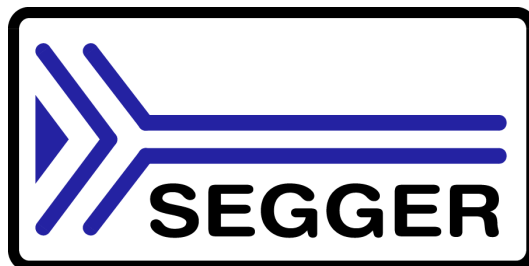# embOS & embOS-MPU

Real-Time Operating System

CPU-independent User & Reference Guide

Document: UM01001

Software version 4.24

Revision: 0

Date: June 28, 2016

A product of SEGGER Microcontroller GmbH & Co. KG

www.segger.com

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Manual versions

This manual describes the current software version. If any error occurs, inform us and we will try to assist you as soon as possible.
Contact us for further information on topics or routines not yet specified.

Print date: June 28, 2016

Software	Revision	Date	By	Description
4.24	0	160628	MC	Chapter "Multi-core support" added. Chapter "Debugging" updated.
4.22	0	160525	MC	New functions in chapter "Queues" added: OS_Q_PutEx(), OS_Q_PutBlockedEx(), and OS_Q_PutTimedEx().
4.20	0	160421	TS	Chapter "MPU - memory protection" added. OS_AddExtendTaskContext() added.
4.16	0	160210	TS	Minor corrections/updates
4.14a	0	160115	TS	Minor corrections/updates
4.14	0	151029	TS	Chapter "Interrupts" updated. Description of new API function OS_SetDefaultTaskContextExtension() added. Chapter "System variables": embOS info routines added. Chapter "Shipment updated". Chapter "Low power support" updated. Chapter "Interrupts": Description of OS_INT_PRIO_PRESERVE() and OS_INT_PRIO_RESTORE() added. Chapter "Software timers": Description of OS_TriggerTimer() and OS_TriggerTimerEx() added.
4.12b	0	150922	TS	Update to latest software version.
4.12a	0	150916	TS	Description of API function OS_InInterrupt() updated.
4.12	0	150715	TS	New functrions in chapter "Mailbox" added: OS_Mail_GetPtr() OS_Mail_GetPtrCond() OS_Mail_Purge() Chapter "Debugging" with new error codes updated.
4.10b	1	150703	MC	Minor spelling and wording corrections.
4.10b	0	150527	TS	Minor spelling and wording corrections. Chapter "Source code of kernel and library" updated. New chapter "embOS shipment" New chapter "Update" New chapter "Low power support"
4.10a	0	150519	MC	Minor spelling and wording corrections. Chapter "embOSView": added JTAG chain configuration.
4.10	0	150430	TS	Chapter "embOSView" updated.
4.06b	0	150324	MC	Minor spelling and wording corrections.
4.06a	0	150318	MC	Minor spelling and wording corrections.
4.06	0	150312	TS	Update to latest software version.
4.04a	0	141201	TS	Update to latest software version.
4.04	0	141112	TS	Chapter "Tasks" * Task priority description updated. Chapter "Debugging" * New error number
4.02a	0	140918	TS	Update to latest software version. Minor corrections.
4.02	0	140818	TS	New functions in chapter Time Measurement added: OS_Config_SysTimer() OS_GetTime_us() OS_GetTime_us64()
4.00a	0	140723	TS	New function added in chapter SystemTick: OS_StopTicklessMode() New function added in chapter Profiling: OS_STAT_Start() OS_STAT_Stop() OS_STAT_GetTaskExecTime()
4.00	0	140606	TS	Tickless suppport added.

Software	Revision	Date	By	Description
3.90a	0	140410	AW	Software-Update, OS_TerminateTask() modified / corrected.
3.90	1	140312	SC	Added cross-references to the API-lists.
3.90	0	140303	AW	New functions to globally enable / diasble Interrupts: OS_INTERRUPT_MaskGlobal() OS_INTERRUPT_UnmaskGlobal() OS_INTERRUPT_PreserveGlobal() OS_INTERRUPT_RestoreGlobal() OS_INTERRUPT_PreserveAndMaskGlobal()
3.88h	0	131220	AW	New functions added, chapter "Sytem tick": OS_GetNumIdleTicks(); OS_AdjustTime(); Chapter "System variable" Description of internal variable OS_Global.TimeDex corrected
3.88g	1	131104	TS	Corrections.
3.88g	0	131030	TS	Update to latest software version. Minor corrections.
3.88f	0	130922	TS	Update to latest software version.
3.88e	0	130906	TS	Update to latest software version.
3.88d	0	130904	AW	Update to latest software version.
3.88c	0	130808	TS	Update to latest software version.
3.88b	0	130528	TS	Update to latest software version.
3.88a	0	130503	AW	Software update. Event handling modified, the reset behaviour of events can be controlled. New functions added, chapter "Events": OS_EVENT_CreateEx(); OS_EVENT_SetResetMode(); OS_EVENT_GetResetMode(); Mailbox message size limits enlarged.
3.88	0	130219	TS	Minor corrections.
3.86n	0	121210	AW/TS	Update to latest software version.
3.86l	0	121122	AW	Software update OS_AddTickHook() function corrected. Several functions modified to allow most of MISRA rule checks
3.86k	0	121004	TS	Chapter "Queue" * OS_Q_GetMessageSize() and OS_Q_PeekPtr() added.
3.86i	0	120926	TS	Update to latest software version.
3.86h	0	120906	AW	Software update, OS_EVENT handling with timeout corrected.
3.86g	0	120806	AW	Software update, OS_RetriggerTimer() corrected. Task events explained more in detail. Additional software examples in the manual.
3.86f	0	120723	AW	Task events modified, default set to 32bit on 32bit CPUs. Chapter 4: New API function OS_AddOnTerminateHook() OS_ERR_TIMESLICE removed. A time slice value of zero is legal when creating tasks.
3.86e	0	120529	AW	Update to latest software version with corrected functions: OS_GetSysStackBase() OS_GetSysStackSize() OS_GetSysStackSpace() OS_GetSysStackUsed() OS_GetIntStackBase() OS_GetIntStackSize() OS_GetIntStackSpace() OS_GetIntStackUsed() could not be used in release builds of embOS. Manual corrections: Several index entries corrected. OS_EnterRegion() described more in detail.
3.86d	0	120510	TS	Update to latest software version.
3.86c	0	120508	TS	Update to latest software version.
3.86b	0	120502	TS	Chapter "Mailbox" * OS_PeekMail() added. Chapter "Support" added. Chapter "Debugging": * Application defined error codes added.

Software	Revision	Date	By	Description
3.86	0	120323	AW	Timeout handling for waitable objects modified. A timeout will be returned from the waiting function, when the obeject was not avaialbale during the timeout time. Previous implementation of timeout functions might have returned a signaled state when the object was signaled after the timeout when the calling task was blocked for a longer period by higher priorized tasks. Modified functions: OS_UseTimed(), Chapter 6.2.3 OS_WaitCSemaTimed(), Chapter 7.2.6 OS_GetMailTimed(), Chapter 8.5.8 OS_WaitMailTimed(), Chapter 8.5.10 OS_Q_GetPtrTimed(), Chapter 9.3.10 OS_EVENT_WaitTimed(), Chapter 11.2.4 OS_MEMF_AllocTimed(), Chapter 13.2.4 New Chapter 4.3. "Extending the task context" added. New functions added and described in the manual: Chapter 4.4.14: OS_GetTaskName() Chapter 4.4.14: OS_GetTimeSliceRem() Handling of queues described mor in detail: Chapter 9.3.8: OS_Q_GetPtr() Chapter 9.3.9: OS_Q_GetPtrCond() Chapter 9.3.10: OS_Q_GetPtrTimed() Chapter 9.3.11: OS_Q_Purge() Chapter 10, Task Events: Type for task events OS_TASK_EVENT introduced. This type is used for all events and event masks. it defaults to unsigned char. Chapter 2.4.3 "Priority inversion / inheritance" updated Chapter 17.3.1 function names OS_Timing_Start() and OS_Timing_End() corrected in the API table.
3.84c	1	120130	AW /TS	Since version 3.82w of embOS, all pointer parameter pointing to objects which were not modified by the function were declared as const, but the manual was not updated accordingly. The prototype descriptions of the following API functions are corrected now: OS_GetTimerValue() OS_GetTimerStatus() OS_GetTimerPeriod() OS_GetSemaValue() OS_GetResourceOwner() OS_Q_IsInUse() OS_Q_GetMessageCnt() OS_IsTask() OS_GetEventsOccurred() OS_GetCSemaValue() OS_TICK_RemoveHook() OS_MEMF_IsInPool() OS_MEMF_GetMaxUsed() OS_MEMF_GetNumBlocks() OS_MEMF_GetBlockSize() OS_GetSuspendCnt() OS_GetPriority() OS_EVENT_Get() OS_Timing_Getus() Chapter "Preface" * Segger Logo replaced. Chapter "Mailbox" * OS_CREARTEMB() changed to OS_CreateMB(). Chapter "Queues" * Typos corrected.
3.84c	0	120104	TS	Chapter "Events" * Return value of OS_EVENT_WaitTimed() explained in more detail

Software	Revision	Date	By	Description
3.84b	0	111221	TS	Chapter "Queues" * OS_Q_PutBlocked() added.
3.84a	0	111207	TS	General updates and corrections.
3.84	0	110927	TS	Chapter "Stacks" * OS_GetSysStackBase() added. * OS_GetSysStackSize() added. * OS_GetSysStackUsed() added. * OS_GetSysStackSpace() added. * OS_GetIntStackBase() added. * OS_GetIntStackSize() added. * OS_GetIntStackUsed() added. * OS_GetIntStackSpace() added.
3.82x	0	110829	TS	Chapter "Debugging" * New error code "OS_ERR_REGIONCNT" added.
3.82w	0	110812	TS	New embOS generic sources. Chapter 24 "Debugging" updated.
3.82v	0	110715	AW	OS_Terminate() renamed to OS_TerminateTask().
3.82u	0	110630	TS	New embOS generic sources. Chapter 13: Fixed size memory pools modified.
3.82t	0	110503	TS	New embOS generic sources. Trial time limitation increased.
3.82s	0	110318	AW	Chapter 5.2, "Timer" API functions table corrected. All functions can be called from main(), task, ISR or Timer. Chapter 6: OS_UseTimed() added. Chapter 9: OS_Q_IsInUse() added.
3.82p	0	110112	AW	Chapter "Mailboxes" * OS_PutMail() * OS_PutMailCond() * OS_PutMailFront() * OS_PutMailFrontCond() parameter declaration changed. Chapter 4.3 API functions table corrected. OS_Suspend() cannot be called from ISR or Timer.
3.82o	0	110104	AW	Chapter "Mailboxes" * OS_WaitMailTimed() added.
3.82n	0	101206	AW	Chapter "Taskroutines" * OS_ResumeAllSuspendedTasks() added. * OS_SetInitialSuspendCnt() added. * OS_SuspendAllTasks() added. Chapter "Time Measurement" * Description of OS_GetTime32() corrected. Chapter "List of error codes" * New error codes added.
3.82k	0	100927	TS	Chapter "Taskroutines" * OS_Delayus() added * OS_Q_Delete() added
3.82i	0	100917	TS	General updates and corrections.
3.82h	0	100621	AW	Chapter Event objects: Samples added. Chapter: Configuration of target system: Detailed description of OS_idle() added
3.82f	1	100505	TS	Chapter Profiling added Chapter SystemTick: OS_TickHandleNoHook() added.
3.82f	0	100419	AW	Chapter Tasks: New function OS_IsRunning()added. Chapter Tasks: Description of OS_Start() added.
3.82e	0	100309	TS	Chapter "Working with embOS - Recommendations" added Chapter Basics * Priority inversion image added Chapter Interrupt * subchapter "Using OS functions from high priority inter-rupts" added Added text at chapter 22 "Performance and resource usage"
3.82	0	090922	TS	API function overview now contains information about allowed context of function usage (main, task, ISR or timer) TOC format corrected
3.80	0	090612	AW	Scheduler optimized for higher task switching speed.

Software	Revision	Date	By	Description

3.62.c	0	080903	SK	Chapter structure updated.
				Chapter "Interrupts":
				  * OS_LeaveNestableInterruptNoSwitch() removed.
				  * OS_LeaveInterruptNoSwitch() removed.
				Chapter "System tick":
				  * OS_TICK_Config() added.

3.60	2	080722	SK	Contact address updated.
3.60	1	080617	SK	General updates. Chapter "Mailboxes": - OS_GetMailCond() / OS_GetMailCond1() corrected.
3.60	0	080117	OO	General updates. Chapter "System tick" added.
3.52	1	071026	AW	Chapter "Task routines": Added OS_SetTaskName().
3.52	0	070824	OO	Chapter "Task routines": Added OS_ExtendTaskContext(). Chapter "Interrupts": Updated, added OS_CallISR() and OS_CallNestableISR().
3.50c	0	070814	AW	Chapter "List of libraries" updated, XR library type added.
3.40C	3	070716	OO	Chapter "Performance and resource usage" updated,

3.40C	2	070625	SK	Chapter "Debugging", error codes updated:
				  - OS_ERR_ISR_INDEX added.
				  - OS_ERR_ISR_VECTOR added.
				  - OS_ERR_RESOURCE_OWNER added.
				  - OS_ERR_CSEMA_OVERFLOW added.
				Chapter "Task routines":
				  - OS_Yield() added.
				Chapter "Counting semaphores" updated.
				  - OS_SignalCSema(), additional information adjusted.
				Chapter "Performance and resource usage" updated:
				  - Minor changes in wording.

3.40A	1	070608	SK	Chapter "Counting semaphores" updated.
				  - OS_SetCSemaValue() added.
				  - OS_CreateCSema(): Data type of parameter InitValue changed from unsigned char to unsigned int.
				  - OS_SignalCSemaMax(): Data type of parameter MaxValue changed from unsigned char to unsigned int.
				  - OS_SignalCSema(): Additional information updated.

3.40	0	070516	SK	Chapter "Performance and resource usage" added. Chapter "Configuration of your target system (RTOSInit.c)" renamed to "Configuration of your target system". Chapter "STOP\WAIT\IDLE modes" moved into chapter "Configuration of your target system". Chapter "time-related routines" renamed to "Time measurement".
3.32o	9	070422	SK	Chapter 4: OS_CREATETIMER_EX(), additional information corrected.
3.32m	8	070402	AW	Chapter 4: Extended timer added. Chapter 8: API overview corrected, OS_Q_GetMessageCount()
3.32j	7	070216	AW	Chapter 6: OS_CSemaRequest() function added.
3.32e	6	061220	SK	About: Company description added. Some minor formatting changes.
3.32e	5	061107	AW	Chapter 7: OS_GetMessageCnt() return value corrected to unsigned int.
3.32d	4	061106	AW	Chapter 8: OS_Q_GetPtrTimed() function added.
3.32a	3	061012	AW	Chapter 3: OS_CreateTaskEx() function, description of parameter pContext corrected. Chapter 3: OS_CreateTaskEx() function, type of parameter TimeSlice corrected. Chapter 3: OS_CreateTask() function, type of parameter TimeSlice corrected. Chapter 9: OS_GetEventsOccured() renamed to OS_GetEventsOccurred(). Chapter 10: OS_EVENT_WaitTimed() added.
3.32a	2	060804	AW	Chapter 3: OS_CREATETASK_EX() function added. Chapter 3: OS_CreateTaskEx() function added.

Software	Revision	Date	By	Description
3.32	1	060717	OO	Event objects introduced. Chapter 10 inserted which describes event objects. Previous chapter "Events" renamed to "Task events"
3.30	1	060519	OO	New software version.
3.28	5	060223	OO	All chapters: Added API tables. Some minor changes.
3.28	4	051109	AW	Chapter 7: OS_SignalCSemaMax() function added. Chapter 14: Explanation of interrupt latencies and high / low priorities added.
3.28	3	050926	AW	Chapter 6: OS_DeleteRSema() function added.
3.28	2	050707	AW	Chapter 4: OS_GetSuspendCnt() function added.
3.28	1	050425	AW	Version number changed to 3.28 to fit to current ombOS version. Chapter 18.1.2: Type of return value of OS GetTime32() corrected
3.26		050209	AW	Chapter 4: OS_Terminate() modified due to new features of version 3.26. Chapter 24: Source code version: additional compile time switches and build process of libraries explained more in detail.
3.24		041115	AW	Chapter 6: Some prototype declarations showed in OS_SEMA instead of OS_RSEMA. Corrected.
3.22	1	040816	AW	Chapter 8: New Mailbox functions added OS_PutMailFront() OS_PutMailFront1() OS_PutMailFrontCond() OS_PutMailFrontCond1()
3.20	5	040621	RS AW	Software timers: Maximum timeout values and OS_TIMER_MAX_TIME described. Chapter 14: Description of rules for interrupt handlers revised. OS_LeaveNestableInterruptNoSwitch() added which was not described before.
3.20	4	040329	AW	OS_CreateCSema() prototype declaration corrected. Return type is void. OS_Q_GetMessageCnt() prototype declaration corrected. OS_Q_Clear() function description added. OS_MEMF_FreeBlock() prototype declaration corrected.
3.20	2	031128	AW	OS_CREATEMB() Range for parameter MaxnofMsg corrected. Upper limit is 65535, but was declared 65536 in previous manuals.
3.	1	040831	AW	Code samples modified: Task stacks defined as array of int, because most CPUs require alignment of stack on integer aligned addresses.

Software	Revision	Date	By	Description
3.20	1	031016	AW	Chapter 4: Type of task priority parameter corrected to unsigned char. Chapter 4: OS_DelayUntil(): Sample program modified. Chapter 4: OS_Suspend() added. Chapter 4: OS_Resume() added. Chapter 5: OS_GetTimerValue(): Range of return value corrected. Chapter 6: Sample program for usage of resource semaphores modified. Chapter 6: OS_GetResourceOwner(): Type of return value corrected. Chapter 8: OS_CREATEMB(): Types and valid range of parameter corrected. Chapter 8: OS_WaitMail() added Chapter 10: OS_WaitEventTimed(): Range of timeout value specified.
3.12	1	021015	AW	Chapter 8: OS_GetMailTimed() added Chapter 11 (Heap type memory management) inserted Chapter 12 (Fixed block size memory pools) inserted
3.10	3	020926 020924 020910	KG KG KG	Index and glossary revised. Section 16.3 (Example) added to Chapter 16 (Time-related routines). Revised for language/grammar. Version control table added. Screenshots added: superloop, cooperative/preemptive multi-tasking, nested interrupts, low-res and hi-res measurement. Section 1.3 (Typographic conventions) changed to table. Section 3.2 added (Single-task system). Section 3.8 merged with section 3.9 (How the OS gains control). Chapter 4 (Configuration for your target system) moved to after Chapter 15 (System variables). Chapter 16 (Time-related routines) added.

About this document

Assumptions

This document assumes that you already have a solid knowledge of the following:

- The software tools used for building your application (assembler, linker, C compiler)
- The C programming language
- The target processor
- DOS command line

If you feel that your knowledge of C is not sufficient, we recommend The C Programming Language by Kernighan and Richie (ISBN 0-13-1103628), which describes the standard in C-programming and, in newer editions, also covers the ANSI C standard.

How to use this manual

This manual explains all the functions and macros that the product offers. It assumes you have a working knowledge of the C language. Knowledge of assembly programming is not required.

Typographic conventions for syntax

This manual uses the following typographic conventions:

Style	Used for
Body	Body text.
Keyword	Text that you enter at the command-prompt or that appears on the display (that is system functions, file- or pathnames).
Parameter	Parameters in API functions.
Sample	Sample code in program examples.
Sample comment	Comments in programm examples.
Reference	Reference to chapters, sections, tables and figures or other documents.
GUIElement	Buttons, dialog boxes, menu names, menu commands.
Emphasis	Very important sections.

Table 1.1: Typographic conventions

SEGGER Microcontroller GmbH & Co. KG develops and distributes software development tools and ANSI C software components (middleware) for embedded systems in several industries such as telecom, medical technology, consumer electronics, automotive industry and industrial automation.

SEGGER's intention is to cut software development time for embedded applications by offering compact flexible and easy to use middleware, allowing developers to concentrate on their application.

Our most popular products are emWin, a universal graphic software package for embedded applications, and embOS, a small yet efficient real-time kernel. emWin, written entirely in ANSI C, can easily be used on any CPU and most any display. It is complemented by the available PC tools: Bitmap Converter, Font Converter, Simulator and Viewer. embOS supports most 8/16/32-bit CPUs. Its small memory footprint makes it suitable for single-chip applications.

Apart from its main focus on software tools, SEGGER develops and produces programming tools for flash micro controllers, as well as J-Link, a JTAG emulator to assist in development, debugging and production, which has rapidly become the industry standard for debug access to ARM cores.

Corporate Office:
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United States Office:
http://www.segger-us.com

EMBEDDED SOFTWARE (Middleware)

emWin
Graphics software and GUI
emWin is designed to provide an efficient, processor- and display controller-independent graphical user interface (GUI) for any application that operates with a graphical display.

embOS
Real Time Operating System
embOS is an RTOS designed to offer the benefits of a complete multitasking system for hard real time applications with minimal resources.

embOS/IP
TCP/IP stack
embOS/IP a high-performance TCP/IP stack that has been optimized for speed, versatility and a small memory footprint.

emFile
File system
emFile is an embedded file system with FAT12, FAT16 and FAT32 support. Various Device drivers, e.g. for NAND and NOR flashes, SD/MMC and Compact-Flash cards, are available.

USB-Stack
USB device/host stack
A USB stack designed to work on any embedded system with a USB controller. Bulk communication and most standard device classes are supported.

SEGGER TOOLS

Flasher
Flash programmer
Flash Programming tool primarily for micro controllers.

J-Link
JTAG emulator for ARM cores
USB driven JTAG interface for ARM cores.

J-Trace
JTAG emulator with trace
USB driven JTAG interface for ARM cores with Trace memory. supporting the ARM ETM (Embedded Trace Macrocell).

J-Link / J-Trace Related Software
Add-on software to be used with SEGGER's industry standard JTAG emulator, this includes flash programming software and flash breakpoints.

Table of Contents

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Chapter 1

Introduction to embOS

1.1   What is embOS

embOS is a priority-controlled multitasking system, designed to be used as an embedded operating system for the development of real-time applications for a variety of microcontrollers.

embOS is a high-performance tool that has been optimized for minimal memory consumption in both RAM and ROM, as well as high speed and versatility.

1.2   Features

Throughout the development process of embOS, the limited resources of microcontrollers have always been kept in mind. The internal structure of the real-time operating system (RTOS) has been optimized in a variety of applications with different customers, to fit the needs of industry. Fully source-compatible implementations of embOS are available for a variety of microcontrollers, making it well worth the time and effort to learn how to structure real-time programs with real-time operating systems.

embOS is highly modular. This means that only those functions that are required are linked into an application, keeping the ROM size very small. The minimum memory consumption is little more than 1 Kbyte of ROM and about 30 bytes of RAM (plus memory for stacks). A couple of files are supplied in source code to make sure that you do not loose any flexibility by using embOS and that you can customize the system to fully fit your needs.

The tasks you create can easily and safely communicate with each other using a number of communication mechanisms such as semaphores, mailboxes, and events.

Some features of embOS include:

- Preemptive scheduling:
  Guarantees that of all tasks in READY state the one with the highest priority executes, except for situations where priority inheritance applies.
- Round-robin scheduling for tasks with identical priorities.
- Preemptions can be disabled for entire tasks or for sections of a program.
- Up to 4.294.967.296 priorities.
- Every task can have an individual priority, which means that the response of tasks can be precisely defined according to the requirements of the application.
- Unlimited number of tasks
  (limited only by the amount of available memory).
- Unlimited number of semaphores
  (limited only by the amount of available memory).
- Two types of semaphores: resource and counting.
- Unlimited number of mailboxes
  (limited only by the amount of available memory).
- Size and number of messages can be freely defined when initializing mailboxes.
- Unlimited number of software timers
  (limited only by the amount of available memory).
- Up to 32 bit events for every task.
- Time resolution can be freely selected (default is 1ms).
- Easily accessible time variable.
- Power management.
- Calculation time in which embOS is idle can automatically be spent in low-power mode.
  power-consumption is minimized.
- Full interrupt support:
  Interrupts can call any function except those that require waiting for data,
  as well as create, delete or change the priority of a task.
  Interrupts can wake up or suspend tasks and directly communicate with tasks using all available communication methods (mailboxes, semaphores, events).
- Disabling interrupts for very short periods allows minimal interrupt latency.
- Nested interrupts are permitted.
- embOS has its own interrupt stack (usage optional).
- Application samples for an easy start.
- Debug build performs runtime checks that catch common programming errors early on.
- Profiling and stack-check may be implemented by choosing specified libraries.
- Monitoring during runtime is available using embOSView via UART, Debug Communications Channel (DCC) and memory read/write, or else via Ethernet.
- Very fast and efficient, yet small code.
- Minimal RAM usage.

- Core written in assembly language.
- API can be called from assembly, C or C++ code.
- Initialization of microcontroller hardware as sources (BSP).

Chapter 2

Basic concepts

This chapter explains some basic concepts behind embOS. It should be relativly easy to read and is recommended before moving to other chapters.

2.1   Tasks

In this context, a task is a program running on the CPU core of a microcontroller. Without a multitasking kernel (an RTOS), only one task can be executed by the CPU at a time. This is called a single-task system. A real-time operating system allows the execution of multiple tasks on a single CPU. All tasks execute as if they completely "own" the entire CPU. The tasks are scheduled for execution, meaning that the RTOS can activate and deactivate each task according to its priority, with the highest priority task being executed in general.

2.1.1   Threads

Threads are tasks which share the same memory layout. Two threads can access the same memory locations. If virtual memory is used, the same virtual to physical translation and access rights are used.

The embOS tasks are threads; they all have the same memory access rights and translation (in systems with virtual memory).

2.1.2   Processes

Processs are tasks with their own memory layout. Two processes cannot normally access the same memory locations. Different processes typically have different access rights and (in case of MMUs) different translation tables.

Processes are not supported by the present version of embOS.

2.2   Single-task systems (superloop)

The classic way of designing embedded systems does not use the services of an RTOS, which is also called "superloop design". Typically, no real time kernel is used, so interrupt service routines (ISRs) are used for the real-time parts of the application and for critical operations (at interrupt level). This type of system is typically used in small, simple systems or if real-time behavior is not critical.
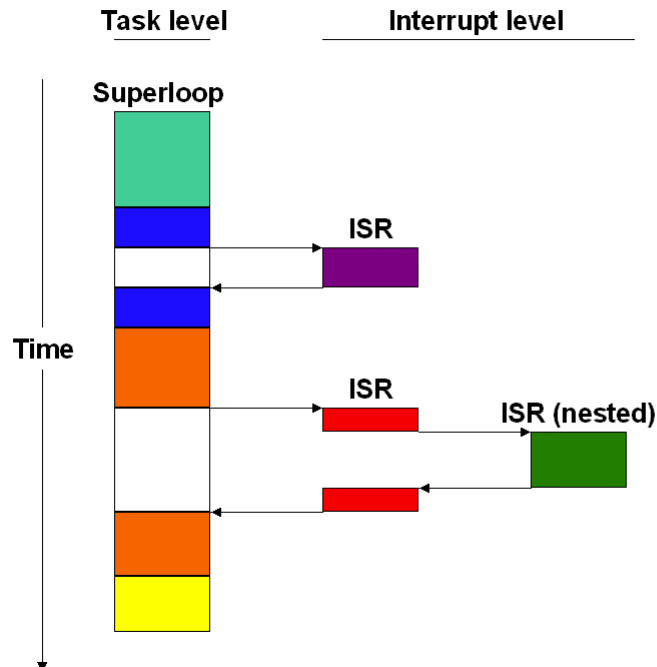
Typically, because no real-time kernel and only one stack is used, both program (ROM) and RAM size for simple applications are smaller when compared to using an RTOS. Of course, there are no inter-task synchronization problems with a superloop application. However, superloops can become difficult to maintain if the program becomes too large or uses complex interactions. As sequential processes cannot interrupt themselves, reaction times depend on the execution time of the entire sequence, resulting in a poor real-time behavior.

2.2.1   Advantages & disadvantages

Advantages

- Simple structure (for small applications)
- Low stack usage (only one stack required)

Disadvantages

- No "delay" capability
- Higher power consumption due to the lack of a sleep mode in most architectures
- Difficult to maintain as program grows
- Timing of all software components depends on all other software componts: Small change in one place can have major side effects in other places
- Defeats modular programming
- Real time behavior only with interrupts

2.2.2   Using embOS in super-loop applications

In a true superloop application, no tasks are used, so the biggest advantage of using an RTOS cannot be used unless the application is converted to use multitasking. However, even with just a single task, using embOS has the following advantages:

- Software timers are available
- Power saving: Idle mode can be used
- Future extensions can be put in a separate task

2.2.3   Migrating from superloop to multi-tasking

A common situation is that an application exists for some time and has been designed as single task, super loop application. At a certain point, the disadvantages of this approach lead to a decision to use an RTOS. The typical question is then: How do I do this?

The easiest way is to take the start application that comes with the embOS and put your existing "superloop code" into one task. At this point you should also make sure that the stack size of this task is sufficient. Later, additional functionality which is added to the software can be put in one or more additional tasks; the functionality of the super loop can also be distributed over multiple tasks.

2.3 Multitasking systems

In a multitasking system, there are different ways of distributing the CPU time amongst different tasks. This process is called scheduling.
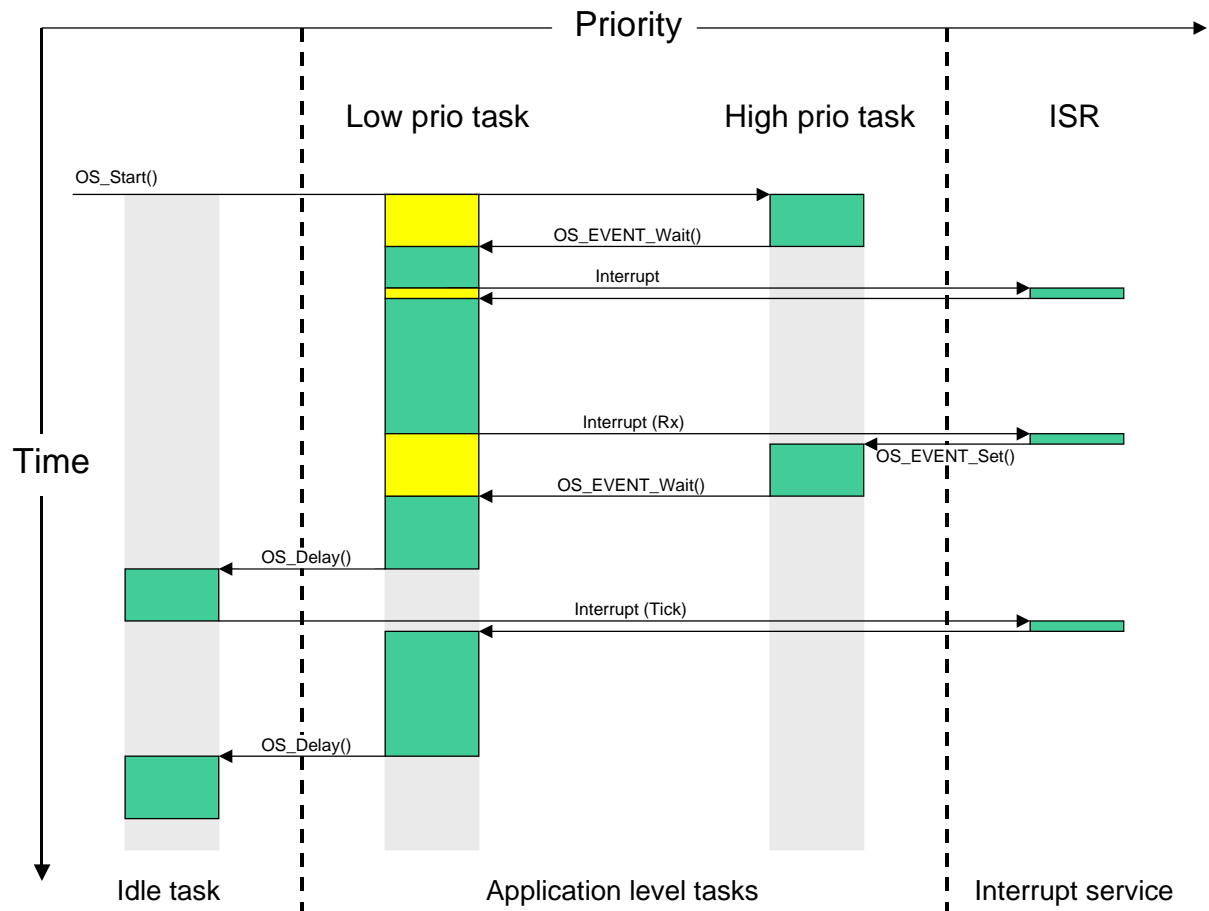
2.3.1 Task switches

There are two types of task switches, also called context switches: Cooperative and preemptive task switches.

2.3.2 Cooperative task switch

A cooperative task switch is performed by the task itself. It requires the cooperation of the task, hence the name. What happens is that the task blocks itself by calling a blocking RTOS function such as OS_Delay() or OS_WaitEvent().

2.3.3 Preemptive task switch

A preemptive task switch is a task switch caused by an interrupt. Typically some other high priority task becomes ready for execution and, as a result, the current task is suspended.

2.3.4   Preemptive multitasking

Real-time operating systems like embOS operate with preemptive multitasking. The highest-priority task in the READY state always executes as long as the task is not suspended by a call of any operating system function. A high-priority task waiting for an event is signaled READY as soon as the event occurs. The event can be set by an interrupt handler, which then activates the task immediately. Other tasks with lower priority are suspended (preempted) as long as the high-priority task is executing.

A real-time operating system, such as embOS, normally comes with a regular timer interrupt to interrupt tasks at regular intervals and to perform task switches if timed task switches are necessary.

Low priority task

Executing task is interrupted

ISR

ISR puts high priority
task in READY state;
task switch occurs

Time

High priority task

Higher priority task
Is executed

Interrupted task
is completed
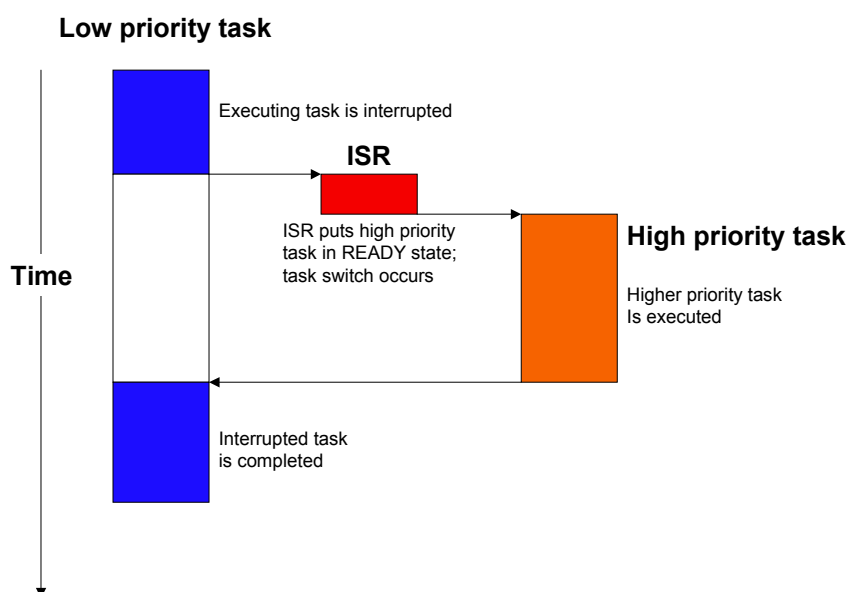
2.3.5   Cooperative multitasking

Cooperative multitasking requires all tasks to cooperate by using blocking functions. A task switch can only take place if the running task blocks itself by calling a blocking function such as `OS_Delay()` or `OS_Wait...()`. If tasks do not cooperate, the system "hangs", which means that other tasks have no chance of being executed by the CPU while the first task is being carried out. This is illustrated in the diagram below. Even if an ISR makes a higher-priority task ready to run, the interrupted task will be resumed and complete before the task switch is made.
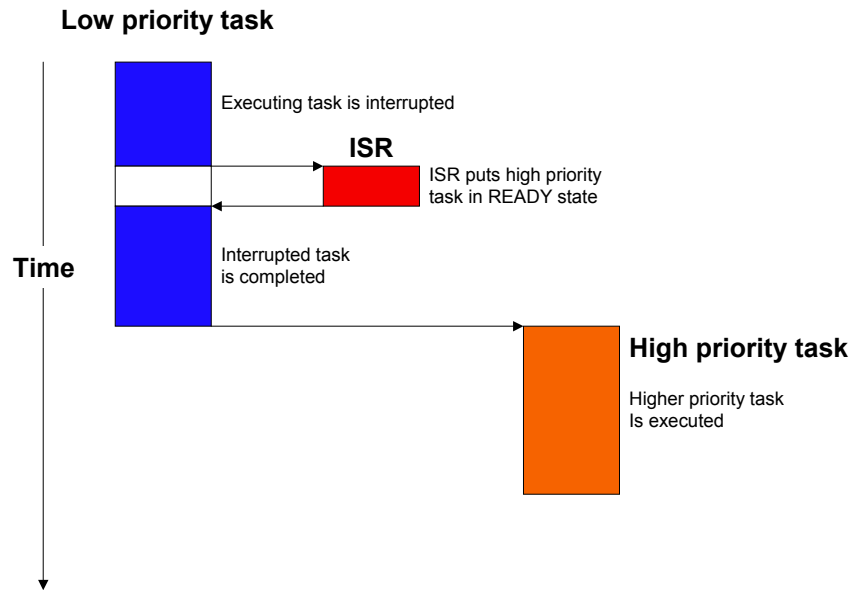
A pure cooperative multi-tasking system has the disadvantage of longer reaction times when high priority tasks become ready for execution. This makes their usage in embedded real-time systems uncommon.

2.4   Scheduling

There are different algorithms that determine which task to execute, called schedulers. All schedulers have one thing in common: they distinguish between tasks that are ready to be executed (in the READY state) and other tasks that are suspended for some reason (delay, waiting for mailbox, waiting for semaphore, waiting for event, and so on). The scheduler selects one of the tasks in the READY state and activates it (executes the body of this task). The task which is currently executing is referred to as the running task. The main difference between schedulers is the way they distribute computation time between tasks in the READY state.

2.4.1   Round-robin scheduling algorithm

With round-robin scheduling, the scheduler has a list of tasks and, when deactivating the running task, activates the next task that is in the READY state. Round-robin can be used with either preemptive or cooperative multitasking. It works well if you do not need to guarantee response time. Round-robin scheduling can be illustrated as follows:
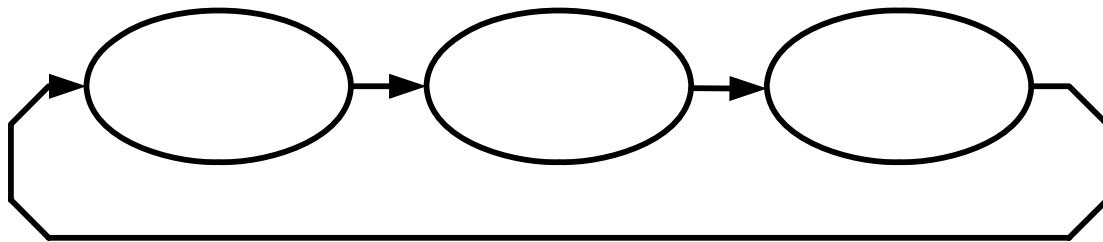
All tasks share the same priority; the possession of the CPU changes periodically after a predefined execution time. This time is called a *time slice*, and may be defined individually for every task.

2.4.2   Priority-controlled scheduling algorithm

In real-world applications, different tasks require different response times. For example, in an application that controls a motor, a keyboard, and a display, the motor usually requires faster reaction time than the keyboard and display. While the display is being updated, the motor needs to be controlled. This makes preemptive multitasking essential. Round-robin might work, but because it cannot guarantee a specific reaction time, an improved algorithm should be used.

In priority-controlled scheduling, every task is assigned a priority. Depending on these priorities, one task gets chosen for execution according to one simple rule:

Note: The scheduler activates the task that has the highest priority of all tasks in the READY state.

This means that every time a task with a priority higher than the running task becomes ready, it immediately becomes the running task, thus the previous task gets preempted. However, the scheduler can be switched off in sections of a program where task switches are prohibited, known as critical regions.

embOS uses a priority-controlled scheduling algorithm with round-robin between tasks of identical priority. One hint at this point: round-robin scheduling is a nice feature because you do not need to decide whether one task is more important than another. Tasks with identical priority cannot block each other for longer than their time slices. But round-robin scheduling also costs time if two or more tasks of identical priority are ready and no task of higher priority is ready, because execution constantly switch between the identical-priority tasks. It is more efficient to assign a different priority to each task, which will avoid unnecessary task switches.

2.4.3   Priority inversion / priority inheritance

The rule the scheduler obeys is:

Activate the task that has the highest priority of all tasks in the READY state.

But what happens if the highest-priority task is blocked because it is waiting for a resource owned by a lower-priority task? According to the above rule, it would wait until the low-priority task is resumed and releases the resource.
Up to this point, everything works as expected.
Problems arise when a task with medium priority becomes ready during the execution of the higher prioritized task.
When the higher priority task is suspended waiting for the resource, the task with the medium priority will run until it finishes its work, because it has a higher priority than the low-priority task.
In this scenario, a task with medium priority runs in place of the task with high priority. This is known as **priority inversion**.

With Priority Inversion

Low priority task   Medium priority task   High priority task

OS_Use()

Interrupt activates high prio task

OS_Use()

OS_Delay()

Time

OS_Unuse()

OS_Unuse()
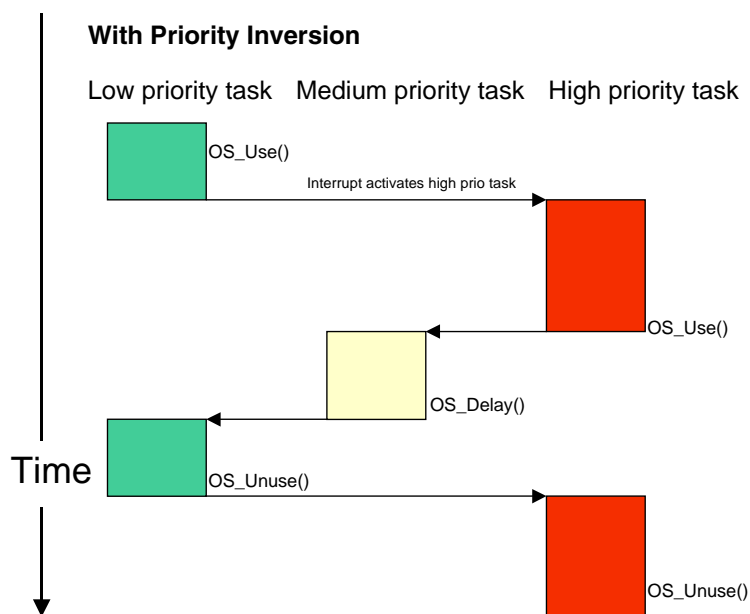
The low priority task claims the semaphore with OS_Use(). An interrupt activates the high priority task, which also calls OS_Use().
Meanwhile a task with medium priority becomes ready and runs when the high priority task is suspended.
The task with medium priority eventually calls OS_Delay() and is therefore suspended. The task with lower priority now continues and calls OS_Unuse() to release the resource semaphore. After the low priority task releases the semaphore, the high priority task is activated and claims the semaphore.

To avoid this situation, embOS temporarily raises the low-priority task to high priority until it releases the resource. This unblocks the task that originally had the highest priority and can now be resumed. This is known as **priority inheritance**.

With Priority Inheritance

Low priority task   Medium priority task   High priority task

OS_Use()

Interrupt activates high prio task

Priority inheritance

OS_Use()

OS_Unuse()

OS_Unuse()

Time
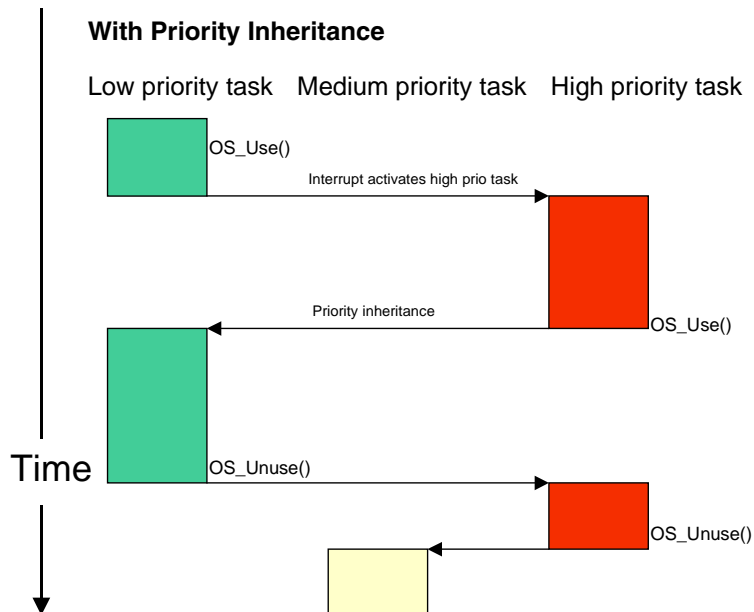
With priority inheritance, the low priority task inherits the priority of the waiting high priority task as long as it holds the resource semaphore. The lower priority task is activated instead of the medium priority task when the high priority task tries to claim the semaphore.

2.5   Communication between tasks

In a multitasking (multithreaded) program, multiple tasks and ISRs work completely separately. Because they all work in the same application, it will sometimes be necessary for them to exchange information with each other.

2.5.1   Periodic polling

The easiest way to communicate between different pieces of code is by using global variables. In certain situations, it can make sense for tasks to communicate via global variables, but most of the time this method has disadvantages.

For example, if you want to synchronize a task to start when the value of a global variable changes, you must continually poll this variable, wasting precious computation time and energy, and the reaction time depends on how often you poll.

2.5.2   Event-driven communication mechanisms

When multiple tasks work with each other, they often have to:

* exchange data,
* synchronize with another task, or
* make sure that a resource is used by no more than one task at a time.

For these purposes embOS offers mailboxes, queues, semaphores and events.

2.5.3   Mailboxes and queues

A mailbox is a data buffer managed by the RTOS and is used for sending a message to a task. It works without conflicts even if multiple tasks and interrupts try to access the same mailbox simultaneously. embOS activates any task that is waiting for a message in a mailbox the moment it receives new data and, if necessary, switches to this task.

A queue works in a similar manner, but handles larger messages than mailboxes, and each message may have an individual size.
For more information, refer to the chapters *Mailboxes* on page 147 and *Queues* on page 171.

2.5.4   Semaphores

Two types of semaphores are used for synchronizing tasks and to manage resources of any kind. The most common are resource semaphores, although counting semaphores are also used. For details and samples, refer to the chapters *Resource semaphores* on page 119 and *Counting Semaphores* on page 133.

2.5.5   Events

A task can wait for a particular event without consuming any calculation time. The idea is as simple as it is convincing, there is no sense in polling if we can simply activate a task the moment the event it is waiting for occurs. This saves processor cycles and energy and ensures that the task can respond to the event without delay. Typical applications for events are those where a task waits for some data, a pressed key, a received command or character, or the pulse of an external real-time clock.
For further details, refer to the chapters *Task events* on page 193 and *Event objects* on page 203.

2.6   How task switching works

A real-time multitasking system lets multiple tasks run like multiple single-task programs, quasi-simultaneously, on a single CPU. A task consists of three parts in the multitasking world:

- The program code, which typically resides in ROM
- A stack, residing in a RAM area that can be accessed by the stack pointer
- A task control block, residing in RAM.

The task's stack has the same function as in a single-task system: storage of return addresses of function calls, parameters and local variables, and temporary storage of intermediate results and register values. Each task can have a different stack size. More information can be found in chapter *Stacks* on page 243.

The task control block (TCB) is a data structure assigned to a task when it is created. The TCB contains status information for the task, including the stack pointer, task priority, current task status (ready, waiting, reason for suspension) and other management data. Knowledge of the stack pointer allows access to the other registers, which are typically stored (pushed onto) the stack when the task is created and each time it is suspended. This information allows an interrupted task to continue execution exactly where it left off. TCBs are only accessed by the RTOS.

2.6.1   Switching stacks

The following diagram demonstrates the process of switching from one stack to another.
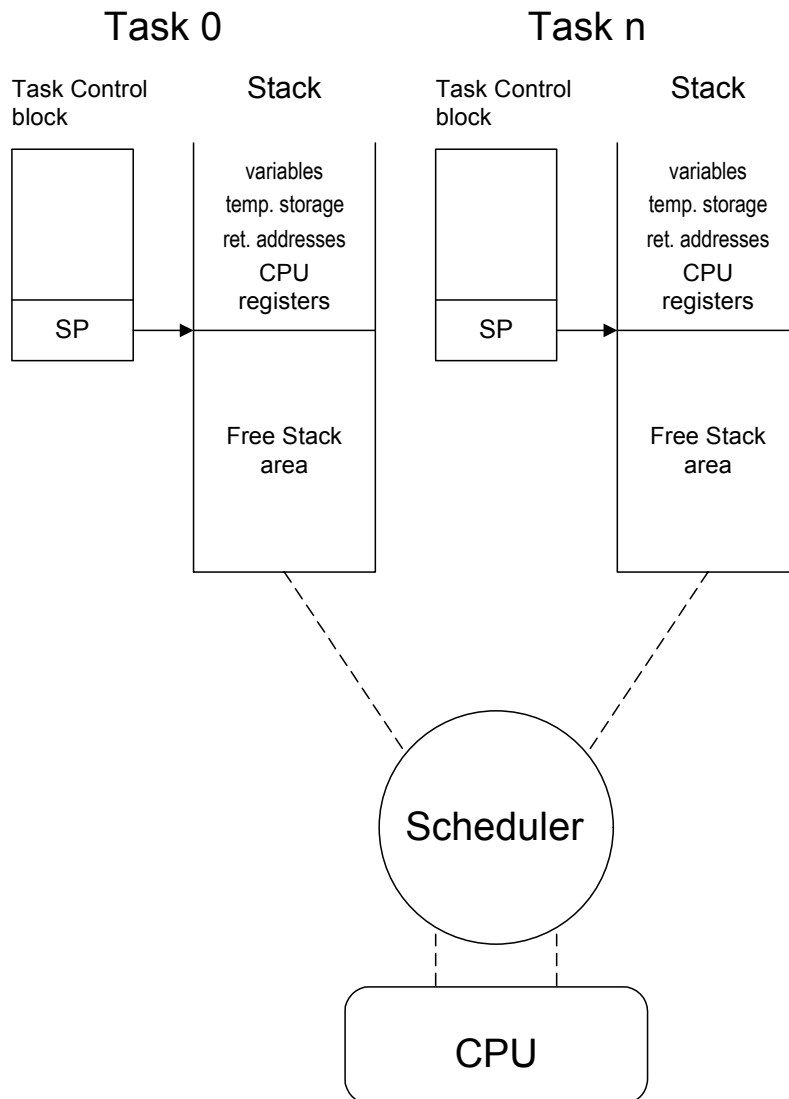
The scheduler deactivates the task to be suspended (Task 0) by saving the processor registers on its stack. It then activates the higher-priority task (Task n) by loading the stack pointer (SP) and the processor registers from the values stored on Task n's stack.

Deactivating a task

The scheduler deactivates the task to be suspended (Task 0) as follows:

1. Save (push) the processor registers on the task's stack.
2. Save the stack pointer in the Task Control Block.

Activating a task

The scheduler activates the higher-priority task (Task n) by performing the sequence in reverse order:

1. Load (pop) the stack pointer (SP) from the Task Control Block.
2. Load the processor registers from the values stored on Task n's stack.

2.7   Change of task status

A task may be in one of several states at any given time. When a task is created, it is placed into the READY state.

A task in the READY state is activated as soon as there is no other task in the READY state with higher priority. Only one task may be running at a time. If a task with higher priority becomes READY, this higher priority task is activated and the pre-empted task remains in the READY state.

The running task may be delayed for or until a specified time; in this case it is placed into the WAITING state and the next-highest-priority task in the READY state is activated.

The running task might need to wait for an event (or semaphore, mailbox or queue). If the event has not yet occurred, the task is placed into the waiting state and the next-highest-priority task in the READY state is activated.

A non-existent task is one that is not yet available to embOS; it either has been terminated or was not created at all.

