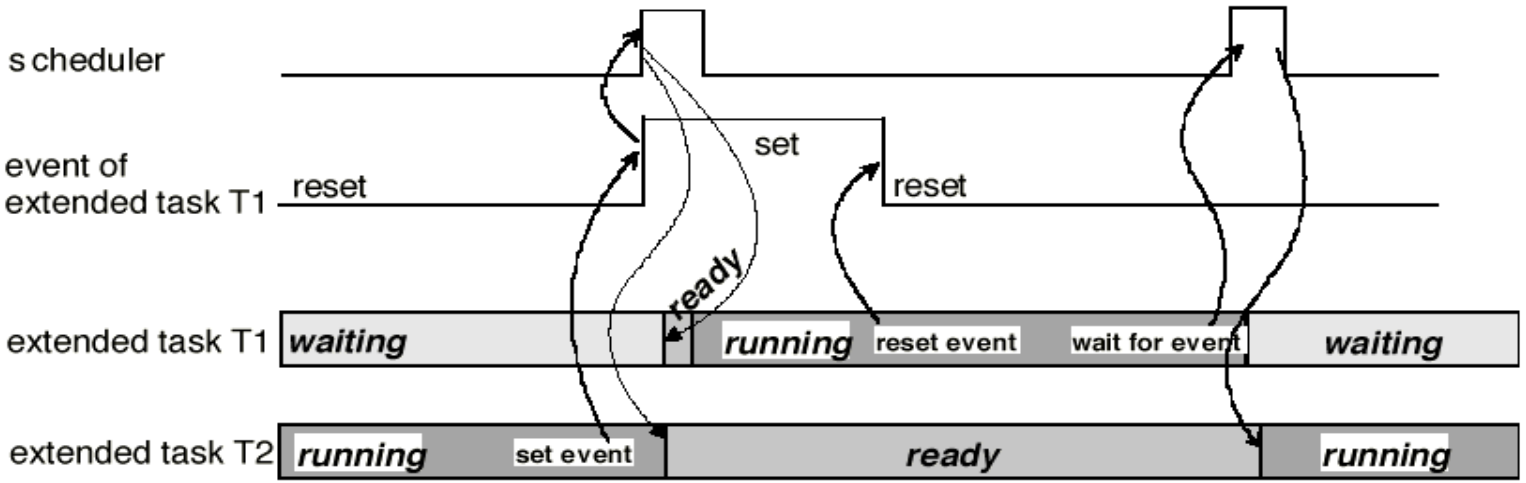
Service Name	Description
SetEvent	Sets events of the given task according to the event mask
ClearEvent	Clears events of the calling task according to the event mask
GetEvent	Gets the current event setting of the given task
WaitEvent	Transfers the calling task into the waiting state until specified events are set

```
Beispiele:
SetEventOnMessage( <MsgName>, <TaskId>, <EventMask> );
DefineAlarm( <AlarmID>, <CounterID>, <TaskID> [,<Event>]);
```

Synchronisation of non-preemtive tasks



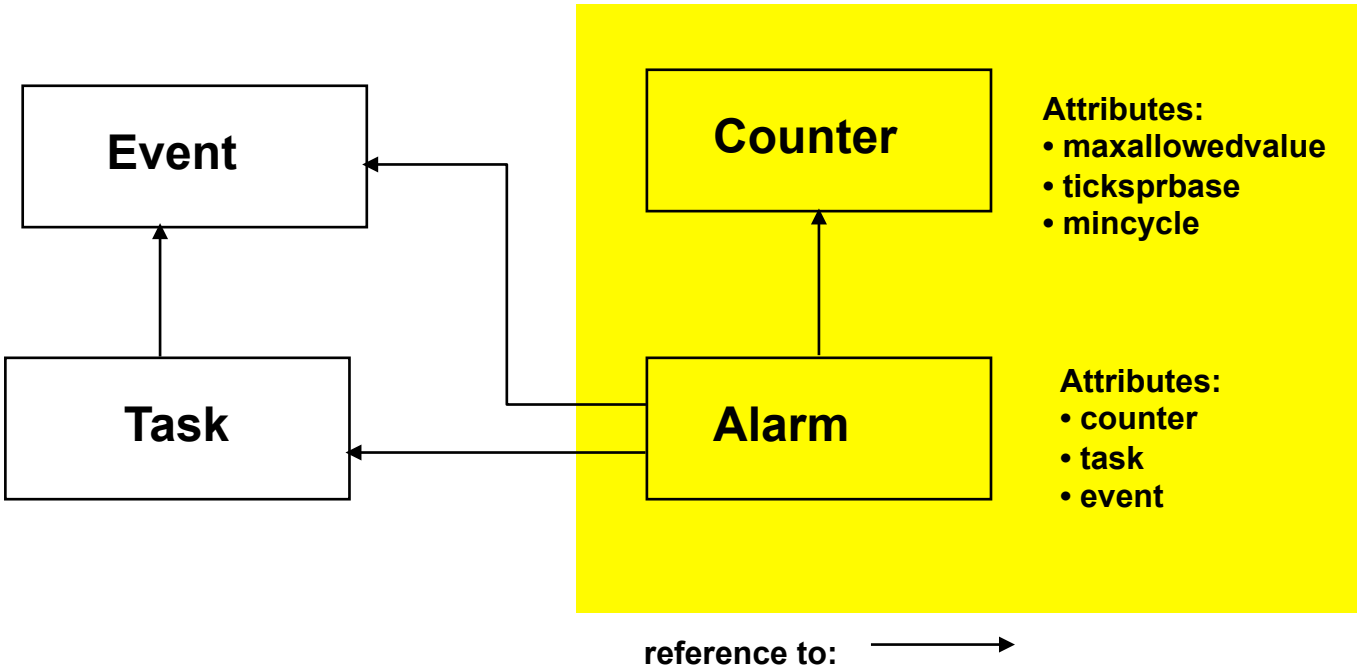
Synchronisation of fully-preemtive tasks



An Alarm may start a task or set an event.

An alarm is statically assigned at system generation time to:

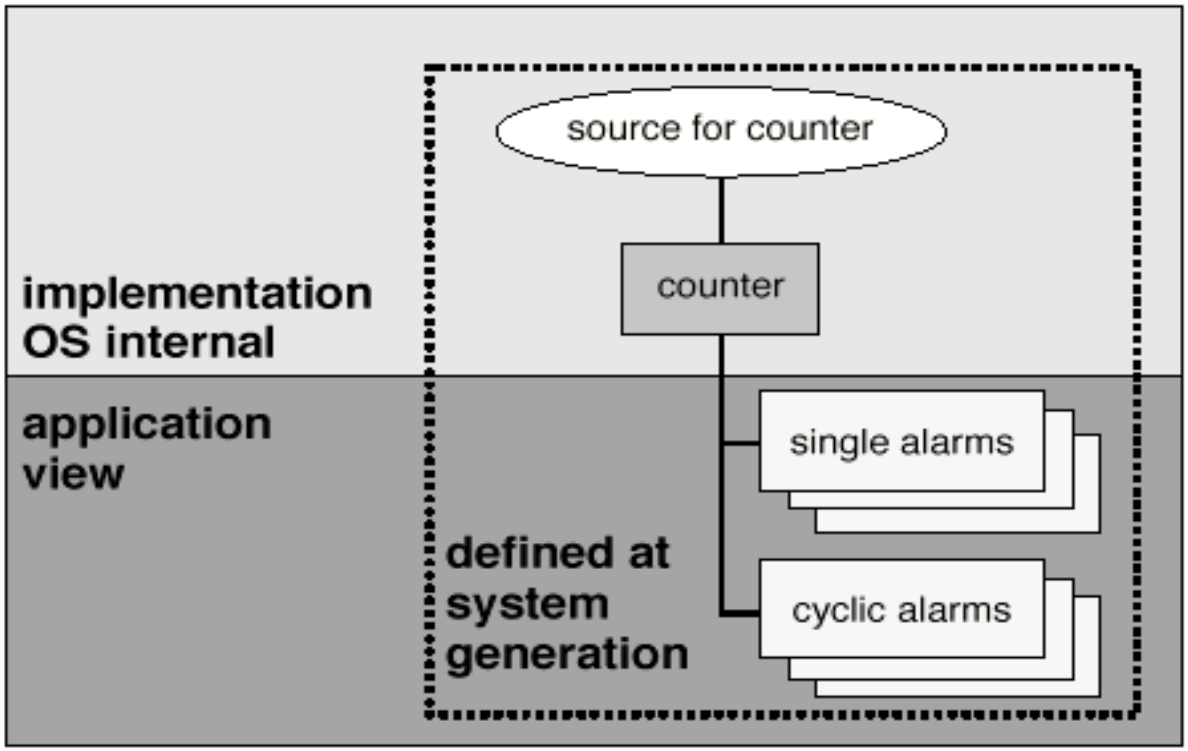
- **one counter**
- **one task**
- **a notation if the task is to be activated or the event is to be set**



Alarms

- **Processing of reccuring events**
  - **single alarm and cyclic alarm**
  - **relative (to a timer value) and absolute points in time**
  - **time (clock ticks) and event counting**

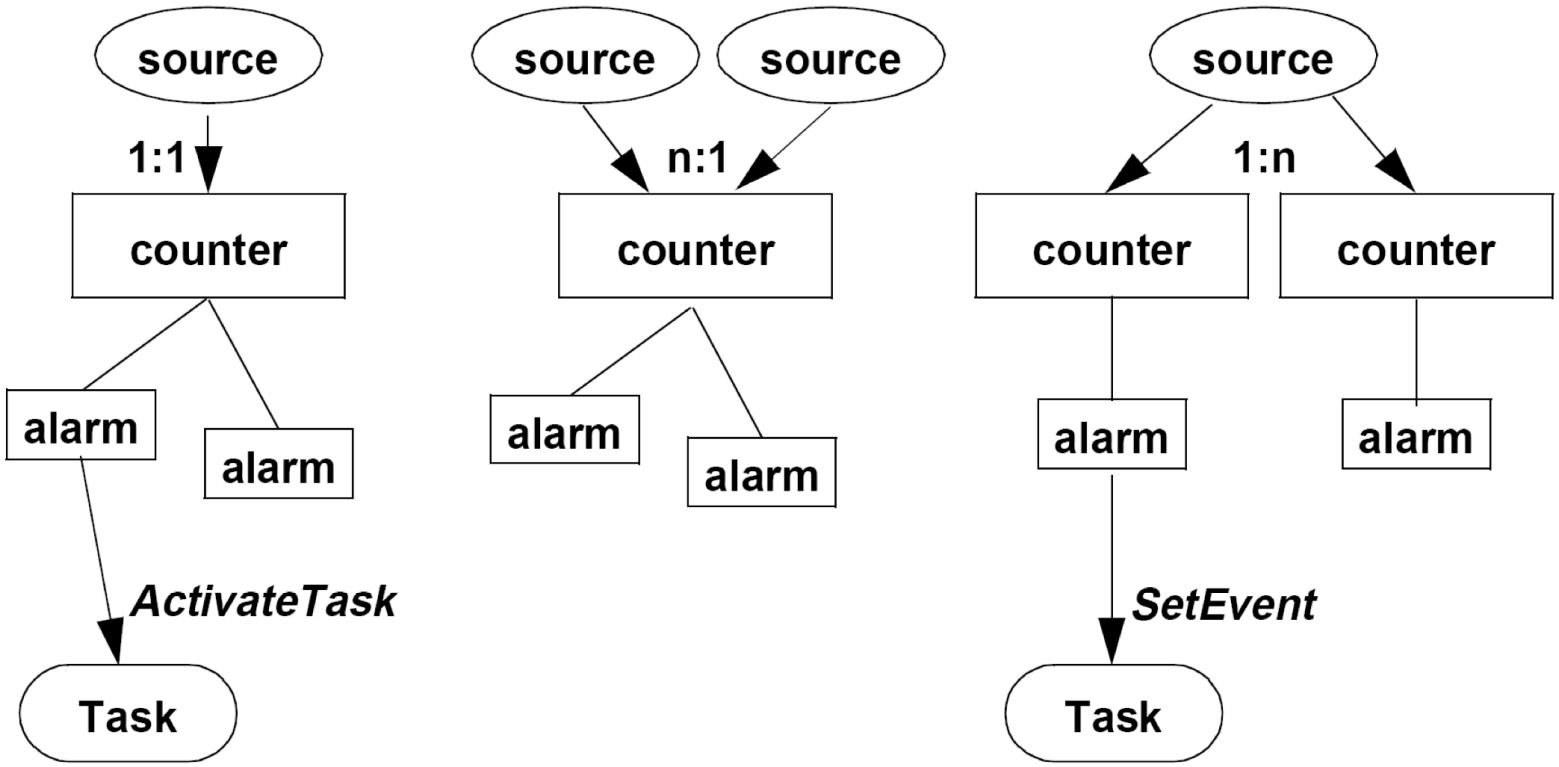
Layered model of alarm management



Counter and Alarm Management Run-time Services

Service Name	Description
InitCounter	Sets the initial value of the counter
CounterTrigger	Increments the counter value
GetCounterValue	Gets the counter current value
GetCounterInfo	Gets counter parameters
SetRelAlarm	Sets the alarm with a relative start value
SetAbsAlarm	Sets the alarm with an absolute start value
CancelAlarm	Cancels the alarm: the alarm is transferred into the STOP state
GetAlarm	Gets the time left before the alarm expires

Counters and Alarms



Counters and Alarms

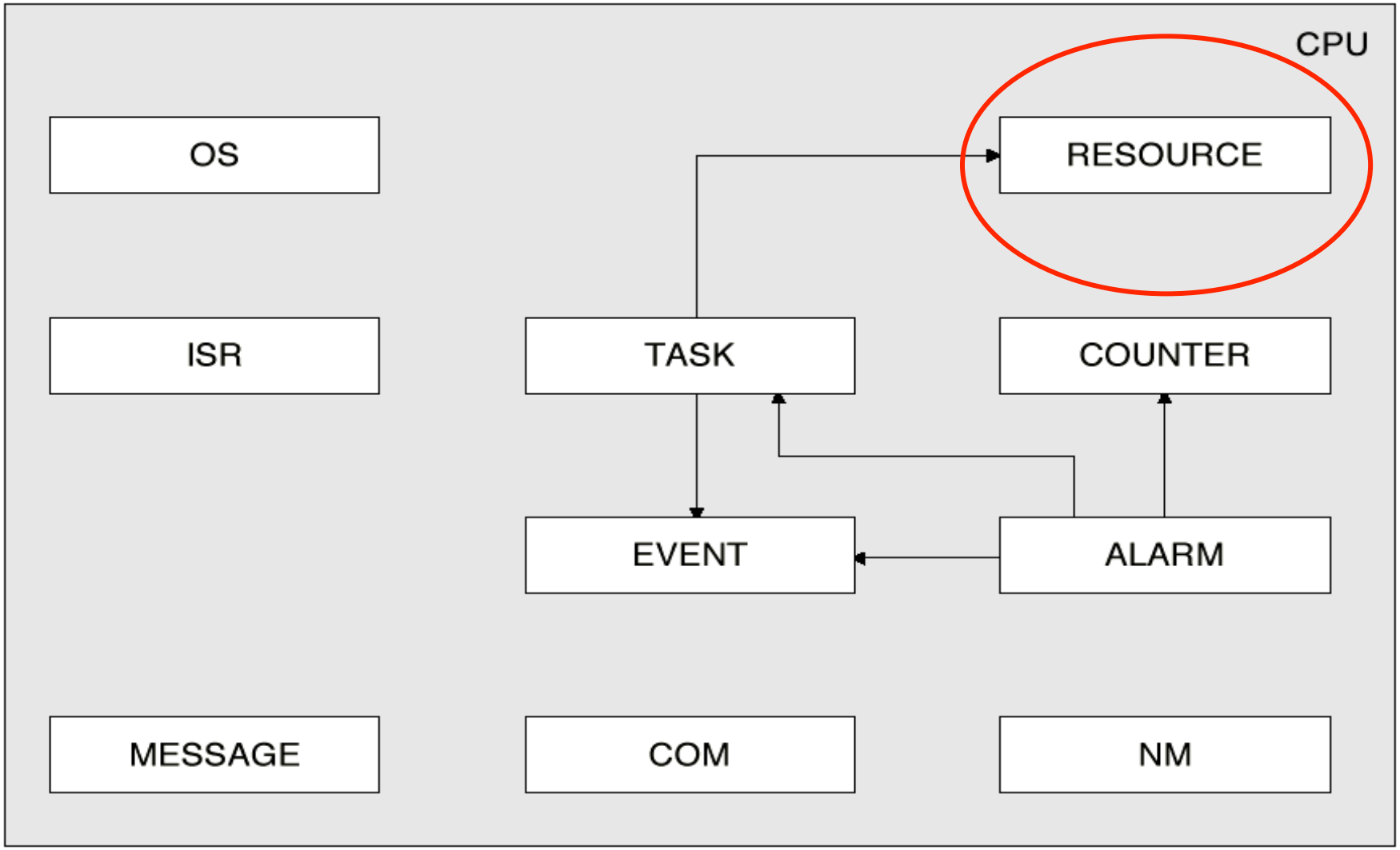
Konfigurationsdefinitionen:

```
DefineSystemTimer( <CounterID>, <maxallowedvalue>, <ticksperbase>,
<tickduration> [,<mincycle>][, <HardwareType> [, <HardwareParams>]] );

Beisp.: DefineSystemTimer( Watch, 24, 1, 5, PIT, 4, 128 );

DefineCounter( <CounterName>, <maxallowedvalue>, <ticksperbase>
[,<mincycle>] );

DefineAlarm( <AlarmID>, <CounterID>, <TaskID> [,<Event>]);
```



OSEK Komponenten

Resource Management

The resource management is used to coordinate concurrent accesses of several full preemptive tasks with different priorities to shared resources, e.g. management entities (scheduler), program sequences, memory or hardware areas.

Resource management ensures that:
- two tasks cannot occupy the same resource at the same time.
- priority inversion can not occur.
- deadlocks do not occur by use of these resources.
- access to resources never results in a waiting state.

The functionality of resource management is only required in the following cases:
- full-preemptive tasks
- non-preemptive scheduling, if resources are also to remain occupied beyond a scheduling point (in OSEK this only applies to the system service "*Schedule( )*")
- non-preemptive scheduling, if the user intends to have the application code executed under other scheduling policies, too

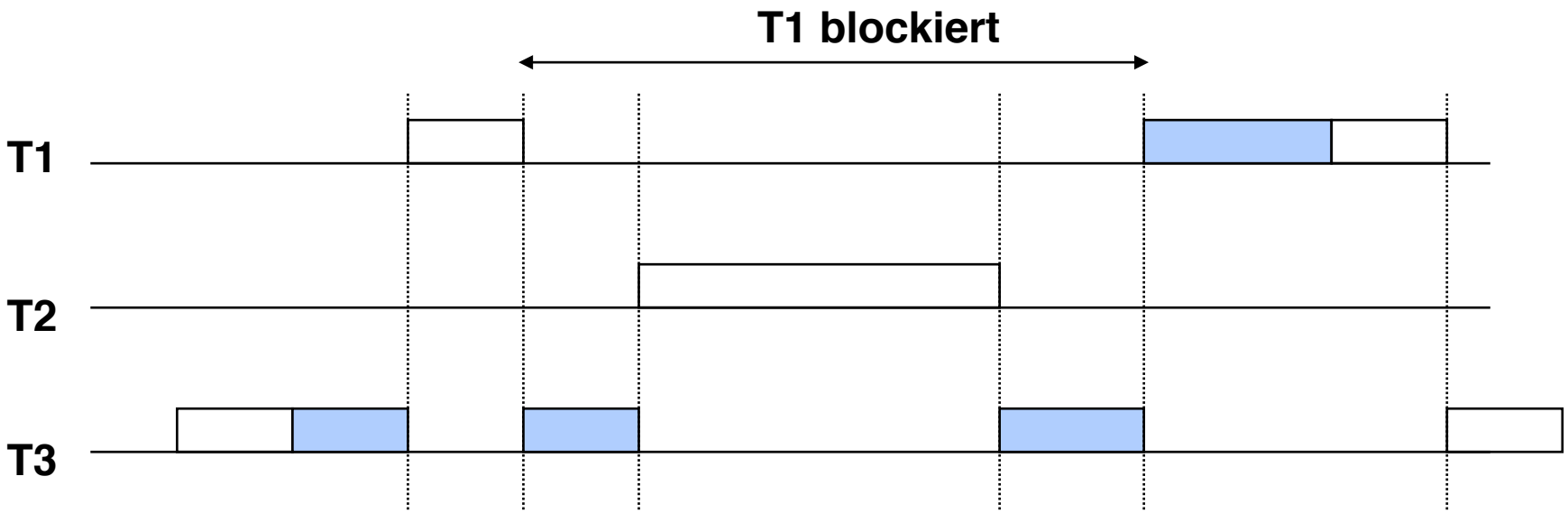
The resource management is mandatory for all conformance classes.