The following illustration shows all possible task states and transitions between them.
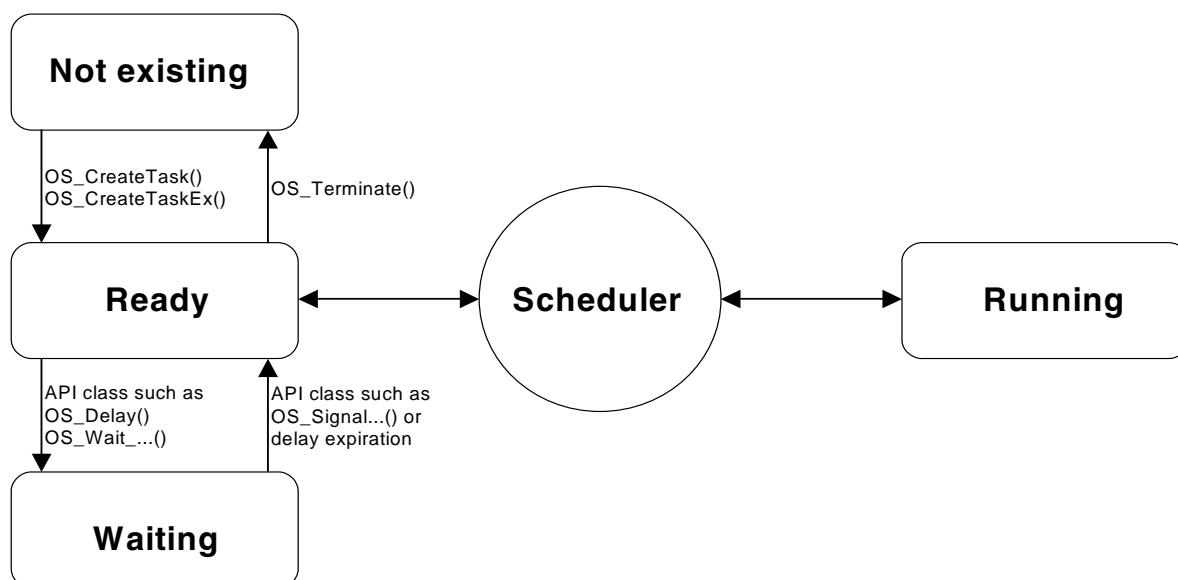
2.8   How the OS gains control

When the CPU is reset, the special-function registers are set to their default values. After reset, program execution begins. The PC register is set to the start address defined by the start vector or start address (depending on the CPU). This start address is usually in a startup module shipped with the C compiler, and is sometimes part of the standard library.

The startup code performs the following:

*   Loads the stack pointer(s) with the default values, which is for most CPUs the end of the defined stack segment(s)
*   Initializes all data segments to their respective values
*   Calls the `main()` function.

The `main()` function is the part of your program which takes control immediately after the C startup. Normally, embOS works with the standard C startup module without any modification. If there are any changes required, they are documented in the *CPU & Compiler Specifics manual* of the embOS documentation.

With embOS, the `main()` function is still part of your application program. Essentially, `main()` creates one or more tasks and then starts multitasking by calling `OS_Start()`. From this point, the scheduler controls which task is executed.

Startup code
└ **main()**
  ├ **OS_IncDI()**
  ├ **OS_InitKern()**
  ├ **OS_InitHW()**
  ├ **Additional initialization code;**
  │ **creating at least one task.**
  └ **OS_Start()**

The `main()` function will not be interrupted by any of the created tasks because those tasks execute only following the call to `OS_Start()`. It is therefore usually recommended to create all or most of your tasks here, as well as your control structures such as mailboxes and semaphores. Good practice is to write software in the form of modules which are (up to a point) reusable. These modules usually have an initialization routine, which creates any required task(s) and control structures.
A typical `main()` function looks similar to the following example:

Example

```
/**************************************************************************
*
*                      main
*
***************************************************************************
*/

void main(void) {
  OS_IncDI();
  OS_InitKern();         /* Initialize OS (should be first !)          */
  OS_InitHW();           /* Initialize Hardware for OS (in RtosInit.c) */
  /* Call Init routines of all program modules which in turn will create */
  /* the tasks they need ... (Order of creation may be important)        */
  MODULE1_Init();
  MODULE2_Init();
  MODULE3_Init();
  MODULE4_Init();
  MODULE5_Init();
  OS_Start();            /* Start multitasking */
}
```

With the call to `OS_Start()`, the scheduler starts the highest-priority task created in `main()`.
Note that `OS_Start()` is called only once during the startup process and does not return.

2.9   Different builds of embOS

embOS comes in different builds or versions of the libraries. The reason for different builds is that requirements vary during development. While developing software, the performance (and resource usage) is not as important as in the final version which usually goes as release build into the product. But during development, even small programming errors should be caught by use of assertions. These assertions are compiled into the debug build of the embOS libraries and make the code a little bigger (about 50%) and also slightly slower than the release or stack-check build used for the final product.

This concept gives you the best of both worlds: a compact and very efficient build for your final product (release or stack-check build of the libraries), and a safer (though bigger and slower) build for development which will catch most common application programming errors. Of course, you may also use the release build of embOS during development, but it will not catch these errors.

2.9.1   Profiling

embOS supports profiling in profiling builds. Profiling makes precise information available about the execution time of individual tasks. You may always use the profiling libraries, but they require larger task control blocks, additional ROM (approximately 200 bytes) and additional runtime overhead. This overhead is usually acceptable, but for best performance you may want to use non-profiling builds of embOS if you do not use this feature.

2.9.2   List of libraries

In your application program, you need to let the compiler know which build of embOS you are using. This is done by defining a single identifier prior to including `RTOS.h`.

Name	Define	Debug code	Stack check	Profiling	Trace	Round Robin	Task names	Description
Extreme Release	`OS_LIBMODE_XR`							Smallest fastest build.
Release	`OS_LIBMODE_R`					X	X	Small, fast build, normally used for release build of application.
Stack check	`OS_LIBMODE_S`		X			X	X	Same as release, plus stack checking.
Stackcheck plus profiling	`OS_LIBMODE_SP`		X	X		X	X	Same as stack check, plus profiling.
Debug	`OS_LIBMODE_D`	X	X			X	X	Maximum runtime checking.
Debug plus profiling	`OS_LIBMODE_DP`	X	X	X		X	X	Maximum runtime checking, plus profiling.
Debug including trace, profiling	`OS_LIBMODE_DT`	X	X	X	X	X	X	Maximum runtime checking, plus tracing API calls and profiling.

Table 2.1: List of libraries

2.9.3   embOS functions context

Not all embOS functions can be called from every place in your application. We need to distinguish between Main (before the call of OS_Start()), Task, ISR and Software timer.

Please consult the embOS API tables to be sure that an embOS function is allowed to be called from your execution context, e.g. from an ISR. The embOS debug build helps you to check that you do not violate these rules.

Chapter 3

Working with embOS

This chapter gives some recommendations on how to use embOS in your applications. These are simply recommendations that we feel are helpful when designing and structuring an application.

3.1   General advice

- Avoid Round Robin if possible

- Avoid dynamically creating and terminating tasks

- Avoid nesting interrupts if possible

3.1.1   Timers or task

For periodic jobs you can use either a task or a software timer. An embOS software timer has the advantage that it does not need its own task stack since it runs on the system stack.

Chapter 4

Tasks

This chapter explains some basic concepts related to tasks and embOS task API functions. It should be relatively easy to read and is recommended before moving to other chapters.

4.1   Introduction

A task that should run under embOS needs a task control block (TCB), a stack, and a task body written in C. The following rules apply to task routines:

- The task routine can either not take parameters (void parameter list), in which case `OS_CreateTask()` is used to create it, or take a single void pointer as parameter, in which case `OS_CreateTaskEx()` is used to create it.
- The task routine must not return.
- The task routine must be implemented as an endless loop or it must terminate itself (see examples below).

4.1.1   Example of a task routine as an endless loop

```
/*  Example of a task routine as an endless loop    */
void Task1(void) {
  while(1) {
    DoSomething();                    /* Do something  */
    OS_Delay(1);          /* Give other tasks a chance */
  }
}
```

4.1.2   Example of a task routine that terminates itself

```
/*  Example of a task routine that terminates       */
void Task2(void) {
  char DoSomeMore;
  do {
    DoSomeMore = DoSomethingElse(); /* Do something */
    OS_Delay(1);          /* Give other tasks a chance */
  } while (DoSomeMore);
  OS_TerminateTask(0);          /* Terminate yourself */
}
```

There are different ways to create a task; embOS offers a simple macro that makes this easy and which is sufficient in most cases. However, if you are dynamically creating and deleting tasks, a function is available allowing "fine-tuning" of all parameters. For most applications, at least initially, using the macro as in the sample start project works fine.

4.2   Cooperative vs. preemptive task switches

In general, preemptive task switches are an important feature of an RTOS. Preemptive task switches are required to guarantee responsiveness of high-priority, time-critical tasks. However, it may be desireable to disable preemptive task switches for certain tasks in some circumstances. The default behavior of embOS is to always allow preemptive task switches.

4.2.1   Disabling preemptive task switches for tasks of equal priority

In some situations, preemptive task switches between tasks running at identical priorities are not desireable. To inhibit time slicing of equal-priority tasks, the time slice of the tasks running at identical priorities must be set to zero as in the example below:

```
#include "RTOS.h"

#define PRIO_COOP       10
#define TIME_SLICE_NULL 0

OS_STACKPTR int StackHP[128], StackLP[128];          /* Task stacks */
OS_TASK TCBHP, TCBLP;                          /* Task-control-blocks */
/************************************************************************/
static void TaskEx(void *pData) {
  while (1) {
    OS_Delay ((OS_TIME) pData);
  }
}
/************************************************************************
*
*      main
*
************************************************************************/
int main(void) {
  OS_IncDI();                        /* Initially disable interrupts  */
  OS_InitKern();                     /* initialize OS                 */
  OS_InitHW();                       /* initialize Hardware for OS    */
  /* You need to create at least one task before calling OS_Start() */
  OS_CreateTaskEx(&TCBHP, "HP Task", PRIO_COOP, TaskEx, StackHP,
                  sizeof(StackHP), TIME_SLICE_NULL, (void *) 50);
  OS_CreateTaskEx(&TCBLP, "LP Task", PRIO_COOP, TaskEx, StackLP,
                  sizeof(StackLP), TIME_SLICE_NULL, (void *) 200);
  OS_Start();                        /* Start multitasking            */
  return 0;
}
```

4.2.2   Completely disabling preemptions for a task

This is simple: The first line of code should be OS_EnterRegion() as shown in the following sample:

```
void MyTask(void *pContext) {
  OS_EnterRegion();          /* Disable preemptive context switches */
  while (1) {
    // Do something. In the code, make sure that you call a blocking
    // funtion periodically to give other tasks a chance to run.
  }
}
```

Note: This will entirely disable preemptive context switches from that particular task and will therefore affect the timing of higher-priority-tasks. Do not use this carelessly.

4.3   Extending the task context

For some applications it might be useful or required to have individual data in tasks that are unique to the task.

Local variables, declared in the task, are unique to the task and remain valid, even when the task is suspended and resumed again.

When the same task function is used for multiple tasks, local variables in the task may be used, but cannot be initialized individually for every task.

embOS offers different options to extend the task context.

4.3.1   Passing one parameter to a task during task creation

Very often it is sufficient to have just one individual parameter passed to a task.

Using the `OS_CREATETASK_EX()` or `OS_CreateTaskEx()` function to create a task allows passing a void-pointer to the task. The pointer may point to individual data, or may represent any data type that can be held within a pointer.

4.3.2   Extending the task context individually at runtime

Sometimes it may be required to have an extended task context for individual tasks to store global data or special CPU registers such as floating-point registers in the task context.

The standard libraries for file I/O, locale support and others may require task-local storage for specific data like `errno` and other variables.

embOS enables extension of the task context for individual tasks during runtime by a call of `OS_ExtendTaskContext()`.

The sample application file `OS_ExtendTaskContext.c` delivered in the application samples folder of embOS demonstrates how the individual task context extension can be used.

4.3.3   Extending the task context by using own task structures

When complex data is needed for an individual task context, the `OS_CREATETASK_EX()` or `OS_CreateTaskEx()` functions may be used, passing a pointer to individual data structures to the task.

Alternatively you may define your own task structure which can be used.

Note, that the first item in the task structure must be an embOS task control structure OS_TASK. This can be followed by any amount and type of additional data of different types.

The following code shows the example application `OS_ExtendedTask.c` which is delivered in the sample application folder of embOS.

```c
/*************************************************************************
*               SEGGER MICROCONTROLLER GmbH & Co KG                     *
*       Solutions for real time microcontroller applications            *
**************************************************************************
-------------------------------------------------------------------------
File    : OS_ExtendedTask.c
Purpose : Skeleton program for OS to demonstrate extended tasks
--------   END-OF-HEADER  ------------------------------------------------
*/
#include "RTOS.h"
#include <stdio.h>

/****** Define an own task structure with extended task context *****/
typedef struct {
  OS_TASK   Task;      // OS_TASK must be the first element
  OS_TIME   Timeout;   // Any other data may follow
  char     *pString;
} MY_APP_TASK;

/****** Variables ****************************************************/
OS_STACKPTR int StackHP[128], StackLP[128];          /* Task stacks */
MY_APP_TASK     TCBHP, TCBLP;                 /* Task-control-blocks */

/*************************************************************************
*
*       Task function
*/
static void MyTask(void) {
  char*         pString;
  OS_TIME       Delay;
  MY_APP_TASK *pThis;
  pThis = (MY_APP_TASK *) OS_GetTaskID();
  while (1) {
    Delay   = pThis->Timeout;
    pString = pThis->pString;
    printf(pString);
    OS_Delay (Delay);
  }
}

/*************************************************************************
*
*       main
*
*************************************************************************/
int main(void) {
  OS_IncDI();                       /* Initially disable interrupts  */
  OS_InitKern();                    /* Initialize OS                 */
  OS_InitHW();                      /* Initialize Hardware for OS     */
  /*
   *  Create the extended tasks just as normal tasks.
   *  Note that the first paramater must be of type OS_TASK
   */
  OS_CREATETASK(&TCBHP.Task, "HP Task", MyTask, 100, StackHP);
  OS_CREATETASK(&TCBLP.Task, "LP Task", MyTask,  50, StackLP);
  /*
   *  Give task contexts individual data
   */
  TCBHP.Timeout = 200;
  TCBHP.pString = "HP task running\n";
  TCBLP.Timeout = 500;
  TCBLP.pString = "LP task running\n";
  OS_Start();                       /* Start multitasking            */
  return 0;
}
```

4.4   API functions

Routine	Description	main	Task	ISR	Timer
OS_AddOnTerminateHook()	Adds a hook (callback) function to the list of functions which are called when a task is terminated.	X	X		
OS_CREATETASK()	Creates a task.	X	X		
OS_CreateTask()	Creates a task.	X	X		
OS_CREATETASK_EX()	Creates a task with parameter.	X	X		
OS_CreateTaskEx()	Creates a task with parameter.	X	X		
OS_Delay()	Suspends the calling task for a specified period of time.	X	X		
OS_DelayUntil()	Suspends the calling task until a specified time.	X	X		
OS_Delayus()	Waits for the given time in microseconds	X	X		
OS_ExtendTaskContext()	Make global variables or processor registers task-specific.		X		
OS_AddExtendTaskContext()	Adds an additional task context extension.		X		
OS_GetPriority()	Returns the priority of a specified task	X	X	X	X
OS_GetSuspendCnt()	Returns the suspension count.	X	X	X	X
OS_GetTaskID()	Returns a pointer to the task control block structure of the currently running task.	X	X	X	X
OS_GetTaskName()	Returns the name of a task.	X	X	X	X
OS_GetTimeSliceRem()	Returns the remaining time slice time of a task.	X	X	X	X
OS_IsRunning()	Examine whether OS_Start() was called.	X	X	X	X
OS_IsTask()	Determines whether a task control block actually belongs to a valid task.	X	X	X	X
OS_Resume()	Decrements the suspend count of specified task and resumes the task, if the suspend count reaches zero.		X	X	
OS_ResumeAllSuspendedTasks()	Decrements the suspend count of specified task and resumes the task, if the suspend count reaches zero.		X	X	
OS_SetDefaultTaskContextExtension()	Sets the default task context extension for newly created tasks	X			
OS_SetInitialSuspendCnt()	Sets an initial suspension count for newly created tasks.	X	X	X	X
OS_SetPriority()	Assigns a specified priority to a specified task.	X	X		
OS_SetTaskName()	Allows modification of a task name at runtime.	X	X	X	X
OS_SetTimeSlice()	Assigns a specified time slice value to a specified task.	X	X	X	X
OS_Start()	Start the embOS kernel.	X			
OS_Suspend()	Suspends the specified task and increments a counter.		X		
OS_SuspendAllTasks()	Suspends all tasks except the running task.	X	X	X	X

Table 4.1: Task routine API list

Routine	Description	main	Task	ISR	Timer
OS_TaskIndex2Ptr()	Returns the task control block of the task with the Index TaskIndex.	X	X	X	X
OS_TerminateTask()	Ends (terminates) a task.	X	X		
OS_WakeTask()	Ends delay of a task immediately.	X	X	X	
OS_Yield()	Calls the scheduler to force a task switch.		X		

Table 4.1: Task routine API list

4.4.1 OS_AddOnTerminateHook()

Description

Adds a handler function to a list of functions that are called when a task is terminated.

Prototype

```
void OS_AddOnTerminateHook (OS_ON_TERMINATE_HOOK *pHook,
                            OS_ON_TERMINATE_FUNC *pfUser);
```

Parameter	Description
pHook	Pointer to a variable of type OS_ON_TERMINATE_HOOK which will be inserted into the linked list of functions to be called during OS_TerminateTask().
pfUser	Pointer to the function of type OS_TERMINATE_FUNC which shall be called when a task is terminated.

Table 4.2: OS_AddOnTerminateHook() parameter list

Additional Information

For some applications, it may be useful to allocate memory or objects specific to tasks. For other applications, it may be useful to have task-specific information on the stack.
When a task is terminated, the task-specific objects may become invalid.
A callback function may be hooked into OS_TerminateTask() by calling OS_AddOnTerminateHook() to allow the application to invalidate all task-specific objects before the task is terminated.

The callback function of type OS_ON_TERMINATE_FUNC receives the ID of the terminated task as its parameter.
OS_ON_TERMINATE_FUNC is defined as:
```
typedef void OS_ON_TERMINATE_FUNC(OS_CONST_PTR OS_TASK * pTask);
```

Important

The variable of type OS_ON_TERMINATE_HOOK must reside in memory as a global or static variable. It may be located on a task stack, as local variable, but it must **not** be located on any stack of any task that might be terminated.

Example

```
OS_ON_TERMINATE_HOOK _OnTerminateHook; /* Stack-space */

...
void OnTerminateHookFunc(OS_CONST_PTR OS_TASK *pTask) {
  // This function is called when OS_TerminateTask() is called.
  if (pTask == &MyTask) {
    free(MytaskBuffer);
  }
}
...
main(void) {
  OS_AddOnTerminateHook(&_OnTerminateHook, OnTerminateHookFunc);
  ...
}
```

4.4.2   OS_CREATETASK()

Description

Creates a task.

Prototype

```
void  OS_CREATETASK ( OS_TASK *pTask,
                      char    *pName,
                      void    *pRoutine,
                      OS_PRIO  Priority,
                      void    *pStack);
```

Parameter	Description
pTask	Pointer to a task control block structure.
pName	Pointer to the name of the task. Can be NULL (or 0) if not used.
pRoutine	Pointer to a function that should run as the task body.
Priority	Priority of the task. Must be within the following range: $1 <= $ Priority $<= 2^8\text{-}1 = $ 0xFF for 8/16 bit CPUs $1 <= $ Priority $<= 2^{32}\text{-}1 = $ 0xFFFFFFFF for 32 bit CPUs Higher values indicate higher priorities. The type OS_PRIO is defined as 32 bit value for 32 bit CPUs and 8bit value for 8 or 16 bit CPUs by default.
pStack	Pointer to an area of memory in RAM that will serve as stack area for the task. The size of this block of memory determines the size of the stack area.

Table 4.3: OS_CREATETASK() parameter list

Additional Information

OS_CREATETASK() is a macro which calls an OS library function. It creates a task and makes it ready for execution by placing it into the READY state. The newly created task will be activated by the scheduler as soon as there is no other task with higher priority in the READY state. If there is another task with the same priority, the new task will be placed immediately before it. This macro is normally used for creating a task instead of the function call OS_CreateTask() because it has fewer parameters and is therefore easier to use.

OS_CREATETASK() can be called either from main() during initialization or from any other task. The recommended strategy is to create all tasks during initialization in main() to keep the structure of your tasks easy to understand.
The absolute value of Priority is of no importance, only the value in comparison to the priorities of other tasks matters.

OS_CREATETASK() determines the size of the stack automatically, using sizeof(). This is possible only if the memory area has been defined at compile time.

Important

The stack that you define must reside in an area that the CPU can address as stack. Most CPUs cannot use the entire memory area as stack and require the stack to be aligned to a multiple of the processor word size.
The task stack cannot be shared between multiple tasks and must be assigned to one task only. The memory used as task stack cannot be used for other purposes unless the task is terminated.

Example

```
OS_STACKPTR int UserStack[150]; /* Stack-space */
OS_TASK UserTCB;                /* Task-control-blocks */

void UserTask(void) {
  while (1) {
    Delay (100);
  }
}

void InitTask(void) {
  OS_CREATETASK(&UserTCB, "UserTask", UserTask, 100, UserStack);
}
```

```
OS_STACKPTR int UserStack[150]; /* Stack-space */
OS_TASK UserTCB;                /* Task-control-blocks */
```

4.4.3   OS_CreateTask()

Description

Creates a task.

Prototype

```
void OS_CreateTask ( OS_TASK        *pTask,
                     char           *pName,
                     OS_PRIO         Priority,
                     voidRoutine    *pRoutine,
                     void           *pStack,
                     unsigned        StackSize,
                     unsigned char   TimeSlice );
```

Parameter	Description
pTask	Pointer to a task control block structure.
pName	Pointer to the name of the task. Can be NULL (or 0) if not used.
Priority	Priority of the task. Must be within the following range: $1 <=$ Priority $<= 2^8-1 = 0xFF$ for 8/16 bit CPUs $1 <=$ Priority $<= 2^{32}-1 = 0xFFFFFFFF$ for 32 bit CPUs Higher values indicate higher priorities. The type OS_PRIO is defined as a 32 bit value for 32 bit CPUs and as an 8 bit value for 8 or 16 bit CPUs by default.
pRoutine	Pointer to a function that should run as the task body.
pStack	Pointer to an area of memory in RAM that will serve as stack area for the task. The size of this block of memory determines the size of the stack area.
StackSize	Size of the stack in bytes.
TimeSlice	Time slice value for round-robin scheduling. Has an effect only if other tasks are running at the same priority. TimeSlice denotes the time in embOS timer ticks that the task will run before it suspends, thus enabling another task with the same priority. The time slice value must be in the following range: $0 <=$ TimeSlice $<= 255$.

Table 4.4: OS_CreateTask() parameter list

Additional Information

This function works the same way as OS_CREATETASK(), except that all parameters of the task can be specified.
The task can be dynamically created because the stack size is not calculated automatically as it is with the macro.
A time slice value of zero is allowed and disables round-robin task switches (see sample in chapter *Disabling preemptive task switches for tasks of equal priority* on page 49).

Important

The stack that you define must reside in an area that the CPU can address as stack. Most CPUs cannot use the entire memory area as stack and require the stack to be aligned to a multiple of the processor word size.
The task stack cannot be shared between multiple tasks and must be assigned to one task only. The memory used as task stack cannot be used for other purposes unless the task is terminated.

Example

```
/* Demo-program to illustrate the use of OS_CreateTask */

OS_STACKPTR int StackMain[100], StackClock[50];
OS_TASK TaskMain,TaskClock;
OS_SEMA SemaLCD;

void Clock(void) {
  while(1) {
    /* Code to update the clock */
  }
}

void Main(void) {
  while (1) {
    /* Your code  */
  }
}

void InitTask(void) {
  OS_CreateTask(&TaskMain,  NULL, 50, Main,  StackMain, sizeof(StackMain), 2);
  OS_CreateTask(&TaskClock, NULL, 100, Clock,StackClock,sizeof(StackClock),2);
}
```

4.4.4   OS_CREATETASK_EX()

Description

Creates a task and passes a parameter to the task.

Prototype

```
void  OS_CREATETASK_EX ( OS_TASK *pTask,
                         char    *pName,
                         void    *pRoutine,
                         OS_PRIO  Priority,
                         void    *pStack,
                         void    *pContext );
```

Parameter	Description
pTask	Pointer to a task control block structure.
pName	Pointer to the name of the task. Can be NULL (or 0) if not used.
pRoutine	Pointer to a function that should run as the task body.
Priority	Priority of the task. Must be within the following range: $1 <= $ Priority $ <= 2^8-1 = $ 0xFF for 8/16 bit CPUs $1 <= $ Priority $ <= 2^{32}-1 = $ 0xFFFFFFFF for 32 bit CPUs Higher values indicate higher priorities. The type OS_PRIO is defined as a 32 bit value for 32 bit CPUs and an 8 bit value for 8 or 16 bit CPUs per default.
pStack	Pointer to an area of memory in RAM that will serve as stack area for the task. The size of this block of memory determines the size of the stack area.
pContext	Parameter passed to the created task function.

Table 4.5: OS_CREATETASK_EX() parameter list

Additional Information

OS_CREATETASK_EX() is a macro calling an embOS library function. It works like OS_CREATETASK() but allows passing a parameter to the task.
Using a void pointer as an additional parameter gives the flexibility to pass any kind of data to the task function.

Example

The following example is delivered in the Samples folder of embOS.

```
/*-----------------------------------------------------------------
File    : OS_CreateTaskEx.c
Purpose : Sample program for embOS using OC_CREATETASK_EX
--------- END-OF-HEADER -------------------------------------------*/

#include "RTOS.h"
OS_STACKPTR int StackHP[128], StackLP[128];            /* Task stacks */
OS_TASK TCBHP, TCBLP;                          /* Task-control-blocks */
/********************************************************************/
static void TaskEx(void *pVoid) {
  while (1) {
    OS_Delay ((OS_TIME) pVoid);
  }
}
/********************************************************************
*
*       main
*
********************************************************************/
int main(void) {
  OS_IncDI();                          /* Initially disable interrupts  */
  OS_InitKern();                       /* initialize OS                 */
  OS_InitHW();                         /* initialize Hardware for OS     */
  /* You need to create at least one task before calling OS_Start() */
  OS_CREATETASK_EX(&TCBHP, "HP Task", TaskEx, 100, StackHP, (void*) 50);
  OS_CREATETASK_EX(&TCBLP, "LP Task", TaskEx,  50, StackLP, (void*) 200);
  OS_SendString("Start project will start multitasking !\n");
  OS_Start();                          /* Start multitasking            */
  return 0;
}
```

4.4.5   OS_CreateTaskEx()

Description

Creates a task and passes a parameter to the task.

Prototype

```
void OS_CreateTaskEx ( OS_TASK        *pTask,
                       char           *pName,
                       OS_PRIO         Priority,
                       voidRoutine    *pRoutine,
                       void           *pStack,
                       unsigned        StackSize,
                       unsigned char   TimeSlice,
                       void           *pContext );
```

Parameter	Description
pTask	Pointer to a task control block structure.
pName	Pointer to the name of the task. Can be NULL (or 0) if not used.
Priority	Priority of the task. Must be within the following range: $1 <= $ Priority $<= 2^8\text{-}1 = $ 0xFF for 8/16 bit CPUs $1 <= $ Priority $<= 2^{32}\text{-}1 = $ 0xFFFFFFFF for 32 bit CPUs Higher values indicate higher priorities. The type OS_PRIO is defined as a 32 bit value for 32 bit CPUs and an 8 bit value for 8 or 16 bit CPUs per default.
pRoutine	Pointer to a function that should run as the task body.
pStack	Pointer to an area of memory in RAM that will serve as stack area for the task. The size of this block of memory determines the size of the stack area.
StackSize	Size of the stack in bytes.
TimeSlice	Time slice value for round-robin scheduling. Has an effect only if other tasks are running at the same priority. TimeSlice denotes the time in embOS timer ticks that the task will run until it suspends; thus enabling another task with the same priority. The time slice value must be in the following range: $0 <= $ TimeSlice $<= 255$.
pContext	Parameter passed to the created task.

Table 4.6: OS_Create_TaskEx() parameter list

Additional Information

This function works the same way as OS_CreateTask() except that a parameter is passed to the task function.
An example of parameter passing to tasks is shown under OS_CREATETASK_EX().
A time slice value of zero is allowed and disables round-robin task switches (see sample in chapter *Disabling preemptive task switches for tasks of equal priority* on page 49).

Important

The stack that you define must reside in an area that the CPU can address as stack. Most CPUs cannot use the entire memory area as stack and require the stack to be aligned to a multiple of the processor word size.
The task stack cannot be shared between multiple tasks and must be assigned to one task only. The memory used as task stack cannot be used for other purposes unless the task is terminated.

4.4.6   OS_Delay()

Description

Suspends the calling task for a specified period of time.

Prototype

```
void OS_Delay (OS_TIME ms);
```

Parameter	Description
ms	Time interval to delay. Must be within the following range: 2^{15} = 0x8000 <= ms <= 2^{15}-1 = 0x7FFF for 8/16 bit CPUs 2^{31} = 0x80000000 <= ms <= 2^{31}-1 = 0x7FFFFFFF for 32 bit CPUs Please note that these are signed values.

Table 4.7: OS_Delay() parameter list

Additional Information

The calling task is placed into the WAITING state for the period of time specified. The task will stay in the delayed state until the specified time has expired. OS_Delay() returns immediately if the parameter ms is less than or equal to zero. The parameter ms specifies the precise interval during which the task is suspended given in basic time intervals (usually 1/1000 seconds). The actual delay (in basic time intervals) will be in the following range: ms - 1 <= delay <= ms, depending on when the interrupt for the scheduler occurs.
After the expiration of the delay, the task is made ready and activated according to the rules of the scheduler. A delay can be ended prematurely by another task or by an interrupt handler calling OS_WakeTask().

Example

```
void Hello(void) {
  printf("Hello");
  printf("The next output will occur in 5 seconds");
  OS_Delay (5000);
  printf("Delay is over");
}
```

4.4.7   OS_DelayUntil()

Description

Suspends the calling task until a specified time.

Prototype

```
void OS_DelayUntil (OS_TIME t);
```

Parameter	Description
t	Time to delay until. Must be within the following range: $0 <= t <= 2^{16}-1 = $ 0xFFFF = 65535 for 8/16 bit CPUs $0 <= t <= 2^{32}-1 = $ 0xFFFFFFFF for 32 bit CPUs and must meet the following additional condition $1 <= (t - $ OS_Time$) <= 2^{15}-1 = $ 0x7FFF = 32767 for 8/16 bit CPUs $1 <= (t - $ OS_Time$) <= 2^{31}-1 = $ 0x7FFFFFFF for 32 bit CPUs

Table 4.8: OS_DelayUntil() parameter list

Additional Information

The calling task will be put into the WAITING state until the time specified.
The `OS_DelayUntil()` function delays until the value of the time-variable `OS_Time` reaches a certain value. It is very useful to avoid accumulating delays.
An embOS SysTick timer overflow is no problem as long as parameter t is within the specified range.

Example

```
int sec,min;

void TaskShowTime(void) {
  OS_TIME t0;
  t0 = OS_GetTime();
  while (1) {
    ShowTime();                    /* Routine to display time */
    t0 += 1000;
    OS_DelayUntil (t0);
    if (sec < 59) {
      sec++;
    } else {
      sec = 0;
      min++;
    }
  }
}
```

In the example above, using `OS_Delay()` could lead to accumulating delays and would cause the simple "clock" to be slow.

4.4.8   OS_Delayus()

Description

Waits for the given time in microseconds.

Prototype

```
void OS_Delayus (OS_U16 us);
```

Parameter	Description
us	Number of microseconds to delay. Must be within the following range: $1 <= us <= 2^{15}\text{-}1 = 0\text{x7FFF} = 32767$

Table 4.9: OS_Delay() parameter list

Additional Information

This function can be used for short delays.

`OS_Delayus()` must only be called with interrupts enabled and after OS_InitKern() and OS_InitHW() have been called. This only works when the embOS system timer is running. The embOS debug build of `OS_Delayus()` checks that interrupts are enabled, and if not then `OS_Error()` is called.

`OS_Delayus()` does not block task switches and does not block interrupts. Therefore, the delay may not be accurate because the function may be interrupted for an undefined time. The delay duration therefore is a minimum delay.

OS_Delayus() does not suspend the calling task, thus all tasks with lower priority can not interrupt OS_Delayus() and will not be executed before OS_Delayus() returns.

Example

```
void Hello(void) {
  printf("Hello");
  printf("The next output will occur in 500 microseconds");
  OS_Delayus (500);
  printf("Delay is over");
}
```

4.4.9   OS_ExtendTaskContext()

Description

The function may be used for a variety of purposes. Typical applications are:

- global variables such as "errno" in the C library, making the C-lib functions thread-safe.
- additional, optional CPU / registers such as MAC / EMAC registers (multiply and accumulate unit) if they are not saved in the task context per default.
- Coprocessor registers such as registers of a VFP (floating-point coprocessor).
- Data registers of an additional hardware unit such as a CRC calculation unit

This allows the user to extend the task context as required. A major advantage is that the task extension is task-specific. This means that the additional information (such as floating-point registers) needs to be saved only by tasks that actually use these registers. The advantage is that the task switching time of other tasks is not affected. The same is true for the required stack space: Additional stack space is required only for the tasks which actually save the additional registers.

Prototype

```
void OS_ExtendTaskContext(const OS_EXTEND_TASK_CONTEXT * pExtendContext);
```

Parameter	Description
pExtendContext	Pointer to the OS_EXTEND_TASK_CONTEXT structure which contains the addresses of the specific save and restore functions that save and restore the extended task context during task switches.

Table 4.10: OS_ExtendTaskContext() parameter list

Additional Information

The OS_EXTEND_TASK_CONTEXT structure is defined as follows:

```
typedef struct OS_EXTEND_TASK_CONTEXT {
  void* (*pfSave)    (      void *pStack);
  void* (*pfRestore)(const void *pStack);
} OS_EXTEND_TASK_CONTEXT;
```

The save and restore functions must be declared according the function type used in the structure. The sample below shows how the task stack must be addressed to save and restore the extended task context.

OS_ExtendTaskContext() is not available in the XR libraries.

Important

The task context can be extended only once per task with OS_ExtendTaskContext(). The function must not be called multple times for one task. Additional task context extensions can be set with OS_AddExtendTaskContext().

Example

The following example is delivered in the `Application` folder of embOS.

```c
/*-------------------------------------------------------------------------
File : OS_ExtendTaskContext.c
Purpose : Sample program for embOS demonstrating how to dynamically
extend the task context.
This example adds a global variable to the task context of
certain tasks.
-------- END-OF-HEADER ------------------------------------------------
*/
#include "RTOS.h"

OS_STACKPTR int StackHP[128], StackLP[128];          /* Task stacks */
OS_TASK TCBHP, TCBLP;                          /* Task-control-blocks */
int GlobalVar;

/***********************************************************************
*
*       _Restore
*       _Save
*
*  Function description
*    This function pair saves and restores an extended task context.
*    In this case, the extended task context consists of just a single
*    member, which is a global variable.
*/
typedef struct {
  int GlobalVar;
} CONTEXT_EXTENSION;

static void* _Save(void *pStack) {
  CONTEXT_EXTENSION *p;
  p = ((CONTEXT_EXTENSION *)pStack) - (1 - OS_STACK_AT_BOTTOM);  // Create pointer
  //
  // Save all members of the structure
  //
  p->GlobalVar = GlobalVar;
  return (void*)p;
}

static void* _Restore(const void *pStack) {
  CONTEXT_EXTENSION *p;
  p = ((CONTEXT_EXTENSION *)pStack) - (1 - OS_STACK_AT_BOTTOM);  // Create pointer
  //
  // Restore all members of the structure
  //
  GlobalVar = p->GlobalVar;
  return (void*)p;
}

/***********************************************************************
*
*       Global variable which holds the function pointers
*       to save and restore the task context.
*/
const OS_EXTEND_TASK_CONTEXT _SaveRestore = {
  _Save,
  _Restore
};

/**********************************************************************/

/***********************************************************************
*
*       HPTask
*
*  Function description
*    During the execution of this function, the thread-specific
*    global variable has always the same value of 1.
*/
static void HPTask(void) {
  OS_ExtendTaskContext(&_SaveRestore);
  GlobalVar = 1;
  while (1) {
    OS_Delay(10);
  }
}
```

```
/************************************************************************
*
*       LPTask
*
*  Function description
*    During the execution of this function, the thread-specific
*    global variable has always the same value of 2.
*/
static void LPTask(void) {
  OS_ExtendTaskContext(&_SaveRestore);
  GlobalVar = 2;
  while (1) {
    OS_Delay(50);
  }
}

/************************************************************************
*
*       main
*/
int main(void) {
  OS_IncDI();                       /* Initially disable interrupts  */
  OS_InitKern();                    /* initialize OS                 */
  OS_InitHW();                      /* initialize Hardware for OS     */
  /* You need to create at least one task here !                     */
  OS_CREATETASK(&TCBHP, "HP Task", HPTask, 100, StackHP);
  OS_CREATETASK(&TCBLP, "LP Task", LPTask,  50, StackLP);
  OS_Start();                       /* Start multitasking            */
  return 0;
}
```

4.4.10 OS_AddExtendTaskContext()

Description

The task context can be extended with `OS_ExtendTaskContext()` only once. Additional task context extensions can be added with `OS_AddExtendTaskContext()`. The function `OS_AddExtendTaskContext()` requires an additional parameter of type `OS_EXTEND_TASK_CONTEXT_LINK` which is used to create a task specific linked list of task context extensions.

Prototype

```
void OS_AddExtendTaskContext(OS_EXTEND_TASK_CONTEXT_LINK*
                              pExtendContextLink,
                              const OS_EXTEND_TASK_CONTEXT* pExtendContext);
```

Parameter	Description
pExtendContextLink	Pointer to the `OS_EXTEND_TASK_CONTEXT_LINK` structure.
pExtendContext	Pointer to the `OS_EXTEND_TASK_CONTEXT` structure which contains the addresses of the specific save and restore functions that save and restore the extended task context during task switches.

Table 4.11: OS_AddExtendTaskContext() parameter list

Additional Information

The object of type `OS_EXTEND_TASK_CONTEXT_LINK` is task specific and must only be used for one task. It can be located e.g. on the task stack.

Example

```
static void HPTask(void) {
  OS_EXTEND_TASK_CONTEXT_LINK p;
  //
  // Extend the task context with VFP registers and global variable
  //
  OS_ExtendTaskContext(&OS_VFP_ExtendContext);
  OS_AddExtendTaskContext(&p, &_SaveRestore);
  a = 1.2;
  while (1) {
    b = 3 * a;
    GlobalVar = 1;
    OS_Delay(10);
  }
}
```

4.4.11 OS_GetPriority()

Description

Returns the priority of a specified task.

Prototype

```
OS_PRIO OS_GetPriority (const OS_TASK *pTask);
```

Parameter	Description
pTask	Pointer to a task control block structure.

Table 4.12: OS_GetPriority() parameter list

Return value

Priority of the specified task (range 1 to 255).

Additional Information

If pTask is NULL, the function returns the priority of the currently running task. If pTask does not specify a valid task, the debug build of embOS calls OS_Error(). The release build of embOS cannot check the validity of pTask and may therefore return invalid values if pTask does not specify a valid task.

Important

This function must not be called from within an interrupt handler.

4.4.12 OS_GetSuspendCnt()

Description

The function returns the suspension count and thus suspension state of the specified task. This function may be used to examine whether a task is suspended by previous calls of OS_Suspend().

Prototype

```
unsigned char OS_GetSuspendCnt (const OS_TASK *pTask);
```

Parameter	Description
pTask	Pointer to a task control block structure.

Table 4.13: OS_GetSuspendCnt() parameter list

Return value

Suspension count of the specified task.
0: Task is not suspended.
>0: Task is suspended by at least one call of OS_Suspend().

Additional Information

If pTask does not specify a valid task, the debug build of embOS calls OS_Error(). The release build of embOS cannot check the validity of pTask and may therefore return invalid values if pTask does not specify a valid task. When tasks are created and terminated dynamically, OS_IsTask() may be called prior to calling OS_GetSuspendCnt() to determine whether a task is valid. The returned value can be used to resume a suspended task by calling OS_Resume() as often as indicated by the returned value.

Example

```
/* Demo-function to illustrate the use of OS_GetSuspendCnt() */

void ResumeTask(OS_TASK *pTask) {
  unsigned char SuspendCnt;
  SuspendCnt = OS_GetSuspendCnt(pTask);
  while (SuspendCnt > 0) {
    OS_Resume(pTask); /* May cause a task switch */
    SuspendCnt--;
  }
}
```

4.4.13 OS_GetTaskID()

Description

Returns a pointer to the task control block structure of the currently running task. This pointer is unique for the task and is used as a task Id.

Prototype

```
OS_TASK * OS_GetTaskID ( void );
```

Return value

A pointer to the task control block. NULL indicates that no task is executing.

Additional Information

This function may be used for determining which task is executing. This may be helpful if the reaction of any function depends on the currently running task.

4.4.14 OS_GetTaskName()

Description

Returns a pointer to the name of a task.

Prototype

```
const char * OS_GetTaskName(const OS_TASK *pTask);
```

Parameter	Description
pTask	Pointer to a task control block structure.

Table 4.14: OS_GetTaskName() parameter list

Return value

A pointer to the name of the task. NULL indicates that the task has no name.

Additional Information

If pTask is NULL, the function returns the name of the running task. If not called from a task with a NULL pointer as parameter, the return value is "OS_Idle()". If pTask does not specify a valid task, the debug build of embOS calls OS_Error(). The release build of embOS cannot check the validity of pTask and may therefore return invalid values if pTask does not specify a valid task.

4.4.15 OS_GetTimeSliceRem()

Description

Returns the remaining time slice value of a task.

Prototype

```
unsigned char OS_GetTimeSliceRem(const OS_TASK *pTask);
```

Parameter	Description
pTask	Pointer to a task control block structure.

Table 4.15: OS_GetTimeSliceRem() parameter list

Return value

The remaining time slice value of the task.

Additional Information

If pTask is NULL, the function returns the remaining time slice of the running task. If not called from a task with a NULL pointer as parameter, or if pTask does not specify a valid task, the debug build of embOS calls OS_Error(). The release build of embOS cannot check the validity of pTask and may therefore return invalid values if pTask does not specify a valid task.

The function is unavailable when using an embOS build without round-robin support. The embOS eXtreme release libraries do not support round robin. Furthermore, when embOS is recompiled with OS_RR_SUPPORTED set to 0, the function will not be available.

4.4.16 OS_IsRunning()

Description

Determines whether the embOS scheduler was started by a call of OS_Start().

Prototype

```
unsigned char OS_IsRunning (void);
```

Return value

Character value:
0: Scheduler is not started.
!=0: Scheduler is running, `OS_Start()` has been called.

Additional Information

This function may be helpful for some functions which might be called from `main()` or from running tasks.
As long as the scheduler is not started and a function is called from `main()`, blocking task switches are not allowed.
A function which may be called from a task or `main()` may use `OS_IsRunning()` to determine whether a blocking task switch is allowed.

4.4.17 OS_IsTask()

Description

Determines whether a task control block belongs to a valid task.

Prototype

```
char OS_IsTask (const OS_TASK *pTask);
```

Parameter	Description
pTask	Pointer to a task control block structure.

Table 4.16: OS_IsTask() parameter list

Return value

Character value:
0: TCB is not used by any task
1: TCB is used by a task

Additional Information

This function checks if the specified task is present in the internal task list. When a task is terminated it is removed from the internal task list.

In applications that create and terminate tasks dynamically, this function may be useful to determine whether the task control block and stack for one task may be reused for another task.

4.4.18 OS_Resume()

Description

Decrements the suspend count of the specified task and resumes it if the suspend count reaches zero.

Prototype

```
void OS_Resume (OS_TASK *pTask);
```

Parameter	Description
pTask	Pointer to a task control block structure.

Table 4.17: OS_Resume() parameter list

Additional Information

The specified task's suspend count is decremented. When the resulting value is zero, the execution of the specified task is resumed.

If the task is not blocked by other task blocking mechanisms, the task is placed in the READY state and continues operation according to the rules of the scheduler.

In debug builds of embOS, `OS_Resume()` checks the suspend count of the specified task. If the suspend count is zero when `OS_Resume()` is called, `OS_Error()` is called with error `OS_ERR_RESUME_BEFORE_SUSPEND`.

4.4.19 OS_ResumeAllSuspendedTasks()

Description

Decrements the suspend count of all tasks that have a nonzero suspend count and resumes these tasks when their respective suspend count reaches zero.

Prototype

```
void OS_ResumeAllSuspendedTasks (void);
```

Additional Information

This function may be helpful to synchronize or start multiple tasks at the same time. The function resumes all tasks, no specific task must be addressed.
The function may be used together with the functions `OS_SuspendAllTasks()` and `OS_SetInitialSuspendCnt()`.
The function may cause a task switch when a task with higher priority than the calling task is resumed. The task switch will be executed after all suspended tasks are resumed.
As this is a non-blocking function, the function may be called from all contexts, main, ISR or timer.
The function may be called even if no task is suspended.

4.4.20 OS_SetDefaultTaskContextExtension()

Description

Sets the default task context extension for newly created tasks.

Prototype

```
void OS_SetDefaultTaskContextExtension(const OS_EXTEND_TASK_CONTEXT
                                             *pExtendContext)
```

Parameter	Description
pExtendContext	Pointer to the OS_EXTEND_TASK_CONTEXT structure which contains the addresses of the specific save and restore functions that save and restore the extended task context during task switches.

Table 4.18: OS_SetDefaultTaskContextExtension() parameter list

Additional Information

Should be called at any time from main() before the first task is started.
After calling this function all newly created tasks will automatically use the context extension.

Example

```
extern const OS_EXTEND_TASK_CONTEXT OS_VFP_ExtendContext;

int main(void) {

  OS_IncDI();                        // Initially disable interrupts
  OS_InitKern();                     // Initialize OS
  OS_InitHW();                       // Initialize Hardware for OS
  BSP_Init();                        // Initialize LED ports
  OS_CREATETASK(&TCBHP, "HP Task", HPTask, 100, StackHP);
  OS_CREATETASK(&TCBLP, "LP Task", LPTask,  50, StackLP);
  OS_SetDefaultTaskContextExtension(&OS_VFP_ExtendContext);
  OS_Start();                        // Start multitasking
  return 0;
}
```

4.4.21 OS_SetInitialSuspendCnt()

Description

Sets the initial suspend count for newly created tasks to one. May be used to create tasks which are initially suspended.

Prototype

```
void OS_SetInitialSuspendCnt (unsigned char SuspendCnt);
```

Parameter	Description
SuspendCnt	!= 0: Tasks will be created in suspended state. = 0: Tasks will be created normally without suspension.

Table 4.19: OS_SetInitialSuspendCnt() parameter list

Additional Information

Can be called at any time from `main()`, any task, ISR or software timer.
After calling this function with nonzero SuspendCnt, all newly created tasks will be automatically suspended with a suspend count of one.
This function may be used to inhibit further task switches, which may be useful during system initailization.

Important

When this function is called from `main()` to initialize all tasks in suspended state, at least one task must be resumed before the system is started by a call of `OS_Start()`. The initial suspend count should be reset to allow normal creation of tasks before the system is started.

Example

```
/* Sample to demonstrate the use of OS_SetInitialSuspendCnt */

void InitTask(void) {
  //
  // High priority task started first after OS_Start().
  //
  OS_SuspendAllTasks();        // Ensure no other existing task can run.
  OS_SetInitialSuspendCnt(1);  // Ensure no newly created task will run.
  //
  // Perform application initialization.
  //
  ...  // New tasks may be created but cannot start.
  ...  // Even when InitTask() blocks itself by a delay, no other task will run.
  OS_SetInitialSuspendCnt(0);  // Reset the initial suspend count for tasks.
  //
  // Resume all tasks that were blocked before or were created in suspended state.
  //
  OS_ResumeAllSuspendedTasks();
  while (1) {
    ...  // Do the normal work.
  }
}
```

4.4.22   OS_SetPriority()

Description

Assigns a priority to a specified task.

Prototype

```
void OS_SetPriority (OS_TASK *pTask,
                     OS_PRIO  Priority);
```

Parameter	Description
pTask	Pointer to a task control block structure.
Priority	Priority of the task. Must be within the following range: $1 <= $ Priority $<= 2^8-1 = $ 0xFF for 8/16 bit CPUs $1 <= $ Priority $<= 2^{32}-1 = $ 0xFFFFFFFF for 32 bit CPUs Higher values indicate higher priorities. The type OS_PRIO is defined as 32 bit value for 32 bit CPUs and 8 bit value for 8 or 16 bit CPUs per default.

Table 4.20: OS_SetPriority() parameter list

Additional Information

Can be called at any time from any task or software timer. Calling this function might lead to an immediate task switch.

Important

This function must not be called from within an interrupt handler.

4.4.23 OS_SetTaskName()

Description

Allows modification of a task name at runtime.

Prototype

```
void OS_SetTaskName (OS_TASK    *pTask,
                     const char *s);
```

Parameter	Description
pTask	Pointer to a task control block structure.
s	Pointer to a zero terminated string which is used as task name.

Table 4.21: OS_SetTaskName() parameter list

Additional Information

Can be called at any time from any task or software timer.
When pTask is NULL, the name of the currently running task is modified.

4.4.24 OS_SetTimeSlice()

Description

Assigns a time slice period to a specified task.

Prototype

```
unsigned char OS_SetTimeSlice (OS_TASK        *pTask,
                               unsigned char  TimeSlice);
```

Parameter	Description
pTask	Pointer to a task control block structure.
TimeSlice	New time slice period for the task. Must be within the following range: 0 <= TimeSlice <= 255.

Table 4.22: OS_SetTimeSlice() parameter list

Return value

Previous time slice period of the task.

Additional Information

Can be called at any time from any task or software timer. Setting the time slice period only affects tasks running in round-robin mode. This means another task with the same priority must exist.
The new time slice period is interpreted as a reload value. It is used after the next activation of the task. It does not affect the remaining time slice of a running task.

A time slice value of zero is allowed, but disables round-robin task switches (see *Disabling preemptive task switches for tasks of equal priority* on page 49).

4.4.25 OS_Start()

Description

Starts the embOS scheduler.

Prototype

```
void OS_Start (void);
```

Additional Information

This function starts the embOS scheduler and should be the last function called from `main()`.

- `OS_Start()` marks embOS as running. The running state can be examined by a call of the function `OS_IsRunning()`.
- `OS_Start()` will activate and start the task with the highest priority.
- `OS_Start()` automatically enables interrupts.
- `OS_Start()` does not return.
- `OS_Start()` must not be called from a task, from an interrupt or an embOS timer, and must be called from `main()` only once.

4.4.26 OS_Suspend()

Description

Suspends the specified task.

Prototype

```
void OS_Suspend (OS_TASK *pTask);
```

Parameter	Description
pTask	Pointer to a task control block structure.

Table 4.23: OS_Suspend() parameter list

Additional Information

If pTask is NULL, the current task suspends.

If the function succeeds, execution of the specified task is suspended and the task's suspend count is incremented. The specified task will be suspended immediately. It can only be restarted by a call of OS_Resume().

Every task has a suspend count with a maximum value of OS_MAX_SUSPEND_CNT. If the suspend count is greater than zero, the task is suspended.

In debug builds of embOS, upon calling OS_Suspend() more often than the maximum value without calling OS_Resume() the task's internal suspend count is not incremented and OS_Error() is called with error OS_ERR_SUSPEND_TOO_OFTEN.

Cannot be called from an interrupt handler or timer as this function may cause an immediate task switch. The debug build of embOS will call the OS_Error() function when OS_Suspend() is called from an interrupt handler.

4.4.27 OS_SuspendAllTasks()

Description

Suspends all tasks except the running task.

Prototype

```
void OS_SuspendAllTasks (void);
```

Additional Information

This function may be used to inhibit task switches. It may be useful during application initialization or supervising.
The calling task will not be suspended.
After calling `OS_SuspendAllTasks()`, the calling task may block or suspend itself. No other task will be activated unless one or more tasks are resumed again. The tasks may be resumed individually by a call of `OS_Resume()` or all at once by a call of `OS_ResumeAllSuspendedTasks()`.

Example

```
/* Sample to demonstrate the use of OS_SuspendAllTasks */

void InitTask(void) {
  //
  // High priority task started first after OS_Start().
  //
  OS_SuspendAllTasks();        // Ensure no other existing task can run.
  OS_SetInitialSuspendCnt(1);  // Ensure no newly created task will run.
  //
  // Perform application initialization.
  //
  ...  // New tasks may be created but cannot start.
  ...  // Even when InitTask() blocks itself by a delay, no other task will run.
  OS_SetInitialSuspendCnt(0);  // Reset the initial suspend count for tasks.
  //
  // Resume all tasks that were blocked before or were created in suspended state.
  //
  OS_ResumeAllSuspendedTasks();
  while (1) {
    ...  // Do the normal work.
  }
}
```

4.4.28 OS_TaskIndex2Ptr()

Description

Returns the task control block of the task with the Index TaskIndex.

Prototype

```
OS_TASK* OS_TaskIndex2Ptr(int TaskIndex);
```

Parameter	Description
TaskIndex	Index of task control block in the task list

Table 4.24: OS_Terminate() parameter list

Return value

NULL: No task control block with this index found.
!= NULL: Pointer to the task control block with the index TaskIndex.

4.4.29 OS_TerminateTask()

Description

Ends (terminates) a task.

Prototype

```
void OS_TerminateTask (OS_TASK *pTask);
```

Parameter	Description
pTask	Pointer to a task control block structure.

Table 4.25: OS_Terminate() parameter list

Additional Information

If pTask is NULL, the current task terminates. The specified task will terminate immediately. The memory used for stack and task control block can be reassigned.

Since version 3.26 of embOS, all resources which are held by a task are released upon its termination. Any task may be terminated regardless of its state. This functionality is default for any 16 bit or 32 bit CPU and may be changed by recompiling embOS sources. On 8 bit CPUs, terminating tasks that hold any resources such as semaphores, which may block other tasks, is prohibited.
Since embOS version 3.82u, OS_TerminateTask() replaces the deprecated function OS_Terminate(), which may still be used.

Important

This function must not be called from within an interrupt handler.

4.4.30 OS_WakeTask()

Description

Ends delay of a specified task immediately.

Prototype

```
void OS_WakeTask (OS_TASK *pTask);
```

Parameter	Description
pTask	Pointer to a task control block structure.

Table 4.26: OS_WakeTask() parameter list

Additional Information

Places the specified task, which is already suspended for a certain amount of time by a call of OS_Delay() or OS_DelayUntil(), back into the READY state.
The specified task will be activated immediately if it has a higher priority than the task that had the highest priority before. If the specified task is not in the WAITING state (because it has already been activated, or the delay has already expired, or for some other reason), calling this function has no effect.

4.4.31 OS_Yield()

Description

Calls the scheduler to force a task switch.

Prototype

```
void OS_Yield (void);
```

Additional Information

If the task is running round-robin, it will be suspended if there is another task with equal priority ready for execution.

Chapter 5

Software timers

5.1   Introduction

A software timer is an object that calls a user-specified routine after a specified delay. An unlimited number of software timers can be defined with the macro `OS_CREATETIMER()`.

Timers can be stopped, started and retriggered much like hardware timers. When defining a timer, you specify a routine to be called after the expiration of the delay. Timer routines are similar to interrupt routines: they have a priority higher than the priority of any task. For that reason they should be kept short just like interrupt routines.

Software timers are called by embOS with interrupts enabled, so they can be interrupted by any hardware interrupt. Generally, timers run in single-shot mode, which means they expire exactly once and call their callback routine exactly once. By calling `OS_RetriggerTimer()` from within the callback routine, the timer is restarted with its initial delay time and therefore functions as a periodic timer.

The state of timers can be checked by the functions `OS_GetTimerStatus()`, `OS_GetTimerValue()` and `OS_GetTimerPeriod()`.

Maximum timeout / period

The timeout value is stored as an integer, thus a 16 bit value on 8/16 bit CPUs, a 32 bit value on 32 bit CPUs. The comparisons are done as signed comparisons because expired time-outs are permitted. This means that only 15 bits can be used on 8/16 bit CPUs, 31 bits on 32 bit CPUs. Another factor to take into account is the maximum time spent in critical regions. Timers may expire during critical regions, but because the timer routine cannot be called from a critical region (timers are "put on hold"), the maximum time that the system continuously spends in a critical region needs to be deducted. In most systems, this is no more than a single tick. However, to be safe, we have assumed that your system spends no more than a maximum of 255 consecutive ticks in a critical region and defined a macro which defines the maximum timeout value. This macro, `OS_TIMER_MAX_TIME`, defaults to `0x7F00` on 8/16 bit systems and to `0x7FFFFF00` on 32 bit Systems as defined in `RTOS.h`. If your system spends more than 255 consecutive ticks in a critical section, effectively disabling the scheduler during this time (which is not recommended), you must make sure your application uses shorter timeouts.

Extended software timers

Sometimes it may be useful to pass a parameter to the timer callback function. This allows the callback function to be shared between different software timers.
Since version 3.32m of embOS, the extended timer structure and related extended timer functions were implemented to allow parameter passing to the callback function.
Except for the different callback function with parameter passing, extended timers behave exactly the same as regular embOS software timers and may be used in parallel with these.

5.2   API functions

Routine	Description	main	Task	ISR	Timer
OS_CREATETIMER()	Macro that creates and starts a software-timer.	X	X	X	X
OS_CreateTimer()	Creates a software timer without starting it.	X	X	X	X
OS_StartTimer()	Starts a software timer.	X	X	X	X
OS_StopTimer()	Stops a software timer.	X	X	X	X
OS_RetriggerTimer()	Restarts a software timer with its initial time value.	X	X	X	X
OS_TriggerTimer()	Ends a software at once.		X	X	
OS_SetTimerPeriod()	Sets a new timer reload value for a software timer.	X	X	X	X
OS_DeleteTimer()	Stops and deletes a software timer.	X	X	X	X
OS_GetTimerPeriod()	Returns the current reload value of a software timer.	X	X	X	X
OS_GetTimerValue()	Returns the remaining timer value of a software timer.	X	X	X	X
OS_GetTimerStatus()	Returns the current timer status of a software timer.	X	X	X	X
OS_GetpCurrentTimer()	Returns a pointer to the data structure of the timer that just expired.	X	X	X	X
OS_CREATETIMER_EX()	Macro that creates and starts an extended software-timer.	X	X	X	X
OS_CreateTimerEx()	Creates an extended software timer without starting it.	X	X	X	X
OS_StartTimerEx()	Starts an extended timer.	X	X	X	X
OS_StopTimerEx()	Stops an extended timer.	X	X	X	X
OS_RetriggerTimerEx()	Restarts an extended timer with its initial time value.	X	X	X	X
OS_TriggerTimerEx()	Ends a software timer at once.		X	X	
OS_SetTimerPeriodEx()	Sets a new timer reload value for an extended timer.	X	X	X	X
OS_DeleteTimerEx()	Stops and deletes an extended timer.	X	X	X	X
OS_GetTimerPeriodEx()	Returns the current reload value of an extended timer.	X	X	X	X
OS_GetTimerValueEx()	Returns the remaining timer value of an extended timer.	X	X	X	X
OS_GetTimerStatusEx()	Returns the current timer status of an extended timer.	X	X	X	X
OS_GetpCurrentTimerEx()	Returns a pointer to the data structure of the extended timer that just expired.	X	X	X	X

Table 5.1: Software timers API

5.2.1   OS_CREATETIMER()

Description

Macro that creates and starts a software timer.

Prototype

```
void OS_CREATETIMER (OS_TIMER        *pTimer,
                     OS_TIMERROUTINE *Callback,
                     OS_TIME          Timeout);
```

Parameter	Description
pTimer	Pointer to the OS_TIMER data structure which contains the data of the timer.
Callback	Pointer to the callback routine to be called by the RTOS after expiration of the delay. The callback function must be a void function which does not take any parameter and does not return any value.
Timeout	Initial timeout in basic embOS time units (nominal ms): The data type OS_TIME is defined as an integer, therefore valid values are $1 <= $ Timeout $<= 2^{15}$-1 = 0x7FFF = 32767 for 8/16 bit CPUs $1 <= $ Timeout $<= 2^{31}$-1 = 0x7FFFFFFF for 32 bit CPUs

Table 5.2: OS_CREATETIMER() parameter list

Additional Information

embOS keeps track of the timers by using a linked list. Once the timeout is expired, the callback routine will be called immediately (unless the current task is in a critical region or has interrupts disabled).
This deprecated macro uses the functions OS_CreateTimer() and OS_StartTimer(). It is supplied for backward compatibility; in newer applications these routines should instead be called directly.
OS_TIMERROUTINE is defined in RTOS.h as follows:

```
typedef void OS_TIMERROUTINE(void);
```

Source of the macro (in RTOS.h):

```
#define OS_CREATETIMER(pTimer, c, d)  \
        OS_CreateTimer(pTimer, c, d); \
        OS_StartTimer(pTimer);
```

Example

```
OS_TIMER TIMER100;

void Timer100(void) {
  LED = LED ? 0 : 1;              /* Toggle LED  */
  OS_RetriggerTimer(&TIMER100);  /* Make timer periodic */
}

void InitTask(void) {
  /* Create and start Timer100 */
  OS_CREATETIMER(&TIMER100, Timer100, 100);
}
```

5.2.2   OS_CreateTimer()

Description

Creates a software timer (but does not start it).

Prototype

```
void OS_CreateTimer (OS_TIMER        *pTimer,
                     OS_TIMERROUTINE *Callback,
                     OS_TIME          Timeout);
```

Parameter	Description
pTimer	Pointer to the OS_TIMER data structure which contains the data of the timer.
Callback	Pointer to the callback routine to be called by the RTOS after expiration of the delay.
Timeout	Initial timeout in basic embOS time units (nominal ms): The data type OS_TIME is defined as an integer, therefore valid values are $1 <=$ Timeout $<= 2^{15}-1 = 0x7FFF = 32767$ for 8/16 bit CPUs $1 <=$ Timeout $<= 2^{31}-1 = 0x7FFFFFFF$ for 32 bit CPUs

Table 5.3: OS_CreateTimer() parameter list

Additional Information

embOS keeps track of the timers by using a linked list. Once the timeout is expired, the callback routine will be called immediately (unless the current task is in a critical region or has interrupts disabled). The timer is not automatically started. This must be done explicitly by a call of OS_StartTimer() or OS_RetriggerTimer(). OS_TIMERROUTINE is defined in RTOS.h as follows:

```
typedef void OS_TIMERROUTINE(void);
```

Example

```
OS_TIMER TIMER100;

void Timer100(void) {
  LED = LED ? 0 : 1;                /* Toggle LED  */
  OS_RetriggerTimer(&TIMER100);  /* Make timer periodic */
}

void InitTask(void) {
  /* Create Timer100, start it elsewhere */
  OS_CreateTimer(&TIMER100, Timer100, 100);
  OS_StartTimer(&TIMER100);
}
```

5.2.3   OS_StartTimer()

Description

Starts a software timer.

Prototype

```
void OS_StartTimer (OS_TIMER *pTimer);
```

Parameter	Description
pTimer	Pointer to the OS_TIMER data structure which contains the data of the timer.

Table 5.4: OS_StartTimer() parameter list

Additional Information

OS_StartTimer() is used for the following reasons:

- Start a timer which was created by OS_CreateTimer(). The timer will start with its initial timer value.
- Restart a timer which was stopped by calling OS_StopTimer(). In this case, the timer will continue with the remaining time value which was preserved by stopping the timer.

Important

This function has no effect on running timers. It also has no effect on timers that are not running, but have expired: use OS_RetriggerTimer() to restart those timers.

5.2.4   OS_StopTimer()

Description

Stops a software timer.

Prototype

```
void OS_StopTimer (OS_TIMER *pTimer);
```

Parameter	Description
pTimer	Pointer to the OS_TIMER data structure which contains the data of the timer.

Table 5.5: OS_StopTimer() parameter list

Additional Information

The actual value of the timer (the time until expiration) is maintained until OS_StartTimer() lets the timer continue. The function has no effect on timers that are not running, but have expired.

5.2.5   OS_RetriggerTimer()

Description

Restarts a software timer with its initial time value.

Prototype

```
void OS_RetriggerTimer (OS_TIMER *pTimer);
```

Parameter	Description
pTimer	Pointer to the OS_TIMER data structure which contains the data of the timer.

Table 5.6: OS_RetriggerTimer() parameter list

Additional Information

OS_RetriggerTimer() restarts the timer using the initial time value programmed at creation of the timer or with the function OS_SetTimerPeriod().
OS_RetriggerTimer() can be called regardless the state of the timer. A running timer will continue using the full initial time. A timer that was stopped before or had expired will be restarted.

Example

```
OS_TIMER TIMERCursor;
BOOL CursorOn;

void TimerCursor(void) {
  if (CursorOn) {
    ToggleCursor();     /* Invert character at cursor-position */
  }
  OS_RetriggerTimer(&TIMERCursor); /* Make timer periodic */
}

void InitTask(void) {
  /* Create and start TimerCursor  */
  OS_CREATETIMER(&TIMERCursor, TimerCursor, 500);
}
```

5.2.6   OS_TriggerTimer()

Description

Stops a software timer at once and calls the timer callback function.

Prototype

```
void OS_TriggerTimer (OS_TIMER *pTimer);
```

Parameter	Description
pTimer	Pointer to the OS_TIMER data structure which contains the data of the timer.

Table 5.7: OS_TriggerTimer() parameter list

Additional Information

OS_TriggerTimer() can be called regardless the state of the timer. A running timer will be stopped and the callback function is called. For a timer that was stopped before or had expired the callback function will not be executed.

Example

```
OS_TIMER TIMERUartRx;

void TimerUart(void) {
  HandleUartRx();
}

void UartRxIntHandler(void) {
  //
  // Character received, stop the software timer
  //
  OS_TriggerTimer(&TIMERUartRx);
}

void UartSendNextCharachter(void) {
  OS_StartTimer(&TIMERUartRx);
  //
  // Send next uart character and wait for Rx character
  //
}

int main(void) {
  OS_CreateTimer(&TIMERUartRx, TimerUart, 20);
}
```

5.2.7   OS_SetTimerPeriod()

Description

Sets a new timer reload value for a software timer.

Prototype

```
void OS_SetTimerPeriod (OS_TIMER *pTimer,
                        OS_TIME   Period);
```

Parameter	Description
pTimer	Pointer to the OS_TIMER data structure which contains the data of the timer.
Period	Timer period in basic embOS time units (nominal ms): The data type OS_TIME is defined as an integer, therefore valid values are $1 <= $ Timeout $<= 2^{15}-1 = $ 0x7FFF $= 32767$ for 8/16 bit CPUs $1 <= $ Timeout $<= 2^{31}-1 = $ 0x7FFFFFFF for 32 bit CPUs

Table 5.8: OS_SetTimerPeriod() parameter list

Additional Information

OS_SetTimerPeriod() sets the initial time value of the specified timer. Period is the reload value of the timer to be used as initial value when the timer is retriggered by OS_RetriggerTimer().

Example

```
OS_TIMER TIMERPulse;

void TimerPulse(void) {
  TogglePulseOutput();              /* Toggle output */
  OS_RetriggerTimer(&TIMERPulse); /* Make timer periodic */
}

void InitTask(void) {
  /* Create and start Pulse Timer with first pulse = 500ms */
  OS_CREATETIMER(&TIMERPulse, TimerPulse, 500);
  /* Set timer period to 200 ms for further pulses */
  OS_SetTimerPeriod(&TIMERPulse, 200);
}
```

5.2.8   OS_DeleteTimer()

Description

Stops and deletes a software timer.

Prototype

```
void OS_DeleteTimer (OS_TIMER *pTimer);
```

Parameter	Description
pTimer	Pointer to the OS_TIMER data structure which contains the data of the timer.

Table 5.9: OS_DeleteTimer() parameter list

Additional Information

The timer is stopped and therefore removed from the linked list of running timers. In debug builds of embOS, the timer is also marked as invalid.

5.2.9   OS_GetTimerPeriod()

Description

Returns the current reload value of a software timer.

Prototype

```
OS_TIME OS_GetTimerPeriod (const OS_TIMER *pTimer);
```

Parameter	Description
pTimer	Pointer to the OS_TIMER data structure which contains the data of the timer.

Table 5.10: OS_GetTimerPeriod() parameter list

Return value

Type OS_TIME, which is defined as an integer between
1 and 2^{15}-1 = 0x7FFF = 32767 for 8/16 bit CPUs and as an integer between
1 and <= 2^{31}-1 = 0x7FFFFFFF for 32 bit CPUs, which is the permitted range of timer values.

Additional Information

The period returned is the reload value of the timer which was set as initial value when the timer was created or which was modified by a call of OS_SetTimerPeriod(). This reload value will be used as time period when the timer is retriggered by OS_RetriggerTimer().

5.2.10 OS_GetTimerValue()

Description

Returns the remaining timer value of a software timer.

Prototype

```
OS_TIME OS_GetTimerValue (const OS_TIMER *pTimer);
```

Parameter	Description
pTimer	Pointer to the OS_TIMER data structure which contains the data of the timer.

Table 5.11: OS_GetTimerValue() parameter list

Return value

Type OS_TIME, which is defined as an integer between
1 and 2^{15}-1 = 0x7FFF = 32767 for 8/16 bit CPUs and as an integer between
1 and <= 2^{31}-1 = 0x7FFFFFFF for 32 bit CPUs, which is the permitted range of timer values.
The returned timer value is the remaining timer time in embOS tick units until expiration of the timer.

5.2.11 OS_GetTimerStatus()

Description

Returns the current timer status of a software timer.

Prototype

```
unsigned char OS_GetTimerStatus (const OS_TIMER *pTimer);
```

Parameter	Description
pTimer	Pointer to the OS_TIMER data structure which contains the data of the timer.

Table 5.12: OS_GetTimerStatus parameter list

Return value

Denotes whether the specified timer is running or not:
0:      timer has stopped
! = 0: timer is running.

5.2.12 OS_GetpCurrentTimer()

Description

Returns a pointer to the data structure of the timer that just expired.

Prototype

```
OS_TIMER * OS_GetpCurrentTimer (void);
```

Return value

A pointer to the control structure of a timer.

Additional Information

The return value of OS_GetpCurrentTimer() is valid during execution of a timer call-
back function; otherwise it is undefined. If only one callback function should be used
for multiple timers, this function can be used for examining the timer that expired.
The example below shows one usage of OS_GetpCurrentTimer(). Since version
3.32m of embOS, the extended timer structure and functions may be used to gener-
ate and use a software timer with an individual parameter for the callback function.
Please be aware that OS_TIMER must be the first member of the structure.

Example

```
#include "RTOS.H"

/**********************************************************
*
*       Types
*/
typedef struct {  /* Timer object with its own user data */
  OS_TIMER  Timer; /* OS_TIMER must be the first element  */
  void      *pUser;
} TIMER_EX;

/**********************************************************
*
*       Variables
*/

TIMER_EX Timer_User;
int a;

/**********************************************************
*
*       Local Functions
*/

static void _CreateTimer(TIMER_EX *timer, OS_TIMERROUTINE *Callback,
                         OS_UINT Timeout, void *pUser) {
  timer->pUser = pUser;
  OS_CreateTimer(&timer->Timer, Callback, Timeout);
}

/* Timer callback function for multiple timers          */
static void _cb(void) {
  TIMER_EX *p      = (TIMER_EX *)OS_GetpCurrentTimer();
  void      *pUser = p->pUser;        /* Examine user data */
  OS_RetriggerTimer(&p->Timer);       /* Retrigger timer   */
}

/**********************************************************
*
*       main
*/
int main(void) {
  OS_InitKern();            /* Initialize OS             */
  OS_InitHW();              /* Initialize Hardware for OS */
  _CreateTimer(&Timer_User, _cb, 100, &a);
  OS_Start();               /* Start multitasking        */
  return 0;
}
```

5.2.13 OS_CREATETIMER_EX()

Description

Macro that creates and starts an extended software timer.

Prototype

```
void OS_CREATETIMER_EX (OS_TIMER_EX         *pTimerEx,
                        OS_TIMER_EX_ROUTINE *Callback,
                        OS_TIME              Timeout
                        void                *pData)
```

Parameter	Description
pTimerEx	Pointer to the OS_TIMER_EX data structure which contains the data of the extended software timer.
Callback	Pointer to the callback routine to be called by the RTOS after expiration of the delay. The callback function must be of type OS_TIMER_EX_ROUTINE which takes a void pointer as parameter and does not return any value.
Timeout	Initial timeout in basic embOS time units (nominal ms): The data type OS_TIME is defined as an integer, therefore valid values are $1 <=$ Timeout $<= 2^{15}-1 = $ 0x7FFF = 32767 for 8/16 bit CPUs $1 <=$ Timeout $<= 2^{31}-1 = $ 0x7FFFFFFF for 32 bit CPUs
pData	A void pointer which is used as parameter for the extended timer callback function.

Table 5.13: OS_CREATETIMER_EX() parameter list

Additional Information

embOS keeps track of the timers by using a linked list. Once the timeout is expired, the callback routine will be called immediately (unless the current task is in a critical region or has interrupts disabled).
This macro uses the functions OS_CreateTimerEx() and OS_StartTimerEx(). OS_TIMER_EX_ROUTINE is defined in RTOS.h as follows:

```
typedef void OS_TIMER_EX_ROUTINE(void *pVoid);
```

Source of the macro (in RTOS.h):

```
#define OS_CREATETIMER_EX(pTimerEx, cb, Timeout, pData)  \
        OS_CreateTimerEx(pTimerEx, cb, Timeout, pData);  \
        OS_StartTimerEx(pTimerEx)
```

Example

```
OS_TIMER_EX TIMER100;
OS_TASK     TCB_HP;

void Timer100(void *pTask) {
  LED = LED ? 0 : 1;                 /* Toggle LED */
  if (pTask != NULL) {
    OS_SignalEvent(0x01, (OS_TASK *)pVoid);
  }
  OS_RetriggerTimerEx(&TIMER100);  /* Make timer periodic */
}

void InitTask(void) {
  /* Create and start Timer100 */
  OS_CREATETIMER_EX(&TIMER100, Timer100, 100, (void *) &TCB_HP);
}
```

5.2.14 OS_CreateTimerEx()

Description

Creates an extended software timer (but does not start it).

Prototype

```
void OS_CreateTimerEx (OS_TIMER_EX        *pTimerEx,
                       OS_TIMER_EX_ROUTINE *Callback,
                       OS_TIME              Timeout,
                       void                 *pData)
```

Parameter	Description
pTimerEx	Pointer to the OS_TIMER_EX data structure which contains the data of the extended software timer.
Callback	Pointer to the callback routine of type OS_TIMER_EX_ROUTINE to be called by the RTOS after expiration of the timer.
Timeout	Initial timeout in basic embOS time units (nominal ms): The data type OS_TIME is defined as an integer, therefore valid values are $1 <= $ Timeout $<= 2^{15}-1 = $ 0x7FFF $= $ 32767 for 8/16 bit CPUs $1 <= $ Timeout $<= 2^{31}-1 = $ 0x7FFFFFFF for 32 bit CPUs
pData	A void pointer which is used as parameter for the extended timer callback function.

Table 5.14: OS_CreateTimerEx() parameter list

Additional Information

embOS keeps track of timers by using a linked list. Once the timeout has expired, the callback routine will be called immediately (unless the current task is in a critical region or has interrupts disabled).
The extended software timer is not automatically started. This must be done explicitly by a call of OS_StartTimerEx() or OS_RetriggerTimerEx().

OS_TIMER_EX_ROUTINE is defined in RTOS.h as follows:

```
typedef void OS_TIMER_EX_ROUTINE(void *pVoid);
```

Example

```
OS_TIMER_EX TIMER100;
OS_TASK     TCB_HP;

void Timer100(void *pTask) {
  LED = LED ? 0 : 1;                /* Toggle LED */
  if (pTask != NULL) {
    OS_SignalEvent(0x01, (OS_TASK *) pVoid);
  }
  OS_RetriggerTimerEx(&TIMER100);  /* Make timer periodic */
}

void InitTask(void) {
  /* Create Timer100, start it elsewhere later on*/
  OS_CreateTimerEx(&TIMER100, Timer100, 100, (void* ) & TCB_HP);
}
```

5.2.15 OS_StartTimerEx()

Description

Starts an extended software timer.

Prototype

```
void OS_StartTimerEx (OS_TIMER_EX *pTimerEx);
```

Parameter	Description
pTimerEx	Pointer to the OS_TIMER_EX data structure which contains the data of the extended software timer.

Table 5.15: OS_StartTimereEx() parameter list

Additional Information

OS_StartTimerEx() is used for the following reasons:

- Start an extended software timer which was created by OS_CreateTimerEx(). The timer will start with its initial timer value.
- Restart a timer which was stopped by calling OS_StopTimerEx(). In this case, the timer will continue with the remaining time value which was preserved by stopping the timer.

Important

This function has no effect on running timers. It also has no effect on timers that are not running, but have expired. Use OS_RetriggerTimerEx() to restart those timers.

5.2.16 OS_StopTimerEx()

Description

Stops an extended software timer.

Prototype

```
void OS_StopTimerEx (OS_TIMER_EX *pTimerEx);
```

Parameter	Description
pTimerEx	Pointer to the OS_TIMER_EX data structure which contains the data of the extended software timer.

Table 5.16: OS_StopTimerEx() parameter list

Additional Information

The actual time value of the extended software timer (the time until expiration) is maintained until OS_StartTimerEx() lets the timer continue. The function has no effect on timers that are not running, but have expired.

5.2.17 OS_RetriggerTimerEx()

Description

Restarts an extended software timer with its initial time value.

Prototype

```
void OS_RetriggerTimerEx (OS_TIMER_EX *pTimerEx);
```

Parameter	Description
pTimerEx	Pointer to the `OS_TIMER_EX` data structure which contains the data of the extended software timer.

Table 5.17: OS_RetriggerTimerEx() parameter list

Additional Information

`OS_RetriggerTimerEx()` restarts the extended software timer using the initial time value which was programmed at creation of the timer or which was set using the function `OS_SetTimerPeriodEx()`.

`OS_RetriggerTimerEx()` can be called regardless of the state of the timer. A running timer will continue using the full initial time. A timer that was stopped before or had expired will be restarted.

Example

```
OS_TIMER_EX TIMERCursor;
OS_TASK     TCB_HP;
BOOL        CursorOn;

void TimerCursor(void *pTask) {
  if (CursorOn != 0) ToggleCursor(); /* Invert character at cursor-position */
  OS_SignalEvent(0x01, (OS_TASK *) pTask);
  OS_RetriggerTimerEx(&TIMERCursor); /* Make timer periodic */
}

void InitTask(void) {
  /* Create and start TimerCursor  */
  OS_CREATETIMER_EX(&TIMERCursor, TimerCursor, 500, (void *)&TCB_HP);
}
```

5.2.18 OS_TriggerTimerEx()

Description

Ends an extended software timer at once and calls the timer callback function.

Prototype

```
void OS_TriggerTimerEx (OS_TIMER_EX *pTimer);
```

Parameter	Description
pTimer	Pointer to the OS_TIMER_EX data structure which contains the data of the extended software timer.

Table 5.18: OS_TriggerTimer() parameter list

Additional Information

OS_TriggerTimerEx() can be called regardless the state of the timer. A running timer will be stopped and the callback function is called. For a timer that was stopped before or had expired the callback function will not be executed.

Example

```
OS_TIMER_EX TIMERUartRx;
OS_U32 UartNum;

void TimerUart(void *pNum) {
  HandleUartRx((OS_U32)*pNum);
}

void UartRxIntHandler(void) {
  //
  // Character received, stop the software timer
  //
  OS_TriggerTimer(&TIMERUartRx);
}

void UartSendNextCharachter(void) {
  OS_StartTimerEx(&TIMERUartRx);
  //
  // Send next uart character and wait for Rx character
  //
}

int main(void) {
  UartNum = 0;
  OS_CreateTimerEx(&TIMERUartRx, TimerUart, 20, (void*)&UartNum);
}
```

5.2.19 OS_SetTimerPeriodEx()

Description

Sets a new timer reload value for an extended software timer.

Prototype

```
void OS_SetTimerPeriodEx (OS_TIMER_EX *pTimerEx,
                          OS_TIME      Period);
```

Parameter	Description
pTimerEx	Pointer to the OS_TIMER_EX data structure which contains the data of the extended software timer.
Period	Timer period in basic embOS time units (nominal ms): The data type OS_TIME is defined as an integer, therefore valid values are $1 <= Timeout <= 2^{15}-1 = 0x7FFF = 32767$ for 8/16 bit CPUs $1 <= Timeout <= 2^{31}-1 = 0x7FFFFFFF$ for 32 bit CPUs

Table 5.19: OS_SetTimerPeriodEx() parameter list

Additional Information

OS_SetTimerPeriodEx() sets the initial time value of the specified extended soft-
ware timer. Period is the reload value of the timer to be used as initial value when
the timer is retriggered the next time by OS_RetriggerTimerEx().
A call of OS_SetTimerPeriodEx() does not affect the remaining time period of an
extended software timer.

Example

```
OS_TIMER_EX TIMERPulse;
OS_TASK     TCB_HP;

void TimerPulse(void *pTask) {
 OS_SignalEvent(0x01, (OS_TASK *) pTask);
 OS_RetriggerTimerEx(&TIMERPulse); /* Make timer periodic */
}

void InitTask(void) {
  /* Create and start Pulse Timer with first pulse == 500ms */
  OS_CREATETIMER_EX(&TIMERPulse, TimerPulse, 500, (void *)&TCB_HP);
  /* Set timer period to 200 ms for further pulses */
  OS_SetTimerPeriodEx(&TIMERPulse, 200);
}
```

5.2.20 OS_DeleteTimerEx()

Description

Stops and deletes an extended software timer.

Prototype

```
void OS_DeleteTimerEx(OS_TIMER_EX *pTimerEx);
```

Parameter	Description
pTimerEx	Pointer to the OS_TIMER_EX data structure which contains the data of the timer.

Table 5.20: OS_DeleteTimerEx() parameter list

Additional Information

The extended software timer is stopped and removed from the linked list of running timers. In debug builds of embOS, the timer is also marked as invalid.

5.2.21 OS_GetTimerPeriodEx()

Description

Returns the current reload value of an extended software timer.

Prototype

```
OS_TIME OS_GetTimerPeriodEx (OS_TIMER_EX *pTimerEx);
```

Parameter	Description
pTimerEx	Pointer to the OS_TIMER_EX data structure which contains the data of the extended timer.

Table 5.21: OS_GetTimerPeriodEx() parameter list

Return value

Type OS_TIME, which is defined as an integer between

1 and 2^{15}-1 = 0x7FFF = 32767 for 8/16 bit CPUs and as an integer between

1 and <= 2^{31}-1 = 0x7FFFFFFF for 32 bit CPUs, which is the permitted range of timer values.

Additional Information

The period returned is the reload value of the timer which was set as initial value when the timer was created or which was modified by a call of OS_SetTimerPeriodEx(). This reload value will be used as time period when the timer is retriggered by OS_RetriggerTimerEx().

5.2.22 OS_GetTimerValueEx()

Description

Returns the remaining timer value of an extended software timer.

Prototype

```
OS_TIME OS_GetTimerValueEx(OS_TIMER_EX *pTimerEx);
```

Parameter	Description
pTimerEx	Pointer to the OS_TIMER_EX data structure which contains the data of the timer.

Table 5.22: OS_GetTimerValueEx() parameter list

Return value

Type OS_TIME, which is defined as an integer between
1 and 2^{15}-1 = 0x7FFF = 32767 for 8/16 bit CPUs and as an integer between
1 and <= 2^{31}-1 = 0x7FFFFFFF for 32 bit CPUs, which is the permitted range of timer values.
The returned time value is the remaining timer value in embOS tick units until expiration of the extended software timer.

5.2.23 OS_GetTimerStatusEx()

Description

Returns the current timer status of an extended software timer.

Prototype

unsigned char OS_GetTimerStatusEx (OS_TIMER_EX *pTimerEx);

Parameter	Description
pTimerEx	Pointer to the OS_TIMER_EX data structure which contains the data of the extended timer.

Table 5.23: OS_GetTimerStatusEx parameter list

Return value

Denotes whether the specified timer is running or not:
0:      timer has stopped
! = 0: timer is running.

5.2.24 OS_GetpCurrentTimerEx()

Description

Returns a pointer to the data structure of the extended timer that just expired.

Prototype

```
OS_TIMER_EX* OS_GetpCurrentTimerEx (void);
```

Return value

A pointer to the control structure of an extended software timer.

Additional Information

The return value of `OS_GetpCurrentTimerEx()` is valid during execution of a timer callback function; otherwise it is undefined. If one callback function should be used for multiple extended timers, this function can be used for examining the timer that expired.

Example

```
#include "RTOS.H"

OS_TIMER_EX MyTimerEx;

/********************************************************
*
*       Local Functions
*/

void cbTimerEx(void *pData) {  /* Timer callback function for multiple timers */
  OS_TIMER_EX *pTimerEx;
  pTimerEx = OS_GetpCurrentTimerEx();
  OS_SignalEvent(0x01, (OS_TASK *) pData);
  OS_RetriggerTimer(pTimerEx); /* Retrigger timer */
}
```

Chapter 6

Resource semaphores

6.1   Introduction

Resource semaphores are used for managing resources by avoiding conflicts caused by simultaneous use of a resource. The resource managed can be of any kind: a part of the program that is not reentrant, a piece of hardware like the display, a flash prom that can only be written to by a single task at a time, a motor in a CNC control that can only be controlled by one task at a time, and a lot more.

The basic procedure is as follows:

Any task that uses a resource first claims it calling the `OS_Use()` or `OS_Request()` routines of embOS. If the resource is available, the program execution of the task continues, but the resource is blocked for other tasks. If a second task now tries to use the same resource while it is in use by the first task, this second task is suspended until the first task releases the resource. However, if the first task that uses the resource calls `OS_Use()` again for that resource, it is not suspended because the resource is blocked only for other tasks.

The following diagram illustrates the process of using a resource:

```
        ┌─────────────────────────┐
        │        OS_Use()         │
        └─────────────────────────┘
                     │
                     ▼
        ┌─────────────────────────┐
        │     Access resource     │
        └─────────────────────────┘
                     │
                     ▼
        ┌─────────────────────────┐
        │       OS_Unuse()        │
        └─────────────────────────┘
```
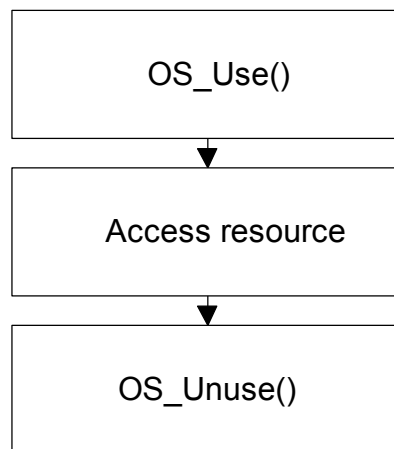
A resource semaphore contains a counter that keeps track of how many times the resource has been claimed by calling `OS_Request()` or `OS_Use()` by a particular task. It is released when that counter reaches zero, which means the `OS_Unuse()` routine must be called exactly the same number of times as `OS_Use()` or `OS_Request()`. If it is not, the resource remains blocked for other tasks.

On the other hand, a task cannot release a resource that it does not own by calling `OS_Unuse()`. In debug builds of embOS, a call of `OS_Unuse()` for a semaphore that is not owned by this task will result in a call to the error handler `OS_Error()`.

Example of using resource semaphores

Here, two tasks access an LC display completely independently from each other. The LCD is a resource that needs to be protected with a resource semaphore. One task may not interrupt another task which is writing to the LCD, because otherwise the following might occur:

*   Task A positions the cursor
*   Task B interrupts Task A and repositions the cursor
*   Task A writes to the wrong place in the LCD's memory.

To avoid this type of situation, every time the LCD must be accessed by a task, it is first claimed by a call to `OS_Use()` (and is automatically waited for if the resource is blocked). After the LCD has been written to, it is released by a call to `OS_Unuse()`.

```
/*
*   Demo program to illustrate the use of resource semaphores
*/
static OS_STACKPTR int StackMain[100], StackClock[50];
static OS_TASK        TaskMain, TaskClock;
static OS_RSEMA       SemaLCD;

void TaskClock(void) {
  char t   = -1;
  char s[] = "00:00";
  while(1) {
    while (TimeSec == t) {
      Delay(10);
    }
    t    = TimeSec;
    s[4] = TimeSec % 10 + '0';
    s[3] = TimeSec / 10 + '0';
    s[1] = TimeMin % 10 + '0';
    s[0] = TimeMin / 10 + '0';
    OS_Use(&SemaLCD);              /* Make sure noone else uses LCD */
    LCD_Write(10, 0, s);
    OS_Unuse(&SemaLCD);           /* Release LCD                   */
  }
}

void TaskMain(void) {
  signed char pos ;
  LCD_Write(0, 0, "Software tools by Segger!");
  OS_Delay(2000);
  while (1) {
    for ( pos=14 ; pos >=0 ; pos-- ) {
      OS_Use(&SemaLCD);           /* Make sure noone else uses LCD */
      LCD_Write(pos, 1, "train");  /* Draw train                   */
      OS_Unuse(&SemaLCD);         /* Release LCD                   */
      OS_Delay(500);
    }
    OS_Use(&SemaLCD);             /* Make sure noone else uses LCD */
    LCD_Write(0, 1, "      ");
    OS_Unuse(&SemaLCD);           /* Release LCD                   */
  }
}

void InitTask(void) {
  OS_CreateRSema(&SemaLCD);        /* Creates resource semaphore    */
  OS_CREATETASK(&TaskMain,  0, Main,   50, StackMain);
  OS_CREATETASK(&TaskClock, 0, Clock, 100, StackClock);
}
```

In most applications the routines that access a resource should automatically call OS_Use() and OS_Unuse() so that when using the resource you do not need to worry about it and can use it just as you would in a single-task system. The following is an example of how to implement a resource into the routines that actually access the display:

```
/*
*   Simple example when accessing single line dot matrix LCD
*/
static OS_RSEMA RDisp; /* Define resource semaphore                      */

void UseDisp() {      /* Simple routine to be called before using display */
  OS_Use(&RDisp);
}

void UnuseDisp() {    /* Simple routine to be called after using display  */
  OS_Unuse(&RDisp);
}

void DispCharAt(char c, char x, char y) {
  UseDisp();
  LCDGoto(x, y);
  LCDWrite1(ASCII2LCD(c));
  UnuseDisp();
}

void DISPInit(void) {
  OS_CreateRSema(&RDisp);
}
```

6.2   API functions

Routine	Description	main	Task	ISR	Timer
OS_CreateRSema	Creates a resource semaphore.	X	X		
OS_Use()	Claims a resource and blocks it for other tasks.	X	X		
OS_UseTimed()	Tries to claim a resource within a given time.	X	X		
OS_Unuse()	Releases a semaphore currently in use by a task.	X	X		
OS_Request()	Requests a specified semaphore, blocks it for other tasks if it is available. Continues execution in any case.	X	X		
OS_GetSemaValue()	Returns the value of the usage counter of a specified resource semaphore.	X	X		
OS_GetResourceOwner()	Returns a pointer to the task that is currently using (blocking) a resource.	X	X		
OS_DeleteRSema()	Deletes a specified resource semaphore.	X	X		

Table 6.1: Resource semaphore API functions

6.2.1   OS_CreateRSema

Description

Creates a resource semaphore.

Prototype

```
void OS_CreateRSema (OS_RSEMA *pRSema);
```

Parameter	Description
pRSema	Pointer to the data structure for a resource semaphore.

Table 6.2: OS_CreateRSema() parameter list

Additional Information

After creation, the resource is not blocked; the value of the counter is zero.

6.2.2 OS_Use()

Description

Claims a resource and blocks it for other tasks.

Prototype

```
int OS_Use (OS_RSEMA *pRSema);
```

Parameter	Description
pRSema	Pointer to the data structure for a resource semaphore.

Table 6.3: OS_Use() parameter list

Return value

The counter value of the semaphore.
A value greater than one denotes the resource was already locked by the calling task.

Additional Information

The following situations are possible:

- Case A: The resource is not in use.
  If the resource is not used by a task, which means the counter of the semaphore is zero, the resource will be blocked for other tasks by incrementing the counter and writing a unique code for the task that uses it into the semaphore.
- Case B: The resource is used by this task.
  The counter of the semaphore is incremented. The program continues without a break.
- Case C: The resource is being used by another task.
  The execution of this task is suspended until the resource semaphore is released. In the meantime if the task blocked by the resource semaphore has a higher priority than the task blocking the semaphore, the blocking task is assigned the priority of the task requesting the resource semaphore. This is called priority inheritance. Priority inheritance can only temporarily increase the priority of a task, never reduce it.

An unlimited number of tasks can wait for a resource semaphore. According to the rules of the scheduler, of all the tasks waiting for the resource the task with the highest priority will acquire the resource and continue program execution.

Important

This function must not be called from within an interrupt handler.

The following diagram illustrates how `OS_Use()` works:

```
                    ┌──────────────────┐
                    │                  │
                    │    OS_Use(...)    │
                    │                  │
                    └──────────────────┘
                             │
                             ▼
                         ◇ Resource ◇    Yes, by      ┌──────────────────┐
                         ◇  in use? ◇──── other task ─▶│ Wait for resource│
                             ◇                         │  to be released  │
                             │                         └──────────────────┘
   Yes, by this task         │ No                               │
         │                   ▼                                  │
         │          ┌──────────────────┐                        │
         │          │ Mark current task│◀───────────────────────┘
         │          │    as owner      │
         │          └──────────────────┘
         │                   │
         ▼                   ▼
  ┌──────────────┐   ┌──────────────────┐
  │ Increase Usage│   │ Usage counter = 1│
  │   counter    │   │                  │
  └──────────────┘   └──────────────────┘
         │                   │
         ▼                   ▼
     ( return )          ( return )
```
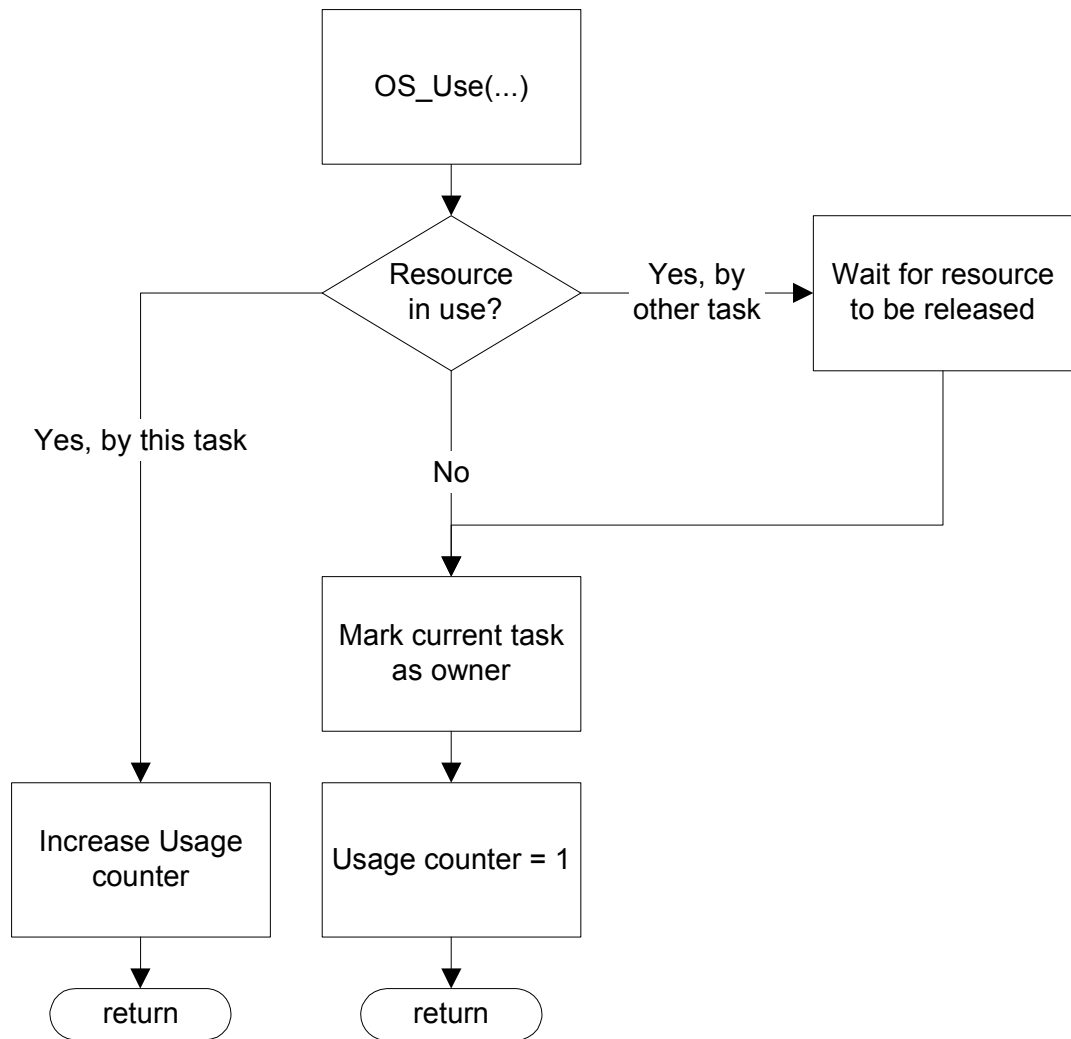
6.2.3   OS_UseTimed()

Description

Tries to claim a resource and blocks it for other tasks if it is available within a specified time.

Prototype

```
int OS_UseTimed(OS_RSEMA *pRSema, OS_TIME TimeOut)
```

Parameter	Description
pRSema	Pointer to the data structure of a resource semaphore.
TimeOut	Maximum time until the resource semaphore should be available. Timer period in basic embOS time units (nominal ms): The data type OS_TIME is defined as an integer, therefore valid values are $1 <=$ Timeout $<= 2^{15}$-1 = 0x7FFF = 32767 for 8/16 bit CPUs $1 <=$ Timeout $<= 2^{31}$-1 = 0x7FFFFFFF for 32 bit CPUs.

Table 6.4: OS_UseTimed() parameter list

Return value

0: Failed, semaphore not available before timeout.
>0: Success, resource semaphore was available. The counter value of the semaphore.
A value greater than one denotes the resource was already locked by the calling task.

Additional Information

The following situations are possible:

- Case A: The resource is not in use.
  If the resource is not used by a task, which means the counter of the semaphore is zero, the resource will be blocked for other tasks by incrementing the counter and writing a unique code for the task that uses it into the semaphore.
- Case B: The resource is used by this task.
  The counter of the semaphore is incremented. The program continues without a break.
- Case C: The resource is being used by another task.
  The execution of this task is suspended until the resource semaphore is released or the timeout time expired. In the meantime if the task blocked by the resource semaphore has a higher priority than the task blocking the semaphore, the blocking task is assigned the priority of the task requesting the resource semaphore. This is called priority inheritance. Priority inheritance can only temporarily increase the priority of a task, never reduce it.
  If the resource semaphore becomes available during the timeout, the calling task claims the resource and the function returns a value greater than zero, otherwise, if the resource does not become available, the function returns zero.

When the calling task is blocked by higher priority tasks for a period longer than the timeout value, it may happen that the resource semaphore becomes available before the calling task is resumed. Anyhow, the function will not claim the semaphore because it was not availbale within the requested time.

An unlimited number of tasks can wait for a resource semaphore. According to the rules of the scheduler, of all the tasks waiting for the resource the task with the highest priority will acquire the resource and continue program execution.

Important

This function must not be called from within an interrupt handler.

6.2.4   OS_Unuse()

Description

Releases a semaphore currently in use by a task.

Prototype

```
void OS_Unuse (OS_RSEMA *pRSema)
```

Parameter	Description
pRSema	Pointer to the data structure for a resource semaphore.

Table 6.5: OS_Unuse() parameter list

Additional Information

OS_Unuse() may be used on a resource semaphore only after that semaphore has been used by calling OS_Use() or OS_Request(). OS_Unuse() decrements the usage counter of the semaphore which must never become negative. If this counter becomes negative, a debug build will call the embOS error handler OS_Error() with error code OS_ERR_UNUSE_BEFORE_USE. In a debug build OS_Error() will also be called if OS_Unuse() is called from a task which does not own the resource. The error code is OS_ERR_RESOURCE_OWNER in this case.

Important

This function must not be called from within an interrupt handler.

6.2.5   OS_Request()

Description

Requests a specified semaphore and blocks it for other tasks if it is available. Continues execution in any case.

Prototype

```
char OS_Request (OS_RSEMA *pRSema);
```

Parameter	Description
pRSema	Pointer to the data structure for a resource semaphore.

Table 6.6: OS-Request() parameter list

Return value

1: Resource was available, now in use by the calling task.
0: Resource was not available.

Additional Information

The following diagram illustrates how OS_Request() works:
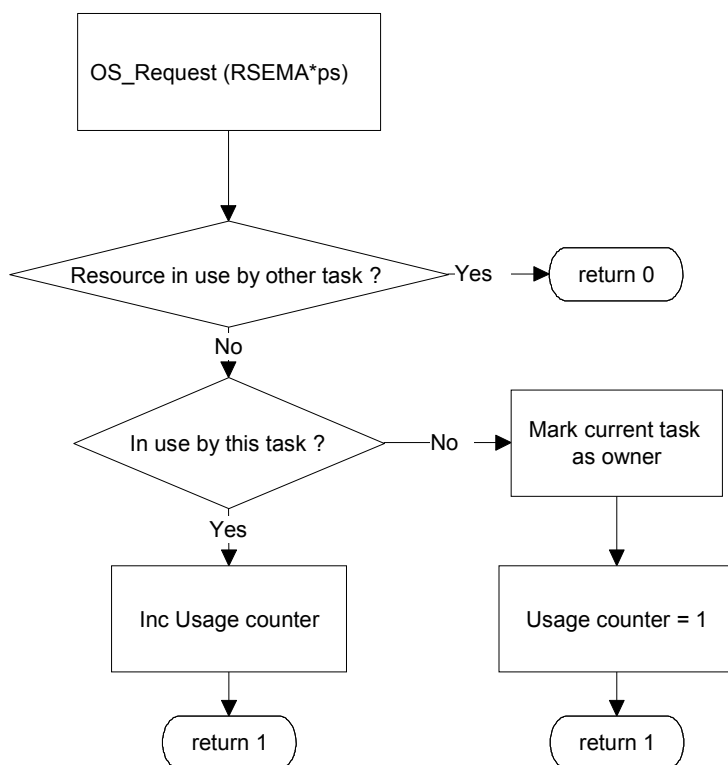
Example

```
if (OS_Request(&RSEMA_LCD) ) {
  DispTime();              /* Access the resource LCD         */
  OS_Unuse(&RSEMA_LCD);   /* Resource LCD is no longer needed */
} else {
  ... // Do something else
}
```

6.2.6   OS_GetSemaValue()

Description

Returns the value of the usage counter of a specified resource semaphore.

Prototype

```
int OS_GetSemaValue (const OS_SEMA *pSema);
```

Parameter	Description
pRSema	Pointer to the data structure for a resource semaphore.

Table 6.7: OS_GetSemaValue() parameter list

Return value

The counter of the semaphore.
A value of zero means the resource is available.

6.2.7   OS_GetResourceOwner()

Description

Returns a pointer to the task that is currently using (blocking) a resource.

Prototype

```
OS_TASK* OS_GetResourceOwner (const OS_RSEMA *pSema);
```

Parameter	Description
pRSema	Pointer to the data structure for a resource semaphore.

Table 6.8: OS_GetResourceOwner() parameter list

Return value

Pointer to the task that holds the resource.
A value of NULL means the resource is available.

6.2.8   OS_DeleteRSema()

Description

Deletes a specified resource semaphore. The memory of that semaphore may be reused for other purposes or may be used for creating another resources semaphore using the same memory.

Prototype

```
void OS_DeleteRSema (OS_RSEMA *pRSema);
```

Parameter	Description
pRSema	Pointer to a data structure of type OS_RSEMA.

Table 6.9: OS_DeleteRSema parameter list

Additional Information

Before deleting a resource semaphore, make sure that no task is claiming the resource semaphore. A debug build of embOS will call OS_Error() with the error code OS_DEL_RSEMA_DELETE if a resource semaphore is deleted when it is already in use. In systems with dynamic creation of resource semaphores, you must delete a resource semaphore before recreating it. Failure to so may cause semaphore handling to work incorrectly.

Chapter 7

Counting Semaphores

7.1   Introduction

Counting semaphores are counters that are managed by embOS. They are not as widely used as resource semaphores, events or mailboxes, but they can be very useful sometimes. They are used in situations where a task needs to wait for something that can be signaled one or more times. The semaphores can be accessed from any point, any task, or any interrupt by any means.