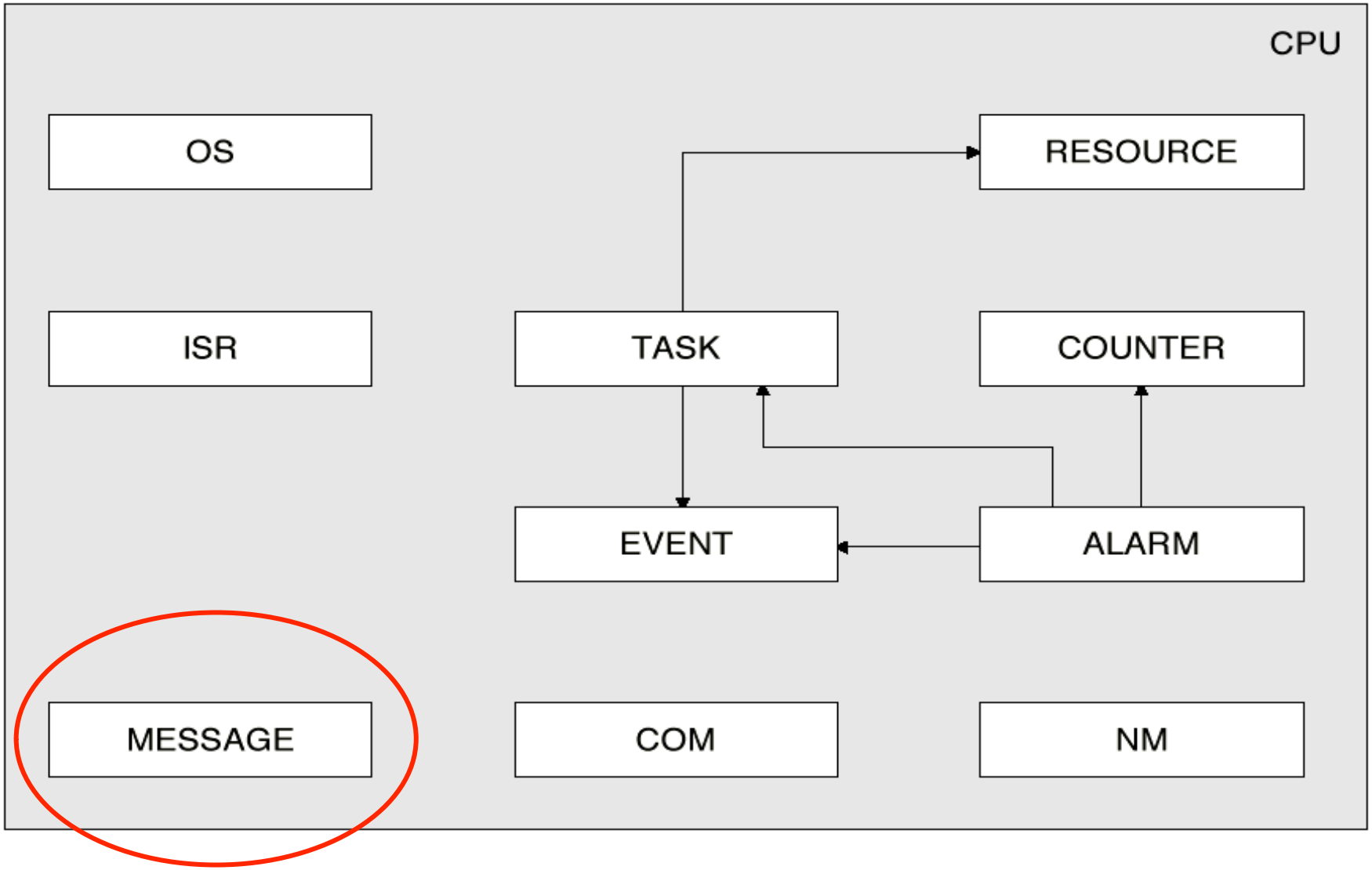
Das Problem: Prioritätsumkehrung (Priority Inversion)

Annahme: Prioritätsbasiertes, unterbrechbares Scheduling.
Standard für die meisten RT-Kerne

Problem: nicht vorhersagbare Blockierung einer Task mit hoher Priorität durch Tasks mit niedrigerer Priorität.

Prioritätsumkehrung !





OSEK Komponenten

Inter-Task Kommunikation

- Transparent local and network communication by messages.
- Messages are encapsulated in message objects which are handled by the OS.
- Message objects are defined at system configuration.
- A unique identifier (UID) is assigned to message objects.
- Tasks reference messages by this UID.
- OSEK distinguishes between queued (event) and unqueued (state) messages.
- Task activation and event signalling can be statically defined to be performed at message arrival for notification.

Inter-Task Kommunikation

OSEK unterscheidet:

- **State Messages und**
- **Event Messages**

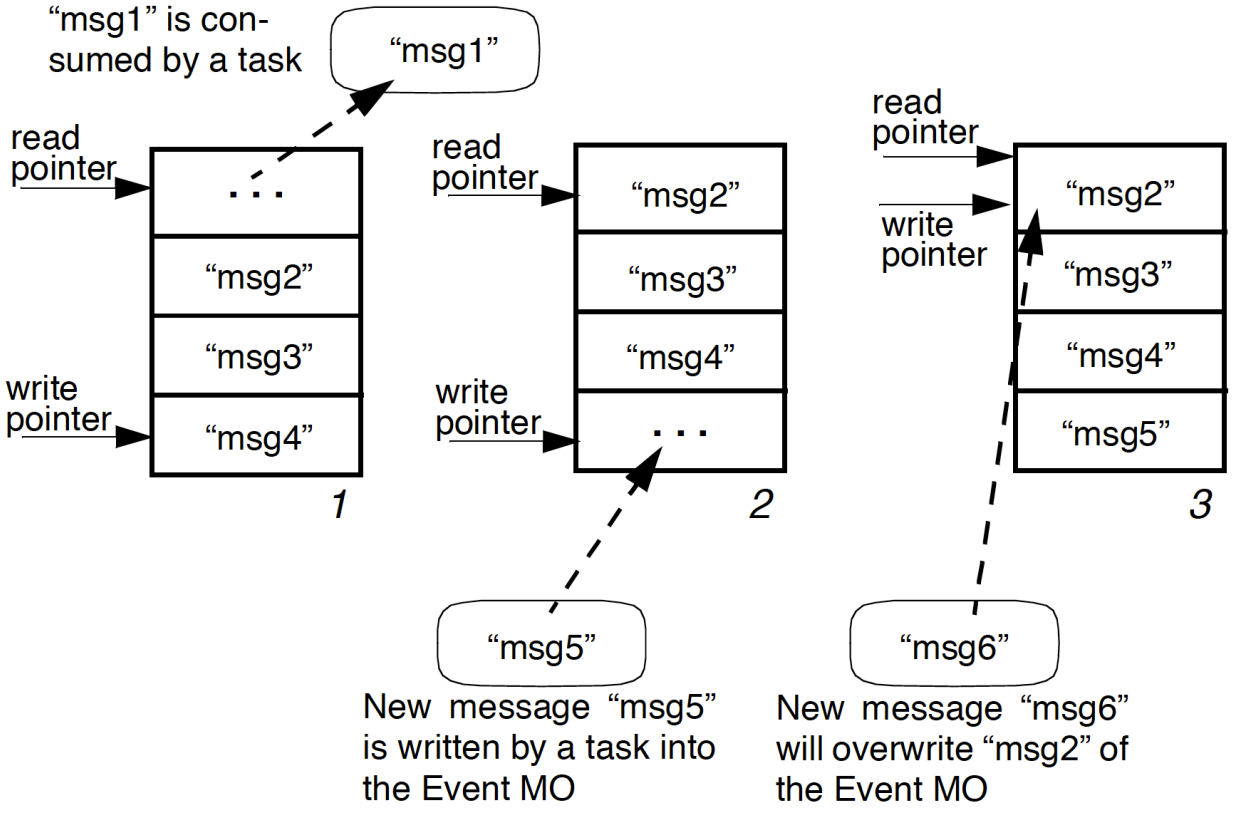
State Messages **repräsentieren den Wert einer Echtzeitvariablen. Die Empfangsoperation liest die Nachricht, ohne sie zu zerstören. Eine State Message enthält stets den aktuellen Wert der Variablen, d.h. ein alter Wert wird von einem neuen Wert beim „send“ überschrieben.**

Event Messages **werden gepuffert, d.h. ein neuer Wert wird in einen neuen Puffer geschrieben. Event Messages werden beim „receive“ konsumiert, d.h. zerstörend gelesen.**

Zusammenfassung: **Features of the Message Concept**

State Message	Event Message
No buffering	Buffering in a FIFO-queue
No consumption of message	Consumption of messages
Direct access possible in non-preemptive systems (no copies)	No direct access possible (always copies)
Static definition of task activation or event signalling	
Static definition of a message alarm	

Inter-Task Kommunikation - Pufferverwaltung



Inter-Task Kommunikation

- **OSEK unterstützt 1:1 und 1:N Kommunikation für State- und Event-messages.**
- **Optional kann statisch festgelegt werden, dass eine Task aktiviert oder notifiziert wird, wenn eine neue Nachricht ankommt.**
- **OSEK stellt keine spezielle Systemunterstüzung für das Warten auf Nachrichten zur Verfügung. Hierzu kann der allgemeine „Event-“ Mechanismus verwendet werden.**

Inter-Task Kommunikation – Nachrichten Definitionen

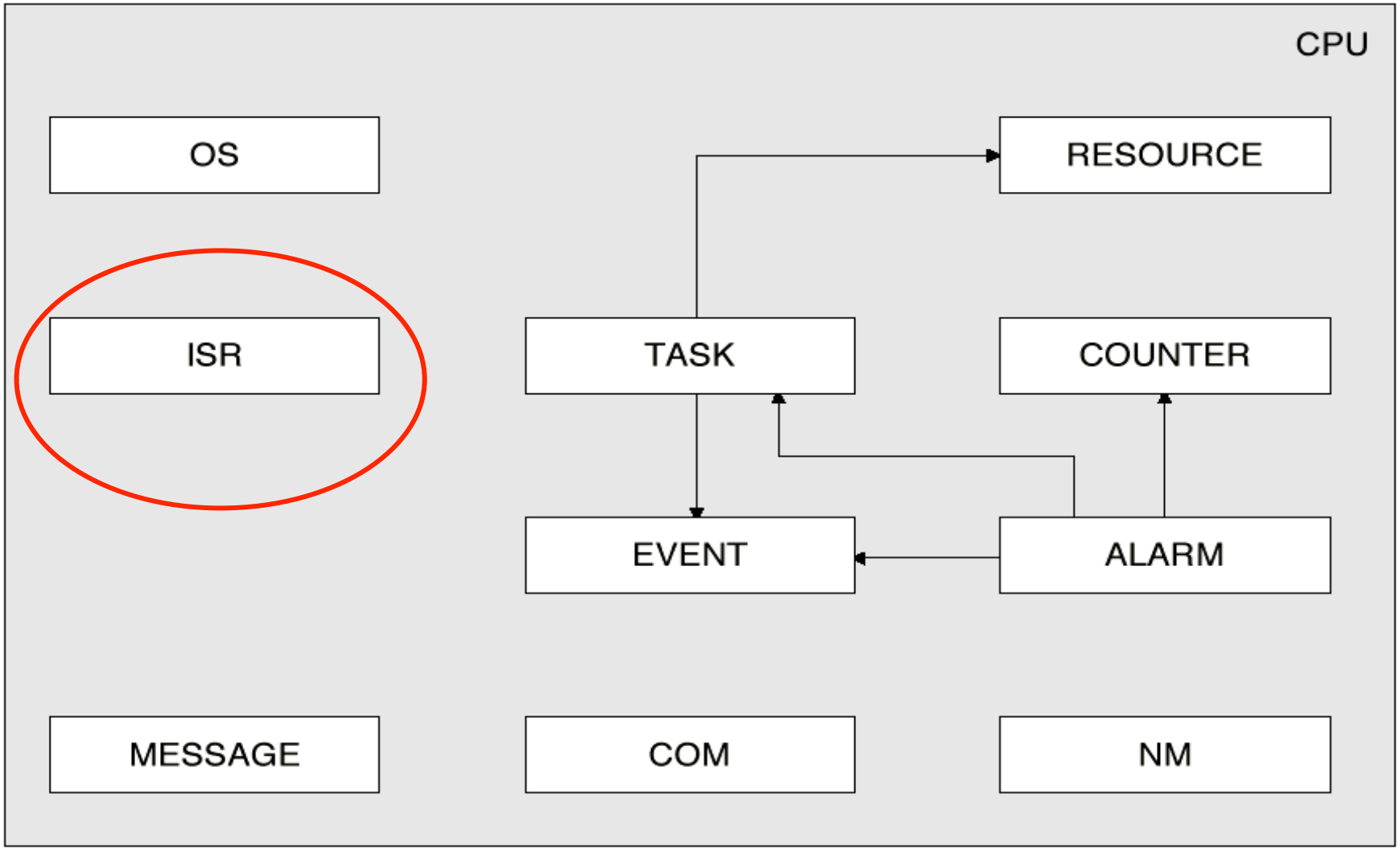
```
DefineStateMessage( <MsgName>, <Type>, <Size>, <TStamp>, [<DefaultValue>]);

DefineEventMessage( <MsgName>, <Type>, <Size>, <BufferSize>, <NRec>,
<OCheck>, <TStamp> );

ActivateOnMessage( <MsgName>, <TaskId> );

SetEventOnMessage( <MsgName>, <TaskId>, <EventMask> );

DefineMessageAlarm( <MsgName>, <AlarmId>, <TimeOut> [, <Start>] );
```



OSEK Komponenten

Interrupt Categories

ISR category 1
ISRs of this type does not use any operating system service. These ISR does not use OS services EnterISR and LeaveISR, consequently, ISR of these type are executed on the current stack. In this case, if ISR uses the stack space for its execution, the user is responsible for the appropriate stack size.