Example of using counting semaphores

```
OS_STACKPTR int Stack0[96], Stack1[64];                    /* Task stacks */
OS_TASK TCB0, TCB1;        /* Data-area for tasks (task-control-blocks)  */
OS_CSEMA SEMALCD;

void Task0(void) {
  while(1) {
    Disp("Task0 will wait for task 1 to signal");
    OS_WaitCSema(&SEMALCD);
    Disp("Task1 has signaled !!");
    OS_Delay(100);
  }
}

void Task1(void) {
  while(1) {
    OS_Delay(5000);
    OS_SignalCSema(&SEMALCD);
  }
}

void InitTask(void) {
  OS_CREATECSEMA(&SEMALCD);                        /* Create Semaphore */
  OS_CREATETASK(&TCB0, NULL, Task0, 100, Stack0);  /* Create Task0      */
  OS_CREATETASK(&TCB1, NULL, Task1,  50, Stack1);  /* Create Task1      */
}
```

7.2   API functions

Routine	Description	main	Task	ISR	Timer
OS_CREATECSEMA()	Macro that creates a counting semaphore with an initial count value of zero.	X	X		
OS_CreateCSema()	Creates a counting semaphore with a specified initial count value.	X	X		
OS_SignalCSema()	Increments the counter of a semaphore.	X	X	X	
OS_SignalCSemaMax()	Increments the counter of a semaphore up to a specified maximum value.	X	X	X	
OS_WaitCSema()	Decrements the counter of a semaphore.	X	X		
OS_CSemaRequest()	Decrements the counter of a semaphore, if available.	X	X	X	
OS_WaitCSemaTimed()	Decrements a semaphore counter if the semaphore is available within a specified time.	X	X		
OS_GetCSemaValue()	Returns the counter value of a specified semaphore.	X	X	X	
OS_SetCSemaValue()	Sets the counter value of a specified semaphore.	X	X		
OS_DeleteCSema()	Deletes a specified semaphore.	X	X		

Table 7.1: Counting semaphores API functions

7.2.1   OS_CREATECSEMA()

Description

Macro that creates a counting semaphore with an initial count value of zero.

Prototype

```
void OS_CREATECSEMA (OS_CSEMA *pCSema);
```

Parameter	Description
pCSema	Pointer to a data structure of type OS_CSEMA.

Table 7.2: OS_CREATECSEMA() parameter list

Additional Information

To create a counting semaphore a data structure of the type OS_CSEMA must be defined in memory and initialized using OS_CREATECSEMA(). The value of a semaphore created by using this macro is zero. If for any reason you need create a semaphore with an initial counting value greater than zero, use the function OS_CreateCSema().

7.2.2   OS_CreateCSema()

Description

Creates a counting semaphore with a specified initial count value.

Prototype

```
void OS_CreateCSema (OS_CSEMA *pCSema,
                     OS_UINT   InitValue);
```

Parameter	Description
pCSema	Pointer to a data structure of type OS_CSEMA.
InitValue	Initial count value of the semaphore: $0 <= InitValue <= 2^{16}\text{-}1 = 0xFFFF$ for 8/16 bit CPUs $0 <= InitValue <= 2^{32}\text{-}1 = 0xFFFFFFFF$ for 32 bit CPUs

Table 7.3: OS_CreateCSema() parameter list

Additional Information

To create a counting semaphore a data structure of the type OS_CSEMA must be defined in memory and initialized using OS_CreateCSema().

7.2.3   OS_SignalCSema()

Description

Increments the counter of a semaphore.

Prototype

```
void OS_SignalCSema (OS_CSEMA *pCSema);
```

Parameter	Description
pCSema	Pointer to a data structure of type `OS_CSEMA`.

Table 7.4: OS_SignalCSema() parameter list

Additional Information

`OS_SignalCSema()` signals an event to a semaphore by incrementing its counter. If one or more tasks are waiting for an event to be signaled to this semaphore, the task with the highest priority becomes the running task. The counter can have a maximum value of 0xFFFF for 8/16 bit CPUs or 0xFFFFFFFF for 32 bit CPUs. It is the responsibility of the application to make sure that this limit is not exceeded. A debug build of embOS detects a counter overflow and calls `OS_Error()` with error code `OS_ERR_CSEMA_OVERFLOW` if an overflow occurs.

7.2.4   OS_SignalCSemaMax()

Description

Increments the counter of a semaphore up to a specified maximum value.

Prototype

```
void OS_SignalCSemaMax (OS_CSEMA *pCSema,
                        OS_UINT   MaxValue);
```

Parameter	Description
pCSema	Pointer to a data structure of type OS_CSEMA.
MaxValue	Limit of semaphore count value. $1 <=$ MaxValue $<= 2^{16}-1 =$ 0xFFFF for 8/16 bit CPUs $1 <=$ MaxValue $<= 2^{32}-1 =$ 0xFFFFFFFF for 32 bit CPUs

Table 7.5: OS_SignalCSemaMax() parameter list

Additional Information

As long as current value of the semaphore counter is below the specified maximum value, OS_SignalCSemaMax() signals an event to a semaphore by incrementing its counter. If one or more tasks are waiting for an event to be signaled to this semaphore, the tasks are placed into the READY state and the task with the highest priority becomes the running task.

Calling OS_SignalCSemaMax() with a MaxValue of 1 makes a counting semaphore behave like a binary semaphore. Consider using a binary resource instead.

7.2.5   OS_WaitCSema()

Description

Decrements the counter of a semaphore.

Prototype

```
void OS_WaitCSema (OS_CSEMA *pCSema);
```

Parameter	Description
pCSema	Pointer to a data structure of type OS_CSEMA.

Table 7.6: OS_WaitCSema() parameter list

Additional Information

If the counter of the semaphore is not zero, the counter is decremented and program execution continues.
If the counter is zero, `WaitCSema()` waits until the counter is incremented by another task, a timer or an interrupt handler by a call to `OS_SignalCSema()`. The counter is then decremented and program execution continues.
An unlimited number of tasks can wait for a semaphore. According to the rules of the scheduler, of all the tasks waiting for the semaphore, the task with the highest priority will continue program execution.

Important

This function must not be called from within an interrupt handler.

7.2.6   OS_WaitCSemaTimed()

Description

Decrements a semaphore counter if the semaphore is available within a specified time.

Prototype

```
int OS_WaitCSemaTimed (OS_CSEMA *pCSema,
                       OS_TIME   TimeOut);
```

Parameter	Description
pCSema	Pointer to a data structure of type OS_CSEMA.
TimeOut	Maximum time until semaphore should be available Timer period in basic embOS time units (nominal ms): The data type OS_TIME is defined as an integer, therefore valid values are $1 <=$ Timeout $<= 2^{15}-1 = $ 0x7FFF = 32767 for 8/16 bit CPUs $1 <=$ Timeout $<= 2^{31}-1 = $ 0x7FFFFFFF for 32 bit CPUs.

Table 7.7: OS_WaitCSemaTimed parameter list

Return value

0: Failed, semaphore not available before timeout.
1: OK, semaphore was available and counter decremented.

Additional Information

If the counter of the semaphore is not zero, the counter is decremented and program execution continues.
If the counter is zero, WaitCSemaTimed() waits until the semaphore is signaled by another task, a timer, or an interrupt handler by a call to OS_SignalCSema(). The counter is then decremented and program execution continues. If the semaphore was not signaled within the specified time the program execution continues, but returns a value of zero. An unlimited number of tasks can wait for a semaphore. According to the rules of the scheduler, of all the tasks waiting for the semaphore, the task with the highest priority will continue program execution.

When the calling task is blocked by higher priority tasks for a period longer than the timeout value, it may happen that the counting semaphore becomes available after the timeout expired, but before the calling task is resumed. Anyhow, the function returns with timeout, because the semaphore was not availbale within the requested time. In this case, the state of the semaphore is not modified by OS_WaitCSemaTimed().

Important

This function must not be called from within an interrupt handler.

7.2.7   OS_CSemaRequest()

Description

Decrements the counter of a semaphore, if it is signaled.

Prototype

```
char OS_CSemaRequest (OS_CSEMA *pCSema);
```

Parameter	Description
pCSema	Pointer to a data structure of type OS_CSEMA.

Table 7.8: OS_CSemaRequest() parameter list

Return value

0: Failed, semaphore was not signaled.
1: OK, semaphore was available and counter was decremented once.

Additional Information

If the counter of the semaphore is not zero, the counter is decremented and program execution continues.
If the counter is zero, OS_CSemaRequest() does not wait and does not modify the semaphore counter. The function returns with error state.
Because this function never blocks a calling task, this function may be called from an interrupt handler.

7.2.8 OS_GetCSemaValue()

Description

Returns the current counter value of a specified semaphore.

Prototype

```
int OS_GetCSemaValue (const OS_SEMA *pCSema);
```

Parameter	Description
pCSema	Pointer to a data structure of type OS_CSEMA.

Table 7.9: OS_GetCSemaValue() parameter list

Return value

The current counter value of the semaphore.

7.2.9   OS_SetCSemaValue()

Description

Sets the counter value of a specified semaphore.

Prototype

```
OS_U8 OS_SetCSemaValue (OS_SEMA *pCSema,
                        OS_UINT  Value);
```

Parameter	Description
pCSema	Pointer to a data structure of type OS_CSEMA.
Value	Count value of the semaphore: $0 <= InitValue <= 2^{16}-1 = 0xFFFF$ for 8/16 bit CPUs $0 <= InitValue <= 2^{32}-1 = 0xFFFFFFFF$ for 32 bit CPUs

Table 7.10: OS_SetCSemaValue() parameter list

Return value

0: In any case.

7.2.10 OS_DeleteCSema()

Description

Deletes a specified semaphore.

Prototype

```
void OS_DeleteCSema (OS_CSEMA *pCSema);
```

Parameter	Description
pCSema	Pointer to a data structure of type OS_CSEMA.

Table 7.11: OS_DeleteCSema() parameter list

Additional Information

Before deleting a semaphore, make sure that no task is waiting for it and that no task will signal that semaphore at a later point.
A debug build of embOS will reflect an error if a deleted semaphore is signaled.

Chapter 8

Mailboxes

8.1   Introduction

In the preceding chapters task synchronization by the use of semaphores was described. Unfortunately, semaphores cannot transfer data from one task to another. If we need to transfer data between tasks for example via a buffer, we could use a resource semaphore every time we accessed the buffer. But doing so would make the program less efficient. Another major disadvantage would be that we could not access the buffer from an interrupt handler, because the interrupt handler is not allowed to wait for the resource semaphore.

One solution would be the usage of global variables. In this case we would need to disable interrupts each time and in each place that we accessed these variables. This is possible, but it is a path full of pitfalls. It is also not easy for a task to wait for a character to be placed in a buffer without polling the global variable that contains the number of characters in the buffer. Again, there is solution — the task could be notified by an event signaled to the task each time a character is placed in the buffer. This is why there is an easier way to do this with a real-time OS:
The use of mailboxes.

8.2   Basics

A mailbox is a buffer that is managed by the real-time operating system. The buffer behaves like a normal buffer; you can deposit something (called a message) and retrieve it later. Mailboxes usually work as FIFO: first in, first out. So a message that is deposited first will usually be retrieved first. "Message" might sound abstract, but very simply it means "item of data". It will become clearer in the typical applications explained in the following section.

A mailbox can be used by more than one producer but should be used by one consumer only. This means that more than one task or interrupt handler is allowed to deposit new data into the mailbox, but it does not make sense to retrieve messages by multiple tasks.

Limitations:

The number of mailboxes and buffers is limited only by the amount of available memory.
The message size, number of messages and buffer size per mailbox are limited by software design.
Message size: $1 <= x <= 32767$ bytes.
Number of messages: $1 <= x <= 32767$ on 8 or 16bit CPUs.

Number of messages: $1 <= x <= 2^{31}-1$ on 32bit CPUs.
Maximum buffer size for one mailbox: 65536 bytes (64KB) on 16bit CPUs

Maximum buffer size for one mailbox: 2^{32} bytes on 32bit CPUs

These limitations have been placed on mailboxes to guarantee efficient coding and also to ensure efficient management. These limitations are normally not a problem.

8.3   Typical applications

8.3.1   A keyboard buffer

In most programs, you use either a task, a software timer or an interrupt handler to check the keyboard. When a key has been pressed, that key is deposited into a mailbox that is used as a keyboard buffer. The message is then retrieved by the task that handles keyboard input. The message in this case is typically a single byte that holds the key code; the message size is therefore one byte.

The advantage of a keyboard buffer is that management is very efficient; you do not need to worry about it, because it is reliable, proven code and you have a type-ahead buffer at no extra cost. In addition, a task can easily wait for a key to be pressed without having to poll the buffer. It simply calls the `OS_GetMail()` routine for that particular mailbox. The number of keys that can be deposited in the type-ahead buffer depends only on the size of the mailbox buffer, which you define when creating the mailbox.

8.3.2   A buffer for serial I/O

In most cases, serial I/O is done with the help of interrupt handlers. The communication to these interrupt handlers is very easy with mailboxes. Both your task programs and your interrupt handlers deposit or retrieve data into/from the same mailbox. As with a keyboard buffer, the message size is one character.

For interrupt-driven sending, the task deposits the character(s) in the mailbox using `OS_PutMail()` or `OS_PutMailCond()`; the interrupt handler that is activated when a new character can be sent retrieves the character(s) with `OS_GetMailCond()`.

For interrupt-driven receiving, the interrupt handler that is activated when a new character is received deposits it in the mailbox using `OS_PutMailCond()`; the task receives it using `OS_GetMail()` or `OS_GetMailCond()`.

8.3.3   A buffer for commands sent to a task

Assume you have one task controlling a motor, as you might have in applications that control a machine. A simple way to give commands to this task would be to define a structure for commands. The message size would then be the size of this structure.

8.4 Single-byte mailbox functions

In many (if not the most) situations, mailboxes are used simply to hold and transfer single-byte messages. This is the case, for example, with a mailbox that takes the character received or sent via serial interface, or normally with a mailbox used as a keyboard buffer. In some of these cases, time is very critical, especially if a lot of data is transferred in short periods of time.

To minimize the overhead caused by the mailbox management of embOS, variations on some mailbox functions are available for single-byte mailboxes. The general functions `OS_PutMail()`, `OS_PutMailCond()`, `OS_GetMail()`, and `OS_GetMailCond()` can transfer messages of sizes between 1 and 32767 bytes each.
Their single-byte equivalents `OS_PutMail1()`, `OS_PutMailCond1()`, `OS_GetMail1()`, and `OS_GetMailCond1()` work the same way with the exception that they execute much faster because management is simpler. It is recommended to use the single-byte versions if you transfer a lot of single-byte data via mailboxes.

The routines `OS_PutMail1()`, `OS_PutMailCond1()`, `OS_GetMail1()`, and `OS_GetMailCond1()` work exactly the same way as their universal equivalents and are therefore not described separately. The only difference is that they can only be used for single-byte mailboxes.

8.5   API functions

Routine	Explanation	main	Task	ISR	Timer
OS_CreateMB()	Creates a new mailbox.	X	X		
OS_PutMail() / OS_PutMail1()	Stores a new message of a predefined size in a mailbox.	X	X		
OS_PutMailCond() / OS_PutMailCond1()	Stores a new message of a predefined size in a mailbox, if the mailbox is able to accept one more message.	X	X	X	X
OS_PutMailFront() / OS_PutMailFront1()	Stores a new message of a predefined size into a mailbox in front of all other messages. This new message will be retrieved first.	X	X		
OS_PutMailFrontCond() / OS_PutMailFrontCond1()	Stores a new message of a predefined size into a mailbox in front of all other messages, if the mailbox is able to accept one more message.	X	X	X	X
OS_GetMail() / OS_GetMail1()	Retrieves a message of a predefined size from a mailbox.		X		
OS_GetMailCond() / OS_GetMailCond1()	Retrieves a message of a predefined size from a mailbox, if a message is available.	X	X	X	X
OS_GetMailTimed()	Retrieves a new message of a predefined size from a mailbox, if a message is available within a given time.	X	X		
OS_WaitMail()	Waits until a mail is available, but does not retrieve the message from the mailbox.	X	X		
OS_WaitMailTimed()	Suspends the calling task until a mail is available or until the timeout expires, but does not retrieve the message from the mailbox.	X	X		
OS_PeekMail()	Reads a mail from a mailbox without removing it	X	X	X	X
OS_Mail_GetPtr()	Gets a pointer to the next mail without removing it		X		
OS_Mail_GetPtrCond()	Gets a pointer to the next mail without removing it, if a message is available	X	X	X	X
OS_Mail_Purge()	Removes a message which was read by OS_Mail_GetPtr()/OS_Mail_GetPtrCond()	X	X	X	X
OS_ClearMB()	Clears all messages in a specified mailbox.	X	X	X	X
OS_GetMessageCnt()	Returns number of messages currently in a specified mailbox.	X	X	X	X
OS_DeleteMB()	Deletes a specified mailbox.	X	X		

Table 8.1: Mailboxes API functions

8.5.1   OS_CreateMB()

Description

Creates a new mailbox.

Prototype

```
void OS_CreateMB (OS_MAILBOX     *pMB,
                  unsigned short  sizeofMsg,
                  unsigned int    maxnofMsg,
                  void           *pMsg);
```

Parameter	Description
pMB	Pointer to a data structure of type `OS_MAILBOX` reserved for managing the mailbox.
sizeofMsg	Size of a message in bytes. (1 <= `sizeofMsg` <= 32767)
maxnoMsg	Maximum number of messages. (1 <= `MaxnofMsg` <= 32767)
pMsg	Pointer to a memory area used as buffer. The buffer must be big enough to hold the given number of messages of the specified size: `sizeofMsg` * `maxnoMsg` bytes.

Table 8.2: OS_CreateMB() parameter list

Example

Mailbox used as keyboard buffer:

```
OS_MAILBOX MBKey;
char MBKeyBuffer[6];

void InitKeyMan(void) {
  /* Create mailbox, functioning as type ahead buffer */
  OS_CreateMB(&MBKey, 1, sizeof(MBKeyBuffer), &MBKeyBuffer);
}
```

Mailbox used for transferring complex commands from one task to another:

```
/*
* Example of mailbox used for transferring commands to a task
* that controls a motor
*/
typedef struct {
  char Cmd;
  int Speed[2];
  int Position[2];
} MOTORCMD ;

OS_MAILBOX MBMotor;

#define NUM_MOTORCMDS 4

char BufferMotor[sizeof(MOTORCMD) * NUM_MOTORCMDS];

void MOTOR_Init(void) {
  /* Create mailbox that holds commands messages */
  OS_CreateMB(&MBMotor, sizeof(MOTORCMD), NUM_MOTORCMDS, &BufferMotor);
}
```

8.5.2   OS_PutMail() / OS_PutMail1()

Description

Stores a new message of a predefined size in a mailbox.

Prototype

```
void OS_PutMail  (OS_MAILBOX *pMB,
                   const void *pMail);
void OS_PutMail1 (OS_MAILBOX *pMB,
                   const char *pMail);
```

Parameter	Description
pMB	Pointer to the mailbox.
pMail	Pointer to the message to store.

Table 8.3: OS_PutMail() / OS_PutMail1() parameter list

Additional Information

If the mailbox is full, the calling task is suspended.
Because this routine might require a suspension, it must not be called from an interrupt routine. Use `OS_PutMailCond()`/`OS_PutMailCond1()` instead if you need to store data in a mailbox from within an ISR.
When using a debug build of embOS, calling from an interrupt routine will call the error handler `OS_Error()` with error code `OS_ERR_IN_ISR`.

Important

This function must not be called from within an interrupt handler.

Example

Single-byte mailbox as keyboard buffer:

```
OS_MAILBOX MBKey;
char MBKeyBuffer[6];

void KEYMAN_StoreKey(char k) {
  OS_PutMail1(&MBKey, &k);  /* Store key, wait if no space in buffer */
}

void KEYMAN_Init(void) {
  /* Create mailbox functioning as type ahead buffer */
  OS_CreateMB(&MBKey, 1, sizeof(MBKeyBuffer), &MBKeyBuffer);
}
```

8.5.3   OS_PutMailCond() / OS_PutMailCond1()

Description

Stores a new message of a predefined size in a mailbox, if the mailbox is able to accept one more message.

Prototype

```
char OS_PutMailCond  (OS_MAILBOX *pMB,
                       const void *pMail);
char OS_PutMailCond1 (OS_MAILBOX *pMB,
                       const char *pMail);
```

Parameter	Description
pMB	Pointer to the mailbox.
pMail	Pointer to the message to store.

Table 8.4: OS_PutMailCond() / OS_PutMailCond1() overview

Return value

0: Success; message stored.
1: Message could not be stored (mailbox is full).

Additional Information

If the mailbox is full, the message is not stored.
This function never suspends the calling task. It may therefore be called from an interrupt routine.

Example

```
OS_MAILBOX MBKey;
char MBKeyBuffer[6];

char KEYMAN_StoreCond(char k) {
  return OS_PutMailCond1(&MBKey, &k); /* Store key if space in buffer */
}
```

This example can be used with the sample program shown earlier to handle a mailbox as keyboard buffer.

8.5.4   OS_PutMailFront() / OS_PutMailFront1()

Description

Stores a new message of a predefined size at the beginning of a mailbox in front of all other messages. This new message will be retrieved first.

Prototype

```
void OS_PutMailFront  (OS_MAILBOX *pMB,
                        const void *pMail);
void OS_PutMailFront1 (OS_MAILBOX *pMB,
                        const char *pMail);
```

Parameter	Description
pMB	Pointer to the mailbox.
pMail	Pointer to the message to store.

Table 8.5: OS_PutMailFront() / OS_PutMailFront1() parameter list

Additional Information

If the mailbox is full, the calling task is suspended. Because this routine might require a suspension, it must not be called from an interrupt routine. Use `OS_PutMailFrontCond()`/`OS_PutMailFrontCond1()` instead if you need to store data in a mailbox from within an ISR.
This function is useful to store "emergency" messages into a mailbox which must be handled quickly.
It may also be used in general instead of `OS_PutMail()` to change the FIFO structure of a mailbox into a LIFO structure.

Important

This function must not be called from within an interrupt handler.

Example

Single-byte mailbox as keyboard buffer which will follow the LIFO pattern:

```
OS_MAILBOX MBCmd;
char MBCmdBuffer[6];

void KEYMAN_StoreCommand(char k) {
  OS_PutMailFront1(&MBCmd, &k); /* Store command, wait if no space in buffer*/
}

void KEYMAN_Init(void) {
  /* Create mailbox for command buffer */
  OS_CreateMB(&MBCmd, 1, sizeof(MBCmdBuffer), &MBCmdBuffer);
}
```

8.5.5   OS_PutMailFrontCond() / OS_PutMailFrontCond1()

Description

Stores a new message of a predefined size into a mailbox in front of all other messages, if the mailbox is able to accept one more message. The new message will be retrieved first.

Prototype

```
char OS_PutMailFrontCond  (OS_MAILBOX *pMB,
                              const void *pMail);
char OS_PutMailFrontCond1 (OS_MAILBOX *pMB,
                              const char *pMail);
```

Parameter	Description
pMB	Pointer to the mailbox.
pMail	Pointer to the message to store.

Table 8.6: OS_PutMailFrontCond() / OS_PutMailFrontCond1() parameter list

Return value

0: Success; message stored.
1: Message could not be stored (mailbox is full).

Additional Information

If the mailbox is full, the message is not stored. This function never suspends the calling task. It may therefore be called from an interrupt routine. This function is useful to store "emergency" messages into a mailbox which must be handled quickly. It may also be used in general instead of `OS_PutMailCond()` to change the FIFO structure of a mailbox into a LIFO structure.

8.5.6   OS_GetMail() / OS_GetMail1()

Description

Retrieves a new message of a predefined size from a mailbox.

Prototype

```
void OS_GetMail  (OS_MAILBOX *pMB,
                   void       *pDest);
void OS_GetMail1 (OS_MAILBOX *pMB,
                   char       *pDest);
```

Parameter	Description
pMB	Pointer to the mailbox.
pDest	Pointer to the memory area that the message should be stored at. Make sure that it points to a valid memory area and that there is sufficient space for an entire message. The message size (in bytes) was defined when the mailbox was created.

Table 8.7: OS_GetMail() / OS_GetMail1() parameter list

Additional Information

If the mailbox is empty, the task is suspended until the mailbox receives a new message. Because this routine might require a suspension, it must not be called from an interrupt routine. Use `OS_GetMailCond`/`OS_GetMailCond1` instead if you need to retrieve data from a mailbox from within an ISR.

Important

This function must not be called from within an interrupt handler.

Example

```
OS_MAILBOX MBKey;

char WaitKey(void) {
  char c;
  OS_GetMail1(&MBKey, &c);
  return c;
}
```

8.5.7 OS_GetMailCond() / OS_GetMailCond1()

Description

Retrieves a new message of a predefined size from a mailbox, if a message is available.

Prototype

```
char OS_GetMailCond  (OS_MAILBOX *pMB,
                       void       *pDest);
char OS_GetMailCond1 (OS_MAILBOX *pMB,
                       char       *pDest);
```

Parameter	Description
pMB	Pointer to the mailbox.
pDest	Pointer to the memory area that the message should be stored at. Make sure that it points to a valid memory area and that there is sufficient space for an entire message. The message size (in bytes) was defined when the mailbox was created.

Table 8.8: OS_GetMailCond() / OS_GetMailCond1() parameter list

Return value

0: Success; message retrieved.
1: Message could not be retrieved (mailbox is empty); destination remains unchanged.

Additional Information

If the mailbox is empty, no message is retrieved and pDest remains unchanged, but the program execution continues. This function never suspends the calling task. It may therefore also be called from an interrupt routine.

Example

```
OS_MAILBOX MBKey;

/*
* If a key has been pressed, it is taken out of the mailbox and returned to caller.
* Otherwise zero is returned.
*/
char GetKey(void) {
  char c = 0;
  OS_GetMailCond1(&MBKey, &c);
  return c;
}
```

8.5.8   OS_GetMailTimed()

Description

Retrieves a new message of a predefined size from a mailbox, if a message is available within a given time.

Prototype

```
char OS_GetMailTimed (OS_MAILBOX *pMB,
                      void       *pDest,
                      OS_TIME    Timeout);
```

Parameter	Description
pMB	Pointer to the mailbox.
pDest	Pointer to the memory area that the message should be stored at. Make sure that it points to a valid memory area and that there is sufficient space for an entire message. The message size (in bytes) has been defined upon creation of the mailbox.
Timeout	Maximum time in timer ticks until the requested mail must be available. The data type OS_TIME is defined as an integer, therefore valid values are $1 <= $ Timeout $ <= 2^{15}\text{-}1 = 0x7FFF = 32767$ for 8/16 bit CPUs $1 <= $ Timeout $ <= 2^{31}\text{-}1 = 0x7FFFFFFF$ for 32 bit CPUs

Table 8.9: OS_GetMailTimed() parameter list

Return value

0: Success; message retrieved.
1: Message could not be retrieved (mailbox is empty); destination remains unchanged.

Additional Information

If the mailbox is empty, no message is retrieved, pDest remains unchanged and the task is suspended for the given timeout. The task continues execution according to the rules of the scheduler as soon as a mail is available within the given timeout, or after the timeout value has expired.

When the calling task is blocked by higher priority tasks for a period longer than the timeout value, it may happen that mail becomes available after the timeout expired, but before the calling task is resumed. Anyhow, the function returns with timeout, because the mail was not availbale within the requested time. In this case, no mail is retrieved from the mailbox.

Important

This function must not be called from within an interrupt handler.

Example

```
OS_MAILBOX MBKey;

/*
* If a key has been pressed, it is taken out of the mailbox and returned to caller.
* Otherwise, zero is returned.
*/
char GetKey(void) {
  char c = 0;
  OS_GetMailTimed(&MBKey, &c, 10); /* Wait for 10 timer ticks */
  return c;
}
```

8.5.9   OS_WaitMail()

Description

Waits until a mail is available, but does not retrieve the message from the mailbox.

Prototype

```
void OS_WaitMail (OS_MAILBOX *pMB);
```

Parameter	Description
pMB	Pointer to the mailbox.

Table 8.10: OS_WaitMail() parameter list

Additional Information

If the mailbox is empty, the task is suspended until a mail is available, otherwise the task continues. The task continues execution according to the rules of the scheduler as soon as a mail is available, but the mail is not retrieved from the mailbox.

Important

This function must not be called from within an interrupt handler.

8.5.10 OS_WaitMailTimed()

Description

Waits until a mail is available or the timeout has expired, but does not retrieve the message from the mailbox.

Prototype

```
char OS_WaitMailTimed (OS_MAILBOX *pMB,
                       OS_TIME     Timeout);
```

Parameter	Description
pMB	Pointer to the mailbox.
Timeout	Maximum time in timer ticks until the requested mail must be available. The data type OS_TIME is defined as an integer, therefore valid values are $1 <= Timeout <= 2^{15}-1 = 0x7FFF = 32767$ for 8/16 bit CPUs $1 <= Timeout <= 2^{31}-1 = 0x7FFFFFFF$ for 32 bit CPUs

Table 8.11: OS_WaitMail() parameter list

Return value

0: Success; message available.
1: Timeout; no message available within the given timeout time.

Additional Information

If the mailbox is empty, the task is suspended for the given timeout. The task continues execution according to the rules of the scheduler as soon as a mail is available within the given timeout, or after the timeout value has expired.

When the calling task is blocked by higher priority tasks for a period longer than the timeout value, it may happen that mail becomes available after the timeout expired, but before the calling task is resumed. Anyhow, the function returns with timeout, because the mail was not availbale within the requested time.

Important

This function must not be called from within an interrupt handler.

8.5.11 OS_PeekMail()

Description

Peeks a mail from a mailbox without removing the mail.

Prototype

```
char OS_PeekMail (OS_MAILBOX *pMB,
                  void       *pDest);
```

Parameter	Description
pMB	Pointer to the mailbox.
pDest	Pointer to a buffer that should receive the mail

Table 8.12: OS_PeekMail() parameter list

Return value

0: Success; message available.
1: Message could not be retrieved (mailbox is empty).

Additional Information

This function is non-blocking and never suspends the calling task. It may therefore be called from an interrupt routine.

8.5.12 OS_Mail_GetPtr()

Description

Retrieves a pointer to a new message of a predefined size from a mailbox.

Prototype

```
void OS_Mail_GetPtr(OS_MAILBOX *pMB, void **ppDest);
```

Parameter	Description
pMB	Pointer to the mailbox.
ppDest	Pointer to the memory area that a pointer to the message should be stored at. The message size (in bytes) was defined when the mailbox was created.

Table 8.13: OS_Mail_GetPtr() parameter list

Additional Information

If the mailbox is empty, the task is suspended until the mailbox receives a new message. Because this routine might require a suspension, it must not be called from an interrupt routine. Use OS_Mail_GetPtrCond() instead if you need to retrieve data from a mailbox from within an ISR.

Important

This function must not be called from within an interrupt handler.

Example

```
OS_MAILBOX MBKey;

void PrintMessage(void) {
  char *p;
  OS_Mail_GetPtr(&MBKey, (void**)&p);
  printf("%d\n", *p);
  OS_Mail_Purge(&MBKey);
}
```

8.5.13 OS_Mail_GetPtrCond()

Description

Retrieves a pointer to a new message of a predefined size from a mailbox, if a message is available.

Prototype

```
char OS_Mail_GetPtrCond(OS_MAILBOX *pMB, void **ppDest);
```

Parameter	Description
pMB	Pointer to the mailbox.
ppDest	Pointer to the memory area that a pointer to the message should be stored at. The message size (in bytes) was defined when the mailbox was created.

Table 8.14: OS_Mail_GetPtrCond() parameter list

Return value

0: Success; message retrieved.
1: Message could not be retrieved (mailbox is empty); destination remains unchanged.

Additional Information

If the mailbox is empty, no message is retrieved and ppDest remains unchanged, but the program execution continues. This function never suspends the calling task. It may therefore also be called from an interrupt routine.

Example

```
OS_MAILBOX MBKey;

void PrintMessage(void) {
  char *p;
  char r;
  r = OS_Mail_GetPtrCond(&MBKey, (void**)&p);
  if (r == 0) {
    printf("%d\n", *p);
    OS_Mail_Purge(&MBKey);
  }
}
```

8.5.14 OS_Mail_Purge()

Description

Deletes the last retrieved message in a mailbox.

Prototype

```
void OS_Mail_Purge(OS_MAILBOX *pMB);
```

Parameter	Description
pMB	Pointer to the mailbox.

Table 8.15: OS_WaitMail() parameter list

Additional Information

This routine should be called by the task that retrieved the last message from the mailbox, after the message is processed.
Once a message was retrieved by a call of `OS_Mail_GetPtr()` or `OS_Mail_GetPtrCond()`, the message must be removed from the mailbox by a call of `OS_Mail_Purge()` before a following message can be retrieved from the mailbox. Consecutive calls of `OS_Mail_GetPtr()` or `OS_Mail_GetPtrCond()` will call the embOS error handler `OS_Error()` in embOS debug builds.
Consecutive calls of `OS_Mail_Purge()` or calling `OS_Mail_Purge()` without having retrieved a message from the mailbox will also call the embOS error handler `OS_Error()` in embOS debug builds.

Example

```
OS_MAILBOX MBKey;

void PrintMessage(void) {
  char *p;
  OS_Mail_GetPtr(&MBKey, (void**)&p);
  printf("%d\n", *p);
  OS_Mail_Purge(&MBKey);
}
```

8.5.15 OS_ClearMB()

Description

Clears all messages in a specified mailbox.

Prototype

```
void OS_ClearMB (OS_MAILBOX *pMB);
```

Parameter	Description
pMB	Pointer to the mailbox.

Table 8.16: OS_ClearMB() parameter list

Additional Information

OS_ClearMB() may cause a task switch.

Example

```
OS_MAILBOX MBKey;

/*
* Clear keyboard type ahead buffer
*/
void ClearKeyBuffer(void) {
  OS_ClearMB(&MBKey);
}
```

8.5.16 OS_GetMessageCnt()

Description

Returns the number of messages currently available in a specified mailbox.

Prototype

```
unsigned int OS_GetMessageCnt (OS_MAILBOX *pMB);
```

Parameter	Description
pMB	Pointer to the mailbox.

Table 8.17: OS_GetMessageCnt() parameter list

Return value

The number of messages in the mailbox.

8.5.17 OS_DeleteMB()

Description

Deletes a specified mailbox.

Prototype

```
void OS_DeleteMB (OS_MAILBOX *pMB);
```

Parameter	Description
pMB	Pointer to the mailbox.

Table 8.18: OS_DeleteMB() parameter list

Additional Information

To keep the system fully dynamic, it is essential that mailboxes can be created dynamically. This also means there must be a way to delete a mailbox when it is no longer needed. The memory that has been used by the mailbox for the control structure and the buffer can then be reused or reallocated.
It is the programmer's responsibility to:

- make sure that the program no longer uses the mailbox to be deleted
- make sure that the mailbox to be deleted actually exists (i.e. has been created first).

In a debug build `OS_Error()` will also be called, if `OS_DeleteMB()` is called while tasks are waiting for new data from the mailbox. The error code in this case is `OS_ERR_MAILBOX_DELETE`.

Example

```
OS_MAILBOX MBSerIn;

void Cleanup(void) {
  OS_DeleteMB(&MBSerIn);
}
```

Chapter 9

Queues

9.1   Introduction

In the preceding chapter, intertask communication using mailboxes was described. Mailboxes can handle small messages with fixed data size only.

Queues enable intertask communication with larger messages or with messages of differing lengths.

9.2   Basics

A queue consists of a data buffer and a control structure that is managed by the real-time operating system. The queue behaves like a normal buffer; you can deposit something (called a message) in the queue and retrieve it later. Queues work as FIFO: first in, first out. So a message that is deposited first will be retrieved first.
There are three major differences between queues and mailboxes:

1. Queues accept messages of differing lengths. When depositing a message into a queue, the message size is passed as a parameter.
2. Retrieving a message from the queue does not copy the message, but returns a pointer to the message and its size. This enhances performance because the data is copied only when the message is written into the queue.
3. The retrieving function must delete every message after processing it.
4. A new message can only be retrieved from the queue when the previous message was deleted from the queue.

Both the number and size of queues is limited only by the amount of available memory. Any data structure can be written into a queue, the message size is not fixed.

Similar to mailboxes, queues can be used by more than one producer but should be used by one consumer only. This means that more than one task or interrupt handler is allowed to deposit new data into the queue, but it does not make sense to retrieve messages by multiple tasks.

The queue data buffer contains the messages and some additional management information. Each message has a message header containing the message size. The define `OS_Q_SIZEOF_HEADER` defines the size of the message header.
Additionally, the queue buffer will be aligned for those CPUs which need data alignment. Therefore the queue data buffer size must be bigger than the sum of all messages.

9.3   API functions

Routine	Description	main	Task	ISR	Timer
OS_Q_Create()	Creates and initializes a message queue.	X	X	X	X
OS_Q_Put()	Stores a new message of given size in a queue.	X	X	X	X
OS_Q_PutBlocked()	Stores a new message of given size in a queue. Blocks the calling task when queue is full.		X		
OS_Q_PutTimed()	Stores a new message of given size in a queue within a given timeout time. Suspends the calling task when the queue is full.	X	X		
OS_Q_PutEx()	Stores a new message, of which the distinct parts are distributed in memory as indicated by a OS_Q_SRCLIST structure, in a queue.	X	X	X	X
OS_Q_PutBlockedEx()	Stores a new message, of which the distinct parts are distributed in memory as indicated by a OS_Q_SRCLIST structure, in a queue. Blocks the calling task when queue is full.		X		
OS_Q_PutTimedEx()	Stores a new message, of which the distinct parts are distributed in memory as indicated by a OS_Q_SRCLIST structure, in a queue. Suspends the calling task for a given timeout when the queue is full.	X	X		
OS_Q_GetPtr()	Retrieves a message from a queue.	X	X		
OS_Q_GetPtrCond()	Retrieves a message from a queue, if one message is available or returns without suspension.	X	X	X	X
OS_Q_GetPtrTimed()	Retrieves a message from a queue within a specified time, if one message is available.	X	X		
OS_Q_Purge()	Deletes the last retrieved message in a queue.	X	X	X	X
OS_Q_Clear()	Deletes all message in a queue.	X	X	X	X
OS_Q_GetMessageCnt()	Returns the number of messages currently in a queue.	X	X	X	X
OS_Q_Delete()	Deletes a specified queue.	X	X	X	X
OS_Q_IsInUse()	Delivers information about the usage state of the queue.	X	X	X	X
OS_Q_GetMessageSize()	Returns the size of the first message in the queue.	X	X	X	X
OS_Q_PeekPtr()	Retrieves a message from a queue without removing it.	X	X	X	X

Table 9.1: Queues API

9.3.1   OS_Q_Create()

Description

Creates and initializes a message queue.

Prototype

```
void OS_Q_Create (OS_Q    *pQ,
                   void    *pData,
                   OS_UINT  Size);
```

Parameter	Description
pQ	Pointer to a data structure of type OS_Q reserved for the management of the message queue.
pData	Pointer to a memory area used as data buffer for the queue.
Size	Size in bytes of the data buffer.

Table 9.2: OS_Q_Create() parameter list

Example

```
#define MESSAGE_CNT  100
#define MESSAGE_SIZE 100
#define MEMORY_QSIZE MESSAGE_CNT * (MESSAGE_SIZE + OS_Q_SIZEOF_HEADER)
static OS_Q _MemoryQ;
static char _acMemQBuffer[MEMORY_QSIZE];

void MEMORY_Init(void) {
  OS_Q_Create(&_MemoryQ, &_acMemQBuffer, sizeof(_acMemQBuffer));
}
```

Additional Information

The define OS_Q_SIZEOF_HEADER can be used to calculate the additional management information bytes needed for each message in the queue data buffer. But it does not account for the additional space needed for data alignment. Thus the number of messages that can actually be stored in the queue buffer depends on the message sizes.

9.3.2   OS_Q_Put()

Description

Deposits a new message of given size in a queue.

Prototype

```
int OS_Q_Put (OS_Q        *pQ,
              const void *pSrc,
              OS_UINT     Size);
```

Parameter	Description
pQ	Pointer to a data structure of type os_q reserved for the management of the message queue.
pSrc	Pointer to the message to store.
Size	Size of the message to store.

Table 9.3: OS_Q_Put() parameter list

Return value

0: Success, message stored.
1: Message could not be stored (queue is full).

Additional Information

This routine never suspends the calling task and may therefore be called from an interrupt routine.
When the message is deposited into the queue, the entire message is copied into the queue buffer, not only the pointer to the data. Therefore the message content is protected and remains valid until it is retrieved and accessed by a task reading the message.

Example

```
int MEMORY_Write(const char *pData, OS_UINT Len) {
  return OS_Q_Put(&_MemoryQ, pData, Len);
}
```

9.3.3   OS_Q_PutBlocked()

Description

Deposits a new message of given size in a queue.

Prototype

```
void OS_Q_PutBlocked (OS_Q       *pQ,
                      const void *pSrc,
                      OS_UINT     Size);
```

Parameter	Description
pQ	Pointer to a data structure of type OS_Q reserved for the manage-ment of the message queue.
pSrc	Pointer to the message to store.
Size	Size of the message to store.

Table 9.4: OS_Q_PutBlocked() parameter list

Additional Information

If the queue is full, the calling task is suspended. Because this routine might require a suspension, it must not be called from an interrupt routine. Use OS_Q_Put() instead if you need to deposit messages in a queue from within an ISR.

Important

This function must not be called from within an interrupt handler.
When using a debug build of embOS, calling from an interrupt handler will call the error handler OS_Error() with error code OS_ERR_IN_ISR .

Example

```
void StoreMessage(const char *pData, OS_UINT Len)
  OS_Q_PutBlocked(&_MemoryQ, pData, Len);
}
```

9.3.4   OS_Q_PutTimed()

Description

Deposits a new message of given size in a queue if space is available within a given time.

Prototype

```
int OS_Q_PutTimed (OS_Q        *pQ,
                   const void *pSrc,
                   OS_UINT     Size,
                   OS_TIME     Timeout);
```

Parameter	Description
pQ	Pointer to a data structure of type OS_Q reserved for the management of the message queue.
pSrc	Pointer to the message to store.
Size	Size of the message to store.
Timeout	Maximum time in timer ticks until the requested message must be stored into the queue. The data type OS_TIME is defined as an integer, therefore valid values are $1 <= $ Timeout $<= 2^{15}\text{-}1 = $ 0x7FFF = 32767 for 8/16 bit CPUs $1 <= $ Timeout $<= 2^{31}\text{-}1 = $ 0x7FFFFFFF for 32 bit CPUs

Table 9.5: OS_Q_PutTimed() parameter list

Return value

0: Success, message stored.
1: Message could not be stored within the specified time (insufficient space).

Additional Information

If the queue holds insufficient space, the calling task is suspended until space for the message is available, or the specified timeout time has expired.
If the message could be deposited into the queue within the sepcified time, the function returns zero.
As the calling function may be suspended, the function must not be called from an interrupt routine or timer. A debug build of embOS will call the embOS error function OS_Error() if this function is called from an interrupt handler or timer.

Example

```
int MEMORY_WriteTimed(const char *pData, OS_UINT Len, OS_TIME Timeout) {
  return OS_Q_PutTimed(&_MemoryQ, pData, Len, Timeout);
}
```

9.3.5   OS_Q_PutEx()

Description

Stores a new message, of which the distinct parts are distributed in memory as indicated by a OS_Q_SRCLIST structure, in a queue.

Prototype

```
int OS_Q_PutEx (OS_Q*                      pQ,
                OS_CONST_PTR OS_Q_SRCLIST* pSrcList,
                OS_UINT                    NumSrc);
```

Parameter	Description
pQ	Pointer to a data structure of type OS_Q reserved for the management of the message queue.
pSrcList	Pointer to an array of OS_Q_SRCLIST structures which contain pointers to the data to store.
NumSrc	Number of OS_Q_SRCLIST structures at pSrcList.

Table 9.6: OS_Q_PutEx() parameter list

Return value

0: Success, message stored.
1: Message could not be stored (queue is full).

Additional Information

This routine never suspends the calling task and may therefore be called from an interrupt routine.
When the message is deposited into the queue, the entire message is copied into the queue buffer, not only the pointer(s) to the data. Therefore the message content is protected and remains valid until it is retrieved and accessed by a task reading the message.

Example

```
OS_CONST_PTR OS_Q_SRCLIST aDataList[] = { {"Hello ", 6},
                                          {"World!", 6}
                                        };
OS_Q_PutEx(&_MemoryQ, aDataList, 2);
```

9.3.5.1   The OS_Q_SRCLIST structure

The OS_Q_SRCLIST structure consists of two elements:

Parameter	Description
pSrc	Pointer to a part of the message to store.
Size	Size of the part of the message.

Table 9.7: Elements of the OS_Q_SRCLIST structure

9.3.6 OS_Q_PutBlockedEx()

Description

Stores a new message, of which the distinct parts are distributed in memory as indicated by a OS_Q_SRCLIST structure, in a queue. Blocks the calling task when queue is full.

Prototype

```
void OS_Q_PutBlockedEx (OS_Q*                      pQ,
                        OS_CONST_PTR OS_Q_SRCLIST* pSrcList,
                        OS_UINT                    NumSrc);
```

Parameter	Description
pQ	Pointer to a data structure of type OS_Q reserved for the management of the message queue.
pSrcList	Pointer to an array of OS_Q_SRCLIST structures which contain pointers to the data to store.
NumSrc	Number of OS_Q_SRCLIST structures at pSrcList.

Table 9.8: OS_Q_PutBlockedEx() parameter list

Additional Information

If the queue is full, the calling task is suspended. Because this routine might require a suspension, it must not be called from an interrupt routine. Use OS_Q_PutEx() instead if you need to deposit messages in a queue from within an ISR.

For more information on the OS_Q_SRCLIST structure, refer to *The OS_Q_SRCLIST structure* on page 179.

Important

This function must not be called from within an interrupt handler.
When using a debug build of embOS, calling from an interrupt handler will call the error handler OS_Error() with error code OS_ERR_IN_ISR .

Example

```
OS_CONST_PTR OS_Q_SRCLIST aDataList[] = { {"Hello ", 6},
                                          {"World!", 6}
                                        };
OS_Q_PutEx(&_MemoryQ, aDataList, 2);
```

9.3.7   OS_Q_PutTimedEx()

Description

Stores a new message, of which the distinct parts are distributed in memory as indicated by a OS_Q_SRCLIST structure, in a queue. Suspends the calling task for a given timeout when the queue is full.

Prototype

```
int OS_Q_PutTimedEx (OS_Q*                    pQ,
                     OS_CONST_PTR OS_Q_SRCLIST* pSrcList,
                     OS_UINT                  NumSrc,
                     OS_TIME                  Timeout);
```

Parameter	Description
pQ	Pointer to a data structure of type OS_Q reserved for the management of the message queue.
pSrcList	Pointer to an array of OS_Q_SRCLIST structures which contain pointers to the data to store.
NumSrc	Number of OS_Q_SRCLIST structures at pSrcList.
Timeout	Maximum time in timer ticks until the requested message must be stored into the queue. The data type OS_TIME is defined as an integer, therefore valid values are $1 <= $ Timeout $<= 2^{15}-1 = $ 0x7FFF $= 32767$ for 8/16 bit CPUs $1 <= $ Timeout $<= 2^{31}-1 = $ 0x7FFFFFFF for 32 bit CPUs

Table 9.9: OS_Q_PutTimedEx() parameter list

Return value

0: Success, message stored.
1: Message could not be stored within the specified time (insufficient space).

Additional Information

If the queue holds insufficient space, the calling task is suspended until space for the message is available or the specified timeout time has expired.
If the message could be deposited into the queue within the sepcified time, the function returns zero.
As the calling function may be suspended, the function must not be called from an interrupt routine or timer. A debug build of embOS will call the embOS error function OS_Error() if this function is called from an interrupt handler or timer.

For more information on the OS_Q_SRCLIST structure, refer to *The OS_Q_SRCLIST structure* on page 179.

Example

```
OS_CONST_PTR OS_Q_SRCLIST aDataList[] = { {"Hello ", 6},
                                          {"World!", 6}
                                        };
OS_Q_PutEx(&MemoryQ, aDataList, 2, 100);
```

9.3.8 OS_Q_GetPtr()

Description

Retrieves a message from a queue.

Prototype

```
int OS_Q_GetPtr (OS_Q  *pQ,
                 void **ppData);
```

Parameter	Description
pQ	Pointer to the queue.
ppData	Address of pointer to the message to be retrieved from queue.

Table 9.10: OS_Q_GetPtr() parameter list

Return value

The size of the retrieved message.
Sets the pointer ppData to the message that should be retrieved.

Additional Information

If the queue is empty, the calling task is suspended until the queue receives a new message. Because this routine might require a suspension, it must not be called from an interrupt routine or timer. Use OS_GetPtrCond() instead. The retrieved message is not removed from the queue, this must be done by a call of OS_Q_Purge() after the message was processed. Only one message can be processed at a time.
As long as the message is not removed from the queue, the queue is marked "in use".
A following call of OS_Q_GetPtr() or OS_Q_GetPtrCond() is not allowed before OS_Q_Purge() is called as long as the queue is in use.
Consecutive calls of OS_Q_GetPtr() without calling OS_Q_Purge() will call the embOS error handler OS_Error() in debug builds of embOS.

Example

```
static void MemoryTask(void) {
  int   Len;
  char *pData;

  while (1) {
    Len = OS_Q_GetPtr(&_MemoryQ, &pData);     /* Get message     */
    Memory_WritePacket(*(U32 *)pData, Len);   /* Process message */
    OS_Q_Purge(&_MemoryQ);                    /* Delete message  */
  }
}
```

9.3.9   OS_Q_GetPtrCond()

Description

Retrieves a message from a queue if a message is available.

Prototype

```
int OS_Q_GetPtrCond (OS_Q  *pQ,
                     void **ppData);
```

Parameter	Description
pQ	Pointer to the queue.
ppData	Address of pointer to the message to be retrieved from queue.

Table 9.11: OS_Q_GetPtrCond() parameter list

Return value

0:   No message available in queue.
>0: Size of the message that was retrieved from the queue.
Sets the pointer ppData to the message that should be retrieved.

Additional Information

If the queue is empty, the function returns zero and the value of ppData is undefined. This function never suspends the calling task. It may therefore be called from an interrupt routine or timer. If a message could be retrieved it is not removed from the queue, this must be done by a call of OS_Q_Purge() after the message was processed.

As long as the message is not removed from the queue, the queue is marked "in use".

A following call of OS_Q_GetPtrCond() or OS_Q_GetPtr() is not allowed before OS_Q_Purge() is called as long as the queue is in use.

Consecutive calls of OS_Q_GetPtrCond() without calling OS_Q_Purge() will call the embOS error handler OS_Error() in debug builds of embOS.

Example

```
static void MemoryTask(void) {
  int   Len;
  char *pData;
  while (1) {
    Len = OS_Q_GetPtrCond(&_MemoryQ, &pData);  /* Check message   */
    if (Len > 0) {
      Memory_WritePacket(*(U32 *)pData, Len);  /* Process message */
      OS_Q_Purge(&_MemoryQ);                   /* Delete message  */
    } else {
      DoSomethingElse();
    }
  }
}
```

9.3.10 OS_Q_GetPtrTimed()

Description

Retrieves a message from a queue within a specified time if a message is available.

Prototype

```
int OS_Q_GetPtrTimed (OS_Q    *pQ,
                      void    **ppData,
                      OS_TIME  Timeout);
```

Parameter	Description
pQ	Pointer to the queue.
ppData	Address of pointer to the message to be retrieved from queue.
Timeout	Maximum time in timer ticks until the requested message must be available. The data type OS_TIME is defined as an integer, therefore valid values are $1 <= $ Timeout $ <= 2^{15}\text{-}1 = $ 0x7FFF = 32767 for 8/16 bit CPUs $1 <= $ Timeout $ <= 2^{31}\text{-}1 = $ 0x7FFFFFFF for 32 bit CPUs

Table 9.12: OS_Q_GetPtrTimed() parameter list

Return value

0: No message available in queue.
>0: Size of the message that was retrieved from the queue.
Sets the pointer ppData to the message that should be retrieved.

Additional Information

If the queue is empty no message is retrieved, the task is suspended for the given timeout and the value of ppData is undefined. The task continues execution according to the rules of the scheduler as soon as a message is available within the given timeout, or after the timeout value has expired.

When the calling task is blocked by higher priority tasks for a period longer than the timeout value, it may happen that a message becomes available after the timeout expired, but before the calling task is resumed. Anyhow, the function returns with timeout, because the message was not availbale within the requested time. In this case the state of the queue is not modified by OS_Q_GetPtrTimed() and a pointer to the message is not delivered.

As long as a message was retrieved and the message is not removed from the queue, the queue is marked "in use".
A following call of OS_Q_GetPtrTimed() is not allowed before OS_Q_Purge() is called as long as the queue is in use.
Consecutive calls of OS_Q_GetPtrTimed() without calling OS_Q_Purge() after retrieving a message call the embOS error handler OS_Error() in debug builds of embOS.

Example

```
static void MemoryTask(void) {
  int   Len;
  char *pData;
  while (1) {
    Len = OS_Q_GetPtrTimed(&_MemoryQ, &pData, 10);   /* Check message   */
    if (Len > 0) {
      Memory_WritePacket(*(U32 *)pData, Len);         /* Process message */
      OS_Q_Purge(&_MemoryQ);                          /* Delete message  */
    } else {                                          /* Timeout         */
      DoSomethingElse();
    }
  }
}
```

9.3.11 OS_Q_Purge()

Description

Deletes the last retrieved message in a queue.

Prototype

```
void OS_Q_Purge (OS_Q *pQ);
```

Parameter	Description
pQ	Pointer to the queue.