ISR category 2
In ISR category 2 the OSEK Operating System provides the ISR frame to execute more complicated user code. The ISR frame are instructions between OS services EnterISR and LeaveISR. Such ISRs must have the EnterISR call at their beginning to switch to the ISR stack and save the initial interrupt mask. At the end of the ISR the LeaveISR service must be executed to switch back to the task stack and restore the interrupt mask.

ISR category 3
Such ISR's are similar to those of category 2. But the location of the ISR-frame in the code segment is application dependent and user defined.

Interrupt Management

Service Name	Description
Interrupt Management Services	
EnterISR	Registers the switching to the interrupt level and switch context to the ISR stack
LeaveISR	Registers the leaving of the ISR level
EnableInterrupt	Enables interrupts in accordance with the given mask
DisableInterrupt	Disables interrupts in accordance with the given mask
GetInterruptMask	Returns the current state of interrupts
Services allowed for use in ISR	
ActivateTask	Activates the specified task (puts it into the *ready* state)
SendStateMessage	Sends a state message to the specified task
SendEventMessage	Sends an event message to the specified task
CounterTrigger	Increments a counter value

Error Handling, Tracing, Debugging

Hook Routines

The OSEK operating system provides system specific hook routines to allow user-defined actions within the OS internal processing.

Those hook routines are:

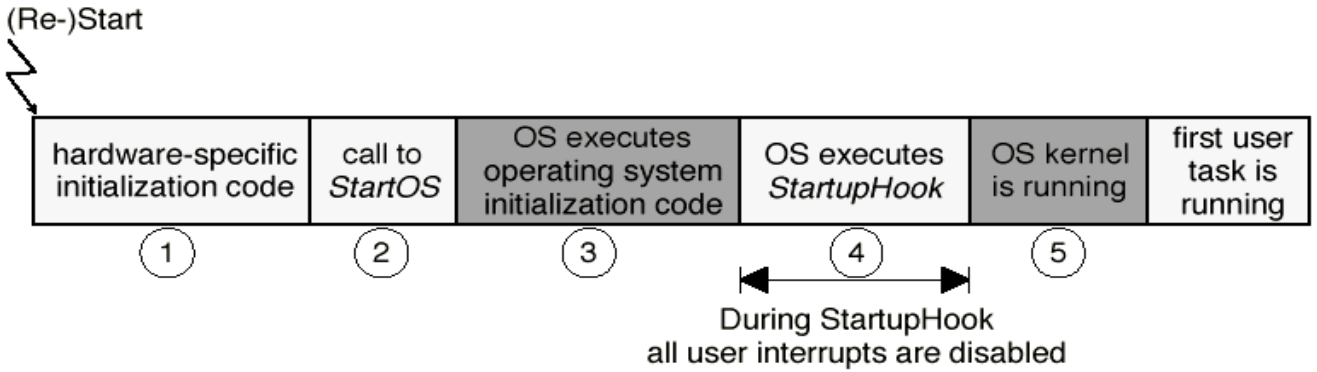
- **called by the operating system, in a special context depending on the implementation of the operating system**
- **higher priority than all tasks**
- **using an implementation dependent calling interface.**
- **part of the operating system but user defined**
- **implemented by the user**
- **standardised in interface per OSEK OS implementation, but not standardised in functionality (environment and behaviour of the hook routine itself), therefore usually hook routines are not portable**
- **are only allowed to use a subset of API functions**
- **optional (the implementation should omit calls to hook routines which do not exist)**

In the OSEK operating system hook routines may be used for:

- **system start-up. The corresponding hook routine (StartupHook) is called after the operating system start-up and before the scheduler is running.**
- **system shutdown. The corresponding hook routine (ShutdownHook) is called to a) request a shutdown by the application and b) force a system shutdown in case of a severe error.**
- **tracing or application dependent debugging purposes as well as user defined extensions of the context switch.**
- **error handling. The corresponding hook routine (ErrorHook) is called if a system call returns a value not equal to E_OK.**

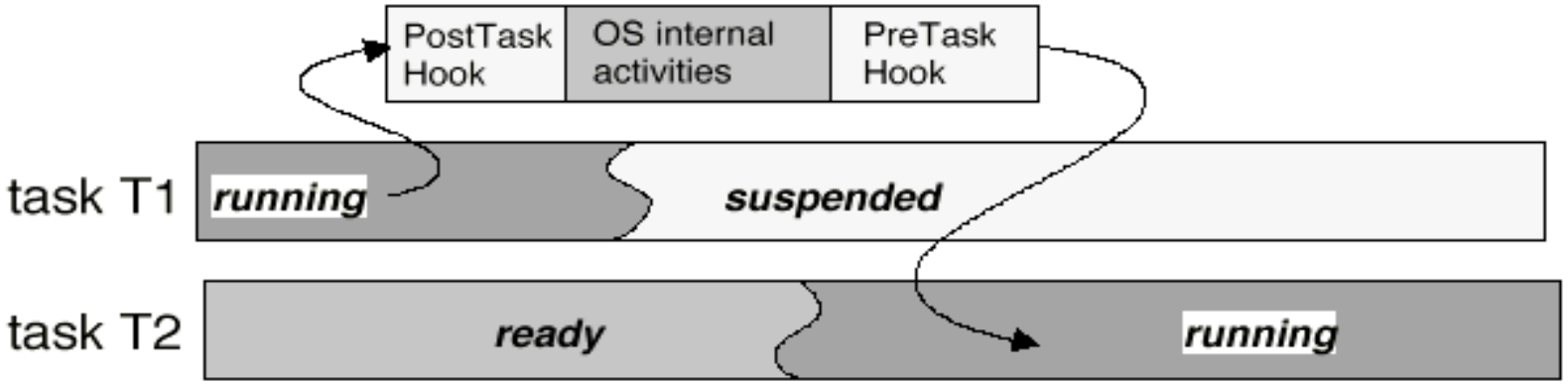
Each implementation of OSEK has to describe the interfaces and conventions for the hook routines, e.g. interfaces of system functions that may be called by the hook routines.

Example: StartupHook



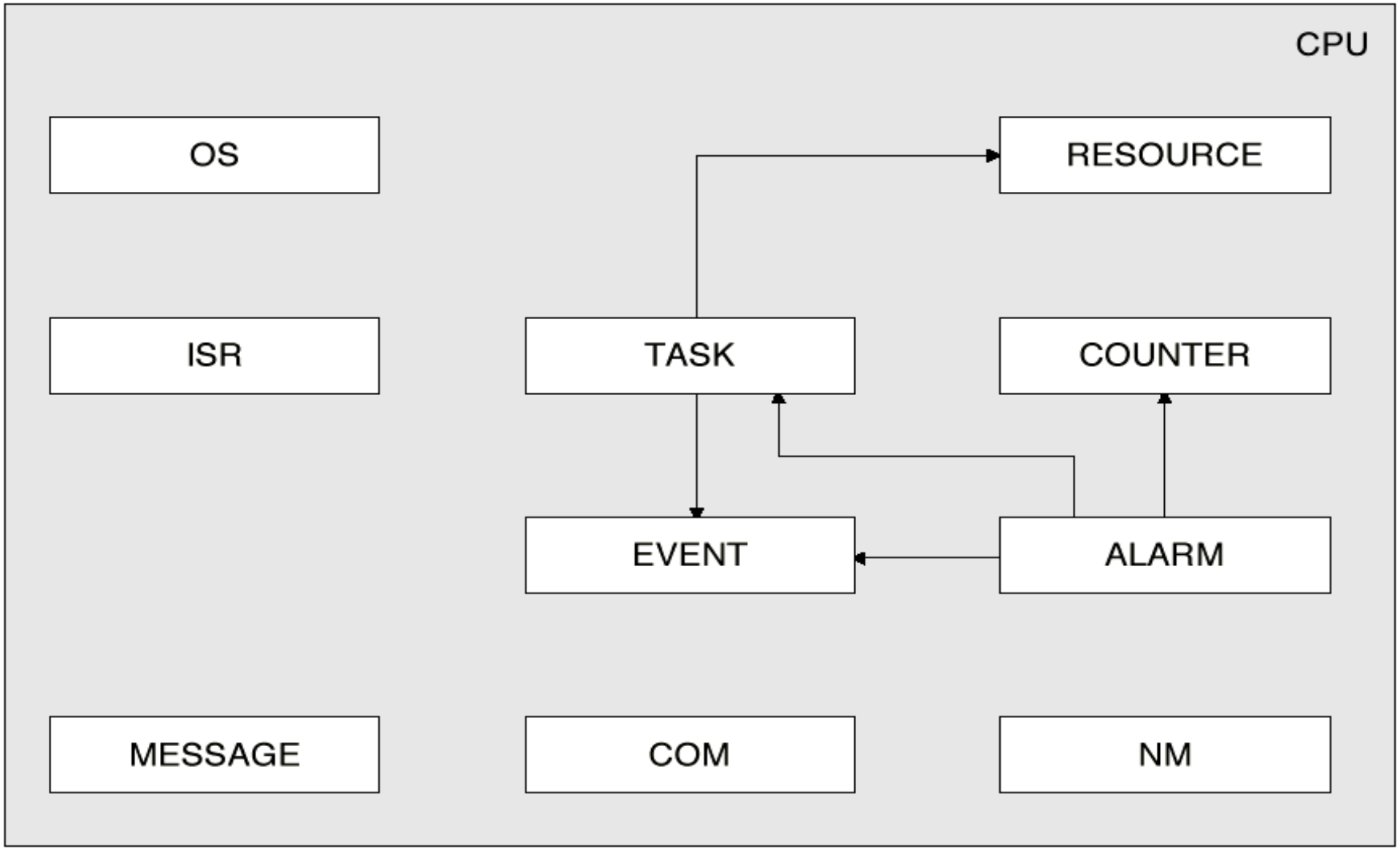
1) After a reset, the user is free to execute (non-portable) hardware specific code. The non-portable section ends by detection of the application mode.
2) Call StartOS with the application mode as a parameter. This call starts the operating system.
3) The operating system performs internal start-up functions and
4) calls the hook routine StartupHook, where the user may place initialisation procedures. During this hook routine, all user interrupts are disabled.
5) The operating system enables user interrupt according to the INITIAL_INTERRUPT_DESCRIPTOR, and starts the scheduler.

Example: Debugging with “OSPreTask” and “OSPostTask”



Two hook routines (PreTaskHook and PostTaskHook) are called on task context switches.

These two hook routines may be used for debugging or time measurement (including context switch time). Therefore PostTaskHook is called after leaving the context of the old task, PreTaskHook is called before entering the context of a new task.