Table 9.13: OS_Q_Purge() parameter list

Additional Information

This routine should be called by the task that retrieved the last message from the queue, after the message is processed.
Once a message was retrieved by a call of OS_Q_GetPtr(), OS_Q_GetPtrCond() or OS_Q_GetPtrTimed(), the message must be removed from the queue by a call of OS_Q_Purge() before a following message can be retrieved from the queue. Consecutive calls of OS_Q_GetPtr(), OS_Q_GetPtrCond() or OS_Q_GetPtrTimed() will call the embOS error handler OS_Error() in embOS debug builds.
Consecutive calls of OS_Q_Purge() or calling OS_Q_Purge() without having retrieved a message from the queue will also call the embOS error handler OS_Error() in embOS debug builds.

Example

```
static void MemoryTask(void) {
  int   Len;
  char *pData;

  while (1) {
    Len = OS_Q_GetPtr(&_MemoryQ, &pData);     /* Get message     */
    Memory_WritePacket(*(U32 *)pData, Len);   /* Process message */
    OS_Q_Purge(&_MemoryQ);                     /* Delete message  */
  }
}
```

9.3.12 OS_Q_Clear()

Description

Deletes all message in a queue.

Prototype

```
void OS_Q_Clear (OS_Q *pQ);
```

Parameter	Description
pQ	Pointer to the queue.

Table 9.14: OS_Q_Clear() parameter list

Additional Information

When the queue is in use, a debug build of embOS will call `OS_Error()` with error code `OS_ERR_QUEUE_INUSE`.

9.3.13   OS_Q_GetMessageCnt()

Description

Returns the number of messages that are currently stored in a queue.

Prototype

```
int OS_Q_GetMessageCnt (const OS_Q *pQ);
```

Parameter	Description
pQ	Pointer to the queue.

Table 9.15: OS_Q_GetMessageCnt() parameter list

Return value

The number of messages in the queue.

9.3.14 OS_Q_Delete()

Description

Deletes a specific queue.

Prototype

```
void OS_Q_Delete (OS_Q *pQ);
```

Parameter	Description
pQ	Pointer to the queue.

Table 9.16: OS_Q_Delete() parameter list

Additional Information

To keep the system fully dynamic, it is essential that queues can be created dynami-
cally. This also means there must be a way to delete a queue when it is no longer
needed. The memory that has been used by the queue for the control structure and
the buffer can then be reused or reallocated.
It is the programmer's responsibility to:

* make sure that the program no longer uses the queue to be deleted
* make sure that the queue to be deleted actually exists (i.e. has been created
  first).

When the queue is in use, a debug build of embOS will call `OS_Error()` with error
code `OS_ERR_QUEUE_INUSE`.
When tasks are waiting, a debug build of embOS will call `OS_Error()` with error code
`OS_ERR_QUEUE_DELETE` is called.

Example

```
OS_Q QSerIn;

void Cleanup(void) {
  OS_Q_Delete(&QSerIn);
}
```

9.3.15 OS_Q_IsInUse()

Description

Delivers information whether the queue is actually in use.

Prototype

```
OS_BOOL OS_Q_IsInUse(const OS_Q *pQ)
```

Parameter	Description
pQ	Pointer to the queue.

Table 9.17: OS_Q_IsInUse() parameter list

Return value

0: Queue is not in use
!=0: Queue is in use and may not be deleted or cleared.

Additional Information

A queue must not be cleared or deleted when it is in use.
In use means a task or function actually accesses the queue and holds a pointer to a message in the queue.
OS_Q_IsInUse() can be used to examine the state of the queue before it can be cleared or deleted, as these functions must not be performed as long as the queue is used.

Example

```
void DeleteQ(OS_Q *pQ) {
  OS_IncDI();  // Avoid state change of the queue by task or interrupt
  //
  // Wait until queue is not used
  //
  while (OS_Q_IsInUse(pQ) != 0) {
    OS_Delay(1);
  }
  OS_Q_Delete(pQ);
  OS_DecRI();
}
```

9.3.16 OS_Q_GetMessageSize()

Description

Returns the size of the first message.

Prototype

```
int OS_Q_GetMessageSize (OS_Q *pQ)
```

Parameter	Description
pQ	Pointer to the queue.

Table 9.18: OS_Q_GetMessageSize() parameter list

Return value

The size of the first message or zero when no message is available.

Additional Information

If the queue is empty OS_Q_GetMessageSize returns zero. If a message is available OS_Q_GetMessageSize returns the size of that message. The message is not retrieved from the queue.

Example

```
static void MemoryTask(void) {
  int Len;

  while (1) {
    Len = OS_Q_GetMessageSize(&_MemoryQ);  /* Get message length */
    if (Len > 0) {
      printf("Message with size %d retrieved\n", Len);
      OS_Q_Purge(&_MemoryQ);                 /* Delete message  */
    }
    OS_Delay(10);
  }
}
```

9.3.17 OS_Q_PeekPtr()

Description

Retrieves a message from a queue.

Prototype

```
int OS_Q_PeekPtr (OS_Q  *pQ,
                   void **ppData);
```

Parameter	Description
pQ	Pointer to the queue.
ppData	Address of pointer to the message to be retrieved from queue.

Table 9.19: OS_Q_PeekPtr() parameter list

Return value

The size of the retrieved message or zero when no new message is available.
Sets the pointer ppData to the message that should be retrieved.

Additional Information

If the queue is empty zero is returned.
The retrieved message is not removed from the queue. Use OS_GetPtr()/
OS_Q_Purge() to retrieve and remove a message from the queue.

Example

```
static void MemoryTask(void) {
  int   Len;
  char *pData;

  while (1) {
    OS_IncDI();  // Avoid state changes of the queue by task or interrupt
    Len = OS_Q_PeekPtr(&_MemoryQ, &pData);     /* Get message      */
    if (Len > 0) {
      Memory_WritePacket(*(U32 *)pData, Len);  /* Process message */
    }
    OS_RESTORE_I();
  }
}
```

Warning

Ensure the queues state is not altered as long as a message is processed. That is the reason for calling OS_IncDI() in the sample. Ensure no cooperative task switch is performed, as this may also alter the queue state and buffer. OS_EnterRegion() does not inhibit cooperative task switches!

Chapter 10

Task events

10.1 Introduction

Task events are another way of communicating between tasks. In contrast to semaphores and mailboxes, task events are messages to a single, specified recipient. In other words, a task event is sent to a specified task.

The purpose of a task event is to enable a task to wait for a particular event (or for one of several events) to occur. This task can be kept inactive until the event is signaled by another task, a software timer or an interrupt handler. An event can be, for example, the change of an input signal, the expiration of a timer, a key press, the reception of a character, or a complete command.

Every task has an individual bit mask, which by default is the width of an usigned interger, usually the word size of the target processor. This means that 32 or 8 different events can be signaled to and distinguished by every task. By calling `OS_WaitEvent()`, a task waits for one of the events specified as a bitmask. As soon as one of the events occurs, this task must be signaled by calling `OS_SignalEvent()`. The waiting task will then be put in the READY state immediately. It will be activated according to the rules of the scheduler as soon as it becomes the task with the highest priority of all tasks in the READY state.

By changing the definition of `OS_TASK_EVENT`, which is defined as unsigned long on 32 bit CPUs and unsigned char on 16 or 8 bit CPUs per default, the task events can be expanded to 16 or 32 bits thus allowing more individual events, or reduced to smaller data types on 32 bit CPUs.

Changing the definition of `OS_TASK_EVENT` can only be done when using the embOS sources in a project, or when the libraries are rebuilt from sources with the modified definition.

10.2   API functions

Routine	Description	main	Task	ISR	Timer
OS_WaitEvent()	Waits for one of the events specified in the bitmask and clears the event memory after an event occurs.		X		
OS_WaitSingleEvent()	Waits for one of the events specified as bitmask and clears only that event after it occurs.		X		
OS_WaitEventTimed()	Waits for the specified events for a given time, and clears the event memory after an event occurs.		X		
OS_WaitSingleEventTimed()	Waits for the specified events for a given time; after an event occurs, only that event is cleared.		X		
OS_SignalEvent()	Signals event(s) to a specified task.	X	X	X	X
OS_GetEventsOccurred()	Returns a list of events that have occurred for a specified task.	X	X		
OS_ClearEvents()	Returns the actual state of events and then clears the events of a specified task.	X	X	X	X

Table 10.1: Events API functions

10.2.1 OS_WaitEvent()

Description

Waits for one of the events specified in the bitmask and clears the event memory after an event occurs.

Prototype

```
OS_TASK_EVENT OS_WaitEvent (OS_TASK_EVENT EventMask);
```

Parameter	Description
EventMask	The events that the task will be waiting for.

Table 10.2: OS_WaitEvent() parameter list

Return value

All events that have been signaled.

Additional Information

If none of the specified events are signaled, the task is suspended. The first of the specified events will wake the task. These events are signaled by another task, a software timer or an interrupt handler. Any bit that is set in the event mask enables the corresponding event.

When a task waits on multiple events, all of the specified events shall be requested by a single call of `OS_WaitEvent()` and all events must be be handled when the function returns.

Note that all events of the task are cleared when the function returns, even those events that were not set in the parameters in the eventmask. Consecutive calls of `OS_WaitEvent()` with different event masks will not work, as all events are cleared when the function returns. Events may be lost. `OS_WaitSingleEvent()` may be used for this case.

Example

```
void Task(void) {
  OS_TASK_EVENT MyEvents;

  while(1) {
    MyEvents = OS_WaitEvent(3);             /* Wait for event 0 or 1 to be signaled */
    /* Handle ALL events */

    if (MyEvents & (1 << 0)) {
      _HandleEvent0();
    }
    if (MyEvents & (1 << 1)) {
      _HandleEvent1();
    }
  }
}
```

For a further example, see *OS_SignalEvent()* on page 200.

10.2.2 OS_WaitSingleEvent()

Description

Waits for one or more of the events specified by the Eventmask and clears only those events that were specified in the eventmask.

Prototype

```
OS_TASK_EVENT OS_WaitSingleEvent (OS_TASK_EVENT EventMask);
```

Parameter	Description
EventMask	The events that the task will be waiting for.

Table 10.3: OS_WaitSingleEvent() parameter list

Return value

All requested events that have been signaled.

Additional Information

If none of the specified events are signaled, the task is suspended. The first of the requested events will wake the task. These events are signaled by another task, a software timer, or an interrupt handler. Any bit in the event mask may enable the corresponding event. When the function returns, it delivers all of the requested events. The requested events are cleared in the event state of the task. All other events remain unchanged and will not be returned.

`OS_WaitSingleEvent()` may be used in consecutive calls with individual requests. Only requested events will be handled, no other events can get lost.

When the function waits on multiple events, the returned value must be evaluated because the function returns when at least one of the requested events was signaled. When the function requests a single event, the returned value does not need to be evaluated.

Example

```
void Task(void) {
  OS_TASK_EVENT MyEvents;

  while(1) {
    MyEvents = OS_WaitSingleEvent(3);  /* Wait for event 0 or 1 to be signaled */
    /* Handle ALL events */

    if (MyEvents & (1 << 0)) {
      _HandleEvent0();
    }
    if (MyEvents & (1 << 1)) {
      _HandleEvent1();
    }
    OS_WaitSingleEvent(1 << 2);       /* Wait for event 2 to be signaled */
    _HandleEvent2();
    OS_WaitSingleEvent(1 << 3);       /* Wait for event 3 to be signaled */
    _HandleEvent3();
  }
}
```

10.2.3 OS_WaitEventTimed()

Description

Waits for the specified events for a given time, and clears the event memory after one of the requsted events occurs, or after the timeout expired.

Prototype

```
OS_TASK_EVENT OS_WaitEventTimed (OS_TASK_EVENT EventMask,
                                 OS_TIME       TimeOut);
```

Parameter	Description
EventMask	The events that the task will be waiting for.
TimeOut	Maximum time in timer ticks waiting for events to be signaled.

Table 10.4: OS_WaitEventTimed() parameter list

Return value

The events that have been signaled within the specified time.
0 if no events were signaled in time.

Additional Information

If none of the specified events are available, the task is suspended for the given time. The first of the requested events will wake the task if the event is signaled by another task, a software timer, or an interrupt handler within the specified TimeOut time.

If none of the requested events is signaled, the task is activated after the specified timeout and all signaled events are returned and then cleared.
Note that the function returns all events that were signaled within the given timeout time, even those which were not requested.
The calling function must handle the returned value.
Consecutive calls of OS_WaitEventTimed() with different event masks will not work, as all events are cleared when the function returns. Events may got lost. OS_WaitSingleEventTimed() may be used for this case.

Example

```
void Task(void) {
  OS_TASK_EVENT MyEvents;

  while(1) {
    MyEvents = OS_WaitEvent_Timed(3, 10); /* Wait for events 0+1 for 10 ms */
    if ((MyEvents & 0x3) == 0) {
      _HandleTimeout();
    } else {
      if (MyEvents & (1 << 0)) {
        _HandleEvent0();
      }
      if (MyEvents & (1 << 1)) {
        _HandleEvent1();
      }
    }
  }
}
```

10.2.4 OS_WaitSingleEventTimed()

Description

Waits for the specified events for a given time; after an event occurs, only the requested events are cleared.

Prototype

```
OS_TASK_EVENT OS_WaitSingleEventTimed (OS_TASK_EVENT EventMask,
                                       OS_TIME       TimeOut);
```

Parameter	Description
EventMask	The events that the task will be waiting for.
TimeOut	Maximum time in timer ticks until the events must be signaled.

Table 10.5: OS_WaitSingleEventTimed() parameter list

Return value

The masked events that have are signaled within the specified time.
Zero if no masked events were signaled in time.

Additional Information

If none of the specified events are available, the task is suspended for the given time. The first of the specified events will wake the task if the event is signaled by another task, a software timer or an interrupt handler within the specified TimeOut time.
If no event is signaled, the task is activated after the specified timeout and the function returns zero. Any bit in the event mask may enable the corresponding event. All unmasked events remain unchanged.

Example

```
void Task(void) {
  OS_TASK_EVENT MyEvents;

  while(1) {
    MyEvents = OS_WaitSingleEventTimed(3, 10);  /* Wait for event 0 or 1 to be
                                                    signaled within 10ms        */
    /* Handle requested events */

    if (MyEvents == 0) {
      _HandleTimeout;
    } else {
      if (MyEvents & (1 << 0)) {
        _HandleEvent0();
      }
      if (MyEvents & (1 << 1)) {
        _HandleEvent1();
      }
    }
    if (OS_WaitSingleEvent((1 << 2), 10) == 0) {
      _HandleTimeout();
    } else {
      _HandleEvent2();
    }
  }
}
```

10.2.5 OS_SignalEvent()

Description

Signals event(s) to a specified task.

Prototype

```
void OS_SignalEvent (OS_TASK_EVENT  Event,
                     OS_TASK        *pTask);
```

Parameter	Description
Event	The event(s) to signal: 1 means event 1 2 means event 2 4 means event 3 … 128 means event 8. Multiple events can be signaled as the sum of the single events (for example, 6 will signal events 2 & 3).
pTask	Task that the events are sent to.

Table 10.6: OS_SignalEvent() parameter list

Additional Information

If the specified task is waiting for one of these events, it will be put in the READY state and activated according to the rules of the scheduler.

Example

The task that handles the serial input and the keyboard waits for a character to be received either via the keyboard (`EVENT_KEYPRESSED`) or serial interface (`EVENT_SERIN`):

```
/*
* Just a small demo for events
*/
#define EVENT_KEYPRESSED (1 << 0)
#define EVENT_SERIN (1 << 1)

OS_STACKPTR int Stack0[96];      // Task stacks
OS_TASK TCB0;                     // Data area for tasks (task control blocks)

void Task0(void) {
  OS_TASK_EVENT MyEvent;
  while(1)
    MyEvent = OS_WaitEvent(EVENT_KEYPRESSED | EVENT_SERIN)
    if (MyEvent & EVENT_KEYPRESSED) {
      /* handle key press        */
    }
    if (MyEvent & EVENT_SERIN) {
      /* Handle serial reception  */
    }
  }
}

void TimerKey(void) {
 /* More code to find out if key has been pressed  */
  OS_SignalEvent(EVENT_SERIN, &TCB0); /* Notify Task that key was pressed */
}

void InitTask(void) {
  OS_CREATETASK(&TCB0, 0, Task0, 100, Stack0);         /* Create Task0 */
}
```

If the task was only waiting for a key to be pressed, `OS_GetMail()` could simply be called. The task would then be deactivated until a key is pressed. If the task has to handle multiple mailboxes, as in this case, events are a good option.

10.2.6 OS_GetEventsOccurred()

Description

Returns a list of events that have occurred for a specified task.

Prototype

```
OS_TASK_EVENT OS_GetEventsOccurred (const OS_TASK *pTask);
```

Parameter	Description
pTask	The task whose event mask is to be returned, NULL means current task.

Table 10.7: OS_GetEventsOccurred() parameter list

Return value

The event mask of the events that have been signaled.

Additional Information

By calling this function, all events remain signaled: event memory is not cleared. This is one way for a task to query which events are signaled. The task is not suspended if no events are signaled.

10.2.7 OS_ClearEvents()

Description

Returns the actual state of events and then clears the events of a specified task.

Prototype

```
OS_TASK_EVENT OS_ClearEvents (OS_TASK *pTask);
```

Parameter	Description
pTask	The task whose event mask is to be returned, NULL means current task.

Table 10.8: OS_ClearEvents() parameter list

Return value

The events that were signaled before clearing.

Chapter 11

Event objects

11.1   Introduction

Event objects are another type of communication and synchronization object. In contrast to task-events, event objects are standalone objects which are not owned by any task.

The purpose of an event object is to enable one or multiple tasks to wait for a particular event to occur. The tasks can be kept suspended until the event is set by another task, a software timer, or an interrupt handler. An event can be, for example, the change of an input signal, the expiration of a timer, a key press, the reception of a character, or a complete command.

Compared to a task event, the signaling function does not need to know which task is waiting for the event to occur.

11.2 API functions

Routine	Description	main	Task	ISR	Timer
OS_EVENT_Create()	Creates an event object. Must be called before the event object can be used.	X	X	X	X
OS_EVENT_CreateEx()	Creates an event object and allows selection of the reset behavior of the event.	X	X	X	X
OS_EVENT_Wait()	Waits for an event.		X		
OS_EVENT_WaitTimed()	Waits for an event with timeout and optionally resets the event according the reset mode.	X	X		
OS_EVENT_Set()	Sets the events, or resumes waiting tasks.	X	X	X	X
OS_EVENT_Reset()	Resets the event to non-signaled state.	X	X	X	X
OS_EVENT_Pulse()	Sets the event, resumes waiting tasks, if any, and then resets the event.	X	X	X	X
OS_EVENT_Get()	Returns the state of an event object.	X	X		
OS_EVENT_Delete()	Deletes the specified event object.	X	X		
OS_EVENT_SetResetMode()	Sets the reset behaviour of events to automatic, manual or semiauto.	X	X	X	X
OS_EVENT_GetResetMode()	Retrieves the current the reset behavior mode of an event object.	X	X	X	X

Table 11.1: Event object API functions

11.2.1 OS_EVENT_Create()

Description

Creates an event object and resets the event.

Prototype

```
void OS_EVENT_Create (OS_EVENT *pEvent)
```

Parameter	Description
pEvent	Pointer to an event object data structure.

Table 11.2: OS_EVENT_Create() parameter list

Additional Information

Before the event object can be used, it must be created by a call of OS_EVENT_Create(). On creation, the event is set in non-signaled state, and the list of waiting tasks is empty. Therefore, OS_EVENT_Create() must not be called for an event object which is already created.

A debug build of embOS cannot check whether the specified event object was already created.

The event is created with the default reset behavior which is semiauto.

Since version 3.88a of embOS, the reset behavior of the event can be modified by a call of the function OS_EVENT_SetResetMode().

11.2.2 OS_EVENT_CreateEx()

Description

Creates an event object with specified rest behavior and resets the event.

Prototype

```
void OS_EVENT_CreateEx (OS_EVENT *pEvent, OS_EVENT_RESET_MODE ResetMode)
```

Parameter	Description
pEvent	Pointer to an event object data structure.
ResetMode	Specifies the reset behavior of the event object. One of the pre-defined reset modes can be used: OS_EVENT_RESET_MODE_SEMIAUTO OS_EVENT_RESET_MODE_AUTO OS_EVENT_RESET_MODE_MANUAL which are dscribed under Additional information

Table 11.3: OS_EVENT_CreateEx() parameter list

Additional Information

Before the event object can be used, it must be created by a call of `OS_EVENT_Create()` or `OS_EVENT_CreateEx()`. On creation, the event is set in non-signaled state, and the list of waiting tasks is empty.

Therefore, `OS_EVENT_CreateEx()` must not be called for an event object which is already created.

A debug build of embOS cannot check whether the specified event object was already created.

Since version 3.88a of embOS, the reset behavior of the event can be controlled by different reset modes which may be passed as parameter to the new function `OS_EVENT_CreateEx()` or may be modified by a call of `OS_EVENT_SetResetMode()`.

- OS_EVENT_RESET_MODE_SEMIAUTO:
  This reset mode is the default mode used with all previous versions of embOS. The reset behavior unfortunately is not consistent and depends on the function called to set or wait for an event. This reset mode is defined for compatibility with older embOS versions (prior version 3.88a). Calling `OS_EVENT_Create()` sets the reset mode to `OS_EVENT_RESET_MODE_SEMIAUTO` to be compatible with older embOS versions.
- OS_EVENT_RESET_MODE_AUTO:
  This mode sets the reset behavior of an event object to automatic clear. When an event is set, all waiting tasks are resumed and the event is cleared automatically. An exception to this is when a task called `OS_EVENT_WaitTimed()` and the time-out expired before the event was signaled, in which case the function returns with timeout and the event is not cleared automatically.
- OS_EVENT_RESET_MODE_MANUAL:
  This mode sets the event to manual reset mode. When an event is set, all waiting tasks are resumed and the event object remains signaled. The event must be reset by one task which was waiting for the event.

11.2.3 OS_EVENT_Wait()

Description

Waits for an event and suspends the calling task until the event is signaled.

Prototype

```
void OS_EVENT_Wait (OS_EVENT *pEvent)
```

Parameter	Description
pEvent	Pointer to the event object that the task will be waiting for.

Table 11.4: OS_EVENT_Wait() parameter list

Additional Information

pEvent addresses an existing event object, which must be created before the call of OS_EVENT_Wait(). A debug build of embOS will check whether pEvent addresses a valid event object and will call OS_Error() with error code OS_ERR_EVENT_INVALID in case of an error.

The state of the event object after calling OS_EVENT_Wait() depends on the reset mode of the event object wich was set by creating the event object by a call of OS_EVENT_CreateEx() or OS_EVENT_SetResetMode().

- With reset mode OS_EVENT_RESET_MODE_SEMIAUTO:
  This is the default mode when the event object was created with OS_EVENT_Create(). This was the only mode available in embOS versions prior version 3.88a.
  If the specified event object is already set, the calling task resets the event and continues operation.
  If the specified event object is not set, the calling task is suspended until the event object becomes signaled. The event is not reset when the task resumes.
- With reset mode OS_EVENT_RESET_MODE_AUTO:
  If the specified event object is already set, the calling task resets the event and continues operation.
  If the specified event object is not set, the calling task is suspended until the event object becomes signaled and then the event object is reset when the waiting task resumes.
- With reset mode OS_EVENT_RESET_MODE_MANUAL:
  If the specified event object is already set, the calling task continues operation. The event object remains signaled.
  If the specified event object is not set, the calling task is suspended until the event object becomes signaled. Then the waiting task is resumed and the event object remains signaled. The event object must be reset by the calling task.

Important

This function must not be called from within an interrupt handler or software timer. A debug build of embOS will call OS_Error() when OS_EVENT_Wait() is called from an ISR or timer.

Example

```
OS_EVENT_Wait(&_HW_Event);     // Wait for event object
OS_EVENT_Reset(&_HW_Event);    // Reset the event
```

11.2.4 OS_EVENT_WaitTimed()

Description

Waits for an event and suspends the calling task for a specified time as long as the event is not signaled.

Prototype

```
char OS_EVENT_WaitTimed (OS_EVENT *pEvent,
                         OS_TIME   TimeOut)
```

Parameter	Description
pEvent	Pointer to the event object that the task will be waiting for.
TimeOut	Maximum time in timer ticks until the event must be signaled.

Table 11.5: OS_EVENT_WaitTimed() parameter list

Return value

0 success, the event was signaled within the specified time.
1 if the event was not signaled within the specified time.

Additional Information

pEvent addresses an existing event object, which must be created before the call of OS_EVENT_WaitTimed(). A debug build of embOS will check whether pEvent addresses a valid event object and will call OS_Error() with error code OS_ERR_EVENT_INVALID in case of an error.

If the specified event object is not set, the calling task is suspended until the event object becomes signaled or the timeout time has expired.
When the timeout expired and the event was not signaled during the specified time-out time, OS_EVENT_WaitTimed() returns 1.
If the specified event object is already set, or becomes signaled within the specified timeout time, the state of the event depends on the reset mode of the event.

- With reset mode OS_EVENT_RESET_MODE_SEMIAUTO:
  This is the default mode when the event object was created with OS_EVENT_Create(). This was the only mode available in embOS versions prior version 3.88a.
  If the specified event object is already set, the calling task resets the event and continues operation.
  If the event object becomes signaled within the specified timeout time, the event is reset and the function returns without timeout result.
- With reset mode OS_EVENT_RESET_MODE_AUTO:
  If the specified event object is already set, the calling task resets the event and continues operation.
  If the event object becomes signaled within the specified timeout time, the event is reset and the function returns without timeout result.
- With reset mode OS_EVENT_RESET_MODE_MANUAL:
  If the specified event object is already set, the calling task continues operation. The event object remains signaled.
  If the specified event object is not set, the calling task is suspended until the event object becomes signaled. When the event object is signaled within the specified timeout time, the waiting task is resumed and the event object remains signaled. The event object must be reset by the calling task.
  The function returns without timeout result.

When the calling task is blocked by higher priority tasks for a period longer than the timeout value, it may happen that the event is signaled after the timeout expired, but before the calling task is resumed. Anyhow, the function returns with timeout, because the event was not singnaled within the requested time, and the state of the event is not modified by OS_EVENT_WaitTimed().

Important

This function must not be called from within an interrupt handler or software timer.
A debug build of embOS will call `OS_Error()` when `OS_EVENT_Wait()` is called from
an ISR or timer.

Example

```
if (OS_EVENT_WaitTimed(&_HW_Event, 10) == 0) {
  /* event was signaled within timeout time, handle event */
  ...
} else {
  /* event was not signaled within timeout time, handle timeout */
  ...
}
```

11.2.5 OS_EVENT_Set()

Description

Sets an event object to signaled state, or resumes tasks which are waiting at the event object.

Prototype

```
void OS_EVENT_Set (OS_EVENT *pEvent)
```

Parameter	Description
pEvent	Pointer to the event object which should be set to signaled state.

Table 11.6: OS_EVENT_Set() parameter list

Additional Information

pEvent must address an existing event object, which must be created before by a call of OS_EVENT_Create(). A debug build of embOS will check whether pEvent addresses a valid event object and will call OS_Error() with error code OS_ERR_EVENT_INVALID in case of an error.

If no tasks are waiting at the event object, the event object is set to signaled state.

If at least one task is already waiting at the event object, all waiting tasks are resumed. The state of the event object after calling OS_EVENT_Set() then depends on the reset mode of the event object.

- With reset mode OS_EVENT_RESET_MODE_SEMIAUTO:
  This is the default mode when the event object was created with OS_EVENT_Create(). This was the only mode available in embOS versions prior version 3.88a.
  If tasks were waiting, the event is reset when the waiting tasks are resumed.
- With reset mode OS_EVENT_RESET_MODE_AUTO:
  The event object is automatically reset when waiting tasks are resumed and continue operation.
- With reset mode OS_EVENT_RESET_MODE_MANUAL:
  The event object remains signaled when waiting tasks are resumed and continue operation. The event object must be reset by the calling task.

Example

Examples on how to use the OS_EVENT_Set() function are shown in the section "Examples".

11.2.6 OS_EVENT_Reset()

Description

Resets the specified event object to non-signaled state.

Prototype

```
void OS_EVENT_Reset (OS_EVENT *pEvent)
```

Parameter	Description
pEvent	Pointer to the event object which should be reset to non-signaled state.

Table 11.7: OS_EVENT_Reset() parameter list

Additional Information

pEvent must address an existing event object, which has been created before by a call of OS_EVENT_Create(). A debug build of embOS will check whether pEvent addresses a valid event object and will call OS_Error() with the error code OS_ERR_EVENT_INVALID in case of an error.

11.2.7 OS_EVENT_Pulse()

Description

Signals an event object and resumes waiting tasks, then resets the event object to non-signaled state.

Prototype

```
void OS_EVENT_Pulse (OS_EVENT *pEvent);
```

Parameter	Description
pEvent	Pointer to the event object which should be pulsed.

Table 11.8: OS_EVENT_Pulse() parameter list

Additional Information

If any tasks are waiting at the event object, the tasks are resumed. The event object remains in non-signaled state, regardless the reset mode.

A debug build of embOS will check whether pEvent addresses a valid event object and will call OS_Error() with the error code OS_ERR_EVENT_INVALID in case of an error.

11.2.8 OS_EVENT_Get()

Description

Returns the state of an event object.

Prototype

```
unsigned char OS_EVENT_Get (const OS_EVENT *pEvent);
```

Parameter	Description
pEvent	Pointer to an event object who's state should be examined.

Table 11.9: OS_EVENT_Get() parameter list

Return value

0: Event object is not set to signaled state
1: Event object is set to signaled state.

Additional Information

By calling this function, the actual state of the event object remains unchanged. pEvent must address an existing event object, which has been created before by a call of OS_EVENT_Create().
A debug build of embOS will check whether pEvent addresses a valid event object and will call OS_Error() with error code OS_ERR_EVENT_INVALID in case of an error.

11.2.9 OS_EVENT_Delete()

Description

Deletes an event object.

Prototype

```
void OS_EVENT_Delete (OS_EVENT *pEvent);
```

Parameter	Description
pEvent	Pointer to an event object which should be deleted.

Table 11.10: OS_EVENT_Delete() parameter list

Additional Information

To keep the system fully dynamic, it is essential that event objects can be created dynamically. This also means there must be a way to delete an event object when it is no longer needed. The memory that has been used by the event object's control structure can then be reused or reallocated.
It is your responsibility to make sure that:

*   the program no longer uses the event object to be deleted
*   the event object to be deleted actually exists (has been created first)
*   no tasks are waiting at the event object when it is deleted.

pEvent must address an existing event object, which has been created before by a call of OS_EVENT_Create() or OS_EVENT_CreateEx().
A debug build of embOS will check whether pEvent addresses a valid event object and will call OS_Error() with error code OS_ERR_EVENT_INVALID in case of an error.
If any task is waiting at the event object which is deleted, a debug build of embOS calls OS_Error() with error code OS_ERR_EVENT_DELETE.
To avoid any problems, an event object should not be deleted in a normal application.

11.2.10 OS_EVENT_SetResetMode()

Description

Used to set the reset behavior mode of an event object.

Prototype

```
void OS_EVENT_SetResetMode (OS_EVENT *pEvent, OS_EVENT_RESET_MODE ResetMode)
```

Parameter	Description
pEvent	Pointer to an event object which should be deleted.
ResetMode	Specifies the reset behavior of the event object. One of the pre-defined reset modes can be used: OS_EVENT_RESET_MODE_SEMIAUTO OS_EVENT_RESET_MODE_AUTO OS_EVENT_RESET_MODE_MANUAL which are described under Additional information

Table 11.11: OS_EVENT_SetResetMode() parameter list

Additional Information

pEvent must address an existing event object, which has been created before by a call of OS_EVENT_Create() or OS_EVENT_CreateEx().
A debug build of embOS will check whether pEvent addresses a valid event object and will call OS_Error() with error code OS_ERR_EVENT_INVALID in case of an error.

Implementation of event objects in embOS versions before 3.88a unfortunately was not consistent with respect to the state of the event after calling OS_EVENT_Set() or OS_EVENT_Wait() functions.
The state of the event was different when tasks were waiting or not.
Since embOS version 3.88a, the state of the event (reset behavior) can be controlled after creation by the new function OS_EVENT_SetResetMode(), or during creation by the new OS_EVENT_CreateEx() function.
The following reset modes are defined and can be used as parameter:

- OS_EVENT_RESET_MODE_SEMIAUTO:
  This reset mode is the default mode used with all previous versions of embOS. The reset behavior unfortunately is not consistent and depends on the function called to set or wait for an event. This reset mode is defined for compatibility with older embOS versions (prior version 3.88a). Calling OS_EVENT_Create() sets the reset mode to OS_EVENT_RESET_MODE_SEMIAUTO to be compatible with older embOS versions.
- OS_EVENT_RESET_MODE_AUTO:
  This mode sets the reset behavior of an event object to automatic clear. When an event is set, all waiting tasks are resumed and the event is cleared automatically. An exception to this is when a task called OS_EVENT_WaitTimed() and the time-out expired before the event was signaled, in which case the function returns with timeout and the event is not cleared automatically.
- OS_EVENT_RESET_MODE_MANUAL:
  This mode sets the event to manual reset mode. When an event is set, all waiting tasks are resumed and the event object remains signaled. The event must be reset by one task which was waiting for the event.

11.2.11 OS_EVENT_GetResetMode()

Description

Retrieves the current reset mode of an event object.

Prototype

```
OS_EVENT_RESET_MODE OS_EVENT_GetResetMode (OS_EVENT *pEvent);
```

Parameter	Description
pEvent	Pointer to an event object which should be deleted.

Table 11.12: OS_EVENT_GetResetMode() parameter list

Additional Information

pEvent must address an existing event object, which has been created before by a call of OS_EVENT_Create() or OS_EVENT_CreateEx().
A debug build of embOS will check whether pEvent addresses a valid event object and will call OS_Error() with error code OS_ERR_EVENT_INVALID in case of an error.
Since version 3.88a of embOS, the reset mode of an event object can be controlled by the new OS_EVENT_CreateEx() function or set after creation using the new function OS_EVENT_SetResetMode(). If needed, the current setting of the reset mode can be retrieved with OS_EVENT_GetResetMode().

11.3 Examples of using event objects

This section shows some examples on how to use event objects in an application.

11.3.1 Activate a task from interrupt by an event object

The following code example shows usage of an event object which is signaled from an ISR handler to activate a task.
The waiting task should reset the event after waiting for it.

```c
static OS_EVENT _HW_Event;


/**************************************************************
*
*       _ISRhandler
*/
static void _ISRhandler(void) {
  //
  // Perform some simple & fast processing in ISR  //
  //
 ...
  //
  // Wake up task to do the rest of the work
  //
  OS_EVENT_Set(&_Event);
}


/**************************************************************
*
*       _Task
*/
static void _Task(void) {
  while (1) {
    OS_EVENT_Wait(&_Event);
    OS_EVENT_Reset(&_Event);
    //
    // Do the rest of the work (which has not been done in the ISR)
    //
    ...
  }
}
```

11.3.2 Activating multiple tasks using a single event object

The following sample program shows how to synchronize multiple tasks with one event object. The sample program is delivered with embOS in the "Application" or "Samples" folder.

```c
/************************************************************************
* SEGGER Microcontroller GmbH & Co. KG
* Solutions for real time microcontroller applications
*************************************************************************
File    : OS_EventObject.c
Purpose : Sample program for embOS using EVENT object
--------- END-OF-HEADER --------------------------------------------*/

#include "RTOS.h"


OS_STACKPTR int StackHP[128], StackLP[128];         /* Task stacks */
OS_TASK         TCBHP, TCBLP;                 /* Task-control-blocks */


/************************************************************************/

/****** Interface to HW module *************************************/


void HW_Wait(void);
void HW_Free(void);
void HW_Init(void);


/************************************************************************/

/****** HW module ************************************************/

OS_STACKPTR int _StackHW[128];                      /* Task stacks */
OS_TASK         _TCBHW;                       /* Task-control-blocks */

/****** local data ***********************************************/

static OS_EVENT _HW_Event;

/****** local functions ****************************************/
static void _HWTask(void) {
  /* Initialize HW functionality    */
  OS_Delay(100);
  /* Init done, send broadcast to waiting tasks */
  HW_Ready();
  while (1) {
    OS_Delay (40);
  }
}

/****** global functions ***************************************/
void HW_Wait(void) {
  OS_EVENT_Wait(&_HW_Event);
}

void HW_Free(void) {
  OS_EVENT_Set(&_HW_Event);
}

void HW_Init(void) {
  OS_CREATETASK(&_TCBHW, "HWTask", _HWTask, 25, _StackHW);
  OS_EVENT_Create(&_HW_Event);
}
```

```
/********************************************************************/

/****** Main application ********************************************/

static void HPTask(void) {
  HW_Wait();                      /* Wait until HW module is set up */
  while (1) {
    OS_Delay (50);
  }
}

static void LPTask(void) {
  HW_Wait();                      /* Wait until HW module is set up */
  while (1) {
    OS_Delay (200);
  }
}

/********************************************************************
*
*       main
*
********************************************************************/

int main(void) {
  OS_IncDI();                         /* Initially disable interrupts  */
  OS_InitKern();                      /* Initialize OS                 */
  OS_InitHW();                        /* Initialize Hardware for OS    */
  HW_Init();                          /* Initialize HW module          */
  /* You need to create at least one task before calling OS_Start() */
  OS_CREATETASK(&TCBHP, "HP Task", HPTask, 100, StackHP);
  OS_CREATETASK(&TCBLP, "LP Task", LPTask,  50, StackLP);
  OS_SendString("Start project will start multitasking !\n");
  OS_Start();                         /* Start multitasking            */
  return 0;
}
```

Chapter 12

Heap type memory management

12.1 Introduction

ANSI C offers some basic dynamic memory management functions. These are `mal-loc`, `free`, and `realloc`.

Unfortunately, these routines are not thread-safe, unless a special thread-safe implementation exists in the compiler runtime libraries; they can only be used from one task or by multiple tasks if they are called sequentially. Therefore, embOS offer task-safe variants of these routines. These variants have the same names as their ANSI counterparts, but are prefixed `OS_`; they are called `OS_malloc()`, `OS_free()`, `OS_realloc()`. The thread-safe variants that embOS offers use the standard ANSI routines, but they guarantee that the calls are serialized using a resource semaphore.

If heap memory management is not supported by the standard C libraries, embOS heap memory management is not implemented.

Heap type memory management is part of the embOS libraries. It does not use any resources if it is not referenced by the application (that is, if the application does not use any memory management API function).

Note that another aspect of these routines may still be a problem: the memory used for the functions (known as heap) may fragment. This can lead to a situation where the total amount of memory is sufficient, but there is not enough memory available in a single block to satisfy an allocation request.

12.2   API functions

API routine	Description	main	Task	ISR	Timer
OS_malloc()	Allocates a block of memory on the heap.	X	X		
OS_free()	Frees a block of memory previously allocated.	X	X		
OS_realloc()	Changes allocation size.	X	X		

Table 12.1: Heap type memory manager API functions

12.2.1 OS_malloc()

Description

`OS_malloc()` is a thread safe malloc function.

Prototype

```
void * OS_malloc(unsigned int Size);
```

Parameter	Description
Size	Size of memory block to be allocated in bytes.

Table 12.2: OS_malloc() parameter list

Return value

Upon successful completion with size not equal zero, `OS_malloc()` returns a pointer to the allocated space. Otherwise, it returns a NULL pointer.

12.2.2 OS_free()

Description

`OS_free()` is a thread safe free function.

Prototype

```
void OS_free(void *pMemBlock);
```

Parameter	Description
pMemBlock	Pointer to a memory block previously allocated with `OS_Malloc()`.

Table 12.3: OS_free() parameter list

12.2.3 OS_realloc()

Description

`OS_realloc()` is a thread safe reallocation function.

Prototype

```
void * OS_realloc(void          *pMemBlock,
                  unsigned int  NewSize);
```

Parameter	Description
pMemBlock	Pointer to a memory block previously allocated with `OS_Malloc()`.
NewSize	New size for the memory block in bytes.

Table 12.4: OS_realloc() paramter list

Return value

Upon successful completion, `OS_realloc()` returns a pointer to the reallocated memory block. Otherwise, it returns a NULL pointer.

Chapter 13

Fixed block size memory pools

13.1 Introduction

Fixed block size memory pools contain a specific number of fixed-size blocks of memory. The location in memory of the pool, the size of each block, and the number of blocks are set at runtime by the application via a call to the `OS_MEMF_CREATE()` function. The advantage of fixed memory pools is that a block of memory can be allocated from within any task in a very short, determined period of time.

13.2 API functions

All API functions for fixed block size memory pools are prefixed `OS_MEMF_`.

API routine	Description	main	Task	ISR	Timer
Create / Delete					
OS_MEMF_Create()	Creates fixed block memory pool.	X	X		
OS_MEMF_Delete()	Deletes fixed block memory pool.	X	X		
Allocation					
OS_MEMF_Alloc()	Allocates memory block from a given pool. Wait indefinitely if no block is available.	X	X		
OS_MEMF_AllocTimed()	Allocates memory block from a given pool. Wait no longer than the given time limit if no block is available.	X	X		
OS_MEMF_Request()	Allocates memory block from a given pool if available. Non-blocking.	X	X	X	X
Release					
OS_MEMF_Release()	Releases memory block from a given pool.	X	X	X	X
OS_MEMF_FreeBlock()	Releases memory block from any pool.	X	X	X	X
Info					
OS_MEMF_GetNumFreeBlocks()	Returns the number of available blocks in a pool.	X	X	X	X
OS_MEMF_IsInPool()	Indicates if a block is within a given pool.	X	X	X	X
OS_MEMF_GetMaxUsed()	Returns the maximum number of blocks in a pool that have been used simultaneously since creation of the pool.	X	X	X	X
OS_MEMF_GetNumBlocks()	Returns the number of blocks in a pool.	X	X	X	X
OS_MEMF_GetBlockSize()	Returns the size of one block in a pool.	X	X	X	X

Table 13.1: Memory pools API functions

13.2.1 OS_MEMF_Create()

Description

Creates and initializes a fixed block size memory pool.

Prototype

```
void OS_MEMF_Create (OS_MEMF *pMEMF,
                     void    *pPool,
                     OS_UINT  NumBlocks,
                     OS_UINT  BlockSize);
```

Parameter	Description
pMEMF	Pointer to the control data structure of memory pool.
pPool	Pointer to memory to be used for the memory pool. Required size is: NumBlocks * (BlockSize + OS_MEMF_SIZEOF_BLOCKCONTROL).
NumBlocks	Number of blocks in the pool.
BlockSize	Size in bytes of one block.

Table 13.2: OS_MEMF_Create() parameter list

Additional Information

OS_MEMF_SIZEOF_BLOCKCONTROL gives the number of bytes used for control and debug purposes. It is guaranteed to be zero in release or stack-check builds. Before using any memory pool, it must be created. A debug build of libraries keeps track of created and deleted memory pools. The release and stack-check builds do not.
The maximum number of blocks and the maximum block size is for 16Bit CPUs 32768 and for 32Bit CPUs 2147483648.

Example

```
#define NUM_BLOCKS (16)
#define BLOCK_SIZE (16)
#define POOL_SIZE   (NUM_BLOCKS * (BLOCK_SIZE + OS_MEMF_SIZEOF_BLOCKCONTROL))

OS_U8   aPool[POOL_SIZE];
OS_MEMF MyMEMF;

void Init(void) {
  /* Create 16 Blocks with size of 16 Bytes */
  OS_MEMF_Create(&MyMEMF, aPool, NUM_BLOCKS, BLOCK_SIZE);
}
```

13.2.2 OS_MEMF_Delete()

Description

Deletes a fixed block size memory pool. After deletion, the memory pool and memory blocks inside this pool can no longer be used.

Prototype

```
void OS_MEMF_Delete (OS_MEMF *pMEMF);
```

Parameter	Description
pMEMF	Pointer to the control data structure of memory pool.

Table 13.3: OS_MEMF_Delete() parameter list

Additional Information

This routine is provided for completeness. It is not used in the majority of applications because there is no need to dynamically create/delete memory pools.
For most applications it is preferred to have a static memory pool design: memory pools are created at startup (before calling `OS_Start()`) and will never be deleted.
A debug build of embOS will mark the memory pool as deleted.

13.2.3 OS_MEMF_Alloc()

Description

Requests allocation of a memory block. Waits until a block of memory is available.

Prototype

```
void * OS_MEMF_Alloc (OS_MEMF *pMEMF,
                      int      Purpose);
```

Parameter	Description
pMEMF	Pointer to the control data structure of memory pool.
Purpose	This is a parameter which is used for debugging purposes only. Its value has no effect on program execution, but may be remembered in debug builds to allow runtime analysis of memory allocation problems.

Table 13.4: OS_MEMF_Alloc() parameter list

Return value

Pointer to the allocated block.

Additional Information

If there is no free memory block in the pool, the calling task is suspended until a memory block becomes available. The retrieved pointer must be delivered to `OS_MEMF_Release()` as a parameter to free the memory block. The pointer must not be modified.

Note

The parameter `Purpose` is never used because additional debug code is not implemented. It is only designed for future use.

13.2.4 OS_MEMF_AllocTimed()

Description

Requests allocation of a memory block. Waits until a block of memory is available or the timeout has expired.

Prototype

```
void * OS_MEMF_AllocTimed (OS_MEMF *pMEMF,
                           OS_TIME  TimeOut,
                           int      Purpose);
```

Parameter	Description
pMEMF	Pointer to the control data structure of memory pool.
TimeOut	Time limit before timeout, given in ticks. Zero or negative values are permitted.
Purpose	This is a parameter which is used for debugging purpose only. Its value has no effect on program execution, but may be remembered in debug builds to allow runtime analysis of memory allocation problems.

Table 13.5: OS_MEMF_AllocTimed()

Return value

!=NULL pointer to the allocated block
NULL   no block could be allocated within the specified time.

Additional Information

If there is no free memory block in the pool, the calling task is suspended until a memory block becomes available or the timeout has expired. The returned pointer must be delivered to OS_MEMF_Release() as parameter to free the memory block. The pointer must not be modified.

When the calling task is blocked by higher priority tasks for a period longer than the timeout value, it may happen that the memory block becomes available after the timeout expired, but before the calling task is resumed. Anyhow, the function returns with timeout, because the memory block was not availbale within the requested time.

Note

The parameter Purpose is never used because additional debug code is not implemented. It is only designed for future use.

13.2.5 OS_MEMF_Request()

Description

Requests allocation of a memory block. Continues execution without blocking.

Prototype

```
void * OS_MEMF_Request (OS_MEMF *pMEMF,
                        int      Purpose);
```

Parameter	Description
pMEMF	Pointer to the control data structure of memory pool.
Purpose	This is a parameter which is used for debugging purpose only. Its value has no effect on program execution, but may be remembered in debug builds to allow runtime analysis of memory allocation problems.

Table 13.6: OS_MEMF_Request() parameter list

Return value

!=NULL pointer to the allocated block
NULL   if no block has been allocated.

Additional Information

The calling task is never suspended by calling OS_MEMF_Request(). The returned pointer must be delivered to OS_MEMF_Release() as parameter to free the memory block. The pointer must not be modified.

Note

The parameter Purpose is never used because additional debug code is not implemented. It is only designed for future use.

13.2.6 OS_MEMF_Release()

Description

Releases a memory block that was previously allocated.

Prototype

```
void OS_MEMF_Release (OS_MEMF *pMEMF,
                      void    *pMemBlock);
```

Parameter	Description
pMEMF	Pointer to the control data structure of memory pool.
pMemBlock	Pointer to the memory block to free.

Table 13.7: OS_MEMF_Release() parameter list

Additional Information

The pMemBlock pointer must be the one that was delivered from any memory block allocation function. The pointer must not be modified between allocation and release. The memory block becomes available for other tasks waiting for a memory block from the pool. If any task is waiting for a fixed memory block, it is activated according to the rules of the scheduler.

13.2.7 OS_MEMF_FreeBlock()

Description

Releases a memory block that was previously allocated. The memory pool does not need to be denoted.

Prototype

```
void OS_MEMF_FreeBlock (void *pMemBlock);
```

Parameter	Description
pMemBlock	Pointer to the memory block to free.

Table 13.8: OS_MEMF_FreeBlock() parameter list

Additional Information

The `pMemBlock` pointer must be the one that was delivered form any allocation function described above. The pointer must not be modified between allocation and release. This function may be used instead of `OS_MEMF_Release()`. It has the advantage that only one parameter is needed and embOS will find the associated memory pool. The memory block becomes available for other tasks waiting for a memory block from the pool. If any task is waiting for a fixed memory block, it is activated according to the rules of the scheduler.

13.2.8 OS_MEMF_GetNumBlocks()

Description

Inquires the total number of memory blocks in the pool.

Prototype

```
int OS_MEMF_GetNumBlocks (const OS_MEMF *pMEMF);
```

Parameter	Description
pMEMF	Pointer to the control data structure of memory pool.

Table 13.9: OS_MEMF_GetNumBlocks() parameter list

Return value

Returns the number of blocks in the specified memory pool. This is the value that was given as parameter during creation of the memory pool.

13.2.9 OS_MEMF_GetBlockSize()

Description

Inquires the size of one memory block in the pool.

Prototype

```
int OS_MEMF_GetBlockSize (const OS_MEMF *pMEMF);
```

Parameter	Description
pMEMF	Pointer to the control data structure of memory pool.

Table 13.10: OS_MEMF_GetBlockSize() parameter list

Return value

Size in bytes of one memory block in the specified memory pool. This is the value of the parameter when the memory pool was created.

13.2.10 OS_MEMF_GetNumFreeBlocks()

Description

Inquires the number of free memory blocks in the pool.

Prototype

```
int OS_MEMF_GetNumFreeBlocks (OS_MEMF *pMEMF);
```

Parameter	Description
pMEMF	Pointer to the control data structure of memory pool.

Table 13.11: OS_MEMF_GetNumFreeBlocks() parameter list

Return value

The number of free blocks in the specified memory pool.

13.2.11 OS_MEMF_GetMaxUsed()

Description

Inquires the maximum number of blocks in a pool that have been used simultaneously since creation of the pool.

Prototype

```
int OS_MEMF_GetMaxUsed (const OS_MEMF *pMEMF);
```

Parameter	Description
pMEMF	Pointer to the control data structure of memory pool.

Table 13.12: OS_MEMF_GetMaxUsed() parameter list

Return value

Maximum number of blocks in the specified memory pool that were used simultaneously since the pool was created.

13.2.12 OS_MEMF_IsInPool()

Description

Information routine to examine whether a memory block reference pointer belongs to the specified memory pool.

Prototype

```
char OS_MEMF_IsInPool (const OS_MEMF *pMEMF,
                       const void    *pMemBlock);
```

Parameter	Description
pMEMF	Pointer to the control data structure of memory pool.
pMemBlock	Pointer to a memory block that should be checked

Table 13.13: OS_MEMF_IsInPool() parameter list

Return value

0: Pointer does not belong to memory pool.
1: Pointer belongs to the pool.

Chapter 14

Stacks

14.1 Introduction

The stack is the memory area used for storing the return address of function calls, parameters, and local variables, as well as for temporary storage. Interrupt routines also use the stack to save the return address and flag registers, except in cases where the CPU has a separate stack for interrupt functions. Refer to the *CPU & Compiler Specifics manual* of embOS documentation for details on your processor's stack. A "normal" single-task program needs exactly one stack. In a multitasking system, every task must have its own stack.

The stack needs to have a minimum size which is determined by the sum of the stack usage of the routines in the worst-case nesting. If the stack is too small, a section of the memory that is not reserved for the stack will be overwritten, and a serious program failure is most likely to occur. Therefore, the debug and stack-check builds of embOS monitor the stack size (and, if available, also interrupt stack size) and call `OS_Error()` if they detect stack overflows.

To detect a stack overflow, the stack is filled with control characters upon its creation, thereby allowing for a check on these characters every time a task is deactivated. However, embOS does not guarantee to reliably detect all stack overflows. A stack that has been defined larger than necessary, on the other hand, does no harm; even though it is a waste of memory.

14.1.1 System stack

Before embOS takes control (before the call to `OS_Start()`), a program uses the so-called system stack. This is the same stack that a non-embOS program for this CPU would use. After transferring control to the embOS scheduler by calling `OS_Start()`, the system stack is used for the following (when no task is executing):

- embOS scheduler
- embOS software timers (and the callback).

For details regarding required size of your system stack, refer to the *CPU & Compiler Specifics manual* of embOS documentation.

14.1.2 Task stack

Each embOS task has a separate stack. The location and size of this stack is defined when creating the task. The minimum size of a task stack depends on the CPU and the compiler. For details, see the *CPU & Compiler Specifics manual* of embOS documentation.

14.1.3 Interrupt stack

To reduce stack size in a multitasking environment, some processors use a specific stack area for interrupt service routines (called a hardware interrupt stack). If there is no interrupt stack, you will need to add stack requirements of your interrupt service routines to each task stack.