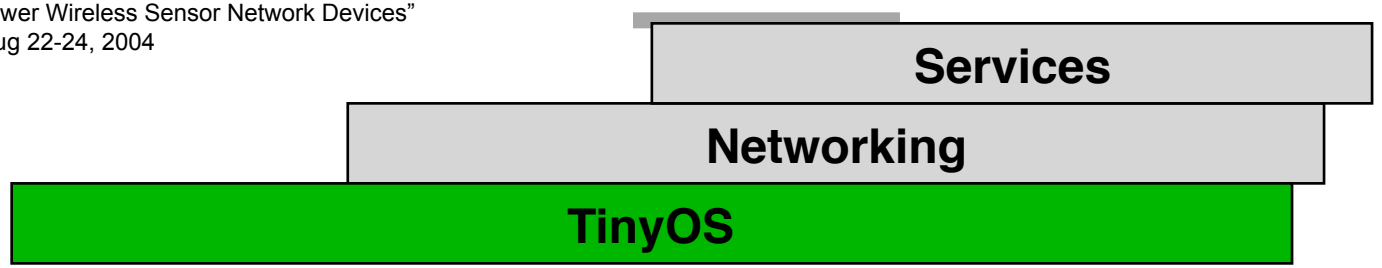


OSEK Komponenten

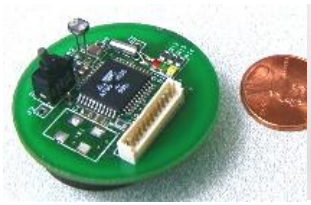
Operating Systems for networked resource constrained embedded systems

Open Experimental Platform

Joseph Polastre, Robert Szewczyk, Cory Sharp, David Culler, "The Mote Revolution: Low Power Wireless Sensor Network Devices"
Hot Chips 2004 : Aug 22-24, 2004



WeC 99
"Smart Rock"



Small microcontroller
- **8 kB code**
- **512 B data**

Simple, low-power radio
- **10 kbps ASK**

EEPROM (32 KB)

Simple sensors

Rene 11/00

Designed for experimentation

-sensor boards

-power boards

Dot 9/01

Demonstrate scale

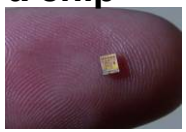
Mica 1/02

NEST open exp. Platform
128 kB code, 4 kB data
40kbps OOK/ASK radio
512 kB Flash

Telos 4/04
Robust
Low Power
250kbps
Easy to use

Mica2 12/02
38.4kbps radio
FSK

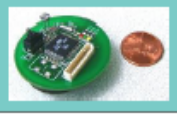
Spec 6/03
"Mote on a chip"



Commercial Off The Shelf Components (COTS)

Mote Evolution

Joseph Polastre, Robert Szewczyk, Cory Sharp, David Culler, "The Mote Revolution: Low Power Wireless Sensor Network Devices"
Hot Chips 2004 : Aug 22-24, 2004

Mote Type Year	*WeC* 1998	*René* 1999	*René 2* 2000	*Dot* 2000	*Mica* 2001	*Mica2Dot* 2002	*Mica 2* 2002	*Telos* 2004
								
Microcontroller								
Type	AT90LS8535		ATmega163		ATmega128			TI MSP430
Program memory (KB)	8		16		128			60
RAM (KB)	0.5		1		4			2
Active Power (mW)	15		15		8		33	3
Sleep Power (μW)	45		45		75		75	6
Wakeup Time (μs)	1000		36		180		180	6
Nonvolatile storage								
Chip	24LC256				AT45DB041B			ST M24M01S
Connection type	I^2C				SPI			I^2C
Size (KB)	32				512			128
Communication								
Radio	TR1000				TR1000	CC1000		CC2420
Data rate (kbps)	10				40	38.4		250
Modulation type	OOK				ASK	FSK		O-QPSK
Receive Power (mW)	9				12	29		38
Transmit Power at 0dBm (mW)	36				36	42		35
Power Consumption								
Minimum Operation (V)	2.7		2.7		2.7			1.8
Total Active Power (mW)	24				27	44	89	41
Programming and Sensor Interface								
Expansion	none	51-pin	51-pin	none	51-pin	19-pin	51-pin	10-pin
Communication	IEEE 1284 (programming) and RS232 (requires additional hardware)							USB
Integrated Sensors	no	no	no	yes	no	no	no	yes

TinyOS

Ein Betriebssystem für "sehr kleine" Systeme.
Aus der Forschung über Sensornetze in Berkeley entstanden.

Unterstützung von Nebenläufigkeit
→Strukturierung von Aktivitäten in unabhängige Tasks

Extreme Beschränkung der Ressourcen
→Typisch: RAM < 10k, Flash < 100k, Batterielebensdauer > 1Jahr,
Kommunikation mit geringer Bandbreite und sehr wenig Energie.

Adaptierung an Hardware-Änderungen
→Hardwareunabhängige Abstraktionen zur Programmierung von Anwendungen.

Robuste Software
→ Modularisierung, Komponentenorientierung

Literatur

D. Gay, M. Welsh, P. Lewis, E. Brewer, R.v. Behren, D. Culler, "The nesC Language: A HolisticApproach to Networked Embedded Systems", in Proceedings of Programming Language Design and Implementation (PLDI, 2003 (available from http://nesc.sourceforge.net)

P. Lewis, S. Madden, D. Gay, J. Polastre, R. Szewczyk, A. Woll, E. Brewer, D. Culler, "The Emergence of Networking Abstractions and Techniques in TinyOS", in Proceedings of 1st conference on Symposium on Networked Systems Design and Implementation –vol.1, San Francisco, CA, USA, 2004

Hill, J., Szewczyk, R., Woo, A., Hollar, S., Culler, D., and Pister, K. 2000. System architecture directions for networked sensors. SIGPLAN Not. 35, 11 (Nov. 2000), 93-104

William Stallings "Operating Systems, Internals and Design Principles, 6. Edition, Pearson Education, 2009

A. Dunkels, O. Schmidt, T. Voigt, "Using Protothreads for Sensor Node Programming", in Proceedings of the REALWSN 2005 Workshop on RealWorld Wireless Sensor Networks

E.A. Lee, Y. Zhao "Reinventing Real Time", in F.Kordon, J. Sztipanovits (Eds.): Monterey Workshop 2006, LNCS 4322, pp. 1-25, Springer-Verlag Berlin heidelberg, 2007

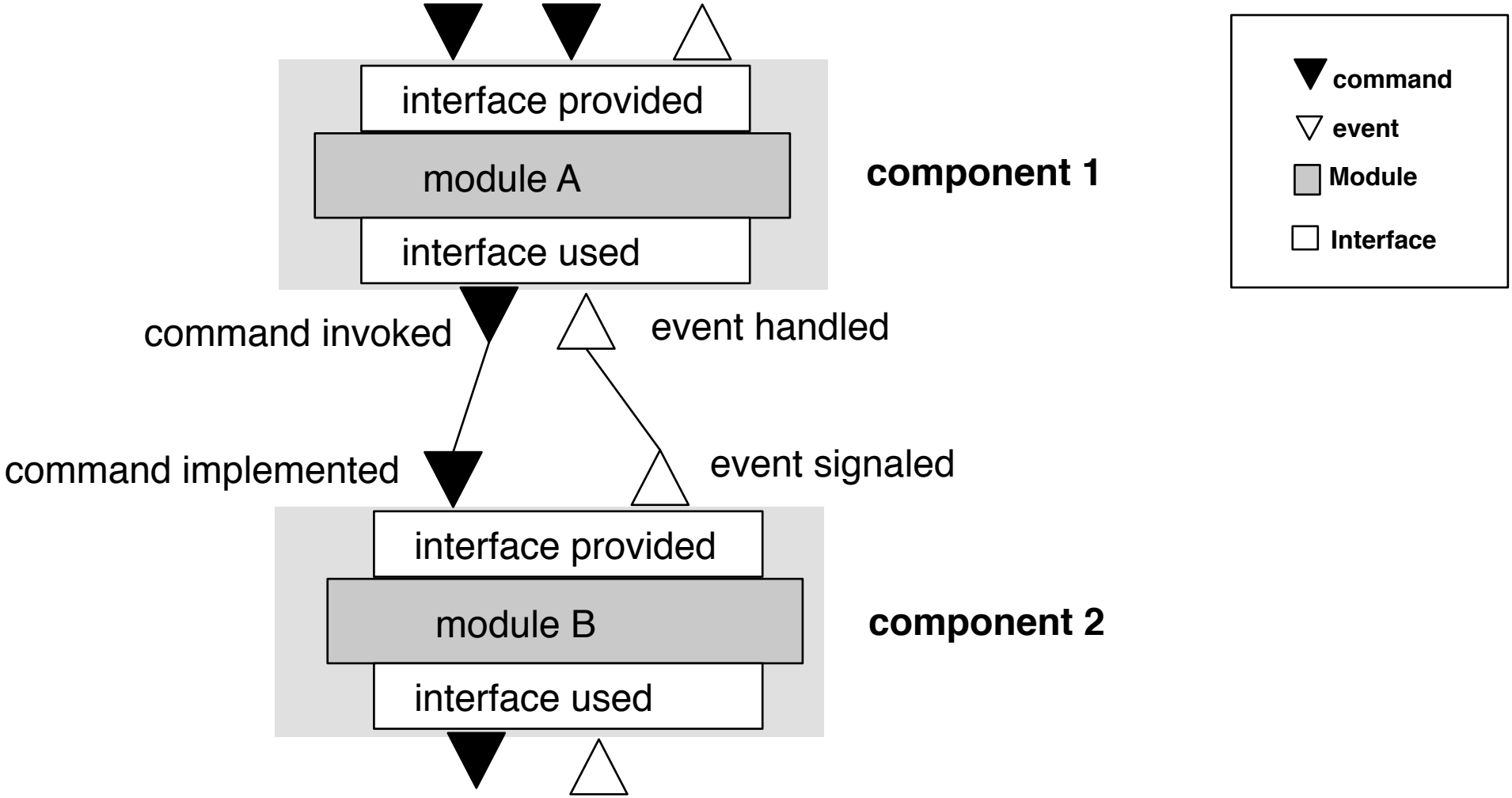
TinyOS Abstraktionen

Interagierende Komponenten

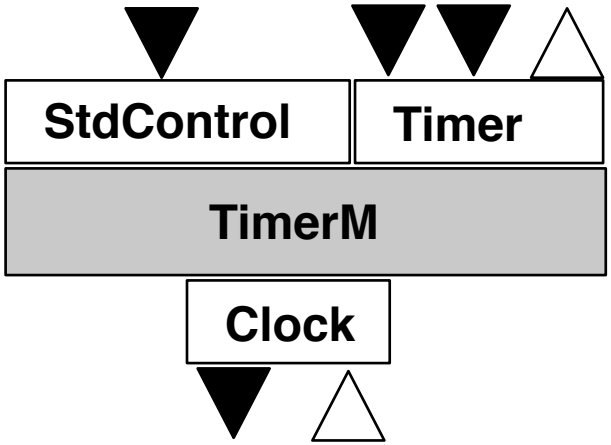
Aktivität:	Struktur:	Zustand:
Events Commands Tasks Handlers	Components Modules Configurations	frame (static memory) Resources (T2)

Ausführungsmodell: Zustandsmaschinen
Ausführungskomponente: (FIFO-) Scheduler

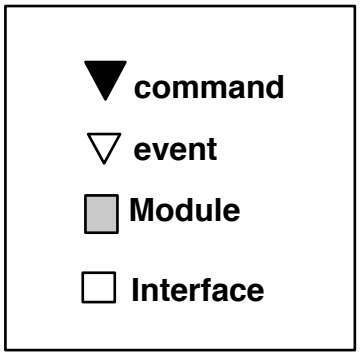
TinyOS Komponenten



TinyOS Module




```
Module TimerM {
  provides {
            interface StdControl
            interface Timer;
  }
use interface Clock as Clock;
} . . .
```

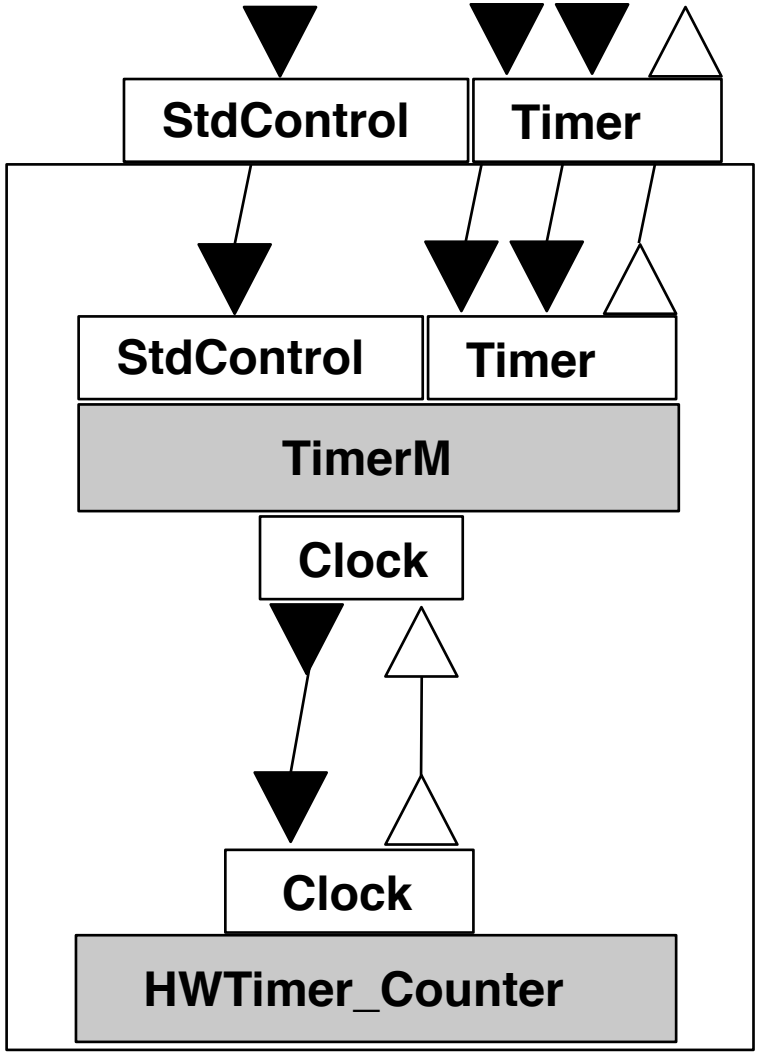



```
interface StdControl {
    command result_t init ();
    command result_t start();
    command result_t stop();
}

interface Timer {
    command result_t start(char type, uint32_t, interval);
    command result_t stop();
    event result_t fired();
}
```

```
interface Clock {
    command result_t setRate(char interval, char scale);
    event result_t fire();
}
```

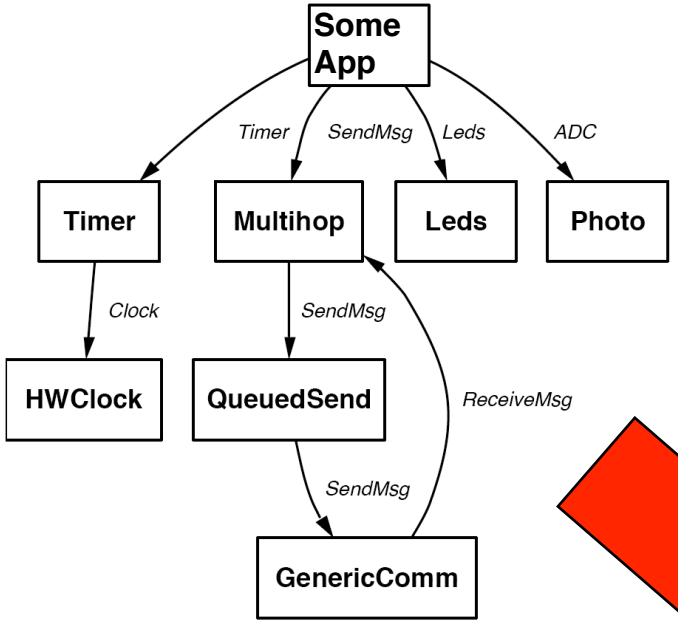
TinyOS Configuration

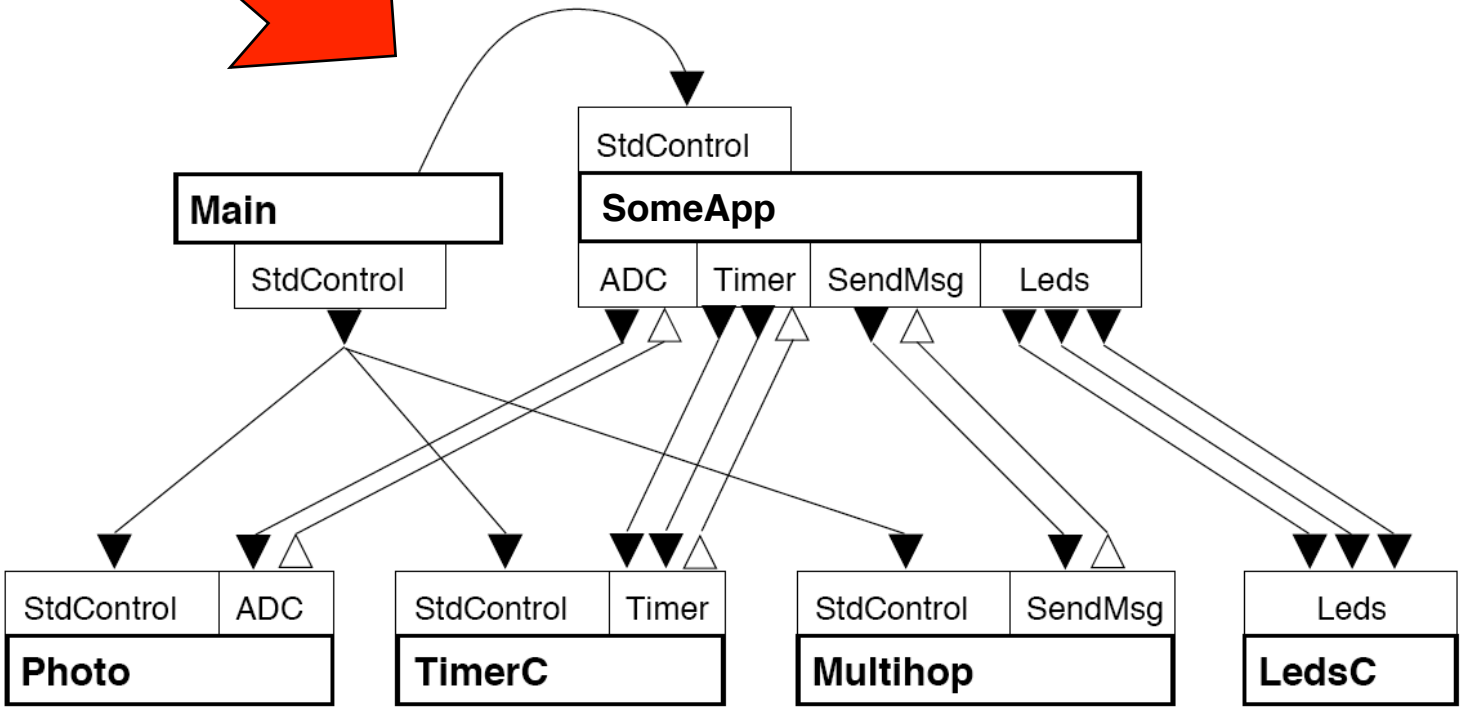



```
configuration TimerC {
   provides {
       interface StdControl;
      interface Timer;
   }
}


implementation {
   components TimerM, HWTimer_Counter;
   StdControl = TimerM.StdControl;
   Timer = TimerM.Timer;
   TimerM.Clk → HWTimer_Counter.Clock
}
```

Beispielanwendung: "SomeApp"





Interface:

is **bi-directional**
contains:

commands
events

split phase operations

Component definitions:

```
interface StdControl {
   command result_t init();
}

interface Timer {
   command result_t start(char type, uint32_t interval);
   command result_t stop();
   event result_t fired();
}

interface Clock {
   command result_t setRate(char interval, char scale);
   event result_t fire();
}

interface Send {
   command result_t send(TOS_Msg *msg, uint16_t length);
   event result_t sendDone(TOS_Msg *msg, result_t success);
}

interface ADC {
   command result_t getData();
   event result_t dataReady(uint16_t data);
}
```

split phase operations

application example

-commands are non-blocking

-effect may be signalled by event

```
module SomeAppM {
   provides interface StdControl;
   uses interface ADC;
   uses interface Timer;
   uses interface Send;
}
implementation {
   uint16_t sensorReading;

   command result_t StdControl.init() {
      return call Timer.start(TIMER_REPEAT, 1000);
   }
event result_t Timer.fired() {
   call ADC.getData();
   return SUCCESS;
   }
event result_t ADC.dataReady(uint16_t data) {
   sensorReading = data;
   ... send message with data in it ...
   return SUCCESS;
   }
...
}
```

split phase operations

Blocking

```
if (send() == SUCCESS) {
  sendCount++;
}
```

Split-Phase

```
// start phase
send();
```

```
//completion phase
void sendDone(error_t err) {
  if (err == SUCCESS) {
    sendCount++;
  }
}
```

Send Interfacs has:
- ***send*** command
- ***sendDone*** event

```
interface Send {
        command result_t send(TOS_Msg *msg, uint16_t length);
        event result_t sendDone(TOS_Msg *msg, result_t success);
```

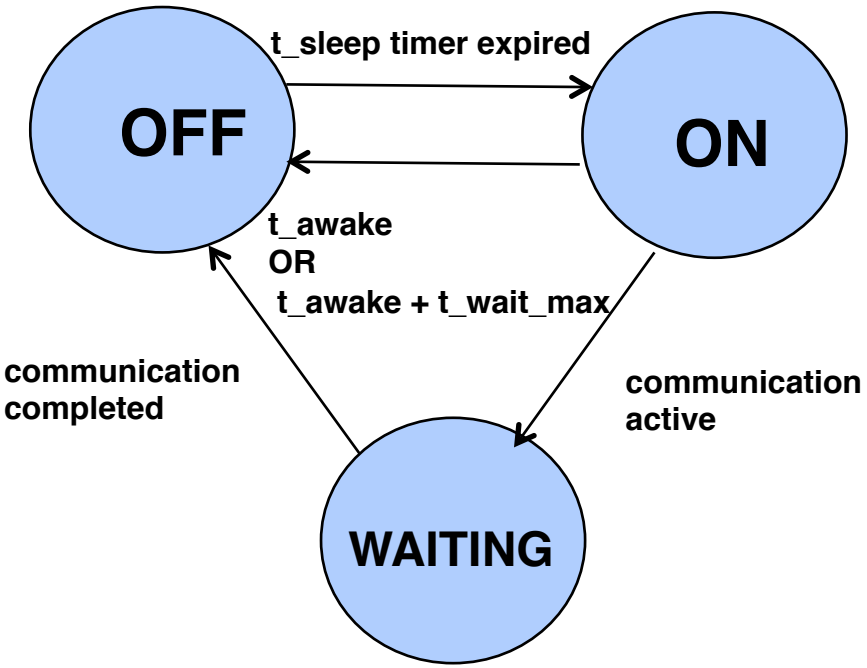
TinyOS Concurrency Model

Tasks: represent deferred execution of code. Tasks run to completion and do not preemt each other.