Even if the CPU does not support a hardware interrupt stack, embOS may support a separate stack for interrupts by calling the function `OS_EnterIntStack()` at beginning of an interrupt service routine and `OS_LeaveIntStack()` at its very end. In case the CPU already supports hardware interrupt stacks or if a separate interrupt stack is not supported at all, these function calls are implemented as empty macros.

We recommend using `OS_EnterIntStack()` and `OS_LeaveIntStack()` even if there is currently no additional benefit for your specific CPU, because code that uses them might reduce stack size on another CPU or a new version of embOS with support for an interrupt stack for your CPU. For details about interrupt stacks, see the *CPU & Compiler Specifics manual* of embOS documentation.

14.1.4 Stack size calculation

embOS includes stack size calculation routines. embOS fills the task stacksand also the system stack and the interrupt stack with a pattern byte.
embOS checks at runtime how many bytes at the end of the stack still include the pattern byte. With it the amount of used and unused stack can be calculated.

14.1.5 Stack-check

embOS includes stack-check routines. embOS fills the task stacks and also the system stack and the interrupt stack with a pattern byte.
embOS checks periodically if the last pattern byte at the end of the stack is overwritten. embOS calls OS_Error() when this bytes is overwritten.

14.2 API functions

Routine	Description	main	Task	ISR	Timer
OS_GetStackBase()	Returns the base address of a task stack.	X	X	X	X
OS_GetStackSize()	Returns the size of a task stack.	X	X	X	X
OS_GetStackSpace()	Returns the unused portion of a task stack.	X	X	X	X
OS_GetStackUsed()	Returns the used portion of a task stack.	X	X	X	X
OS_GetSysStackBase()	Returns the base address of the system stack.	X	X	X	X
OS_GetSysStackSize()	Returns the size of the system stack.	X	X	X	X
OS_GetSysStackSpace()	Returns the unused portion of the system stack.	X	X	X	X
OS_GetSysStackUsed()	Returns the used portion of the system stack.	X	X	X	X
OS_GetIntStackBase()	Returns the base address of the interrupt stack.	X	X	X	X
OS_GetIntStackSize()	Returns the size of the interrupt stack.	X	X	X	X
OS_GetIntStackSpace()	Returns the unused portion of the interrupt stack.	X	X	X	X
OS_GetIntStackUsed()	Returns the used portion of the interrupt stack.	X	X	X	X

Table 14.1: Stacks API functions

14.2.1 OS_GetStackBase()

Description

Returns a pointer to the base of a task stack.

Prototype

```
void * OS_GetStackBase (OS_TASK *pTask);
```

Parameter	Description
pTask	The task whose stack base should be returned. NULL denotes the current task.

Table 14.2: OS_GetStackBase() parameter list

Return value

The pointer to the base address of the task stack.

Additional Information

This function is only available in the debug and stack-check builds of embOS, because only these builds initialize the stack space used for the tasks.

Example

```
void CheckStackBase(void) {
  printf("Addr Stack[0]  %p", OS_GetStackBase(&TCB[0]));
  OS_Delay(1000);
  printf("Addr Stack[1]  %p", OS_GetStackBase(&TCB[1]));
  OS_Delay(1000);
}
```

14.2.2 OS_GetStackSize()

Description

Returns the size of a task stack.

Prototype

```
unsigned int OS_GetStackSize (OS_TASK * pTask);
```

Parameter	Description
pTask	The task whose stack size should be checked. NULL means current task.

Table 14.3: OS_GetStackSize() parameter list

Return value

The size of the task stack in bytes.

Additional Information

This function is only available in the debug and stack-check builds of embOS, because only these builds initialize the stack space used for the tasks.

Example

```
void CheckStackSize(void) {
  printf("Size Stack[0]  %u", OS_GetStackSize(&TCB[0]));
  OS_Delay(1000);
  printf("Size Stack[1]  %u", OS_GetStackSize(&TCB[1]));
  OS_Delay(1000);
}
```

14.2.3 OS_GetStackSpace()

Description

Returns the unused portion of a task stack.

Prototype

```
unsigned int OS_GetStackSpace (OS_TASK * pTask);
```

Parameter	Description
pTask	The task whose stack space should be checked. NULL denotes the current task.

Table 14.4: OS_GetStackSpace() parameter list

Return value

The unused portion of the task stack in bytes.

Additional Information

In most cases, the stack size required by a task cannot be easily calculated because it takes quite some time to calculate the worst-case nesting and the calculation itself is difficult.
However, the required stack size can be calculated using the function OS_GetStackSpace(), which returns the number of unused bytes on the stack. If there is a lot of space left, you can reduce the size of this stack.
This function is only available in the debug and stack-check builds of embOS.

Important

This routine does not reliably detect the amount of stack space left, because it can only detect modified bytes on the stack. Unfortunately, space used for register storage or local variables is not always modified. In most cases, this routine will detect the correct amount of stack bytes, but in case of doubt, be generous with your stack space or use other means to verify that the allocated stack space is sufficient.

Example

```
void CheckStackSpace(void) {
  printf("Unused Stack[0]  %u", OS_GetStackSpace(&TCB[0]);
  OS_Delay(1000);
  printf("Unused Stack[1]  %u", OS_GetStackSpace(&TCB[1]);
  OS_Delay(1000);
}
```

14.2.4 OS_GetStackUsed()

Description

Returns the used portion of a task stack.

Prototype

```
unsigned int OS_GetStackUsed (OS_TASK * pTask);
```

Parameter	Description
pTask	The task whose stack usage should be checked. NULL denotes the current task.

Table 14.5: OS_GetStackUsed() parameter list

Return value

The used portion of the task stack in bytes.

Additional Information

In most cases, the stack size required by a task cannot be easily calculated, because it takes quite some time to calculate the worst-case nesting and the calculation itself is difficult.
However, the required stack size can be calculated using the function OS_GetStackUsed(), which returns the number of used bytes on the stack. If there is a lot of space left, you can reduce the size of this stack.
This function is only available in the debug and stack-check builds of embOS.

Important

This routine does not reliably detect the amount of stack space used, because it can only detect modified bytes on the stack. Unfortunately, space used for register storage or local variables is not always modified. In most cases, this routine will detect the correct amount of stack bytes, but in case of doubt, be generous with your stack space or use other means to verify that the allocated stack space is sufficient.

Example

```
void CheckStackUsed(void) {
  printf("Used Stack[0]  %u", OS_GetStackUsed(&TCB[0]));
  OS_Delay(1000);
  printf("Used Stack[1]  %u", OS_GetStackUsed(&TCB[1]));
  OS_Delay(1000);
}
```

14.2.5 OS_GetSysStackBase()

Description

Returns a pointer to the base of the system stack.

Prototype

```
void * OS_GetSysStackBase (void);
```

Return value

The pointer to the base address of the system stack.

Example

```
void CheckSysStackBase(void) {
  printf("Addr System Stack %p", OS_GetSysStackBase());
}
```

14.2.6 OS_GetSysStackSize()

Description

Returns the size of the system stack.

Prototype

```
unsigned int OS_GetSysStackSize (void);
```

Return value

The size of the system stack in bytes.

Example

```
void CheckSysStackSize(void) {
  printf("Size System Stack %u", OS_GetSysStackSize());
}
```

14.2.7 OS_GetSysStackSpace()

Description

Returns the unused portion of the system stack.

Prototype

```
unsigned int OS_GetSysStackSpace (void);
```

Return value

The unused portion of the system stack in bytes.

Additional Information

This function is only available in the debug and stack-check builds of embOS.

Important

This routine does not reliably detect the amount of stack space left, because it can only detect modified bytes on the stack. Unfortunately, space used for register storage or local variables is not always modified. In most cases, this routine will detect the correct amount of stack bytes, but in case of doubt, be generous with your stack space or use other means to verify that the allocated stack space is sufficient.

Example

```
void CheckSysStackSpace(void) {
  printf("Unused System Stack %u", OS_GetSysStackSpace());
```

14.2.8 OS_GetSysStackUsed()

Description

Returns the used portion of the system stack.

Prototype

```
unsigned int OS_GetSysStackUsed (void);
```

Return value

The used portion of the system stack in bytes.

Additional Information

This function is only available in the debug and stack-check builds of embOS.

Important

This routine does not reliably detect the amount of stack space used, because it can only detect modified bytes on the stack. Unfortunately, space used for register storage or local variables is not always modified. In most cases, this routine will detect the correct amount of stack bytes, but in case of doubt, be generous with your stack space or use other means to verify that the allocated stack space is sufficient.

Example

```
void CheckSysStackUsed(void) {
  printf("Used System Stack %u", OS_GetSysStackUsed());
```

14.2.9 OS_GetIntStackBase()

Description

Returns a pointer to the base of the interrupt stack.

Prototype

```
void * OS_GetIntStackBase (void);
```

Return value

The pointer to the base address of the interrupt stack.

Additional Information

This function is only available when an interrupt stack exists.

Example

```
void CheckIntStackBase(void) {
  printf("Addr Interrupt Stack %p", OS_GetIntStackBase());
}
```

14.2.10 OS_GetIntStackSize()

Description

Returns the size of the interrupt stack.

Prototype

```
unsigned int OS_GetIntStackSize (void);
```

Return value

The size of the interrupt stack in bytes.

Additional Information

This function is only available when an interrupt stack exists.

Example

```
void CheckIntStackSize(void) {
  printf("Size Interrupt Stack %u", OS_GetIntStackSize());
}
```

14.2.11 OS_GetIntStackSpace()

Description

Returns the unused portion of the interrupt stack.

Prototype

```
unsigned int OS_GetIntStackSpace (void);
```

Return value

The unused portion of the interrupt stack in bytes.

Additional Information

This function is only available in the debug and stack-check builds and when an interrupt stack exists.

Important

This routine does not reliably detect the amount of stack space left, because it can only detect modified bytes on the stack. Unfortunately, space used for register storage or local variables is not always modified. In most cases, this routine will detect the correct amount of stack bytes, but in case of doubt, be generous with your stack space or use other means to verify that the allocated stack space is sufficient.

Example

```
void CheckIntStackSpace(void) {
  printf("Unused Interrupt Stack %u", OS_GetIntStackSpace());
}
```

14.2.12 OS_GetIntStackUsed()

Description

Returns the used portion of the interrupt stack.

Prototype

```
unsigned int OS_GetIntStackUsed (void);
```

Return value

The used portion of the interrupt stack in bytes.

Additional Information

This function is only available in the debug and stack-check builds and when an interrupt stack exists.

Important

This routine does not reliably detect the amount of stack space used, because it can only detect modified bytes on the stack. Unfortunately, space used for register storage or local variables is not always modified. In most cases, this routine will detect the correct amount of stack bytes, but in case of doubt, be generous with your stack space or use other means to verify that the allocated stack space is sufficient.

Example

```
void CheckIntStackUsed(void) {
  printf("Used Interrupt Stack %u", OS_GetIntStackUsed());
}
```

Chapter 15

Interrupts

This chapter explains how to use interrupt service routines (ISRs) in cooperation with embOS. Specific details for your CPU and compiler can be found in the CPU & Compiler Specifics manual of the embOS documentation.

15.1 What are interrupts?

Interrupts are interruptions of a program caused by hardware. When an interrupt occurs, the CPU saves its registers and executes a subroutine called an interrupt service routine, or ISR. After the ISR is completed, the program returns to the highest-priority task in the READY state. Normal interrupts are maskable. Maskable interrupts can occur at any time unless they are disabled. ISRs are also nestable — they can be recognized and executed within other ISRs.

There are several good reasons for using interrupt routines. They can respond very quickly to external events such as the status change on an input, the expiration of a hardware timer, reception or completion of transmission of a character via serial interface, or other types of events. Interrupts effectively allow events to be processed as they occur.

15.2 Interrupt latency

Interrupt latency is the time between an interrupt request and the execution of the first instruction of the interrupt service routine.

Every computer system has an interrupt latency. The latency depends on various factors and differs even on the same computer system. The value that one is typically interested in is the worst case interrupt latency.

The interrupt latency is the sum of a number of individual smaller delays explained below.

15.2.1 Causes of interrupt latencies

- The first delay is typically in the hardware: The interrupt request signal needs to be synchronized to the CPU clock. Depending on the synchronization logic, typically up to three CPU cycles can be lost before the interrupt request reaches the CPU core.
- The CPU will typically complete the current instruction. This instruction can take multiple cycles to comeplete; on most systems, divide, push-multiple, or memory-copy instructions are the instructions which require most clock cycles. On top of the cycles required by the CPU, there are in most cases additional cycles required for memory access. In an ARM7 system, the instruction `STMDB SP!,{R0-R11,LR};` typically is the worst case instruction. It stores thirteen 32 bit registers to the stack, which, in an ARM7 system, takes 15 clock cycles to complete.
- The memory system may require additional cycles for wait states.
- After the current instruction is completed, the CPU performs a mode switch or pushes registers (typically, PC and flag registers) to the stack. In general, modern CPUs (such as ARM) perform a mode switch, which requires fewer CPU cycles than saving registers.
- Pipeline fill
  Most modern CPUs are pipelined. Execution of an instruction happens in various stages of the pipeline. An instruction is executed when it has reached its final stage of the pipeline. Because the mode switch flushes the pipeline, a few extra cycles are required to refill the pipeline.

15.2.2 Additional causes for interrupt latencies

There can be additional causes for interrupt latencies.
These depend on the type of system used, but we list a few of them.

- Latencies caused by cache line fill. If the memory system has one or multiple caches, these may not contain the required data. In this case, not only the required data is loaded from memory, but in a lot of cases a complete line fill needs to be performed, reading multiple words from memory.
- Latencies caused by cache write back. A cache miss may cause a line to be replaced. If this line is marked as dirty, it needs to be written back to main memory, causing an additional delay.
- Latencies caused by MMU translation table walks. Translation table walks can take a considerable amount of time, especially as they involve potentially slow main memory accesses. In real-time interrupt handlers, translation table walks caused by the TLB not containing translations for the handler and/or the data it accesses can increase interrupt latency significantly.
- Application program. Of course, the application program can cause additional latencies by disabling interrupts. This can make sense in some situations, but of course causes additional latencies.
- Interrupt routines. On most systems, one interrupt disables further interrupts. Even if the interrupts are re-enabled in the ISR, this takes a few instructions, causing additional latency.
- Real-time Operating system (RTOS). An RTOS also needs to temporarily disable the interrupts which can call API-functions of the RTOS. Some RTOSes disable all interrupts, effectively increasing interrupt latency for all interrupts, some (like embOS) disable only low-priority interrupts and do thereby not affect the latency of high priority interrupts.

15.2.3 How to detect the cause for high interrupt latency

It is sometimes desirable to detect the cause for high interrupt latency. High interrupt latency may occur if interrupts are disabled for a long time, or if a low level interrupt handler is executed before the actual interrupt handler. In any case, this can be avoided by using zero latency interrupts which will be explained later.

To investigate interrupt latency, a timer interrupt may be used. For example, in case a timer counts upwards starting from zero after each compare match interrupt, the current timer value indicates how much time has lapsed between the interrupt and the actual interrupt handler. Using this information, a threshold may be defined to limit the interrupt latency to an acceptable maximum: A breakpoint may be set for when the current timer value exceeds the defined threshold:

```
void TimerIntHandler(void) {
  OS_EnterInterrupt();
  t = TIMER_CNT_VALUE;  // Get current timer value
  if (t > LATENCY_THRESHOLD) {
    while (1);  // Set a breakpoint here
  }
  OS_LeaveInterrupt();
}
```

Furthermore, if code trace information is available, the cause for the latency may be checked through the trace log upon hitting the break point.

15.3 Zero interrupt latency

Zero interrupt latency in the strict sense is not possible as explained above. What we mean when we say "Zero interrupt latency" is that the latency of high-priority interrupts is not affected by the RTOS; a system using embOS will have the same worst-case interrupt latency for high priority interrupts as a system running without embOS.

Why is Zero latency important?

In some systems, a maximum interrupt response time or latency can be clearly defined. This maximum latency can arise from requirements such as maximum reaction time for a protocol or a software UART implementation that requires very precise timing.

For example a UART receiving at up to 800 kHz in software using ARM FIQ on a 48 MHz ARM7. This would be impossible to do if FIQ were disabled even for short periods of time.

In many embedded systems, the quality of the product depends on event reaction time and therefore latency. Typical examples would be systems which periodically read a value from an A/D converter at high speed, where the accuracy depends on accurate timing. Less jitter means a better product.

Why can a high priority ISR not use the OS API ?

embOS disables low priority interrupts when embOS data structures are modified. During this time high priority ISR are enabled. If they would call an embOS function, which also modifies embOS data, the embOS data structures would be corrupted.

How can a high priority ISR communicate with a task ?

The most common way is to use global variables, e.g. a periodical read from an ADC and the result is stored in a global variable.

Another way is to assert an interrupt request for a low priority interrupt from within the high priority ISR, which may then communicate or wake up one or more tasks. This is helpful if you want to receive high amounts of data in your high priority ISR. The low priority ISR may then store the data bytes e.g. in a message queue or in a mailbox.

15.4   High / low priority interrupts

Most CPUs support interrupts with different priorities. Different priorities have two effects:

- If different interrupts occur simultaneously, the interrupt with higher priority takes precedence and its ISR is executed first.
- Interrupts can never be interrupted by other interrupts of the same or lower priority.

The number of interrupt levels depends on the CPU and the interrupt controller. Details are explained in the CPU/MCU/SoC manuals and the *CPU & Compiler Specifics manual* of embOS. embOS distinguishes two different levels of interrupts: High and low priority interrupts. The embOS port-specific documentations explain which interrupts are considered high and which are considered low priority for that specific port. In general, the differences between those two are as follows:

Low priority interrupts

- May call embOS API functions
- Latencies caused by embOS
- Also called "embOS interrupts"

High priority interrupts

- May not call embOS API functions
- No latencies caused by embOS (Zero latency)
- Also called "Zero latency interrupts"

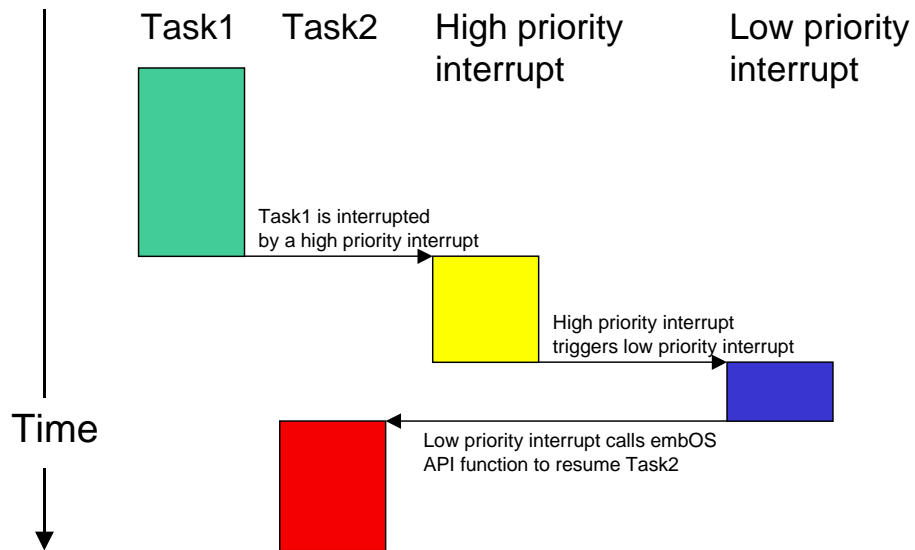**Example of different interrupt priority levels**

Let's assume we have a CPU which supports eight interrupt priority levels. With embOS, the interrupt levels are divided per default equal in low priority and high priority interrupt levels. The four highest priority levels are considered "High priority interrupts" and the four lowest priority interrupts are considered as "Low priority interrupts". For ARM CPUs, which support regular interrupts (IRQ) and fast interrupt (FIQ), FIQ is considered as "High priority interrupt" when using embOS.

For most implementations the high-priority threshold is adjustable. For details, refer to the processor specific embOS manual.

15.4.1   Using OS functions from high priority interrupts

High priority interrupts are prohibited from using embOS functions. This is a consequence of embOS's zero-latency design, according to which embOS never disables high priority interrupts. This means that high priority interrupts can interrupt the operating system at any time, even in critical sections such as the modification of RTOS-maintained linked lists. This design decision has been made because zero interrupt latencies for high priority interrupts usually are more important than the ability to call OS functions.

However, high priority interrupts may use OS functions in an indirect manner:
The high priority interrupt triggers a low priority interrupt by setting the appropiate interrupt request flag. Subsequently, that low priority interrupt may call the OS functions that the high priority interrupt was not allowed to use.

Task1   Task2   High priority   Low priority
                  interrupt   interrupt

Task1 is interrupted
by a high priority interrupt

High priority interrupt
triggers low priority interrupt

Time

Low priority interrupt calls embOS
API function to resume Task2

The task 1 is interrupted by a high priority interrupt. This high priority interrupt is not allowed to call an embOS API function directly. Therefore the high priority interrupt triggers a low priority interrupt, which is allowed to call embOS API functions. The low priority interrupt calls an embOS API function to resume task 2.

15.5   Rules for interrupt handlers

15.5.1   General rules

There are some general rules for interrupt service routines (ISRs). These rules apply to both single-task programming as well as to multitask programming using embOS.

- ISR preserves all registers.
  Interrupt handlers must restore the environment of a task completely. This environment normally consists of the registers only, so the ISR must make sure that all registers modified during interrupt execution are saved at the beginning and restored at the end of the interrupt routine
- Interrupt handlers must finish quickly.
  Intensive calculations should be kept out of interrupt handlers. An interrupt handler should only be used for storing a received value or to trigger an operation in the regular program (task). It should not wait in any form or perform a polling operation.

15.5.2   Additional rules for preemptive multitasking

A preemptive multitasking system like embOS needs to know if the program that is executing is part of the current task or an interrupt handler. This is because embOS cannot perform a task switch during the execution of an ISR; it can only do so at the end of an ISR.

If a task switch were to occur during the execution of an ISR, the ISR would continue as soon as the interrupted task became the current task again. This is not a problem for interrupt handlers that do not allow further interruptions (which do not enable interrupts) and that do not call any embOS functions.

This leads us to the following rule:

- ISRs that re-enable interrupts or use any embOS function need to call `OS_EnterInterrupt()` at the beginning, before executing anything else, and call `OS_LeaveInterrupt()` immediately before returning.

If a higher priority task is made ready by the ISR, the task switch then occurs in the routine `OS_LeaveInterrupt()`. The end of the ISR is executed at a later point, when the interrupted task is made ready again. If you debug an interrupt routine, do not be confused. This has proven to be the most efficient way of initiating a task switch from within an interrupt service routine.

15.6 API functions

The following table lists all interrupt related API functions of embOS.

Routine	Description	main	Task	ISR	Timer
OS_DI()	Disables interrupts. Does not change the interrupt disable counter.	X	X		X
OS_EI()	Unconditionally enables Interrupt.	X	X		X
OS_IncDI()	Increments the interrupt disable counter (OS_DICnt) and disables interrupts.	X	X	X	X
OS_RestoreI()	Restores the state of the interrupt flag, based on the interrupt disable counter.	X	X	X	X
OS_DecRI()	Decrements the counter and enables interrupts if the counter reaches 0.	X	X	X	X
OS_EnterInterrupt()	Informs embOS that interrupt code is executing.			X	
OS_LeaveInterrupt()	Informs embOS that the end of the interrupt routine has been reached; executes task switching within ISR.			X	
OS_EnterNestableInterrupt()	Informs embOS that interrupt code is executing and reenables interrupts.			X	
OS_LeaveNestableInterrupt()	Informs embOS that the end of the interrupt routine has been reached; executes task switching within ISR.			X	
OS_CallISR()	Interrupt entry function.			X	
OS_CallNestableISR()	Interrupt entry function supporting nestable interrupts.			X	
OS_INTERRUPT_MaskGlobal()	Disable all interrupts (high and low priority) unconditionally.	X	X	X	X
OS_INTERRUPT_UnmaskGlobal()	Enable all interrupts (high and low priority) unconditionally.	X	X	X	X
OS_INTERRUPT_PreserveGlobal()	Preserves the current interrupt enable state	X	X	X	X
OS_INTERRUPT_PreserveAndMaskGlobal()	Preserves the current interrupt enable state and then disables all interrupts.	X	X	X	X
OS_INTERRUPT_RestoreGlobal()	Restores the interrupt enable state which was preserved before.	X	X	X	X
OS_INT_PRIO_PRESERVE()	Preserves the embOS interrupt state.	X	X	X	X
OS_INT_PRIO_RESTORE()	Restores the embOS interrupt state.	X	X	X	X

Table 15.1: Interrupt API functions

15.6.1 OS_CallISR()

Description

Entry function for use in an embOS interrupt handler. Nestable interrupts disabled.

Prototype

```
void OS_CallISR (void (*pRoutine)(void));
```

Parameter	Description
pRoutine	Pointer to a routine that should run on interrupt.

Table 15.2: OS_CallISR() parameter list

Additional Information

OS_CallISR() can be used as an entry function in an embOS interrupt handler, when the corresponding interrupt should not be interrupted by another embOS interrupt. OS_CallISR() sets the interrupt priority of the CPU to the user definable 'fast' interrupt priority level, thus locking any other embOS interrupt.
Fast interrupts are not disabled.

Note: For some specific CPUs OS_CallISR() must be used to call an interrupt handler because OS_EnterInterrupt() / OS_LeaveInterrupt() may not be available.
Refer to the CPU specific manual.

Example

```
#pragma interrupt
void OS_ISR_Tick(void) {
  OS_CallISR(_IsrTickHandler);
}
```

15.6.2 OS_CallNestableISR()

Description

Entry function for use in an embOS interrupt handler. Nestable interrupts enabled.

Prototype

```
void OS_CallNestableISR (void (*pRoutine)(void));
```

Parameter	Description
pRoutine	Pointer to a routine that should run on interrupt.

Table 15.3: OS_CallNestableISR() parameter list

Additional Information

`OS_CallNestableISR()` can be used as an entry function in an embOS interrupt handler, when interruption by higher prioritized embOS interrupts should be allowed. `OS_CallNestableISR()` does not alter the interrupt priority of the CPU, thus keeping all interrupts with higher priority enabled.

Note: For some specific CPUs `OS_CallNestableISR()` must be used to call an interrupt handler because `OS_EnterNestableInterrupt()` / `OS_LeaveNestableInterrupt()` may not be available.
Refer to the CPU specific manual.

Example

```
#pragma interrupt
void OS_ISR_Tick(void) {
  OS_CallNestableISR(_IsrTickHandler);
}
```

15.6.3 OS_EnterInterrupt()

Note: This function may not be available in all ports.

Description

Informs embOS that interrupt code is executing.

Prototype

```
void OS_EnterInterrupt (void);
```

Additional Information

If `OS_EnterInterrupt()` is used, it should be the first function to be called in the interrupt handler. It must be paired with `OS_LeaveInterrupt()` as the last function called. The use of this function has the following effects:

*   disables task switches
*   keeps interrupts in internal routines disabled.

An example is shown in the the description of `OS_LeaveInterrupt()`.

15.6.4 OS_LeaveInterrupt()

Note: This function may not be available in all ports.

Description

Informs embOS that the end of the interrupt routine has been reached; executes task switching within ISR.

Prototype

```
void OS_LeaveInterrupt (void);
```

Additional Information

If `OS_LeaveInterrupt()` is used, it should be the last function to be called in the interrupt handler. If the interrupt has caused a task switch, that switch is performed immediately (unless the program which was interrupted was in a critical region).

Example using OS_EnterInterrupt()/OS_LeaveInterrupt()

```
void ISR_Timer(void) {
  OS_EnterInterrupt();
  OS_SignalEvent(1, &Task);  /* Any functionality could be here */
  OS_LeaveInterrupt();
}
```

15.7 Enabling / disabling interrupts from C

During the execution of a task, maskable interrupts are normally enabled. In certain sections of the program, however, it can be necessary to disable interrupts for short periods of time to make a section of the program an atomic operation that cannot be interrupted. An example would be the access to a global volatile variable of type `long` on an 8/16 bit CPU. To make sure that the value does not change between the two or more accesses that are needed, interrupts must be temporarily disabled:

Bad example:

```
volatile long lvar;

void IntHandler(voi
  lvar++;
}

void routine (void) {
  lvar++;
}
```

Good example:

```
volatile long lvar;

void IntHandler(voi
  lvar++;
}

void routine (void) {
  OS_DI();
  lvar++;
  OS_EI();
}
```

The problem with disabling and re-enabling interrupts is that functions that disable/enable the interrupt cannot be nested.

Your C compiler offers two intrinsic functions for enabling and disabling interrupts. These functions can still be used, but it is recommended to use the functions that embOS offers (to be precise, they only look like functions, but are macros in reality). If you do not use these recommended embOS functions, you may run into a problem if routines which require a portion of the code to run with disabled interrupts are nested or call an OS routine.

We recommend disabling interrupts only for short periods of time, if possible. Also, you should not call functions when interrupts are disabled, because this could lead to long interrupt latency times (the longer interrupts are disabled, the higher the interrupt latency). You may also safely use the compiler-provided intrinsics to disable interrupts but you must ensure to not call embOS functions with disabled interrupts.

15.7.1 OS_IncDI() / OS_DecRI()

The following functions are actually macros defined in `RTOS.h`, so they execute very quickly and are very efficient. It is important that they are used as a pair: first `OS_IncDI()`, then `OS_DecRI()`.

OS_IncDI()

Short for **Increment and Disable Interrupts**. Increments the interrupt disable counter (`OS_DICnt`) and disables interrupts.

OS_DecRI()

Short for **Decrement and Restore Interrupts**. Decrements the counter and enables interrupts if the disable counter reaches zero.

Example

```
volatile long lvar;

void routine (void) {
  OS_IncDI();
  lvar ++;
  OS_DecRI();
}
```

`OS_IncDI()` increments the interrupt disable counter which is used for the entire OS and is therefore consistent with the rest of the program in that any function can be called and the interrupts will not be switched on before the matching `OS_DecRI()` is executed.

If you need to disable interrupts for a instant only where no routine is called, as in the example above, you could also use the pair `OS_DI()` and `OS_RestoreI()`. These are slighly more efficient because the interrupt disable counter `OS_DICnt` is not modified twice, but only checked once. They have the disadvantage that they do not work with functions because the status of `OS_DICnt` is not actually changed, and they should therefore be used with great care. In case of doubt, use `OS_IncDI()` and `OS_DecRI()`.

15.7.2 OS_DI() / OS_EI() / OS_RestoreI()

OS_DI()

Short for **Disable Interrupts**. Disables interrupts. Does not change the interrupt disable counter.

OS_EI()

Short for **Enable Interrupts**. Refrain from using this function directly unless you are sure that the interrupt enable count has the value zero, because it does not take the interrupt disable counter into account.

OS_RestoreI()

Short for **Restore Interrupts**. Restores the status of the interrupt flag, based on the interrupt disable counter.

Example

```
volatile long lvar;

void routine (void) {
  OS_DI();
  lvar++;
  OS_RestoreI();
}
```

15.8 Definitions of interrupt control macros (in RTOS.h)

```
#define OS_IncDI()      { OS_ASSERT_DICnt(); OS_DI(); OS_DICnt++; }
#define OS_DecRI()      { OS_ASSERT_DICnt(); if (--OS_DICnt==0) OS_EI(); }
#define OS_RestoreI()   { OS_ASSERT_DICnt(); if (OS_DICnt==0)   OS_EI(); }
```

15.9 Nesting interrupt routines

By default, interrupts are disabled in an ISR because the CPU disables interrupts with the execution of the interrupt handler. Re-enabling interrupts in an interrupt handler allows the execution of further interrupts with equal or higher priority than that of the current interrupt. These are known as nested interrupts, illustrated in the diagram below:
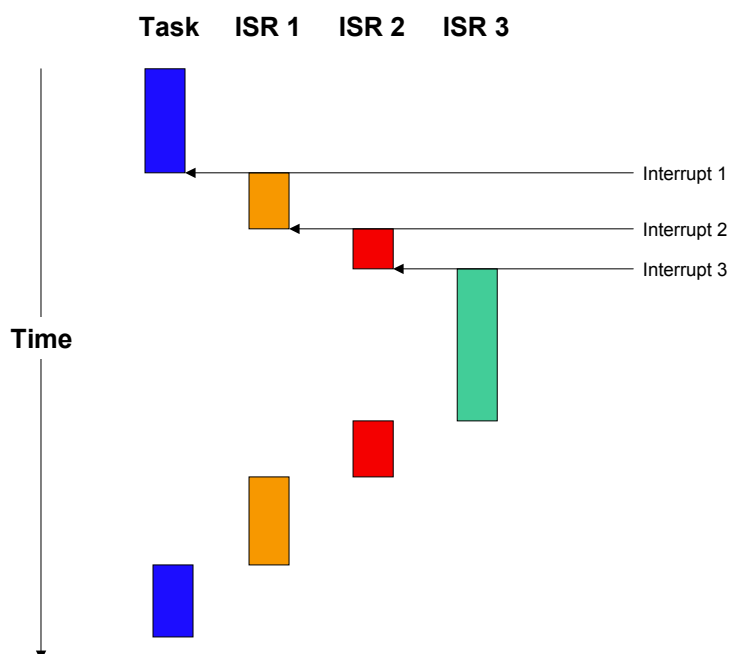
For applications requiring short interrupt latency, you may re-enable interrupts inside an ISR by using `OS_EnterNestableInterrupt()` and `OS_LeaveNestableInterrupt()` within the interrupt handler.

Nested interrupts can lead to problems that are difficult to debug; therefore it is not recommended to enable interrupts within an interrupt handler. As it is important that embOS keeps track of the status of the interrupt enable/disable flag, enabling and disabling of interrupts from within an ISR must be done using the functions that embOS offers for this purpose.

The routine `OS_EnterNestableInterrupt()` enables interrupts within an ISR and prevents further task switches; `OS_LeaveNestableInterrupt()` disables interrupts immediately before ending the interrupt routine, thus restoring the default condition. Re-enabling interrupts will make it possible for an embOS scheduler interrupt to interrupt this ISR. In this case, embOS needs to know that another ISR is still active and that it may not perform a task switch.

15.9.1 OS_EnterNestableInterrupt()

Note: This function may not be available in all ports.

Description

Re-enables interrupts and increments the embOS internal critical region counter, thus disabling further task switches.

Prototype

```
void OS_EnterNestableInterrupt (void);
```

Additional Information

This function should be the first call inside an interrupt handler when nested interrupts are required. The function `OS_EnterNestableInterrupt()` is implemented as a macro and offers the same functionality as `OS_EnterInterrupt()` in combination with `OS_DecRI()`, but is more efficient, resulting in smaller and faster code.

Example

Refer to the example for *OS_LeaveNestableInterrupt()* on page 278.

15.9.2 OS_LeaveNestableInterrupt()

Note: This function may not be available in all ports.

Description

Disables further interrupts, then decrements the embOS internal critical region count, thus re-enabling task switches if the counter has reached zero.

Prototype

```
void OS_LeaveNestableInterrupt (void);
```

Additional Information

This function is the counterpart of `OS_EnterNestableInterrupt()`, and must be the last function call inside an interrupt handler when nested interrupts have been enabled by `OS_EnterNestableInterrupt()`.
The function `OS_LeaveNestableInterrupt()` is implemented as a macro and offers the same functionality as `OS_LeaveInterrupt()` in combination with `OS_IncDI()`, but is more efficient, resulting in smaller and faster code.

Example using OS_EnterNestableInterrupt()/OS_LeaveNestableInterrupt()

```
_interrupt void ISR_Timer(void) {
  OS_EnterNestableInterrupt();
  OS_SignalEvent(1,&Task);        /* Any functionality could be here */
  OS_LeaveNestableInterrupt();
}
```

15.9.3 OS_InInterrupt()

Description

This function can be called to examine if the calling function is running in an interrupt context. For application code, it may be useful to know if it is called from interrupt or task, because some functions must not be called from an interrupt-handler.

Prototype

```
OS_BOOL OS_InInterrupt (void);
```

Return value

0:    Code is not executed in interrupt handler.
!=0: Code is executed in an interrupt handler.

Additional Information

The function delivers the interrupt state by checking the according CPU registers. **This function is not included in all embOS ports!** It is only implemented for those CPUS where it is possible to read the interrupt state from CPU registers. In case of doubt please contact the embOS support.

15.10 Global interrupt enable / disable

The embOS interrupt enable and disable functions enable and disable embOS interrupts only. If a system is set up to support high and low priority interrupts and embOS is configured to suppport "zero latency" interrupts, the embOS functions to enable and disable interrupts affect the low priority interrupts only.

High priority interrupts, called "zero latency interrupts" are never enabled or disabled by embOS functions.

In an application it may be required to disable and enable all interrupts.

Since version 3.90, embOS has API functions which allow enabling and disabling all interrupts. These functions have the prefix `OS_INTERRUPT_` and allow a "global" handling of the interrupt enable state of the CPU.

These functions affect the state of the CPU unconditionally and should be used with care.

15.10.1 OS_INTERRUPT_MaskGlobal()

Description

This function disables high and low priority interrupts unconditionally.

Prototype

```
void  OS_INTERRUPT_MaskGlobal (void);
```

Additional Information

OS_INTERRUPT_MaskGlobal() disables all interrupts in a fast and efficient way.
Note that the system does not track the interrupt state when calling the function.
Therefore the function should not be called when the state is unknown.
Interrupts can be re-enabled by calling OS_INTERRUPT_UnmaskGlobal().
After calling OS_INTERRUPT_MaskGlobal(), no embOS function except the interrupt
enable function OS_INTERRUPT_UnmaskGlobal() should be called, because the inter-
rupt state is not saved by the function. An embOS API function may re-enable inter-
rupts. The exact interrupt enable behaviour depends on the CPU.

15.10.2 OS_INTERRUPT_UnmaskGlobal()

Description

This function enables high and low priority interrupts unconditionally.

Prototype

```
void  OS_INTERRUPT_UnmaskGlobal (void);
```

Additional Information

This function re-enables interrupts which were disabled before by a call of `OS_INTERRUPT_MaskGlobal()`.
The function re-enables high and low priority interrupts unconditionally.
`OS_INTERRUPT_MaskGlobal()` and `OS_INTERRUPT_UnmaskGlobal()` should be used as a pair. The call cannot be nested, because the state is not saved.
This kind of global interrupt disable/enable should only be used when the interrupt enable state is well known and interrupts are enabled.
Between `OS_INTERRUPT_MaskGlobal()` and `OS_INTERRUPT_UnmaskGlobal()`, no function should be called when it is not known if the function alters the interrupt enable state.
If the interrupt state is not known, the functions `OS_INTERRUPT_PreserveGlobal()` or `OS_INTERRUPT_PreserveAndMaskGlobal()` and `OS_INTERRUPT_RestoreGlobal()` shall be used as decribed later on.

Example

```c
void Sample(void) {
  OS_INTERRUPT_MaskGlobal();    // Disable interrupts
  //
  // Execute any code that should be executed with interrupts disabled
  // No embOS function should be called
  //
  ...
  OS_INTERRUPT_UnmaskGlobal();  // Re-enable interrupts unconditionally
}
```

15.10.3 OS_INTERRUPT_PreserveGlobal()

Description

This function can be called to preserve the current interrupt enable state of the CPU.

Prototype

```
void  OS_INTERRUPT_PreserveGlobal (OS_U32 *pState);
```

Parameter	Description
pState	Pointer to an OS_U32 variable that receives the interrupt state.

Table 15.4: OS_CallNestableISR() parameter list

Additional Information

If the interrupt enable state is not known and interrupts should be disabled by a call of `OS_INTERRUPT_MaskGlobal()`, the current interrupt enable state can be preserved and restored later by a call of `OS_INTERRUPT_RestoreGlobal()`.
Note that the interrupt state is not stored by embOS. After disabling the interrupts using a call of OS_INTERRUPT_MaskGlobal(), no embOS API function should be called because embOS functions might re-enable interrupts.

Example

```
void Sample(void) {
  OS_U32 IntState;

  OS_INTERRUPT_PreserveGlobal(&IntState);  // Remember the interrupt enable state.
  OS_INTERRUPT_MaskGlobal();               // Disable interrupts
  //
  // Execute any code that should be executed with interrupts disabled
  // No embOS function should be called
  //
  ...
  OS_INTERRUPT_RestoreGlobal(&IntState);   // Restore the interrupt enable state
}
```

15.10.4 OS_INTERRUPT_PreserveAndMaskGlobal()

Description

This function preserves the current interrupt enable state of the CPU and then disables high and low priority interrupts.

Prototype

```
void  OS_INTERRUPT_PreserveAndMaskGlobal (OS_U32 *pState);
```

Parameter	Description
pState	Pointer to an OS_32 variable that receives the interrupt state.

Table 15.5: OS_CallNestableISR() parameter list

Additional Information

The function store the current interrupt enable state into the variable pointed to by pState and then disables high and low priority interrupts.
The interrupt state can be restored later by a corresponding call of `OS_INTERRUPT_RestoreGlobal()`.
The pair of function calls `OS_INTERRUPT_PreserveAndMaskGlobal()` and `OS_INTERRUPT_RestoreGlobal()` can be nested, as long as the interrupt enable state is stored into an individual variable on each call of `OS_INTERRUPT_PreserveAndMaskGlobal()`.
This function pair should be used when the interrupt enable state is not known when interrupts shall be enabled.

15.10.5 OS_INTERRUPT_RestoreGlobal()

Description

This function must be called to restore the interrupt enable state of the CPU which was preserved before.

Prototype

```
void  OS_INTERRUPT_RestoreGlobal (OS_U32 *pState);
```

Parameter	Description
pState	Pointer to an OS_U32 that holds the interrupt enable state.

Table 15.6: OS_CallNestableISR() parameter list

Additional Information

Restores the interrupt enable state which was saved before by a call of OS_INTERRUPT_PreserveGlobal() or OS_INTERRUPT_PreserveAndMaskGlobal(). If interrupts were enabled before they were disabled globally, the function reenables them.

Example

```
void Sample(void) {
  OS_U32 IntState;

  OS_INTERRUPT_PreserveGlobal(&IntState);  // Remember the interrupt enable state.
  OS_INTERRUPT_MaskGlobal();               // Disable interrupts
  //
  // Execute any code that should be executed with interrupts disabled
  // No embOS function should be called
  //
  ...
  OS_INTERRUPT_RestoreGlobal(&IntState);   // Restore the interrupt enable state
}
```

15.10.6 OS_INT_PRIO_PRESERVE()

Description

This function can be called to preserve the current embOS interrupt enable state of the CPU.

Prototype

```
void  OS_INT_PRIO_PRESERVE (OS_U32 *pState);
```

Parameter	Description
pState	Pointer to an OS_U32 variable that receives the interrupt state.

Table 15.7: OS_CallNestableISR() parameter list

Additional Information

If the interrupt enable state is not known and interrupts should be disabled by a call of OS_DI(), the current embOS interrupt enable state can be preserved and restored later by a call of OS_INT_PRIO_RESTORE().

Example

```
void Sample(void) {
  OS_U32 IntState;

  OS_INT_PRIO_PRESERVE(&IntState);  // Remember the interrupt enable state.
  OS_DI();                          // Disable embOS interrupts
  //
  // Execute any code that should be executed with embOS interrupts disabled
  //
  ...
  OS_INT_PRIO_RESTORE(&IntState);   // Restore the interrupt enable state
}
```

15.10.7 OS_INT_PRIO_RESTORE()

Description

This function must be called to restore the embOS interrupt enable state of the CPU which was preserved before.

Prototype

```
void  OS_INT_PRIO_RESTORE (OS_U32 *pState);
```

Parameter	Description
pState	Pointer to an OS_U32 that holds the interrupt enable state.

Table 15.8: OS_CallNestableISR() parameter list

Additional Information

Restores the embOS interrupt enable state which was saved before by a call of OS_INT_PRIO_PRESERVE().
If embOS interrupts were enabled before they were disabled, the function reenables them.

Example

```
void Sample(void) {
  OS_U32 IntState;

  OS_INT_PRIO_PRESERVE(&IntState);  // Remember the interrupt enable state.
  OS_DI();                          // Disable embOS interrupts
  //
  // Execute any code that should be executed with embOS interrupts disabled
  //
  ...
  OS_INT_PRIO_RESTORE(&IntState);   // Restore the interrupt enable state
}
```

15.11 Non-maskable interrupts (NMIs)

embOS performs atomic operations by disabling interrupts. However, a non-maskable interrupt (NMI) cannot be disabled, meaning it can interrupt these atomic operations. Therefore, NMIs should be used with great care and are prohibited from calling any embOS routines.

Chapter 16

Critical Regions

16.1 Introduction

Critical regions are program sections during which the scheduler is switched off, meaning that no task switch and no execution of software timers are allowed except in situations where the running task must wait. Effectively, preemptions are turned off.

A typical example for a critical region would be the execution of a program section that handles a time-critical hardware access (for example writing multiple bytes into an EEPROM where the bytes must be written in a certain amount of time), or a section that writes data into global variables used by a different task and therefore needs to make sure the data is consistent.

A critical region can be defined anywhere during the execution of a task. Critical regions can be nested; the scheduler will be switched on again after the outermost region is left. Interrupts are still legal in a critical region. Software timers and interrupts are executed as critical regions anyhow, so it does not hurt but does not do any good either to declare them as such. If a task switch becomes due during the execution of a critical region, it will be performed immediately after the region is left.

16.2 API functions

Routine	Description	main	Task	ISR	Timer
OS_EnterRegion()	Indicates to the OS the beginning of a critical region.	X	X	X	X
OS_LeaveRegion()	Indicates to the OS the end of a critical region.	X	X	X	X

Table 16.1: Critical regions API functions

16.2.1 OS_EnterRegion()

Description

Indicates to the OS the beginning of a critical region.

Prototype

```
void OS_EnterRegion (void);
```

Additional Information

Note: `OS_EnterRegion()` is not actually a function but a macro. However, it behaves very much like a function but is much more efficient. Using the macro indicates to embOS the beginning of a critical region.
A critical region counter (OS_Global.Counters.Cnt.Region), which is zero by default, is incremented so that critical regions can be nested. The counter will be decremented by a call to the routine `OS_LeaveRegion()`. When this counter reaches zero again, the critical region ends.
Interrupts are not disabled using `OS_EnterRegion()`; however, preemptive task switches are disabled in a critical region.
If any interrupt triggers a task switch, the task switch is delayed and kept pending until the final call of `OS_LeaveRegion()`. When the `OS_RegionCnt` reaches zero, any pending task switch is executed.
Cooperative task switches are not affected and will be executed in critical regions.
When a task is running in a critical region and calls any blocking embOS function, the task will be suspended.
When the task is resumed, the task-specific `OS_RegionCnt` is restored, the task continues to run in a critical region until `OS_LeaveRegion()` is called.

Example

```
void SubRoutine(void) {
  OS_EnterRegion();
  /* The following code will not be interrupted by the OS                */
  /* Preemptive task switches are blocked until a call of OS_leaveRegion() */

  OS_LeaveRegion();
}
```

16.2.2 OS_LeaveRegion()

Description

Indicates to the OS the end of a critical region.

Prototype

```
void OS_LeaveRegion (void);
```

Additional Information

`OS_LeaveRegion()` is not actually a function but a macro. However, it behaves very much like a function but is much more efficient. Usage of the macro indicates to embOS the end of a critical region.
A critical region counter (OS_Global.Counters.Cnt.Region), which is zero by default, is decremented. If this counter reaches zero, the critical region ends.
A task switch which became pending during a critical region will be executed in `OS_EnterRegion()` when the `OS_RegionCnt` reaches zero.

Example

Refer to the example for `OS_EnterRegion()`.

Chapter 17

Time measurement

embOS supports two types of time measurement:
* Low resolution (using a time variable)
* High resolution (using a hardware timer)

Both are explained in this chapter.

17.1 Introduction

embOS supports two basic types of run-time measurement which may be used for calculating the execution time of any section of user code. Low-resolution measurements use a time base of ticks, while high-resolution measurements are based on a time unit called a cycle. The length of a cycle depends on the timer clock frequency.

17.2 Low-resolution measurement

The system time variable `OS_Global.Time` is measured in ticks, or milliseconds. The low-resolution functions `OS_GetTime()` and `OS_GetTime32()` are used for returning the current contents of this variable. The basic concept behind low-resolution measurement is quite simple: The system time is returned once before the section of code to be timed and once after, and the first value is subtracted from the second to obtain the time it took for the code to execute.

The term low-resolution is used because the time values returned are measured in completed ticks. Consider the following: with a normal tick of one ms, the variable `OS_Time` is incremented with every tick-interrupt, or once every ms. This means that the actual system time can potentially be later than the low-resolution function returns (for example, if an interrupt actually occurs at 1.4 ticks, the system will still have measured only one tick as having elapsed). The problem becomes even greater with runtime measurement, because the system time must be measured twice. Each measurement can potentially be up to one tick less than the actual time, so the difference between two measurements could theoretically be inaccurate by up to one tick.

The following diagram illustrates how low-resolution measurement works. We can see that the section of code begins at 0.5 ms and ends at 5.2 ms, which means that its exact execution time is (5.2 - 0.5) = 4.7 ms. However with a tick of one ms, the first call to `OS_GetTime()` returns 0, and the second call returns 5. The measured execution time of the code would therefore result in (5 - 0) = 5 ms.
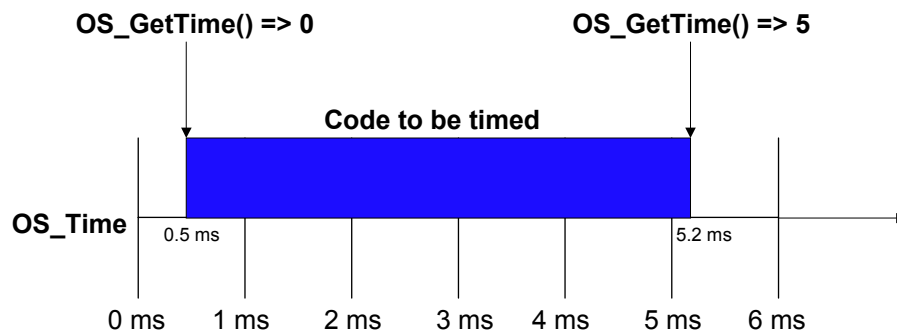
For many applications, low-resolution measurement may be sufficient for your needs. In some cases, it may be more desirable than high-resolution measurement due to its ease of use and faster computation time.

17.2.1 API functions

Routine	Description	main	Task	ISR	Timer
OS_GetTime()	Returns the current system time in ticks.	X	X	X	X
OS_GetTime32()	Returns the current system time in ticks as a 32 bit value.	X	X	X	X

Table 17.1: Low-resolution measurement API functions

17.2.1.1 OS_GetTime()

Description

Returns the current system time in ticks.

Prototype

```
int OS_GetTime (void);
```

Return value

The system variable `OS_Global.Time` as a 16 or 32 bit integer value.

Additional Information

This function returns the system time as a 16 bit value on 8/16 bit CPUs, and as a 32 bit value on 32 bit CPUs. The `OS_Global.Time` variable is a 32 bit value. Therefore, if the return value is 32 bit, it is simply the entire contents of the `OS_Time` variable. If the return value is 16 bit, it is the lower 16 bits of the `OS_Global.OS_Time` variable.

17.2.1.2 OS_GetTime32()

Description

Returns the current system time in ticks as a 32 bit value.

Prototype

```
int OS_GetTime32 (void);
```

Return value

The system variable `OS_Global.Time` as a 32 bit integer value.

Additional Information

This function always returns the system time as a 32 bit value. Because the `OS_Global.Time` variable is also a 32 bit value, the return value is simply the entire contents of the `OS_Global.Time` variable.

17.3 High-resolution measurement

High-resolution measurement uses the same routines as those used in profiling builds of embOS, allowing fine-tuning of time measurement. While system resolution depends on the CPU used, it is typically about one µs, making high-resolution measurement 1000 times more accurate than low-resolution calculations.

Instead of measuring the number of completed ticks at a given time, an internal count is kept of the number of cycles that have been completed. Look at the illustration below, which measures the execution time of the same code used in the low-resolution calculation. For this example, we assume that the CPU has a timer running at 10 MHz and is counting up. The number of cycles per tick is therefore (10 MHz / 1 kHz) = 10,000. This means that with each tick-interrupt, the timer restarts at zero and counts up to 10,000.
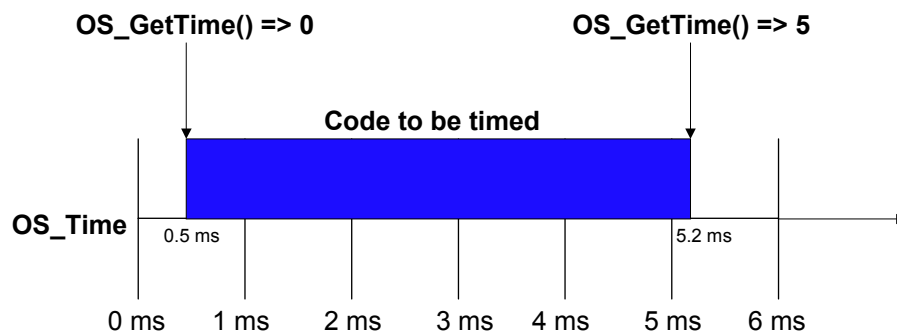
The call to `OS_Timing_Start()` calculates the starting value at 5,000 cycles, while the call to `OS_Timing_End()` calculates the ending value at 52,000 cycles (both values are kept track of internally). The measured execution time of the code in this example would therefore be (52,000 - 5,000) = 47,000 cycles, which corresponds to 4.7 ms.

Although the function `OS_Timing_GetCycles()` may be used for returning the execution time in cycles as above, it is typically more common to use the function `OS_Timing_Getus()`, which returns the value in microseconds (µs). In the above example, the return value would be 4,700 µs.

17.3.1 API functions

Routine	Description	main	Task	ISR	Timer
OS_Timing_Start()	Marks the beginning of a code section to be timed.	X	X	X	X
OS_Timing_End()	Marks the end of a code section to be timed.	X	X	X	X
OS_Timing_Getus()	Returns the execution time of the code between OS_Timing_Start() and OS_Timing_End() in microseconds.	X	X	X	X
OS_Timing_GetCycles()	Returns the execution time of the code between OS_Timing_Start() and OS_Timing_End() in cycles.	X	X	X	X

Table 17.2: High-resolution measurement API functions

17.3.1.1 OS_Timing_Start()

Description

Marks the beginning of a section of code to be timed.

Prototype

```
void OS_Timing_Start (OS_TIMING* pCycle);
```

Parameter	Description
pCycle	Pointer to a data structure of type OS_TIMING.

Table 17.3: OS_TimingStart() parameter list

Additional Information

This function must be used with OS_Timing_End().

17.3.1.2 OS_Timing_End()

Description

Marks the end of a section of code to be timed.

Prototype

```
void OS_Timing_End (OS_TIMING* pCycle);
```

Parameter	Description
pCycle	Pointer to a data structure of type OS_TIMING.

Table 17.4: OS_TimingEnd() parameter list

Additional Information

This function must be used with OS_Timing_Start().

17.3.1.3 OS_Timing_Getus()

Description

Returns the execution time of the code between `OS_Timing_Start()` and `OS_Timing_End()` in microseconds.

Prototype

```
OS_U32 OS_Timing_Getus (const OS_TIMING* pCycle);
```

Parameter	Description
pCycle	Pointer to a data structure of type OS_TIMING.

Table 17.5: OS_Timing_Getus() parameter list

Additional Information

The execution time in microseconds (µs) as a 32 bit integer value.

17.3.1.4 OS_Timing_GetCycles()

Description

Returns the execution time of the code between `OS_Timing_Start()` and `OS_Timing_End()` in cycles.

Prototype

```
OS_U32 OS_Timing_GetCycles (OS_TIMING* pCycle);
```

Parameter	Description
pCycle	Pointer to a data structure of type `OS_TIMING`.

Table 17.6: OS_Timing_GetCycles() parameter list

Return value

The execution time in cycles as a 32 bit integer.

Additional Information

Cycle length depends on the timer clock frequency.

17.4 Example

The following sample demonstrates the use of low-resolution and high-resolution measurement to return the execution time of a section of code:

```c
/**********************************************************
*         SEGGER MICROCONTROLLER SYSTEME GmbH
*   Solutions for real time microcontroller applications
***********************************************************
File        : SampleHiRes.c
Purpose     : Demonstration of embOS Hires Timer
-------------END-OF-HEADER----------------------------*/

#include "RTOS.H"
#include <stdio.h>

OS_STACKPTR int Stack[1000]; /* Task stacks */
OS_TASK TCB;                  /* Task-control-blocks */

volatile int Dummy;
void UserCode(void) {
  for (Dummy=0; Dummy < 11000; Dummy++);  /* Burn some time  */
}

/*
* Measure the execution time with low resolution and return it in ms (ticks)
*/
int BenchmarkLoRes(void) {
  OS_TIME t;
  t = OS_GetTime();
  UserCode();            /* Execute the user code to be benchmarked */
  t = OS_GetTime() - t;
  return (int)t;
}

/*
* Measure the execution time with hi resolution and return it in us
*/
OS_U32 BenchmarkHiRes(void) {
  OS_TIMING t;
  OS_Timing_Start(&t);
  UserCode();            /* Execute the user code to be benchmarked */
  OS_Timing_End(&t);
  return OS_Timing_Getus(&t);
}

void Task(void) {
  int tLo;
  OS_U32 tHi;
  char ac[80];
  while (1) {
    tLo = BenchmarkLoRes();
    tHi = BenchmarkHiRes();
    sprintf(ac, "LoRes: %d ms\n", tLo);
    OS_SendString(ac);
    sprintf(ac, "HiRes: %d us\n", tHi);
    OS_SendString(ac);
  }
}

/**********************************************************
*
*                   main
*
***********************************************************/

void main(void) {
  OS_InitKern();         /* Initialize OS                */
  OS_InitHW();           /* Initialize Hardware for OS    */
  /* You need to create at least one task here !         */
  OS_CREATETASK(&TCB, "HP Task", Task, 100, Stack);
  OS_Start();            /* Start multitasking           */
}
```

The output of the sample is as follows:

```
LoRes: 7 ms
HiRes: 6641 us
LoRes: 7 ms
HiRes: 6641 us
LoRes: 6 ms
```

17.5 Microsecond precise system time

The following functions return the current system time in micro second resolution. The function OS_Config_SysTimer() sets up the necessary parameters.
The following functions are not available when the compiler does not support a 64 bit data type (long long).

17.5.1 API functions

Routine	Description	main	Task	ISR	Timer
OS_GetTime_us()	Returns the current system time in usec as a 32 bit value.	X	X	X	X
OS_GetTime_us64()	Returns the current system time in usec as a 64 bit value. This function is not available with all embOS ports.	X	X	X	X
OS_Config_SysTimer()	Configures system time parameters. In general called from RTOSInit.c.	X	X	X	X

Table 17.7: Micro second accurate system time API functions

17.5.2 OS_GetTime_us()

Description

Returns the current system time in microseconds as a 32 bit value.

Prototype

```
OS_U32 OS_GetTime_us();
```

Return value

The execution time in micro seconds as a 32 bit unsigned integer value.

Additional Information

OS_GetTime_us() returns only correct values if the function OS_Config_SysTimer() was called at initialization time.

17.5.3 OS_GetTime_us64()

Description

Returns the current system time in micro seconds as a 64 bit value.

Prototype

```
OS_U64 OS_GetTime_us();
```

Return value

The execution time in micro seconds as a 64 bit unsigned integer value.

Additional Information

OS_GetTime_us64() returns only correct values if the function OS_Config_SysTimer() was called at initialization time. This function is not available with all embOS ports.

17.5.4 OS_Config_SysTimer()

Description

Configures the system time parameters for the functions OS_GetTime_us() and OS_GetTime_us64(). This function should be called once at initialization time, e.g. in RTOSInit.c.

Prototype

```
void OS_Config_SysTimer(const OS_SYSTIMER_CONFIG *pConfig)
```

Parameter	Description
pConfig	Pointer to a data structure of type OS_SYSTIMER_CONFIG

Table 17.8: OS_Config_SysTimer() parameter list

Additional Information

OS_Config_SysTimer() uses the struct OS_SYSTIMER_CONFIG:

Member	Description
TimerFreq	Timer frequency in Hz
TickFreq	Tick frequency in Hz
IsUpCounter	0: for hardware timer which counts down 1: for hardware timer which counts up
pfGetTimerCycles	Pointer to a function which returns the current hardware timer count value
pfGetTimerIntPending	Pointer to a function which returns if the hardware timer interrupt pending flag is set

Table 17.9: OS_Config_SysTimer() parameter list

17.5.4.1 pfGetTimerCycles()

Description

This callback function must be implemented by the user. It returns the current hardware timer count value.

Prototype

```
unsigned int (*pfGetTimerCycles) (void);
```

Return value

The current hardware timer count value.

17.5.4.2 pfGetTimerIntPending()

Description

This callback function must be implemented by the user. It returns a value unequal to zero if the hardware timer interrupt pending flag is set.

Prototype

```
unsigned int (*pfGetTimerIntPending)(void);
```

Return value

It returns zero if the hardware timer interrupt pending flag is not set and any other value when the pending flag is set.

17.5.4.3 Example

```
#define OS_FSYS        72000000u   // 72 MHz CPU main clock
#define OS_PCLK_TIMER  (OS_FSYS)   // HW timer runs at CPU speed
#define OS_TICK_FREQ   1000u       // 1 KHz => 1 msc per system tick

static unsigned int _OS_GetHWTimer_Cycles(void) {
  return HW_TIMER_VALUE_REG;
}

static unsigned int _OS_GetHWTimer_IntPending(void) {
  return HW_TIMER_INT_REG & (1uL << PENDING_BIT);
}

const OS_SYSTIMER_CONFIG Tick_Config = { OS_PCLK_TIMER,
                                         OS_TICK_FREQ,
                                         0,
                                         _OS_GetHWTimer_Cycles
                                         _OS_GetHWTimer_IntPending };

void OS_InitHW(void) {

  OS_Config_SysTimer(&Tick_Config);
  ...
  ...
}
```

Chapter 18

MPU - Memory protection

This chapter describes embOS-MPU. embOS-MPU is a separate product which adds memory protection to embOS.

18.1   Introduction

Memory protection is a way to control memory access rights, and is a part of most modern processor architectures and operating systems. The main purpose of memory protection is to prevent a task from accessing memory that has not been allocated to it. This prevents a bug or malware within a task from affecting other tasks, or the operating system itself.

embOS-MPU uses the hardware MPU and additional checks to avoid that a task affects the remaining system. Even if a bug in one task occurs all other tasks and the OS continue execution. The task which caused the issue is suspended automatically and the application is informed via an optional callback function.

Since a hardware MPU is required embOS MPU support is unavailable for some embOS ports. The MPU support is included in separate embOS ports and is not part of the general embOS port. The following embOS-MPU ports are currently available:

embOS port	Version
embOS-MPU Cortex-M ES	V4.20

Table 18.1: embOS-MPU ports

18.1.1   Privilege states

Application tasks which may affect other tasks or the OS itself must not have the permission to access the whole memory, special function registers or embOS control structures. Such application code could be e.g. unreliable software from a third party vendor.
Therefore, those application tasks do not run on the same privilege state like the OS. The OS runs in privilige state which means that it has full access to all memory, peripherals and CPU features. Application tasks, on the other hand, run in unprivileged state and have restricted access only to the memory. To access peripherals and memory from unprivileged tasks, additional API and specific device drivers may be used.

State	Description
Priviliged	Full access to memory, peripheral and CPU features
Unpriviliged	Only restricted access to memory, no direct access to peripherals, no access to some CPU features

Table 18.2: Privilege states

18.1.2   Code organization

embOS-MPU assumes that the application code is divided into two parts. The first part runs in privileged state: it initializes the MPU settings and includes the device driver. It contains critical code and must be verified for full reliability by the responsible developers. Usually, this code consists of only a few simple functions which may be located in one single C file.
The second part is the application itself which doesn't need to or in some cases can't be verified for full reliability. As it runs in unprivileged state, it can't affect the remaining system. Usually, this code is organized in several C files.
This can e.g. simplify a certification.

Part	Description
1st part	Task and MPU initialization Device drivers
2nd part	Application code from e.g. third party vendor

Table 18.3: Code organization

18.2 Memory Access permissions

All privileged tasks have full access to the whole memory. An unprivileged task, however, can have access to several memory regions with different access permissions. Access permissions for RAM and ROM can be used combined, e.g. a ROM region could be readable and code execution could be allowed. In that case the permission defines would be used as `OS_MPU_READONLY | OS_MPU_EXECUTION_ALLOWED`.
The following memory access permissions exist:

Permission	Description
OS_MPU_NOACCESS	No access to a memory region
OS_MPU_READONLY	Read only access to a memory region
OS_MPU_READWRITE	Read and write access to a memory region

Table 18.4: RAM Region access permissions

Permission	Description
OS_MPU_EXECUTION_ALLOWED	Code execution is allowed
OS_MPU_EXECUTION_DISALLOWED	Code execution is not allowed

Table 18.5: ROM Region access permissions

18.2.1 Default memory access permissions

A newly created unprivileged task has per default only access to the following memory regions:

Region	Permissions
ROM	OS_MPU_READONLY, OS_MPU_EXECUTION_ALLOWED
RAM	OS_MPU_READONLY, OS_MPU_EXECUTION_DISALLOWED
Task stack	OS_MPU_READWRITE, OS_MPU_EXECUTION_DISALLOWED

Table 18.6: Default task memory access permissions

An unprivileged task can read the whole RAM and ROM. It can execute code in the ROM only. Write access is restricted to its own task stack.

18.2.2 Interrupts

Interrupts are always privileged and can access the whole memory.

18.2.3 Access to additional memory regions

An unprivileged task can have access to additional memory regions. This could be necessary e.g when a task needs to write LCD data to a framebuffer in RAM. Using a device driver could be too inefficient. Additional memory regions can be added with the API function `OS_MPU_AddRegion()`.
It is CPU specific if the region has to be aligned. Pleaser refer to the according CPU/compiler specific embOS manual for more details.

18.2.4 Access to OS objects

An unprivileged task has no direct write access to embOS objects. It also has per default no access via embOS API functions.
Access to OS objects can be added with `OS_MPU_SetAllowedObjects()`. The object list must be located in ROM memory.
The OS object must be created in the privileged part of the task.

18.3   ROM placement of embOS

embOS must be placed in one memory section. embOS-MPU needs this information to e.g. check that supervisor calls are made from embOS API functions only.
The address and the size of this section must be passed to embOS with `OS_MPU_ConfigMem()`. `__os_start__` and `__os_size__` are linker symbols which are defined in the linker file.

Example

This example is for the GCC compiler and linker.

Linker file:

```
__os_load_start__ = ALIGN(__text_end__ , 4);
.os ALIGN(__text_end__ , 4) : AT(ALIGN(__text_end__ , 4))
{
  __os_start__ = .;
  *(.os .os.*)
}
__os_end__  = __os_start__ + SIZEOF(.os);
__os_size__  = SIZEOF(.os);
__os_load_end__  = __os_end__;
```

C Code:

```
void OS_InitHW() {
  OS_MPU_ConfigMem(0x08000000u, 0x00100000u,          // ROM base addr and size
                   0x20000000u, 0x00020000u,          // RAM base addr and size
                   __os_start__, __os_size__);        // OS base addr and size
}
```

18.4   Allowed embOS API in unprivileged tasks

Not all embOS API functions are allowed to be called from an unprivileged task. Only the following API must be called from an unprivileged task:

Allowed embOS API
Task API
OS_Delay()
OS_DelayUntil()
OS_Delayus()
OS_GetNumTasks()
OS_GetpCurrentTask()
OS_GetPriority()
OS_GetSuspendCnt()
OS_GetTaskID()
OS_GetTaskName()
OS_GetTimeSliceRem()
OS_IsRunning()
OS_IsTask()
OS_Resume()
OS_Suspend()
OS_TaskIndex2Ptr()
OS_WakeTask()
OS_Yield()
Software timer API
OS_StartTimer()
OS_StopTimer()
OS_RetriggerTimer()
OS_SetTimerPeriod()
OS_GetTimerPeriod()
OS_GetTimerValue()
OS_GetTimerStatus()
OS_GetpCurrentTimer()
OS_TriggerTimer()
OS_StartTimerEx()
OS_StopTimerEx()
OS_RetriggerTimerEx()
OS_SetTimerPeriodEx()
OS_GetTimerPeriodEx()
OS_GetTimerValueEx()
OS_GetTimerStatusEx()
OS_GetpCurrentTimerEx()
OS_TriggerTimerEx()
Resource Semaphore API
OS_Use()
OS_UseTimed()
OS_Unuse()
OS_Request()
OS_GetSemaValue()
OS_GetResourceOwner()
Counting Semaphore API
OS_SignalCSema()
OS_SignalCSemaMax()

Allowed embOS API
OS_WaitCSema()
OS_CSemaRequest()
OS_WaitCSemaTimed()
OS_GetCSemaValue()
OS_SetCSemaValue()
Mailbox API
OS_PutMail()
OS_PutMail1()
OS_PutMailCond()
OS_PutMailCond1()
OS_PutMailFront()
OS_PutMailFront1()
OS_PutMailFrontCond()
OS_PutMailFrontCond1()
OS_GetMail()
OS_GetMail1()
OS_GetMailCond()
OS_GetMailCond1()
OS_GetMailTimed()
OS_WaitMail()
OS_WaitMailTimed()
OS_PeekMail()
OS_ClearMB()
OS_GetMessageCnt()
OS_Mail_GetPtr()
OS_Mail_GetPtrCond()
OS_Mail_Purge()
Queue API
OS_Q_Put()
OS_Q_PutBlocked()
OS_Q_PutTimed()
OS_Q_GetPtr()
OS_Q_GetPtrCond()
OS_Q_GetPtrTimed()
OS_Q_Purge()
OS_Q_Clear()
OS_Q_GetMessageCnt()
OS_Q_IsInUse()
OS_Q_GetMessageSize()
OS_Q_PeekPtr()
Task events API
OS_WaitEvent()
OS_WaitSingleEvent()
OS_WaitEventTimed()
OS_WaitSingleEventTimed()
OS_SignalEvent()
OS_GetEventsOccurred()
OS_ClearEvents()
Event objects API
OS_EVENT_Wait()
OS_EVENT_WaitTimed()

Allowed embOS API
OS_EVENT_Set()
OS_EVENT_Reset()
OS_EVENT_Pulse()
OS_EVENT_Get()
OS_EVENT_SetResetMode()
OS_EVENT_GetResetMode()
Fixed block size memory pool API
OS_MEMF_Alloc()
OS_MEMF_AllocTimed()
OS_MEMF_Request()
OS_MEMF_Release()
OS_MEMF_FreeBlock()
OS_MEMF_GetNumFreeBlocks()
OS_MEMF_IsInPool()
OS_MEMF_GetMaxUsed()
OS_MEMF_GetNumBlocks()
OS_MEMF_GetBlockSize()
Stack info API
OS_GetStackBase()
OS_GetStackSize()
OS_GetStackSpace()
OS_GetStackUsed()
OS_GetSysStackBase()
OS_GetSysStackSize()
OS_GetSysStackSpace()
OS_GetSysStackUsed()
OS_GetIntStackBase()
OS_GetIntStackSize()
OS_GetIntStackSpace()
OS_GetIntStackUsed()
Timing API
OS_GetTime()
OS_GetTime32()
OS_Timing_Start()
OS_Timing_End()
OS_Timing_Getus()
OS_Timing_GetCycles()
OS_GetTime_us()
OS_GetTime_us64()
OS_ConvertCycles2us()
Debug API
OS_SendString()
Info routines API
OS_WAIT_OBJ_GetSize()
OS_WAIT_OBJ_EX_GetSize()
OS_WAIT_LIST_GetSize()
OS_EXTEND_TASK_CONTEXT_GetSize()
OS_TASK_GetSize()
OS_REGS_GetSize()
OS_TICK_HOOK_GetSize()
OS_RSEMA_GetSize()

Allowed embOS API
OS_CSEMA_GetSize()
OS_MAILBOX_GetSize()
OS_Q_GetSize()
OS_MEMF_GetSize()
OS_EVENT_GetSize()
OS_TRACE_ENTRY_GetSize()
OS_TIMER_GetSize()
OS_TIMER_EX_GetSize()
OS_GetCPU()
OS_GetLibMode()
OS_GetLibName()
OS_GetModel()
OS_GetVersion()
MPU API
OS_MPU_GetThreadState()
OS_MPU_CallDeviceDriver()
Low power API
OS_POWER_UsageInc()
OS_POWER_UsageDec()
OS_POWER_GetMask()

18.5 Device driver

18.5.1 Concept

An unprivileged task has no access to any peripheral. Thus a device driver is necessary to use peripherals like UART, SPI or port pins.

A device driver consists of two parts, an unprivileged part and a privileged part. embOS ensures there is only one explicit and safe way to switch from the unprivileged part to the privileged part. The application must call driver functions only in the unprivileged part. The actual peripheral access is performed in the privileged part only.

`OS_MPU_CallDeviceDriver()` is used to call the device driver. The first parameter is the index of the device driver function. Optional parameters can be passed to the device driver.

Example

A device driver for a LED should be developed. The LED driver can toggle a LED with a given index number. The function `BSP_Toggle_LED()` is the unprivileged part of the driver. It can be called by the unprivileged application.

```
typedef struct BSP_LED_PARAM_STRUCT {
  BSP_LED_DRIVER_API Action;
  OS_U32             Index;
} BSP_LED_PARAM;

void BSP_ToggleLED(int Index) {
  BSP_LED_PARAM p;
  p.Action = BSP_LED_TOGGLE;
  p.Index  = Index;
  OS_MPU_CallDeviceDriver(0u, &p);
}
```

The device driver itself runs in privileged state and accesses the LED port pin.

```
void BSP_LED_DeviceDriver(void* Param) {
  BSP_LED_PARAM* p;
  p = (BSP_LED_PARAM*)Param;
  switch (p->Action) {
    case BSP_LED_SET:
      BSP_SetLED_SVC(p->Index);
      break;
    case BSP_LED_CLR:
      BSP_ClrLED_SVC(p->Index);
      break;
    case BSP_LED_TOGGLE:
      BSP_ToggleLED_SVC(p->Index);
      break;
    default:
      break;
  }
}
```

All device driver addresses are stored in one const list which is passed to embOS-MPU with `OS_MPU_SetDeviceDriverList()`.

```
static const OS_MPU_DEVICE_DRIVER_FUNC _DeviceDriverList[] =
{ BSP_LED_DeviceDriver,
  NULL };                    // Last item must be NULL

void BSP_Init(void) {
  OS_MPU_SetDeviceDriverList(_DeviceDriverList);
}
```

18.6   API functions

Routine	Description	Priv state	Unpriv state
OS_MPU_Enable()	Enables embOS-MPU	X	
OS_MPU_ConfigMem()	Configures RAM/ROM and OS regions	X	
OS_MPU_SetAllowedObjects()	Sets a list of allowed OS objects	X	
OS_MPU_AddRegion()	Adds an additonal memory region	X	
OS_MPU_SetErrorCallback()	Application error callback function	X	
OS_MPU_SwitchToUnprivState()	Switches to unprivileged state	X	
OS_MPU_SetDeviceDriverList()	Sets the device driver list	X	
OS_MPU_CallDeviceDriver()	Calls a device driver		X
OS_MPU_GetThreadState()	Returns the privilege state	X	X
OS_MPU_ExtendTaskContext()	Extends the context for MPU registers	X	

Table 18.7: embOS-MPU API functions

18.6.1 OS_MPU_Enable()

Description

Enables embOS-MPU.

Prototype

```
void OS_MPU_Enable(void);
```

Additional Information

This function must be called before any embOS-MPU related function is used or any task is created.

Example

```
void main(void) {
  OS_MPU_Enable();
}
```

18.6.2 OS_MPU_EnableEx()

Description

Enables embOS-MPU and sets the MPU API list.

Prototype

```
void OS_MPU_EnableEx(const OS_MPU_API_LIST* pAPIList);
```

Parameter	Description
pAPIList	Pointer to the MPU API list

Table 18.8: OS_MPU_EnableEx() parameter list

Additional Information

This function must be called before any embOS-MPU related function is used or any task is created.

Example

```
void main(void) {
  OS_MPU_EnableEx(&OS_ARMv7M_MPU_API);
}
```

18.6.3 OS_MPU_ConfigMem()

Description

Configures the device memory regions.

Prototype

```
void OS_MPU_ConfigMem(OS_U32 ROM_BaseAddr,
                      OS_U32 ROM_Size,
                      OS_U32 RAM_BaseAddr,
                      OS_U32 RAM_Size,
                      OS_U32 OS_BaseAddr,
                      OS_U32 OS_Size);
```

Parameter	Description
ROM_BaseAddr	ROM base address
ROM_Size	ROM size
RAM_BaseAddr	RAM base address
RAM_Size	RAM size
OS_BaseAddr	embOS ROM region base address
OS_Size	embOS ROM region size

Table 18.9: OS_MPU_ConfigMem() parameter list

Additional Information

This function must be called before any task is created.

Example

```
void main(void) {
  OS_MPU_ConfigMem(0x08000000u,
                   0x00100000u,
                   0x20000000u,
                   0x00020000u,
                   __os_start__,
                   __os_size__);
}
```

18.6.4 OS_MPU_SetAllowedObjects()

Description

Sets a task specific list of objects to which the task has access via embOS API functions.

Prototype

```
void OS_MPU_SetAllowedObjects(OS_TASK* pTask, const OS_MPU_OBJ* pObjList);
```

Parameter	Description
pTask	Pointer to task control block
pObjList	Pointer to list of allowed objects

Table 18.10: OS_MPU_SetAllowedObjects() parameter list

Additional Information

Per default a task has neither direct nor indirect write access via embOS API functions to any embOS object like a task control block. Even if the object is in the list of allowed objects a direct write access to a control structure is not possible. But if an object is in the list the task can access the object via embOS API functions. This can be e.g. the own task control block, a mailbox control structure which is mutual used by different taks or even the task control block of another task. It is the developer reponsibility to only add objects which are necessary for the unprivileged task.
The list is NULL terminated which means the last entry must always be:
```
{NULL, OS_MPU_OBJTYPE_INVALID}.
```

The following object types exists:

Object type
OS_MPU_OBJTYPE_TASK
OS_MPU_OBJTYPE_RSEMA
OS_MPU_OBJTYPE_RCEMA
OS_MPU_OBJTYPE_EVENT
OS_MPU_OBJTYPE_QUEUE
OS_MPU_OBJTYPE_MAILBOX
OS_MPU_OBJTYPE_SWTIMER
OS_MPU_OBJTYPE_MEMF
OS_MPU_OBJTYPE_TIMING

Table 18.11: embOS-MPU object types

Example

```
static const OS_MPU_OBJ _ObjList[] = {{(OS_U32)&TCBHP, OS_MPU_OBJTYPE_TASK},
                                       {(OS_U32)NULL,   OS_MPU_OBJTYPE_INVALID}};

static void _Unpriv(void) {
  OS_SetTaskName(&TCBHP, "Segger");
  while (1) {
    OS_Delay(10);
  }
}

static void HPTask(void) {
  OS_MPU_SetAllowedObjects(&TCBHP, _ObjList);
  OS_MPU_SwitchToUnprivState();
  _Unpriv();
}
```

18.6.5 OS_MPU_AddRegion()

Description

Adds a memory region to which the task has access.

Prototype

```
void OS_MPU_AddRegion(OS_TASK* pTask,
                      OS_U32   BaseAddr,
                      OS_U32   Size,
                      OS_U32   Permissions);
```

Parameter	Description
pTask	Pointer to a task control block
BaseAddr	Region base address
Size	Region size
Permissions	Access permissions

Table 18.12: OS_MPU_AddRegion() parameter list

Additional Information

A memory region can have the following access permissions:

Permission	Description
OS_MPU_NOACCESS	No access to memory region
OS_MPU_READONLY	Read only access to memory region
OS_MPU_READWRITE	Read and write access to memory region
OS_MPU_EXECUTION_ALLOWED	Code execution is allowed
OS_MPU_EXECUTION_DISALLOWED	Code execution is not allowed

Table 18.13: Region access permissions

Per default an unprivileged task has only access to the following memory regions:

Region	Permission
ROM	Read and execution access for complete ROM
RAM	Read only access for complete RAM
Task stack	Read and write access to the task stack

Table 18.14: Default task memory access permissions

This function can be used if a task needs access to additional RAM regions. This RAM region can be e.g. a LCD frame buffer or a queue data buffer.
It is CPU specific if the region has to be aligned. Pleaser refer to the according CPU/compiler specific embOS manual for more details.

Example

```
static void HPTask(void) {
 OS_MPU_AddRegion(&TCBHP, (OS_U32)MyQBuffer, 512, OS_MPU_READWRITE);
}
```

18.6.6 OS_MPU_SetErrorCallback()

Description

Sets a user callback function which is called when the MPU detects an error.

Prototype

```
void OS_MPU_SetErrorCallback(OS_MPU_ERROR_CALLBACK pFunc);
```

Parameter	Description
pFunc	Pointer callback function

Table 18.15: OS_MPU_SetErrorCallback() parameter list

Additional Information

embOS suspends a task when it detects an invalid access. The internal error function `OS_MPU_Error()` calls the user callback function in order to inform the application. The application can e.g. turn on an error LED or write the fault into a log file. The callback function is called with the following parameter:

Parameter type	Description
OS_TASK*	Pointer to task control block of the unprivileged task which caused the MPU error
OS_MPU_ERRORCODE	Error code which describes the cause for the MPU error

Table 18.16: Callback function parameter list

Example

```
static void _ErrorCallback(OS_TASK* pTask, OS_MPU_ERRORCODE ErrorCode) {
  printf("%s has been stopped due to error %d\n",
         pTask->Name,
         ErrorCode);
}

int main(void) {
  OS_MPU_SetErrorCallback(&_ErrorCallback);
}
```

18.6.6.1 embOS-MPU error codes

Value	Define	Explanation
0	OS_MPU_ERROR_INVALID_RANGE	The object adress is within an allowed task region. This is not allowed. This can e.g. happen when the object was placed on the task stack.
1	OS_MPU_ERROR_INVALID_OBJECT	The unprivileged task is not allowed to access this object.
2	OS_MPU_ERROR_SVC	The supervisor call was not made within an embOS API function. This is not allowed.
3	OS_MPU_ERROR_MEMFAULT	An illegal memory access was performed. A unprivileged task tried to write memory without having the access permission.
4	OS_MPU_ERROR_HARDFAULT	Indicates that the task caused a hardfault.
5	OS_MPU_ERROR_INVALID_API	The unprivileged task tried to call an embOS API function which is not valid for an unprivileged task. For example unprivileged tasks must not call OS_EnterRegion().

Table 18.17: embOS-MPU error codes

18.6.7 OS_MPU_SwitchToUnprivState()

Description

Switches a task to unprivileged state.

Prototype

```
void OS_MPU_SwitchToUnprivState(void)
```

Additional Information

The task code must be splitted into two parts. The first part runs in privileged state and initialzes the embOS MPU settings. The second part runs in unprivileged state and is called after the privileged part switched to the unprivileged state with OS_MPU_SwitchToUnprivState().

Example

```
static void _Unsecure(void) {
  while (1) {
    OS_Delay(10);
  }
}

static void HPTask(void) {
  //
  // Initialization, e.g. add memory regions
  //
  OS_MPU_SwitchToUnprivState();
  _Unsecure();
}
```

18.6.8 OS_MPU_SetDeviceDriverList()

Description

`OS_MPU_SetDeviceDriverList()` sets the device driver list.

Prototype

```
void OS_MPU_SetDeviceDriverList(const OS_MPU_DEVICE_DRIVER_FUNC* pList)
```

Parameter	Description
pList	Pointer to device driver function address list

Table 18.18: OS_MPU_SetDeviceDriverList() parameter list

Additional Information

All device driver function adresses are stored in one list. The last item must be NULL. A device driver is called with the according index to this list.

Example

```
static const OS_MPU_DEVICE_DRIVER_FUNC _DeviceDriverList[] =
{ BSP_LED_DeviceDriver,
  NULL };                      // Last item must be NULL

void BSP_Init(void) {
  OS_MPU_SetDeviceDriverList(_DeviceDriverList);
}
```

18.6.9 OS_MPU_CallDeviceDriver()

Description

`OS_MPU_CallDeviceDriver()` calls the device driver.

Prototype

```
void OS_MPU_CallDeviceDriver(OS_U32 Index, void* Param)
```

Parameter	Description
Index	Device driver function index
Param	Device driver parameter

Table 18.19: OS_MPU_CallDeviceDriver() parameter list

Additional Information

Unprivileged tasks have no direct access to any peripherals. A device driver is instead necessary. `OS_MPU_CallDeviceDriver()` is used to let embOS call the device driver which then runs in privileged state.
Optional parameter can be passed to the driver function.

Example

```
typedef struct BSP_LED_PARAM_STRUCT {
  BSP_LED_DRIVER_API Action;
  OS_U32             Index;
} BSP_LED_PARAM;

static const OS_MPU_DEVICE_DRIVER_FUNC _DeviceDriverList[] =
{ BSP_LED_DeviceDriver,
  NULL };                        // Last item must be NULL


void BSP_LED_DeviceDriver(void* Param) {
  BSP_LED_PARAM* p;
  p = (BSP_LED_PARAM*)Param;
  switch (p->Action) {
    case BSP_LED_SET:
      BSP_SetLED_SVC(p->Index);
      break;
    case BSP_LED_CLR:
      BSP_ClrLED_SVC(p->Index);
      break;
    case BSP_LED_TOGGLE:
      BSP_ToggleLED_SVC(p->Index);
      break;
    default:
      break;
  }
}

void BSP_ToggleLED(int Index) {
  BSP_LED_PARAM p;
  p.Action = BSP_LED_TOGGLE;
  p.Index  = Index;
  OS_MPU_CallDeviceDriver(0u, &p);
}
```

18.6.10 OS_MPU_GetThreadState()

Description

Returns the current privilege task state.

Prototype

```
OS_MPU_THREAD_STATE OS_MPU_GetThreadState(void)
```

Return value

The current privilege task state which can be `OS_MPU_THREAD_STATE_PRIVILEGED` or `OS_MPU_THREAD_STATE_UNPRIVILEGED`.

Additional Information

A new created task has the task state `OS_MPU_THREAD_STATE_PRIVILEGED`.
It can be set to `OS_MPU_THREAD_STATE_UNPRIVILEGED` with the API function `OS_MPU_SwitchToUnprivState()` . A task can never set itself back to the privileged state `OS_MPU_THREAD_STATE_PRIVILEGED`.

18.6.11 OS_MPU_ExtendTaskContext()

Description

Extends the task context for the MPU registers.

Prototype

```
void OS_MPU_ExtendTaskContext(void)
```

Additional Information

It is device dependent how many MPU regions are available. This function makes it possible to use all MPU regions for every single task. Otherwise the tasks would have to share the MPU regions. To do so the MPU register must be saved and restored with every context switch.
This function allows the user to extend the task context for the MPU registers.
A major advanage is that the task extension is task-specific. This means that the additional MPU register needs to be saved only by tasks that actually use these registers. The advantage is that the task switching time of other tasks is not affected. The same is true for the required stack space: Additional stack space is required only for the tasks which actually save the additional MPU registers.
The task context can be extended only once per task. The function must not be called multiple times for one task.
`OS_MPU_ExtendTaskContext()` is not available in the XR libraries.
`OS_SetDefaultContextExtension()` can be used to automatically add MPU register to the task context of every newly created task.

Chapter 19

System tick

This chapter explains the concept of the system tick, generated by a hardware timer and all options available for it.

19.1 Introduction

Typically a hardware timer generates periodic interrupts used as a time base for the OS. The interrupt service routine then calls one of the tick handlers of the OS. embOS offers tick handlers with different functionality as well as a way to call a hook function from within the system tick handler.

Generating timer interrupts

The hardware timer is normally initialized in the `OS_InitHW()` function which is delivered with the BSP. The BSP also includes the interrupt handler which is called by the hardware timer interrupt. This interrupt handler must call one of the embOS system tick handler functions which are explained in this chapter.

19.2   Tick handler

The interrupt service routine used as time base needs to call a tick handler. There are different tick handlers available; one of these need to be called. The reason why there are different tick handlers is simple: They differ in capabilities, code size and execution speed. Most applications use the standard tick handler `OS_TICK_Handle()`, which increments the tick count by one each time it is called. This tick handler is small and efficient, but it cannot handle situations where the interrupt rate differs-from the tick rate. `OS_TICK_HandleEx()` is capable of handling even fractional interrupt rates, such as 1.6 interrupts per tick.

19.2.1   API functions

Routine	Description	main	Task	ISR	Timer
OS_TICK_Handle()	Standard embOS tick handler.			X	
OS_TICK_HandleEx()	Extended embOS tick handler.			X	
OS_TICK_HandleNoHook()	embOS tick handler without hook functionality.			X	
OS_TICK_Config()	Configures the extended embOS tick handler.	X	X		

Table 19.1: API functions

19.2.1.1 OS_TICK_Handle()

Description

The default embOS timer tick handler, called by the hardware timer interrupt handler.

Prototype

```
void OS_TICK_Handle ( void );
```

Additional Information

The embOS tick handler must not be called by the application, it must be called from an interrupt handler.
`OS_EnterInterrupt()` or `OS_EnterNestableInterrupt()` must be called before calling the embOS tick handler

Example

```
/*  Example of a timer interrupt handler */

/*********************************************************************
*
*       OS_ISR_Tick
*/
__interrupt void OS_ISR_Tick(void) {
  OS_EnterNestableInterrupt();
  OS_TICK_Handle();
  OS_LeaveNestableInterrupt();
}
```

19.2.1.2 OS_TICK_HandleEx()

Description

An alternate tick handler which may be used instead of the standard tick handler. It can be used in situations where the basic timer interrupt interval (tick) is a multiple of one ms and the time values used as parameter for delays still should use one ms as the time base.

Prototype

```
void OS_TICK_HandleEx ( void );
```

Additional Information

The embOS tick handler must not be called by the application, it must be called from an interrupt handler. OS_EnterInterrupt() or OS_EnterNestableInterrupt() must be called before calling the embOS tick handler. Refer to *OS_TICK_Config()* on page 343 about how to configure OS_TICK_HandleEx().

Example

```
/*  Example of a timer interrupt handler using OS_HandleTickEx */

/***********************************************************************
*
*       OS_ISR_Tick
*/
__interrupt void OS_ISR_Tick(void) {
  OS_EnterNestableInterrupt();
  OS_TICK_HandleEx();
  OS_LeaveNestableInterrupt();
}
```

Assuming the hardware timer runs at a frequency of 500Hz, thus interrupting the system every 2ms, the embOS tick handler configuration function OS_TICK_Config() should be called as demonstrated in the *Example* section of OS_TICK_Config(). This should be done during OS_InitHW(), before the embOS timer is started.

19.2.1.3 OS_TICK_HandleNoHook()

Description

Speed-optimized embOS timer tick handler without hook function which is typically called by the hardware timer interrupt handler.

Prototype

```
void OS_TICK_HandleNoHook ( void );
```

Additional Information

The embOS tick handler must not be called by the application, it is only called from an interrupt handler.
`OS_EnterInterrupt()` or `OS_EnterNestableInterrupt()` must be called before calling the embOS tick handler

Example

```
/*  Example of a timer interrupt handler */

/**********************************************************************
*
*       OS_ISR_Tick
*/
__interrupt void OS_ISR_Tick(void) {
  OS_EnterNestableInterrupt();
  OS_TICK_HandleNoHook();
  OS_LeaveNestableInterrupt();
}
```

19.2.1.4 OS_TICK_Config()

Description

Configures the tick to interrupt ratio. The "normal" tick handler `OS_TICK_Handle()` assumes a 1:1 ratio, meaning one interrupt increments the tick count (`OS_Time`) by one. For other ratios, `OS_TICK_HandleEx()` needs to be used; the ratio is defined by calling the `OS_TICK_Config()`.

Prototype

```
void OS_TICK_Config ( unsigned FractPerInt, unsigned FractPerTick );
```

Parameter	Description
FractPerInt	Number of Fractions per interrupt
FractPerTick	Number of Fractions per tick

Table 19.2: OS_TICK_Config() parameter list

Additional Information

FractPerInt/FractPerTick = Time between two tick interrupts / Time for one tick

Note that fractional values are supported, such as tick is 1 ms, where an interrupt is generated every 1.6ms. This means that FractPerInt and FractPerTick are:

```
FractPerInt = 16;
FractPerTick = 10;
or
FractPerInt = 8;
FractPerTick = 5;
```

Examples

```
OS_TICK_Config(2, 1);     // 500 Hz interrupts (2 ms), 1 ms tick
OS_TICK_Config(8, 5);     // Interrupts once per 1.6 ms, 1 ms tick
OS_TICK_Config(1, 10);    // 10 kHz interrupts (0.1 ms), 1 ms tick
OS_TICK_Config(1, 1);     // 10 kHz interrupts (0.1 ms), 0.1 ms tick
OS_TICK_Config(1, 100);   // 10 kHz interrupts (0.1 ms), 1 us tick
```

19.3 Hooking into the system tick

There are various situations in which it can be desirable to call a function from the tick handler. Some examples are:

- Watchdog update
- Periodic status check
- Periodic I/O update

The same functionality can be achieved with a high-priority task or a software timer with one-tick period time.

Advantage of using a hook function

Using a hook function is much faster than performing a task switch or activating a software timer because the hook function is directly called from the embOS timer interrupt handler and does not cause a context switch.

19.3.1 API functions

Routine	Description	main	Task	ISR	Timer
OS_TICK_AddHook()	Adds a tick hook handler.	X	X		
OS_TICK_RemoveHook()	Removes a tick hook handler.	X	X		

Table 19.3: API functions

19.3.1.1 OS_TICK_AddHook()

Description

Adds a tick hook handler.

Prototype

```
void OS_TICK_AddHook ( OS_TICK_HOOK *         pHook,
                       OS_TICK_HOOK_ROUTINE * pfUser );
```

Parameter	Description
pHook	Pointer to a structure of OS_TICK_HOOK.
pfUser	Pointer to an OS_TICK_HOOK_ROUTINE function.

Table 19.4: OS_TICK_AddHook() parameter list

Additional Information

The hook function is called directly from the interrupt handler.
The function therefore should execute as quickly as possible.
The function called by the tick hook must not re-enable interrupts.

19.3.1.2 OS_TICK_RemoveHook()

Description

Removes a tick hook handler.

Prototype

```
void OS_TICK_RemoveHook ( const OS_TICK_HOOK * pHook );
```

Parameter	Description
pHook	Pointer to a structure of OS_TICK_HOOK.

Table 19.5: OS_TICK_RemoveHook() parameter list

Additional Information

The function may be called to dynamically remove a tick hook function installed by a call to OS_TICK_AddHook().

19.4 Tickless support

The embOS tickless support stops the periodic system tick interrupt during idle periods. Idle periods are periods of time when there are no tasks and no software timer ready for execution. Stopping the system tick allows the microcontroller to remain in a deep power saving state until an interrupt occurs.

embOS tickless support comes with the three functions OS_GetNumIdleTicks(), OS_AdjustTime() and OS_StartTicklessMode(). They can be used to add tickless support to any embOS start project.

19.4.1 OS_Idle()

In order to use the tickless support the OS_Idle() function needs to be modified. The default OS_Idle() function is just an endless loop which starts a low power mode:

```
void OS_Idle(void) {
  while (1) {
    _EnterLowPowerMode();
  }
}
```

The tickless OS_Idle() function depends on the hardware:

```
void OS_Idle(void) {
  OS_TIME IdleTicks;
  OS_DI();
  IdleTicks = OS_GetNumIdleTicks();
  if (IdleTicks > 1) {
    if ((OS_U32)IdleTicks > TIMER1_MAX_TICKS) {
      IdleTicks = TIMER1_MAX_TICKS;
    }
    OS_StartTicklessMode(IdleTicks, &_EndTicklessMode);
    _SetHWTimer(IdleTicks);
  }
  OS_EI();
  while (1) {
    _EnterLowPowerMode();
  }
}
```

The following description explains the tickless OS_Idle() function step by step:

```
void OS_Idle(void) {
  OS_TIME IdleTicks;
  OS_DI();
```

Interrupts are disabled to avoid a timer interrupt.

```
  IdleTicks = OS_GetNumIdleTicks();
  if (IdleTicks > 1) {
```

The OS_Idle() function reads the idle ticks with OS_GetNumIdleTicks(). The tickless mode is only used when there is more than one idle tick. If there are zero or one idle ticks the scheduler is executed at the next system tick hence it makes no sense to enter the tickless mode.

```
    if ((OS_U32)IdleTicks > TIMER_MAX_TICKS) {
      IdleTicks = TIMER_MAX_TICKS;
    }
```

If it is not possible due to hardware timer limitations to generate the timer interrupt at the specified time the idle ticks can be reduced to any lower value. For example OS_GetNumIdleTicks() returns 200 idle ticks but the hardware timer is limited to 100 ticks. The variable IdleTicks will be set to 100 ticks and the system will wake up after 100 ticks. OS_Idle() will be again executed and OS_GetNumIdleTicks() returns the remaining 100 idle ticks. This means that the system wakes up two times before the complete 200 idle ticks are expired.

```
    if (IdleTicks > 1) {
      ...
      OS_StartTicklessMode(IdleTicks, &_EndTicklessMode);
      _SetHWTimer(IdleTicks);
    }
```

OS_StartTicklessMode() sets the idle ticks and the callback function. The idle ticks information is later used in the callback function. The callback function is described below. _SetHWTimer() is a hardware-dependent function that reprograms the hardware timer to generate a system tick interrupt at the time defined by idle ticks.

```
    OS_EI();
    while (1) {
      _EnterLowPowerMode();
    }
  }
```

Interrupts are reenabled and the CPU continually enters low power mode. _EnterLowPowerMode() is a hardware-dependent function that activates the low power mode.

19.4.2 Callback Function

The callback function calculates how long the processor slept in low power mode and corrects the system time accordingly.

```
static void _EndTicklessMode(void) {
  OS_U32 NumTicks;

  if (OS_Global.TicklessExpired) {
    OS_AdjustTime(OS_Global.TicklessFactor);
  } else {
    NumTicks = _GetLowPowerTicks();
    OS_AdjustTime(NumTicks);
  }
  _SetHWTimer(OS_TIMER_RELOAD);
}
```

The following description explains the callback function step by step:

```
static void _EndTicklessMode(void) {
  OS_U32 NumTicks;

  if (OS_Global.TicklessExpired) {
    OS_AdjustTime(OS_Global.TicklessFactor);
```

If the hardware timer expired and the system tick interrupt was executed the flag OS_Global.TicklessExpired is set. This can be used to determine if the system slept in low power mode for the entire idle time. If this flag is set we can use the value in OS_Global.TicklessFactor to adjust the system time.

```
  } else {
    NumTicks = _GetLowPowerTicks();
    OS_AdjustTime(NumTicks);
  }
```

_GetLowPowerTicks() is a hardware-dependent function which returns the expired idle ticks if the low power mode was interrupted by any other interrupt than the system tick. We use that value to adjust the system time.

```
    _SetHWTimer(OS_TIMER_RELOAD);
  }
```

_SetHWTimer() is a hardware-dependent function which reprograms the hardware timer to its default value for one system tick.

19.4.3 API functions

Routine	Description
OS_GetNumIdleTicks()	Retrieves the number of embOS timer ticks until the next time-scheduled action will be started.
OS_AdjustTime()	Adjusts the embOS internal time.
OS_StartTicklessMode()	Starts the tickless mode.
OS_StopTicklessMode()	Stops the tickless mode.

Table 19.6: API functions

19.4.3.1 OS_GetNumIdleTicks()

Description

Retrieves the number of embOS timer ticks until the next time-scheduled action will be started.

Prototype

```
OS_TIME OS_GetNumIdleTicks(void)
```

Return value

The number of ticks until the next time-scheduled action.

Additional Information

The function may be useful when the embOS timer and CPU shall be halted by the application and restarted after the idle time to save power.
This works when the application has its own time base and a special interrupt that can wake up the CPU.
When the embOS timer is started again the internal time must be adjusted to guarantee time-scheduled actions to be executed. This can be done by a call of `OS_AdjustTime()`.

19.4.3.2 OS_AdjustTime()

Description

This function adjusts the embOS internal time by adding a quantum to the internal time variable.

Prototype

```
void OS_AdjustTicks(OS_TIME Time)
```

Parameter	Description
Time	The amount of time which should be added to the embOS internal time variable.

Table 19.7: OS_AdjsutTime() parameter list

Additional Information

The function may be useful when the embOS timer was halted by the application for a certain known interval of time.
When the embOS timer is started again the internal time must be adjusted to guarantee time-scheduled actions to be executed.

19.4.3.3 OS_StartTicklessMode()

Description

This function may be used to start the tickless mode.

Prototype

```
void OS_StartTicklessMode(OS_TIME Time, voidRoutine *Callback)
```

Parameter	Description
Time	Time in ticks which will be spent in low power mode.
Callback	Callback function to stop the tickless mode.

Table 19.8: OS_StartTicklessMode() parameter list

Additional Information

This function starts the tickless mode. It must be called in OS_Idle() before the CPU enters a low power mode.

The callback function must stop the tickless mode. It must calculate how many system ticks are actually spent in lower power mode and adjust the system time by calling OS_AdjustTime(). It also must reset the system tick timer to it's default tick period.

19.4.3.4 OS_StopTicklessMode()

Description

This function may be used to stop the tickless mode.

Prototype

```
void OS_StopTicklessMode(void)
```

Additional Information

This function stops the tickless mode. It calls the callback function registered when tickless mode was enabled.

19.4.4 Frequently Asked Questions

1. Q: Where can I find more information about tickless support for a specific CPU?
   A: Segger provides Application Notes for tickless support for different CPUs.

2. Q: Can I use embOS without tickless support?
   A: Yes, you can use embOS without tickless support. There is no change required in your project.

3. Q: What hardware-dependent functions must be implemented and where?
   A: OS_Idle() must be modified and the callback function must be implemented. OS_Idle() is part of the RTOSInit.c file. We suggest to implement the callback function in the same file.

4. Q: What triggers the callback function?
   A: The callback function is executed once from the scheduler when the tickless operation ends and normal operation resumes.

Chapter 20

Multi-core support

20.1   Introduction

embOS can be utilized on multi-core processors by running seperate embOS instances on each individual core. For synchronization purposes and in order to exchange data between the cores, embOS includes a comprehensive spinlock API which can be used to control access to shared memory, peripherals, etc.

20.2 Spinlocks

Spinlocks constitute a general purpose locking mechanism in which any process trying to acquire the lock is caused to actively wait until the lock becomes available. To do so, the process trying to acquire the lock remains active and repeatedly checks the availability of the lock in a loop. Effectively, the process will "spin" until it acquires the lock.

Once acquired by a process, spinlocks are usually held by that process until they are explicitly released. If held by one process for longer durations, spinlocks may severely impact the runtime behavior of other processes trying to acquire the same spinlock. Therefore, spinlocks should be held by one process for short periods of time only.

20.2.1 Usage of spinlocks with embOS

embOS spinlocks are intended for inter-core synchronization and communication. They are not intendend for synchronization of individual tasks running on the same core, on which semaphores, queues and mailboxes should be used instead.

However, multitasking still has to be taken into consideration when using embOS spinlocks. Specifically, an embOS task holding a spinlock should not be preempted, for this would prevent that task from releasing the spinlock as fast as possible, which may in return impact the runtime behavior of other cores attempting to acquire the spinlock. Declaration of critical regions therefore is explicitly recommended while holding spinlocks.

embOS spinlocks are usually implemented using hardware instructions specific to one architecture, but a portable software implementation is provided in addition. If appropiate hardware instructions are unavailable for the specific architecture in use, the software implementation is provided exclusively.

It is important to use matching implementations on each core of the multi-core processor that shall access the same spinlock.

For example, a core supporting a hardware implementation may use that implementation to access a spinlock that is shared with another core that supports the same hardware implementation. At the same time, that core may use the software implementation to access a different spinlock that is shared with a different core that does not support the same hardware implementation. However, in case all three cores in this example should share the same spinlock, each of them has to use the software implementation.
To know the spinlock's location in memory, each core's application must declare the appropiate OS_SPINLOCK variable (or OS_SPINLOCK_SW, respectively) at an identical memory address. Initialization of the spinlock, however, must be performed by one core only.

Example of using spinlocks

Two cores of a multi-core processor shall access an hardware peripheral, e.g. a LC display. To avoid situations in which both cores access the LCD simultaneously, access must be restricted through usage of a spinlock: Every time the LCD is used by one core, it must first claim the spinlock through the respective embOS API call. After the LCD has been written to, the spinlock is released by another embOS API call.

Data exchange between cores can be implemented analogously, e.g. through declaration of a buffer in shared memory: Here, every time a core shall write data to the buffer, it must acquire the spinlock first. After the data has been written to the buffer, the spinlock is released. This ensures that neither core can interfere with the writing of data by the other core.

20.2.2 API functions

API routine	Description	main	Task	ISR	Timer
OS_SPINLOCK_Create()	Creates a hardware-specific spinlock. This function is unavailable for some architectures.	X	X		
OS_SPINLOCK_Lock()	Acquires a hardware-specific spinlock. Busy waiting until the spinlock becomes available. This function is unavailable for some architectures.	X	X		
OS_SPINLOCK_Unlock()	Releases a hardware-specific spinlock. This function is unavailable for some architectures.	X	X		
OS_SPINLOCK_SW_Create()	Creates a software-implementation spinlock.	X	X		
OS_SPINLOCK_SW_Lock()	Acquires a software-implementation spinlock. Busy waiting until the spinlock becomes available.	X	X		
OS_SPINLOCK_SW_Unlock()	Releases a software-implementation spinlock.	X	X		

Table 20.1: Spinlock API functions

20.2.2.1 OS_SPINLOCK_Create()

Description

`OS_SPINLOCK_Create()` creates a hardware-specific spinlock.