Event Handlers: are executed on events including asynchronous interrupts. Event Handlers run to completion but may preemt a task and can be preemted by another Event Handler. Event Handlers may post a task.

Consequences:
- Tasks cannot block and do not (busy) wait.
- Only a single stack needed.
- (nested) preemtion of Event Handlers may cause inconsistencies of shared resources.

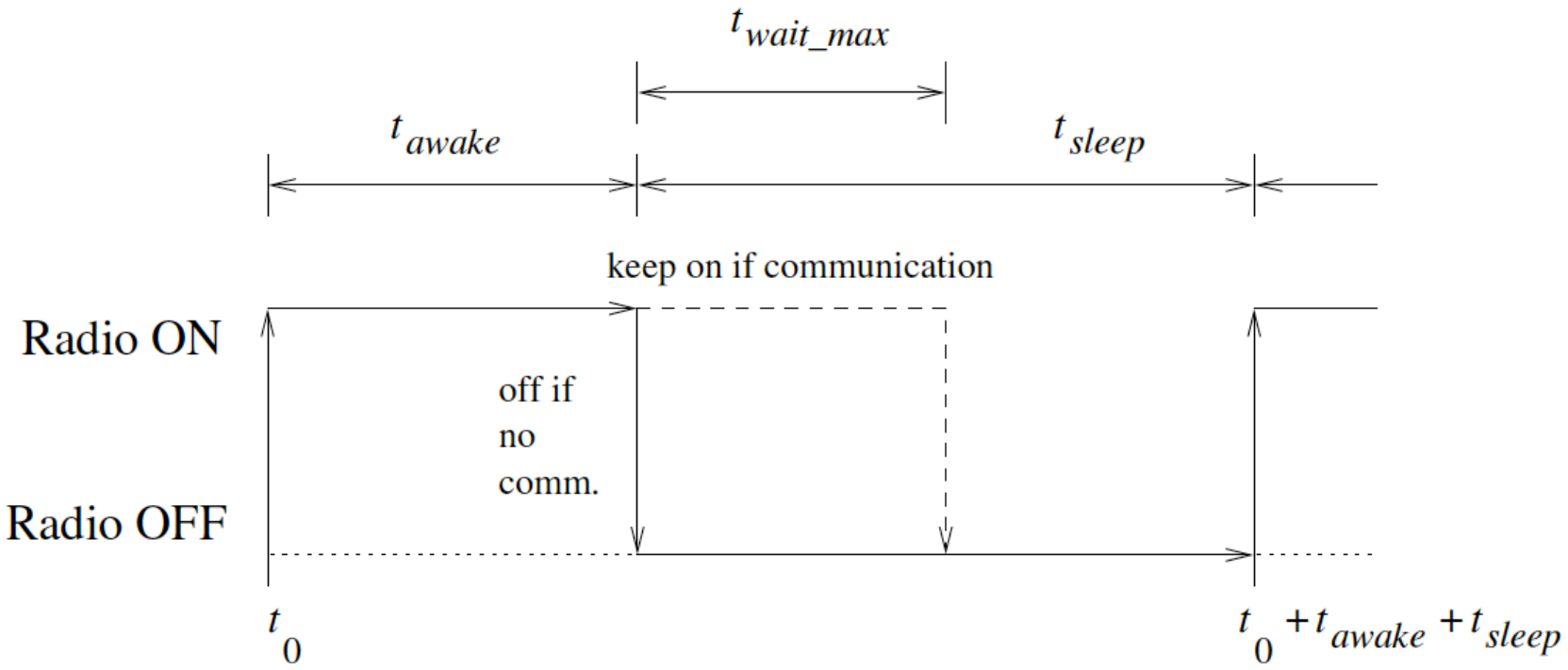
State Machine Modell



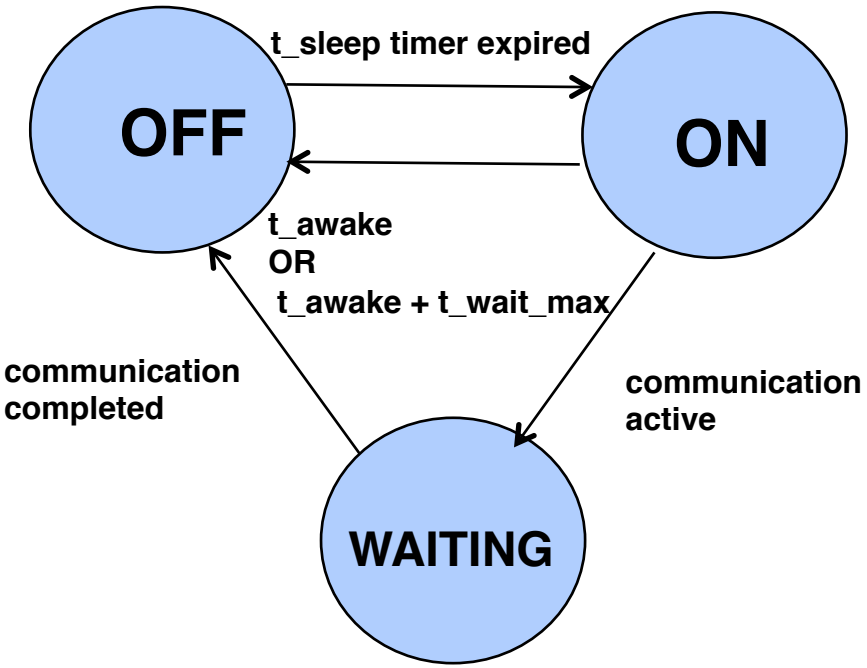
1. Turn radio ON
2. Wait until $t = t_0 + t_{awake}$
   (some time for the radio to turn on)
3. Turn radio OFF, but only if all communication has completed
4. If communication has not completed, WAIT until it has completed or $t = t_0 + t_{awake} + t_{wait\_max}$
5. Turn radio OFF. Wait until $t = t_0 + t_{awake} + t_{sleep}$
6. Repeat from Step 1

Adam Dunkels, Oliver Schmidt, Thiemo Voigt, and Muneeb Ali. Protothreads: Simplifying event-driven programming of memory-constrained embedded systems. In Proceedings of the Fourth ACM Conference on Embedded Networked Sensor Systems (SenSys 2006), Boulder, Colorado, USA, November 2006

Timing of Application



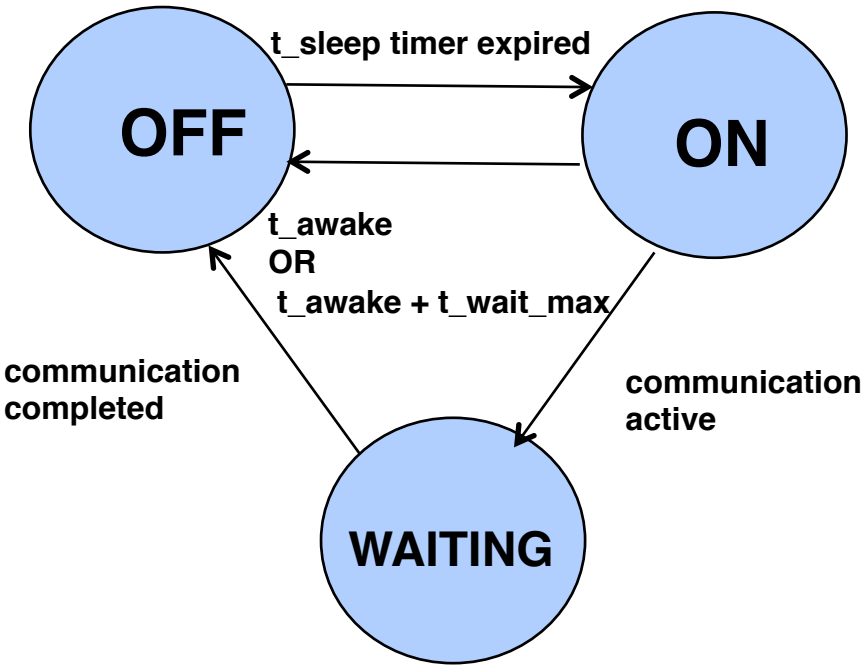
State Machine Modell




```
state: {ON, WAITING, OFF}
radio_wake_eventhandler:
    if (state = ON)
        if (expired(timer))
            timer← t_sleep
    if (not communication_complete())
        state←WAITING
        wait_timer ← t_wait_max
    else
        radio_off()
        state ← OFF
    elseif (state = WAITING)
        if (communication_complete() or
            expired(wait_timer))
        state ← OFF
        radio_off()
     elseif (state = OFF)
        if (expired(timer))
            radio_on()
            state ← ON
            timer ← t_awake
```

Adam Dunkels, Oliver Schmidt, Thiemo Voigt, and Muneeb Ali. Protothreads: Simplifying event-driven programming of memory-constrained embedded systems. In Proceedings of the Fourth ACM Conference on Embedded Networked Sensor Systems (SenSys 2006), Boulder, Colorado, USA, November 2006

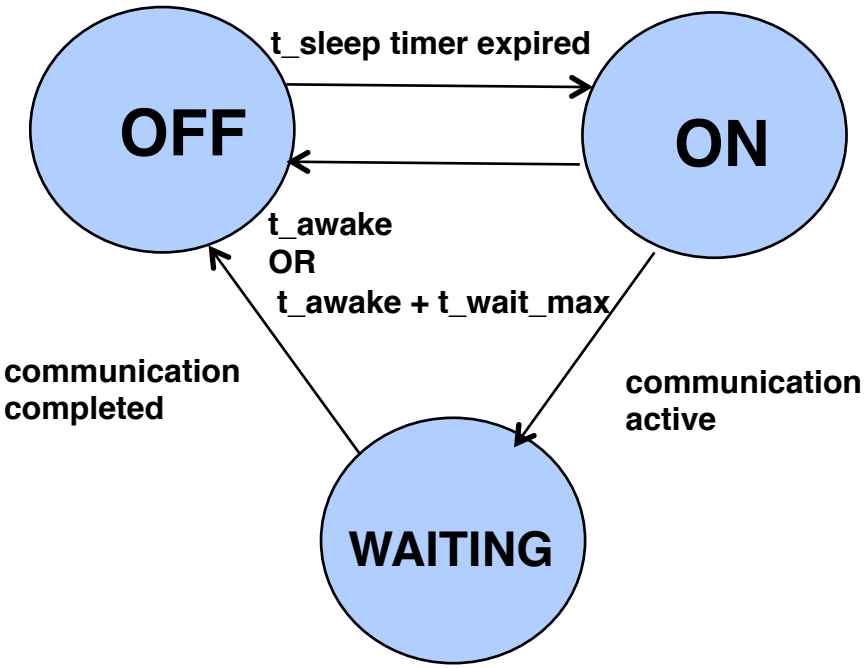
Eine Alternative: Protothreads (Contiki)




```
radio_wake_prototheread:
        PT_BEGIN
        while (true)
                radio_on()
                timer← t_awake
PT_WAIT_UNTIL(expired(timer))
timer  ← t_sleep
if (not communication_complete())
wait timer  t_wait_max
PT_WAIT_UNTIL(communication complete() or
expired(wait timer))
radio off()
PT_WAIT_UNTIL(expired(timer))
```

Adam Dunkels, Oliver Schmidt, Thiemo Voigt, and Muneeb Ali. Protothreads: Simplifying event-driven programming of memory-constrained embedded systems. In Proceedings of the Fourth ACM Conference on Embedded Networked Sensor Systems (SenSys 2006), Boulder, Colorado, USA, November 2006

State Machine Modell



A. Dunkels, O. Schmidt, T. Voigt, "Using Protothreads for Sensor Node Programming", in Proceedings of the REALWSN 2005 Workshop on RealWorld Wireless Sensor Networks

```
enum {
      ON,
      WAITING,
      OFF
} state;

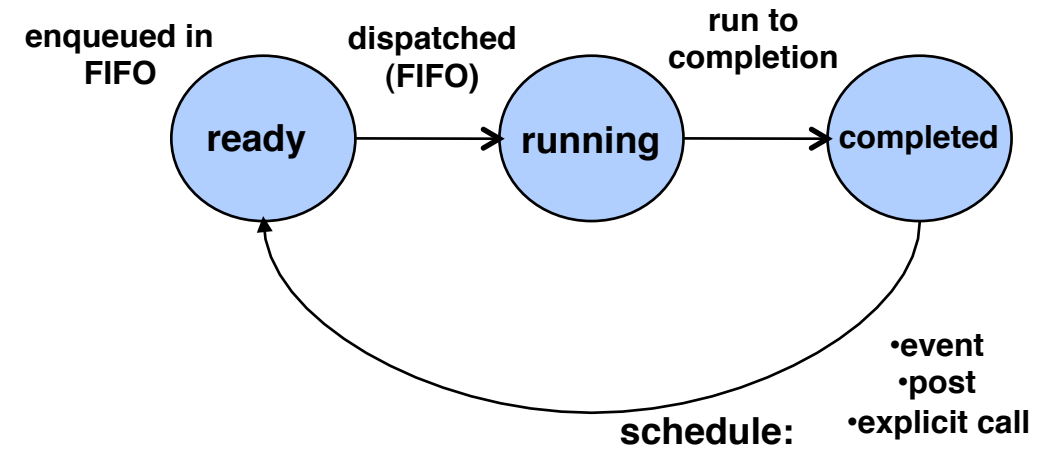
void radio_wake_eventhandler() {
      switch(state) {

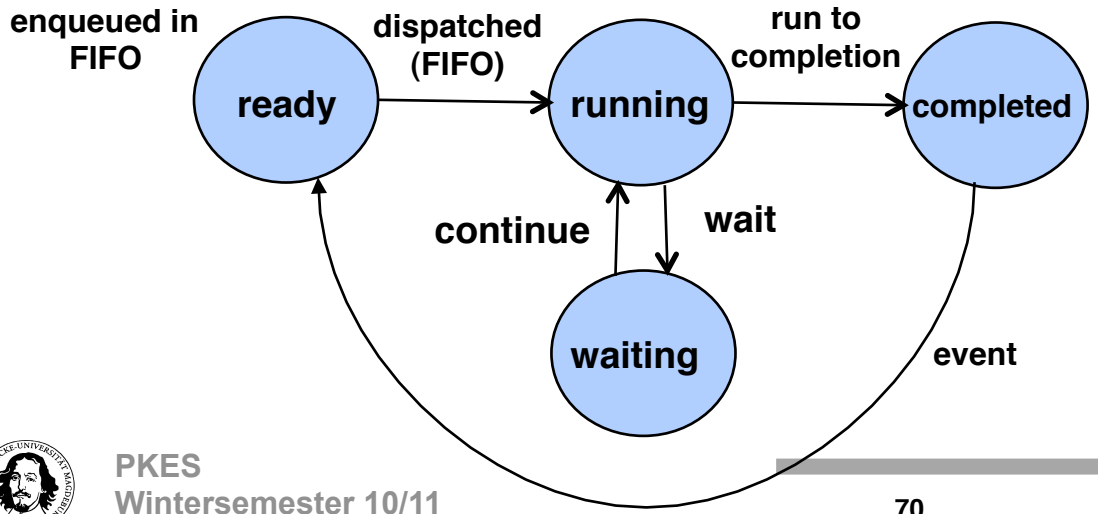
         case OFF:
           if(timer_expired(&timer)) {
                 radio_on();
                 state = ON;
                 timer_set(&timer, T_AWAKE);
           }
           break;

         case ON:
           if(timer_expired(&timer)) {
                 timer_set(&timer, T_SLEEP);
                 if(!communication_complete()) {
                       state = WAITING;
           } else {
             radio_off();
             state = OFF;
           }
      }
      break;

      case WAITING:
            if(communication_complete() & !timer_expired(&timer)) {
                 state = ON;
                 timer_set(&timer, T_AWAKE);
            } else {
              radio_off();
              state = OFF;
            }
            break;
      }
}
```

Task Modelle





Tiny-OS

common

- no preemption
- event based
- single stack only

Contiki

- wait state
- global variables only
- no switch inside a wait

TinyOS Concurrency Model

Synchronous Code (SC): code that is only reachable from tasks

Asynchronous Code (AC): code that is reachable from at least one event handler

Any update to shared state in which at least one AC is involved (AC-AC or AC-SC) may result in an inconsistency.

Consistency problems are handled by "atomic" code sequences that disable interrupts. The "atomic" keyword is the only means for defining mutual exclusion (e.g. no atomic test-and-set mechanism available)

Example: Atomic section

"atomic statements are not allowed to call commands or signal events either directly or in a called function"

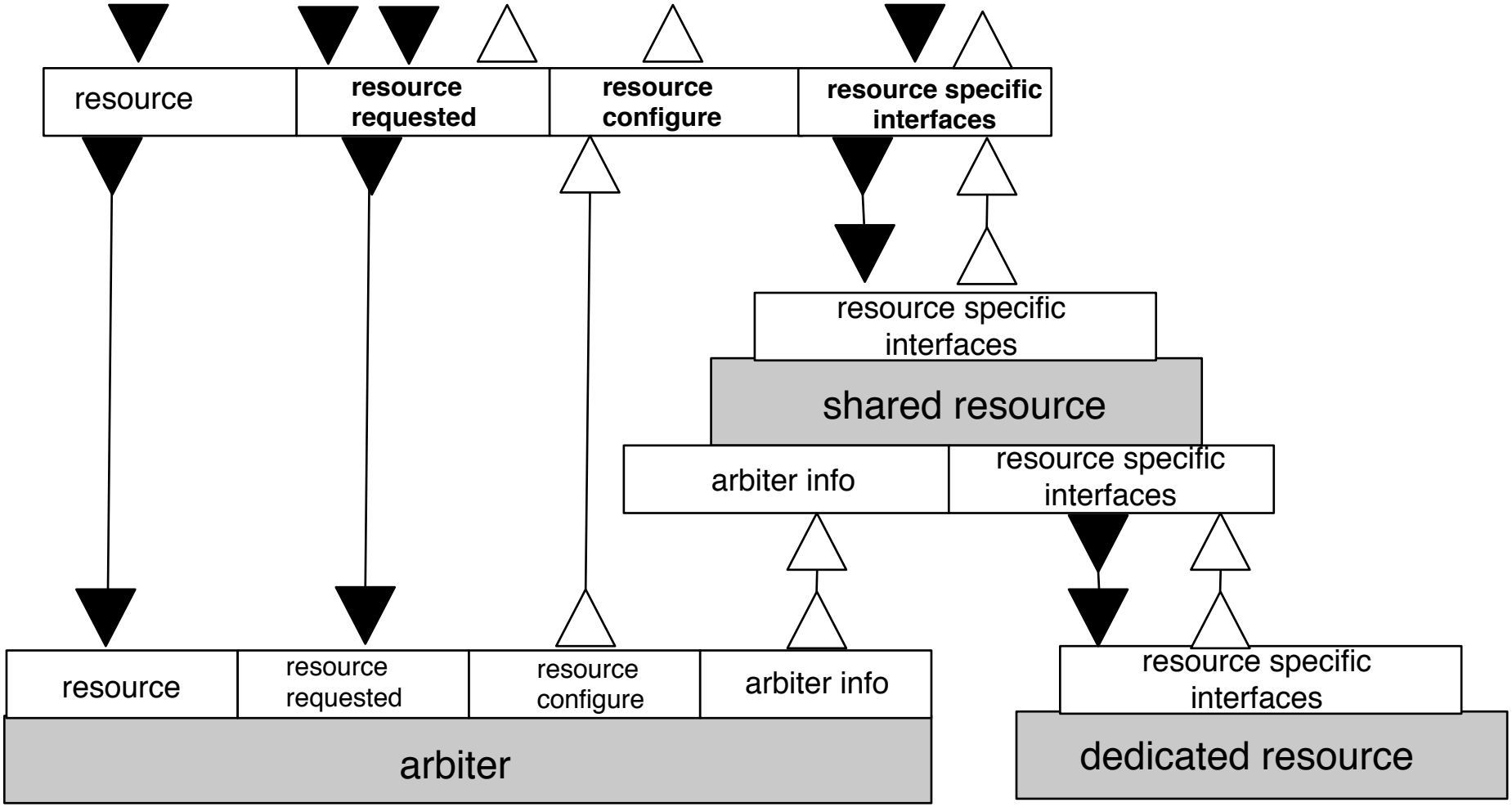
```
module SomeAppM { ... }
implementation {
   bool busy;
   norace uint16_t sensorReading;

   event result_t Timer.fired() {
      bool localBusy;
      atomic {
          localBusy = busy;
          busy = TRUE;
      }
      if (!localBusy)
          call ADC.getData();
      return SUCCESS;
   }

   task void sendData() {                    // send sensorReading
      adcPacket.data = sensorReading;
      call Send.send(&adcPacket, sizeof adcPacket.data);
      return SUCCESS;
   }

   event result_t ADC.dataReady(uint16_t data) {
      sensorReading = data;
      post sendData();
      return SUCCESS;
   }...
}
```

Gemeinsam genutzte Ressourcen in T2



TinyOS

Minimales OS für ressourcenbeschränkte Systeme

Kern benötigt 400 Bytes (Code UND Daten zusammen)

Kein Echtzeitbetriebssystem (lediglich Timer Abstraktionen)

Ereignisgesteuert (Handler werden sofort ausgeführt und können sich gegenseitig unterbrechen).

"State-Machine" Ansatz

Nicht-blockierende Funktionsaufrufe → Split Phase Ansatz (Callbacks)

Nicht-unterbrechbares Taskmodell (single stack, Tasks zueinander synchron)

Explizite Synchronisation und Compilerunterstützung bei der Erkennung und Behandlung von "Race Conditions".

Inhalt

- Einführung: Was ist ein eingebettetes System?
  - Was macht den Unterschied aus?
  - Was muss man können?
- Mikrocontroller: Architektur und Besonderheiten
- Sensoren, Aktoren und ihre Unterstützung durch Funktionseinheiten in Microcontrollern:
  - Analoge Schnittstellen
  - Zeitgeber und Zähler
- Zuverlässigkeit und Fehlertoleranz
- Zeitgerechte Ausführung
- Betriebssysteme für eingebettete Systeme