This function is unavailable for architectures that do not support an appropiate instruction set.

Prototype

`void OS_SPINLOCK_Create(OS_SPINLOCK* pSpinlock);`

Parameter	Description
pSpinlock	Pointer to a variable of type `OS_SPINLOCK` reserved for the management of the spinlock. The variable must reside in shared memory.

Table 20.2: OS_SPINLOCK_Create() parameter list

Additional Information

After creation, the spinlock is not locked.

Example

- Core 0:

```
#include "RTOS.h"

static OS_STACKPTR int Stack[128];                          /* Task stack */
static OS_TASK        TCB;                          /* Task-control-block */
static OS_SPINLOCK    MySpinlock @ ".shared_mem";

static void Task(void) {
  while (1) {
    OS_EnterRegion();                     // Inhibit preemptive task switches
    OS_SPINLOCK_Lock(&MySpinlock);    // Acquire spinlock
    //
    // Perform critical operation
    //
    OS_SPINLOCK_Unlock(&MySpinlock);  // Release spinlock
    OS_LeaveRegion();                     // Re-allow preemptive task switches
  }
}

/***********************************************************************
*
*       main()
*/
int main(void) {
  OS_IncDI();                       /* Initially disable interrupts  */
  OS_InitKern();                    /* Initialize OS                 */
  OS_InitHW();                      /* Initialize Hardware for OS    */
  OS_SPINLOCK_Create(&MySpinlock); /* Initialize Spinlock           */
  /* You need to create at least one task before calling OS_Start() */
  OS_CREATETASK(&TCB, "Task", Task, 100, Stack);
  OS_Start();                       /* Start multitasking            */
  return 0;
}
```

- Core 1:

```
#include "RTOS.h"

static OS_STACKPTR int Stack[128];                          /* Task stack */
static OS_TASK        TCB;                          /* Task-control-block */
static OS_SPINLOCK    MySpinlock @ ".shared_mem";

static void Task(void) {
  while (1) {
    OS_EnterRegion();                     // Inhibit preemptive task switches
    OS_SPINLOCK_Lock(&MySpinlock);    // Acquire spinlock
    //
    // Perform critical operation
    //
    OS_SPINLOCK_Unlock(&MySpinlock);  // Release spinlock
    OS_LeaveRegion();                     // Re-allow preemptive task switches
  }
}

/***********************************************************************
*
*       main()
*/
int main(void) {
  OS_IncDI();                       /* Initially disable interrupts  */
  OS_InitKern();                    /* Initialize OS                 */
  OS_InitHW();                      /* Initialize Hardware for OS    */
  /* You need to create at least one task before calling OS_Start() */
  OS_CREATETASK(&TCB, "Task", Task, 100, Stack);
  OS_Start();                       /* Start multitasking            */
  return 0;
}
```

20.2.2.2 OS_SPINLOCK_Lock()

Description

`OS_SPINLOCK_Lock()` acquires a hardware-specific spinlock. If the spinlock is unavailable, the calling task will not be blocked, but will actively wait until the spinlock becomes available.

This function is unavailable for architectures that do not support an appropiate instruction set.

A task that has acquired a spinlock must not call `OS_SPINLOCK_Lock()` for that spinlock again. The spinlock must first be released by a call to `OS_SPINLOCK_Unlock()`.

Prototype

`void OS_SPINLOCK_Lock(OS_SPINLOCK* pSpinlock);`

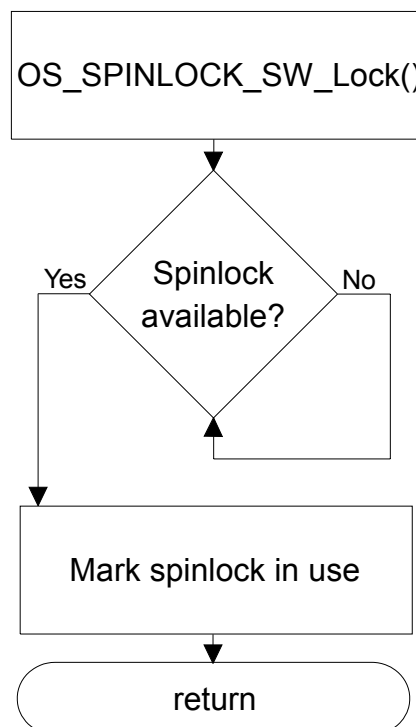| Parameter	Description
pSpinlock	Pointer to a variable of type OS_SPINLOCK reserved for the management of the spinlock.

Table 20.3: OS_SPINLOCK_Lock() parameter list

Additional information

The following diagram illustrates how `OS_SPINLOCK_Lock()` works
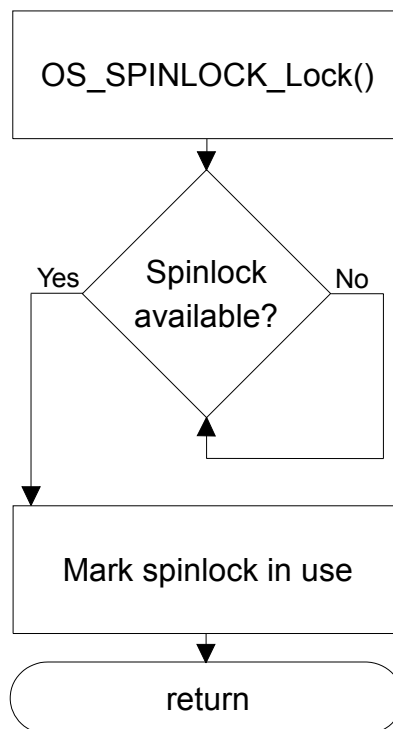
Example

See *Example* on page 360.

20.2.2.3 OS_SPINLOCK_Unlock()

Description

`OS_SPINLOCK_Unlock()` releases a hardware-specific spinlock.

This function is unavailable for architectures that do not support an appropiate instruction set.

Prototype

`void OS_SPINLOCK_Unlock(OS_SPINLOCK* pSpinlock);`

Parameter	Description
pSpinlock	Pointer to a variable of type OS_SPINLOCK reserved for the management of the spinlock.

Table 20.4: OS_SPINLOCK_Unlock() parameter list

Example

See *Example* on page 360.

20.2.2.4 OS_SPINLOCK_SW_Create()

Description

`OS_SPINLOCK_SW_Create()` creates a software-implementation spinlock.

Prototype

```
void OS_SPINLOCK_SW_Create(OS_SPINLOCK_SW* pSpinlock);
```

Parameter	Description
pSpinlock	Pointer to a data structure of type `OS_SPINLOCK_SW` reserved for the management of the spinlock. The variable must reside in shared memory.

Table 20.5: OS_SPINLOCK_SW_Create() parameter list

Additional Information

After creation, the spinlock is not locked.

Example

- Core 0:

```c
#include "RTOS.h"

#define CORE_ID  (0u)

static OS_STACKPTR int Stack[128];                              /* Task stack */
static OS_TASK        TCB;                              /* Task-control-block */
static OS_SPINLOCK_SW  MySpinlock @ ".shared_mem";

static void Task(void) {
  while (1) {
    OS_EnterRegion();                // Inhibit preemptive task switches
    OS_SPINLOCK_SW_Lock(&MySpinlock, CORE_ID);    // Acquire spinlock
    //
    // Perform critical operation
    //
    OS_SPINLOCK_SW_Unlock(&MySpinlock, CORE_ID);  // Release spinlock
    OS_LeaveRegion();                // Re-allow preemptive task switches
  }
}

/**********************************************************************
*
*       main()
*/
int main(void) {
  OS_IncDI();                             /* Initially disable interrupts */
  OS_InitKern();                          /* Initialize OS                */
  OS_InitHW();                            /* Initialize Hardware for OS   */
  OS_SPINLOCK_SW_Create(&MySpinlock); /* Initialize Spinlock         */
  /* You need to create at least one task before calling OS_Start()   */
  OS_CREATETASK(&TCB, "Task", Task, 100, Stack);
  OS_Start();                             /* Start multitasking           */
  return 0;
}
```

- Core 1:

```c
#include "RTOS.h"

#define CORE_ID  (1u)

static OS_STACKPTR int Stack[128];                              /* Task stack */
static OS_TASK        TCB;                              /* Task-control-block */
static OS_SPINLOCK_SW  MySpinlock @ ".shared_mem";

static void Task(void) {
  while (1) {
    OS_EnterRegion();                // Inhibit preemptive task switches
    OS_SPINLOCK_SW_Lock(&MySpinlock, CORE_ID);    // Acquire spinlock
    //
    // Perform critical operation
    //
    OS_SPINLOCK_SW_Unlock(&MySpinlock, CORE_ID);  // Release spinlock
    OS_LeaveRegion();                // Re-allow preemptive task switches
  }
}

/**********************************************************************
*
*       main()
*/
int main(void) {
  OS_IncDI();                             /* Initially disable interrupts */
  OS_InitKern();                          /* Initialize OS                */
  OS_InitHW();                            /* Initialize Hardware for OS   */
  /* You need to create at least one task before calling OS_Start()   */
  OS_CREATETASK(&TCB, "Task", Task, 100, Stack);
  OS_Start();                             /* Start multitasking           */
  return 0;
}
```

20.2.2.5 OS_SPINLOCK_SW_Lock()

Description

`OS_SPINLOCK_SW_Lock()` acquires a software-implementation spinlock. If the spinlock is unavailable, the calling task will not be blocked, but will actively wait until the spinlock becomes available.

A task that has acquired a spinlock must not call `OS_SPINLOCK_SW_Lock()` for that spinlock again. The spinlock must first be released by a call to `OS_SPINLOCK_SW_Unlock()`.

Prototype

```
void OS_SPINLOCK_SW_Lock(OS_SPINLOCK_SW* pSpinlock, OS_UINT Id);
```

Parameter	Description
pSpinlock	Pointer to a data structure of type OS_SPINLOCK_SW reserved for the management of the spinlock.
Id	Unique identifier to specify the core accessing the spinlock. Valid values are 0 <= Id < OS_SPINLOCK_MAX_CORES. By default, OS_SPINLOCK_MAX_CORES is defined to 4 and may be changed when using source code. An embOS debug build calls OS_Error() in case invalid values are used.

Table 20.6: OS_SPINLOCK_SW_Lock() parameter list

Additional information

`OS_SPINLOCK_SW_Lock()` implements Lamport's bakery algorithm, published by Leslie Lamport in "Communications of the Association for Computing Machinery", 1974, Volume 17, Number 8. An excerpt is publicly available at research.microsoft.com.

The following diagram illustrates how `OS_SPINLOCK_SW_Lock()` works

Example

See *Example* on page 364.

20.2.2.6 OS_SPINLOCK_SW_Unlock()

Description

`OS_SPINLOCK_SW_Unlock()` releases a software-implementation spinlock.

Prototype

```
void OS_SPINLOCK_SW_Unlock(OS_SPINLOCK_SW* pSpinlock, OS_UINT Id);
```

Parameter	Description
pSpinlock	Pointer to a data structure of type `OS_SPINLOCK_SW` reserved for the management of the spinlock.
Id	Unique identifier to specify the core accessing the spinlock. Valid values are 0 <= `Id` < OS_SPINLOCK_MAX_CORES. By default, OS_SPINLOCK_MAX_CORES is defined to 4 and may be changed when using source code. An embOS debug build calls OS_Error() in case invalid values are used.

Table 20.7: OS_SPINLOCK_SW_Unlock() parameter list

Example

See *Example* on page 364.

Chapter 21

Low power support

This chapter describes embOS low power support.

21.1 Introduction

The embOS low power support is used to determine if a peripheral's clock or its power supply can be switched off to save power. If a peripheral gets initialized the call of `OS_POWER_UsageInc()` increments a specific entry in the power management counter to signal that it is in use. The power management counter is an array with entries for each clock or power supply depending on the hardware. After a peripheral is no longer in use `OS_POWER_UsageDec()` is called to decrement this counter.
In `OS_Idle()` a call of `OS_POWER_GetMask()` generates a bit mask which describes which clock or power supply is in use.

embOS low power support offers three functions: `OS_POWER_GetMask()`, `OS_POWER_UsageInc()` and `OS_POWER_UsageDec()`. These functions can be used to add low power support to any embOS start project.

For additional power saving related routines refer to *Tickless support* on page 347.

21.2 API functions

Routine	Description
`OS_POWER_GetMask()`	Generate a bit mask to determine which peripheral is in use.
`OS_POWER_UsageInc()`	Increments power management counters.
`OS_POWER_UsageDec()`	Decrements power management counters.

Table 21.1: API functions

21.2.1 OS_POWER_GetMask()

Description

This function retrieves the power management counter.

Prototype

```
OS_UINT OS_POWER_GetMask(void)
```

Return value

A bit mask which describes whether a peripheral is in use or not.

Additional Information

This function generates a bit mask from the power management counter it retrieves. The bit mask describes which peripheral is in use and which one can be turned off. Switching off a peripheral can be done by writing this mask into the specific register. Please refer to the *Example* on page 372 for additional information.

21.2.2 OS_POWER_UsageDec()

Description

`OS_POWER_UsageDec()` decrements the power management counter.

Prototype

`void OS_POWER_UsageDec(OS_UINT Index)`

Parameter	Description
Index	A mask with bits set for counters which should be updated.

Table 21.2: OS_POWER_UsageDec() parameter list

Additional Information

When a peripheral is no longer in use this function is called to mark the peripheral as unused and signal that it can be switched off.

21.2.3 OS_POWER_UsageInc()

Description

This function increments the power management counter.

Prototype

```
void OS_POWER_UsageInc(OS_UINT Index)
```

Parameter	Description
Index	A mask with bits set for counters which should be updated.

Table 21.3: OS_POWER_UsageInc() parameter list

Additional Information

When a peripheral is in use this function is called to mark the peripheral as in use.

21.2.4 Example

This is an example for the low power support usage, since it depends on the used hardware it is fictional.

These are core specific defines for power handling. For this example A, B and C is used for fictional peripherals.

```
#define OS_POWER_USE_A   (1 << 0) // peripheral "A"
#define OS_POWER_USE_B   (1 << 1) // peripheral "B"
#define OS_POWER_USE_C   (1 << 2) // peripheral "C"
#define OS_POWER_USE_ALL (OS_POWER_USE_A | OS_POWER_USE_B | OS_POWER_USE_C)
```

In the following function the peripherals A and C have been initialized and getting marked as used by the call of OS_POWER_UsageInc(). By that call a specific entry in the power management counter for the clock used by the peripheral gets incremented.

```
void _InitAC(void) {
  ...
  OS_POWER_UsageInc(OS_POWER_USE_A); // Mark "A" as used
  OS_POWER_UsageInc(OS_POWER_USE_C); // Mark "C" as used
  ...
}
```

After something has been done, C will not be used any longer and gets marked as not used. This is done by the call of OS_POWER_UsageDec() which decrements the entry in the power management counter.

```
void _SomeThingIsDone(void) {
  ...
  OS_POWER_UsageDec(OS_POWER_USE_C); // Mark "C" as unused
  ...
}
```

While in OS_Idle() a call of OS_POWER_GetMask() generates a bit mask from the power management counter. Afterwards a control register is stored and all bits corresponding to OS_POWER_USE getting cleared. Next the previously stored bits are written back into the control register with only those bits set for used peripherals.

```
void OS_Idle(void) { // Idle loop: No task is ready to exec
  OS_UINT PowerMask;
  OS_U16  ClkControl;

  OS_DI();
  //
  // Examine which peripherals may be switched off
  //
  PowerMask  = OS_POWER_GetMask();
  //
  //  Store the content of CTRLREG and clear all OS_POWER_USE related bits
  //
  ClkControl  = CTRLREG & ~OS_POWER_USE_ALL;
  //
  //  Set only bits for used peripherals and write them to the specific register
  //  In this case only "A" is marked as used, so "C" gets switched off
  //
  CTRLREG     = ClkControl | PowerMask;
  for (;;) {
    _do_nothing();
  };
}
```

21.3 STOP / WAIT Mode

In case your controller supports some kind of power saving mode, it is possible to use it also with embOS. To enter that mode, you usually have to implement some special sequence in the function `OS_Idle()`, which you can find in embOS module `RTOSInit.c`.

For example with Cortex M CPUs per default, the `wfi` instruction is executed in `OS_Idle()` to put the CPU into a low power mode:

```
void OS_Idle(void) { // Idle loop: No task is ready to execute
  while (1) {
    #if (DEBUG == 0) // Enter CPU halt mode when not in DEBUG
    __asm(" wfi");
    #endif
  }
}
```

Chapter 22

Configuration of target system (BSP)

This chapter explains the target system specific parts of embOS, also called a BSP (board support package).

If the software is up and running on your target system, there is no need to read this chapter.

22.1 Introduction

In general, you do not need to configure anything to get started with embOS. The start project supplied will execute on your system. Small changes in the configuration will be necessary at a later point for system frequency or for the UART used for communication with the optional embOSView.

The file `RTOSInit.c` is provided in source code and can be modified to match your target hardware needs. It is compiled and linked with your application program.

22.2 Hardware-specific routines

Routine	Description	main	Task	ISR	Timer
Required for embOS					
OS_InitHW()	Initializes the hardware timer used for generating interrupts. embOS needs a timer interrupt to determine when to activate tasks that wait for the expiration of a delay, when to call a software timer, and to keep the time variable up-to-date.	X			
OS_Idle()	The idle loop is always executed whenever no other task (and no interrupt service routine) is ready for execution.				
OS_ISR_Tick()	The embOS timer interrupt handler. When using a different timer, always check the specified interrupt vector.				
OS_ConvertCycles2us()	Converts cycles into µs (used with profiling only).	X	X	X	X
OS_GetTime_Cycles()	Reads the timestamp in cycles. Cycle length depends on the system. This function is used for system information sent to embOSView.				
Optional for run-time embOSView					
OS_COM_Init()	Initializes communication for embOSView (used with embOSView only).	X			
OS_ISR_rx()	Rx Interrupt service handler for embOSView (used with embOSView only).				
OS_ISR_tx()	Tx Interrupt service handler for embOSView (used with embOSView only).				
OS_COM_Send1()	Send one byte via a UART (used with embOSView only). Do not call this function from your application.				

Table 22.1: Hardware specific routines

22.2.1 OS_Idle()

The embOS function OS_Idle() is called when no task is ready for execution.
The function OS_Idle() is part of the target CPU specific RTOSInit.c file delivered with embOS.
Normally it is programmed as an endless loop without any functionality.
In most embOS ports, it activates a power saving sleep mode of the target CPU.

The embOS OS_Idle() function is not a task, it has no task context and does not have its own stack. Instead it runs on the system's C stack, which is also used for the kernel.
Exceptions and interrupts that occur during OS_Idle() return into OS_Idle() if they didn't trigger a task switch, and the code is continued where it was interrupted.

When a task switch occurs during the execution of OS_Idle(), the OS_Idle() function is interrupted and does not continue execution when it is activated again.
When OS_Idle() is activated, it always starts from the beginning. Interrupted code is not continued.

You might create your own idle task running as an endless loop with the lowest task priority in the system.
When you don't call any blocking or suspending function in this idle task, you will never enter OS_Idle().

You might alternatively use `OS_EnterRegion()` and `OS_LeaveRegion()` to avoid task switches during the execution of any functionality in `OS_Idle()`.

Running in a critical region does not block interrupts, but disables task switches until `OS_LeaveRegion()` is called.

Using a critical region during `OS_Idle()` will affect task activation time, but will not affect interrupt latency.

22.3 Configuration defines

For most embedded systems, configuration is done by simply modifying the following defines, located at the top of the `RTOSInit.c` file:

Define	Description
OS_FSYS	System frequency (in Hz). Example: 20000000 for 20MHz.
OS_UART	Selection of UART to be used with embOSView (-1 will disable communication),
OS_BAUDRATE	Selection of baudrate for communication with embOSView.

Table 22.2: Configuration defines overview

22.4   How to change settings

The only file which you may need to change is `RTOSInit.c`. This file contains all hardware-specific routines. The one exception is that some ports of embOS require an additional interrupt vector table file (details can be found in the *CPU & Compiler Specifics manual* of embOS documentation).

22.4.1   Setting the system frequency OS_FSYS

Relevant defines

`OS_FSYS`

Relevant routines

`OS_ConvertCycles2us()` (used with profiling only)

For most systems it should be sufficient to change the `OS_FSYS` define at the top of `RTOSInit.c`. When using profiling, certain values may require a change in `OS_ConvertCycles2us()`. The `RTOSInit.c` file contains more information about in which cases this is necessary and what needs to be done.

22.4.2   Using a different timer to generate tick interrupts for embOS

Relevant routines

`OS_InitHW()`

embOS usually generates one interrupt per ms, making the timer interrupt, or tick, normally equal to 1 ms. This is done by a timer initialized in the routine `OS_InitHW()`. If you want to use a different timer for your application, you must modify `OS_InitHW()` to initialize the appropriate timer. For details about initialization, read the comments in `RTOSInit.c`.

22.4.3   Using a different UART or baudrate for embOSView

Relevant defines

`OS_UART`
`OS_BAUDRATE`

Relevant routines:

`OS_COM_Init()`
`OS_COM_Send1()`
`OS_ISR_rx()`
`OS_ISR_tx()`

In some cases, this is done by simply changing the define `OS_UART`. Refer to the contents of the `RTOSInit.c` file for more information about which UARTS that are supported for your CPU.

22.4.4   Changing the tick frequency

Relevant defines

`OS_FSYS`

As noted above, embOS usually generates one interrupt per ms. `OS_FSYS` defines the clock frequency of your system in Hz (times per second). The value of `OS_FSYS` is used for calculating the desired reload counter value for the system timer for 1000 interrupts/sec. The interrupt frequency is therefore normally 1 kHz.

Different (lower or higher) interrupt rates are possible. If you choose an interrupt frequency different from 1 kHz, the value of the time variable `OS_Time` will no longer be equivalent to multiples of 1 ms. However, if you use a multiple of 1 ms as tick

time, the basic time unit can be made 1 ms by using the function OS_TICK_Config(). The basic time unit does not need to be 1 ms; it might just as well be 100 µs or 10 ms or any other value. For most applications, 1 ms is an appropriate value.

22.5 STOP / HALT / IDLE modes

Most CPUs support power-saving STOP, HALT, or IDLE modes. Using these types of modes is one possible way to reduce power consumption during idle times. As long as the timer interrupt wakes the system with every embOS tick, or as long as other interrupts will activate tasks, these modes may be used for reducing power consumption.

If required, you may modify the `OS_Idle()` routine, which is part of the hardware-dependant module `RTOSInit.c`, to switch the CPU to power-saving mode during idle times. Refer to the *CPU & Compiler Specifics manual* of embOS documentation for details about your processor.

Chapter 23

Profiling

This chapter explains the profiling functions that can be used by an application.

23.1 API functions

Routine	Description	main	Task	ISR	Timer
OS_STAT_Sample()	Starts a new task cpu load measurement.	X	X	X	X
OS_STAT_GetLoad()	Returns the task-specific cpu load.	X	X	X	X
OS_AddLoadMeasurement()	Adds total CPU load measurement functionality.	X	X		
OS_GetLoadMeasurement()	Returns the total CPU load.	X	X	X	X
OS_STAT_Enable()	Enables profiling	X	X	X	X
OS_STAT_Disable()	Disables profiling	X	X	X	X
OS_STAT_GetTaskExecTime()	Returns the total task execution time	X	X	X	X

Table 23.1: Profiling API functions

23.1.1 OS_STAT_Sample()

Description

`OS_STAT_Sample()` starts profiling and calculates the absolute task run time since the last call to OS_STAT_Sample().

Prototype

```
void OS_STAT_Sample ( void );
```

Additional Information

`OS_STAT_Sample()` starts the profiling for five seconds, the next call to `OS_STAT_Sample()` must be within this five seconds. Please use the embOS function `OS_STAT_GetLoad()` to get the task-specific cpu load in permille.

`OS_STAT_Sample()` cannot be used from multiple tasks simultaneously because it uses a global variable.

23.1.2 OS_STAT_GetLoad()

Description

`OS_STAT_GetLoad()` calculates the current tasks cpu load in permille.

Prototype

```
int OS_STAT_GetLoad(OS_TASK * pTask);
```

Parameter	Description
pTask	Pointer to task control block

Table 23.2: OS_STAT_GetLoad() parameter list

Return value

`OS_STAT_GetLoad()` returns the current tasks cpu load in permille.

Additional Information

`OS_STAT_GetLoad()` requires that `OS_STAT_Sample()` is called periodically.

`OS_STAT_GetLoad()` cannot be used from multiple tasks simultaneously because it uses a global variable.

23.1.3 Sample application for OS_STAT_Sample() and OS_STAT_GetLoad()

```c
#include "RTOS.h"
#include "stdio.h"

OS_STACKPTR int StackHP[128], StackLP[128], StackMP[128]; /* Task stacks */
OS_TASK TCBHP, TCBLP, TCBMP;                        /* Task-control-blocks */

static void HPTask(void) {
  int r;
  while (1) {
    OS_Delay (1000);
    OS_STAT_Sample();
    r = OS_STAT_GetLoad(&TCBMP);
    printf("CPU Usage of MP Task: %d\n", r);
  }
}

static void MPTask(void) {
  while (1) {
  }
}

static void LPTask(void) {
  while (1) {
  }
}


int main(void) {
  OS_IncDI();                       /* Initially disable interrupts  */
  OS_InitKern();                    /* Initialize OS                 */
  OS_InitHW();                      /* Initialize Hardware for OS    */
  /* You need to create at least one task before calling OS_Start() */
  OS_CREATETASK(&TCBHP, "HP Task", HPTask, 100, StackHP);
  OS_CREATETASK(&TCBMP, "MP Task", MPTask,  50, StackMP);
  OS_CREATETASK(&TCBLP, "LP Task", LPTask,  50, StackLP);
  OS_Start();                       /* Start multitasking            */
  return 0;
}
```

Output:
```
500
499
501
500
500
...
```

23.1.4 OS_AddLoadMeasurement()

Description

`OS_AddLoadMeasurement()` may be used to start calculation of the total CPU load of an application.

Prototype

```
void OS_AddLoadMeasurement(int Period,
                           OS_U8 AutoAdjust,
                           int DefaultMaxValue);
```

Parameter	Description
Period	Period for measurement in embOS timer ticks
AutoAdjust	When nonzero, the measurement is autoadjusted once initially.
DefaultMaxValue	May be used to set a default counter value when AutoAdjust is not used. (See additional information)

Table 23.3: OS_STAT_GetLoad() parameter list

Additional Information

`OS_AddLoadMeasurement()` creates a task running at highest priority. The task suspends itself periodically by calling `OS_Delay(Period)`. When the task is resumed after the delay, it calculates the CPU load by comparison of two counter values.
The CPU load is the percentage not spent in `OS_Idle()`.
For the calculation, it is required that `OS_Idle()` is called.
`OS_Idle()` must increment a counter by calling `OS_INC_IDLE_CNT();`
The maximum value of this counter is stored and is compared against the current value of the counter, every time the measurement task is activated.
It is assumed that the maximum value of the counter represents a CPU load of zero, all time spent in `OS_Idle()`.
When AutoAdjust is set, the task will initially suspend all other tasks for the Period-time and than call `OS_Delay(Period)`. This way, the entire period is spent in `OS_Idle()` and the counter incremented in `OS_Idle()` reaches its maximum value initially.
If this behavior is not wanted, because it blocks all tasks for the Period-time once initially, the maximum value for the counter may be examined once and then be set by the parameter `DefaultMaxValue` with `AutoAdjust` disabled.
The value for `DefaultMaxValue` can be examined once from one task before any other tasks are created:

```
void MainTask(void) {
  OS_I32 DefaultMax;
  OS_Delay(100);
  DefaultMax = OS_IdleCnt;  /* This value can be used as DefaultMaxValue. */
  /* Now other tasks can be created and started. */
```

The calculation does not work when `OS_Idle()` puts the CPU in Low-power (Stop) mode.

`OS_Idle()` must have a form similar to:

```
void OS_Idle(void) {  /* Idle loop: No task is ready to execute */
  while (1) {
    OS_INC_IDLE_CNT();
  }
}
```

23.1.5 OS_GetLoadMeasurement()

Description

`Retrieves` the result of the CPU load measurement.

Prototype

`int OS_GetLoadMeasurement(void)`

Return value

Returns the total CPU load in percent.

Additional Information

`OS_GetLoadMeasurement()` delivers correct results when the CPU load measurement was started by calling `OS_AddLoadMeasurement()` with auot-adjustment before, and `OS_Idle()` updates the measurement by calling `OS_INC_IDLE_CNT()`.

The calculation does not work when `OS_Idle()` puts the CPU in low-power (Stop) mode.

`OS_Idle()` must have a form similar to:

```
void OS_Idle(void) {   /* Idle loop: No task is ready to execute */
  while (1) {
    OS_INC_IDLE_CNT();
  }
}
```

23.1.6 OS_CPU_Load

Description

This global variable shows the total CPU load in percent. It may be useful to show the variable in a debugger with live-watch capability during development.

Declaration

```
volatile OS_INT OS_CPU_Load;
```

Additional Information

This variable may not exist. It will not contain correct results unless the CPU load measurement was started by a call of `OS_AddLoadMeasurement()`.
As an additional condition embOS must be running and `OS_Idle()` must call `OS_INC_IDLE_CNT()` to update the CPU load measurement.

23.1.7 OS_STAT_Enable()

Description

`OS_STAT_Enable()` may be used to start the profiling for an infinite time.

Prototype

```
void OS_STAT_Enable(void);
```

Additional Information

The profiling is started and does not disable itself after 5 seconds. The function `OS_STAT_Disable()` may be used to cancel profiling.

23.1.8 OS_STAT_Disable()

Description

`OS_STAT_Disable()` may be used to cancel profiling.

Prototype

`void OS_STAT_Disable(void);`

Additional Information

The function `OS_STAT_Enable()` may be used to start the profiling.

23.1.9 OS_STAT_GetTaskExecTime()

Description

Returns the total task execution time.

Prototype

```
OS_U32 OS_STAT_GetTaskExecTime(const OS_TASK *pTask);
```

Parameter	Description
pTask	Pointer to a task control block.

Return value

Returns the total task execution time.

Additional Information

This function only returns valid values when the profiling is enabled before with OS_STAT_Enable(). If pTask is the NULL pointer, the function returns the total task execution time of the currently running task. If pTask does not specify a valid task, a debug build of embOS calls OS_Error(). A release build of embOS cannot check the validity of pTask and may therefore return invalid values if pTask does not specify a valid task.

Example

```
OS_U32 ExecTime;
void MyTask(void) {
  OS_STAT_Enable();
  while (1) {
    ExecTime = OS_STAT_GetTaskExecTime(NULL);
    OS_Delay(100);
  }
}
```

Chapter 24

embOSView: Profiling and analyzing

24.1 Overview

embOSView displays the state of a running application using embOS. A serial interface (UART) is normally used for communication with the target. But there are also other communication channels like ethernet or memory read/write for Cortex-M and RX CPUs or DCC for ARM7/9 or Cortex A CPUs. The hardware-dependent routines and defines available for communication with embOSView are located in RTOSInit.c. This file must be configured properly. For details on how to configure this file, refer the *CPU & Compiler Specifics manual* of the embOS documentation. The embOSView utility is shipped as embOSView.exe with embOS and runs under Windows 9x / NT / 2000 / Vista and Windows 7/8/10.
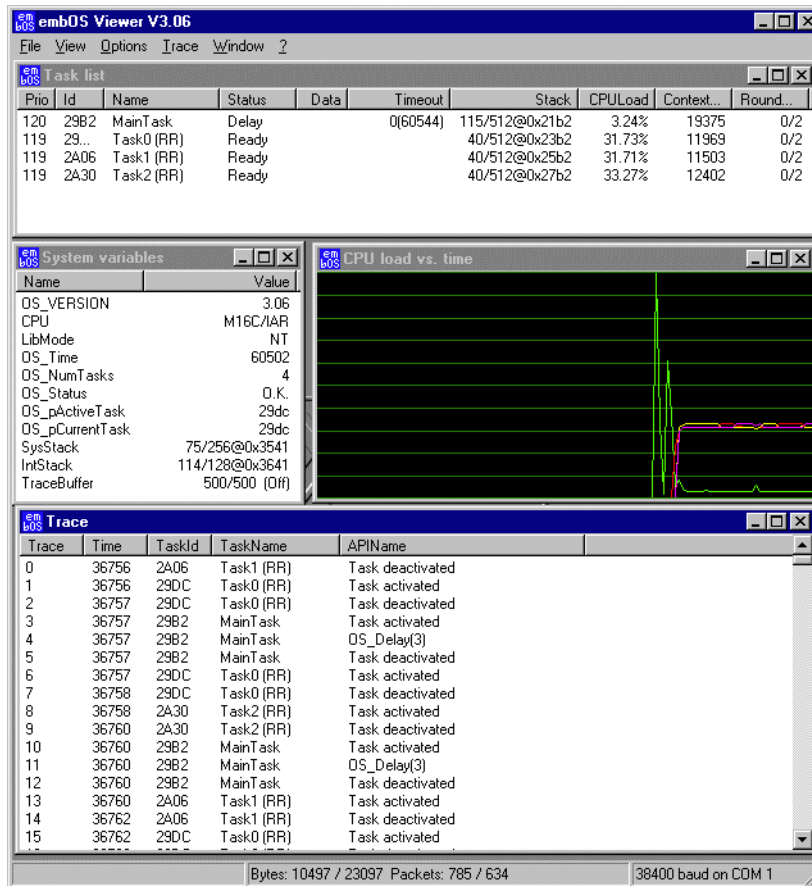
embOSView is a very helpful tool for analysis of the running target application.

The CPU load feature assumes that an embOS library with profiling feature is used, e.g. "stack-check plus profiling", "debug plus profiling" or "debug including trace plus profiling".

Name	Description
SP	Stack-checking plus profiling
DP	Debug plus profiling
DT	Debug including trace plus profiling

Table 24.1: embOS libraries with support for profiling used for CPU load

24.2 Task list window

embOSView shows the state of every task created by the target application in the **Task list window**. The information shown depends on the library used in your application.

Item	Description	Builds
Prio	Current priority of task.	All
Id	Task ID, which is the address of the task control block.	All
Name	Name assigned during creation.	All
Status	Current state of task (ready, executing, delay, reason for suspension).	All
Data	Depends on status.	All
Timeout	Time of next activation.	All
Stack	Used stack size/max. stack size/stack location.	S, SP, D, DP, DT
CPULoad	Percentage CPU load caused by task.	SP, DP, DT
Run Count	Number of activations since reset.	SP, DP, DT
Time slice	Round robin time slice	All

Table 24.2: Task list window overview

The **Task list window** is helpful in analysis of stack usage and CPU load for every running task.

24.3 System variables window

embOSView shows the state of major system variables in the **System variables window**. The information shown also depends on the library used by your application:

Item	Description	Builds
OS_VERSION	Current version of embOS.	All
CPU	Target CPU and compiler.	All
LibMode	Library mode used for target application.	All
OS_Time	Current system time in timer ticks.	All
OS_NumTasks	Current number of defined tasks.	All
OS_Status	Current error code (or O.K.).	All
OS_pActiveTask	Active task that should be running.	SP, D, DP, DT
OS_pCurrentTask	Actual currently running task.	SP, D, DP, DT
SysStack	Used size/max. size/location of system stack.	SP, DP, DT
IntStack	Used size/max. size/location of interrupt stack.	SP, DP, DT
TraceBuffer	Current count/maximum size and current state of trace buffer.	All trace builds

Table 24.3: System variables window overview

24.4 Sharing the SIO for terminal I/O

The serial input/output (SIO) used by embOSView may also be used by the application at the same time for both input and output. Terminal input is often used as keyboard input, where terminal output may be used for outputting debug messages. Input and output is done via the **Terminal window**, which can be shown by selecting **View/Terminal** from the menu.

To ensure communication via the **Terminal window** in parallel with the viewer functions, the application uses the function `OS_SendString()` for sending a string to the **Terminal window** and the function `OS_SetRxCallback()` to hook a reception-routine that receives one byte.

24.5   API functions

Routine	Description	main	Task	ISR	Timer
OS_SendString()	Sends a string over SIO to the **Terminal window**.	X	X		
OS_SetRxCallback()	Sets a callback hook to a routine for receiving one character.	X	X		X

Table 24.4: Shared SIO API functions

24.5.1 OS_SendString()

Description

Sends a string over SIO to the embOSView terminal window.

Prototype

```
void OS_SendString (const char* s);
```

Parameter	Description
s	Pointer to a zero-terminated string that should be sent to the **Terminal window**.

Table 24.5: OS_SendString() parameter list

Additional Information

This function uses `OS_COM_Send1()` which is defined in `RTOSInit.c`.

24.5.2 OS_SetRxCallback()

Description

Sets a callback hook to a routine for receiving one character.

Prototype

```
typedef void OS_RX_CALLBACK (OS_U8 Data);
OS_RX_CALLBACK* OS_SetRxCallback (OS_RX_CALLBACK* cb);
```

Parameter	Description
cb	Pointer to the application routine that should be called when one character is received over the serial interface.

Table 24.6: OS_SetRxCallback() parameter list

Return value

`OS_RX_CALLBACK*` as described above. This is the pointer to the callback function that was hooked before the call.

Additional Information

The user function is called from embOS. The received character is passed as parameter. See the example below.

Example

```
void GUI_X_OnRx(OS_U8 Data); /* Callback ... called from Rx-interrupt */

void GUI_X_Init(void) {
  OS_SetRxCallback(&GUI_X_OnRx);
}
```

24.6 Enable communication to embOSView

The communication to embOSView can be enabled by the compile time switch *OS_VIEW_ENABLE* which may be defined in the project settings or in the configuration file *OS_Config.h*.

If *OS_VIEW_ENABLE* is defined unequal to 0, the communication is enabled. In the *RTOSInit* files the *OS_VIEW_ENABLE* switch is set to 1 if not defined as project option.

The OS_Config.h file sets the compile time switch *OS_VIEW_ENABLE* to 0 when DEBUG is defined as 0.

Therefore, in the embOS start projects, the communication is enabled per default when using the *Debug* configurations, and is disabled when using the *Release* configurations.

24.7 Select the communication channel in the start project

When the communication to embOSView is enabled by setting the compile time switch *OS_VIEW_ENABLE*, the communication can be handled via UART, the memory based communication channel or DCC using J-Link.

24.7.1 Select a UART for communication

Set the compile time switch *OS_VIEW_USE_UART* unequal to 0 by project option/ compiler preprocessor or in RTOSInit.c to switch the communication from J-Link to UART.

In the RTOSInit files delivered with embOS, this switch is set to 0 if not defined by compiler preprocessor/project option.

OS_VIEW_ENABLE has to be set unequal to 0 to enable communication.

24.7.2 Select J-Link for communication

Per default, J-Link is selected as communication device in most embOS start projects, if available. The compile time switch *OS_VIEW_USE_UART* is predefined to 0 in the CPU specific RTOSInit files, thus the J-Link communication is selected when not overwritten by project / compiler preprocessor options.

OS_VIEW_ENABLE has to be set unequal to 0 to enable communication.

24.7.3 Select Ethernet for communication

Set the compile time switch *OS_VIEW_ETHERNET* unequal to 0 by project option/ compiler preprocessor or in RTOSInit.c to switch the communication to Ethernet. This communication mode is only available when embOS/IP is included in the project.

24.8 Setup embOSView for communication

When the communication to embOSView is enabled in the target application, embOS-View can be used to analyze the running application. The communication channel of embOSView has to be setup according the communication channel which was selected in the project.

24.8.1 Select a UART for communication

Start embOSView and chose menu Setup:
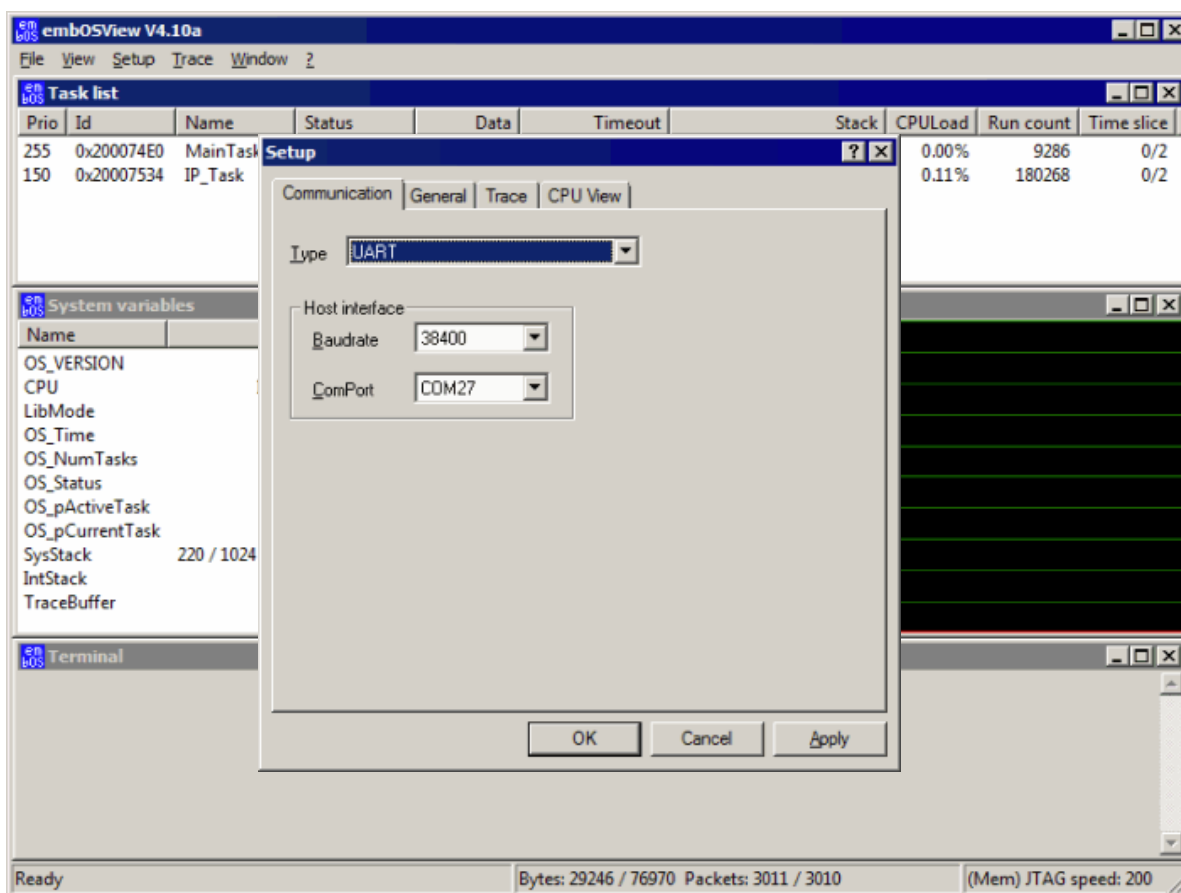
In the Communication TAB choose UART in the Type selection listbox.
In the Host interface box select the Baudrate for communication and the COM port of the PC which should be connected to the target board.
The default baudrate of all projects is 38400 kBaud. The COM port list box lists all COM ports of the PC which are currently available.
The serial communication via UART is available in the target application if the project was compiled with the settings *OS_VIEW_USE_UART* unequal to 0 and *OS_VIEW_ENABLE* set unequal to 0.
The serial communication will work when the target is running stand alone or during a debug session, when the target is connected to the Debugger.
The serial connection can be used when the target board has a spare UART port and the OS_UART functions are enabled and included in the application.

24.8.2 Select J-Link for communication

embOS supports communication channel to embOSView which uses J-Link to communicate with the running application. embOSView version 3.82g or higher and a J-Link-DLL is required to use a J-Link for communication.

To select this communication channel, start embOSView and open the Setup menu:
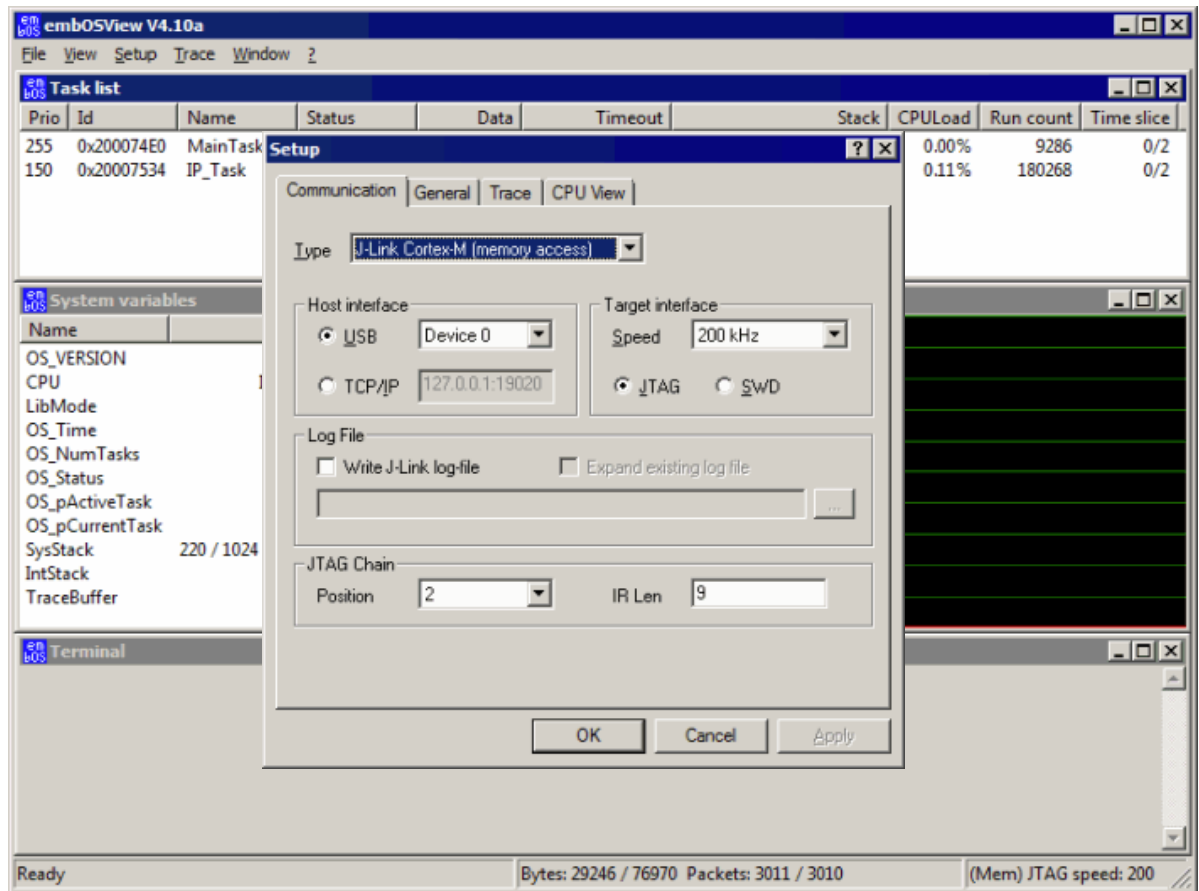
In the Communication TAB choose J-Link Cortex-M (memory access) ,J-Link RX (memory access) or J-Link ARM7/9/11 (DCC) in the Type selection listbox.

In the Host interface box select the USB or TCP/IP channel which is used to communicate to your J-Link.

In the Target interface box select the communication speed of the target interface and the physical target connection, which may be a JTAG, SWD or FINE connection.

In the Log File box choose whether a log file should be created and define its file name and location in case it should.

The JTAG Chain box allows the selection of a specific device in a JTAG scan chain with multiple devices. Currently, up to eight devices in the scan chain are supported. Two values must be configured: the position of the target device in the scan chain and the total number of bits in the instruction registers of the devices before the target device (IR len). Target position is numbered in descending order, which means the target that is closest to the J-Link's `TDI` is in the highest position (max. 7), while the target closest to the J-Link's `TDO` is in the lowest position, which is always 0. Upon selecting the position, the according IR len is determined automatically, which should succeed for most target decives. IR len can also be written manually, which is mandatory in case automatic detection was not successfull. For further information, please refer to the *J-Link / J-Trace User Guide (UM08001, Chapter 5.3 "JTAG interface"*).

Communication via J-Link is available in the target application if the project was compiled with the settings *OS_VIEW_USE_UART* equal to 0 and *OS_VIEW_ENABLE* set unequal to 0.

24.8.3 Select Ethernet for communication

embOS supports communication channel to embOSView which uses Ethernet to communicate with the running application. embOS/IP is required to use Ethernet for communication.

To select this communication channel, start embOSView and open the Setup menu:
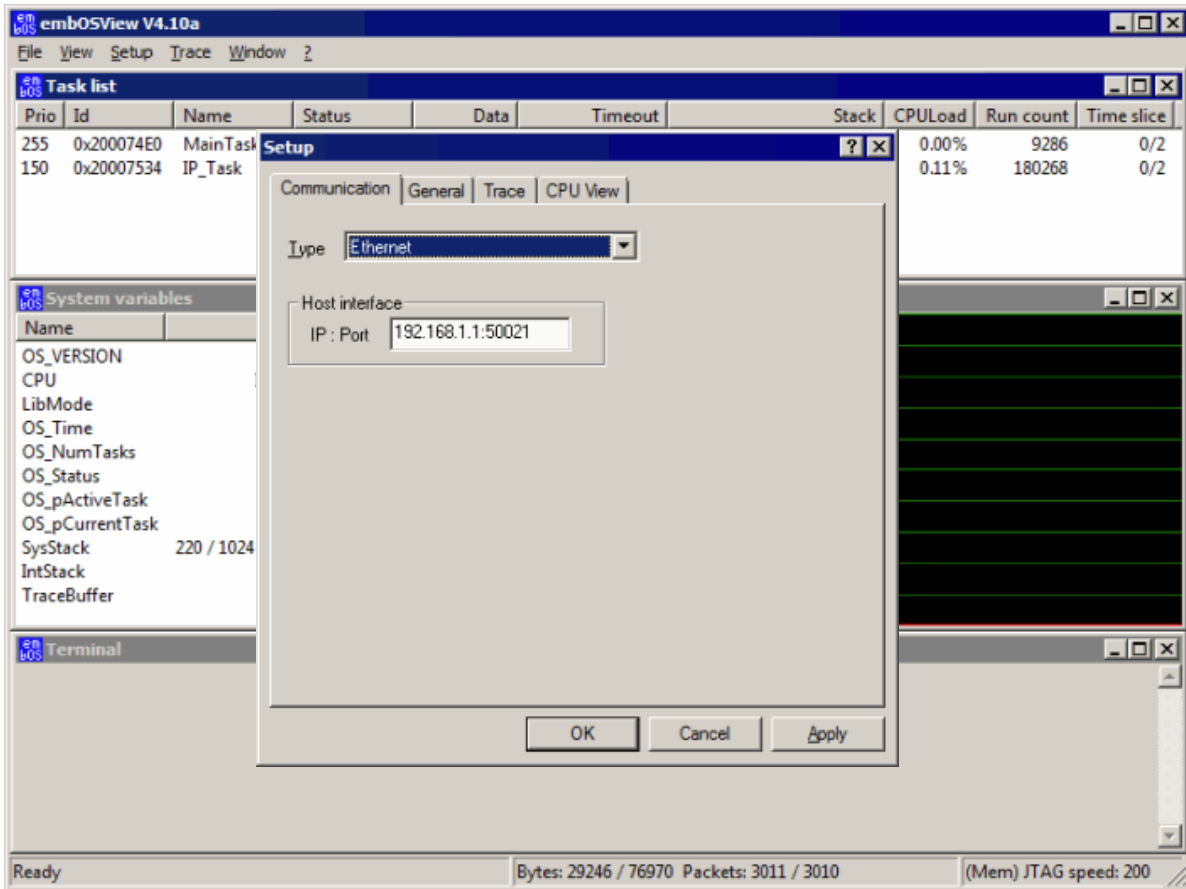
In the Communication TAB choose Ethernet in the Type selection listbox.

In the Host interface box select the IP address of your target and the port number *50021*.

The communication via Ethernet is available in the target application if the project was compiled with the settings *OS_VIEW_USE_ETHERNET* unequal to 0 and *OS_VIEW_ENABLE* set unequal to 0.

24.8.4 Use J-Link for communication and debugging in parallel

J-Link can be used to communicate with embOSView during a running debug session that uses the same J-Link as debug probe. To avoid problems, the target interface settings for J-Link should be the same in the debugger settings and in the embOS-View Target interface settings. To use embOSView during a debug session, proceed as follows:

* Examine the target interface settings in the Debugger settings of the project.
* Before starting the debugger, start embOSView and set the same target interface as found in the debugger settings, for example SWD.
* Close embOSView
* Start the debugger
* Restart embOSView

J-Link will now communicate with the debugger and embOSView will communicate with embOS via J-Link as long as the application is running.

24.8.5 Restrictions for using J-Link with embOSView
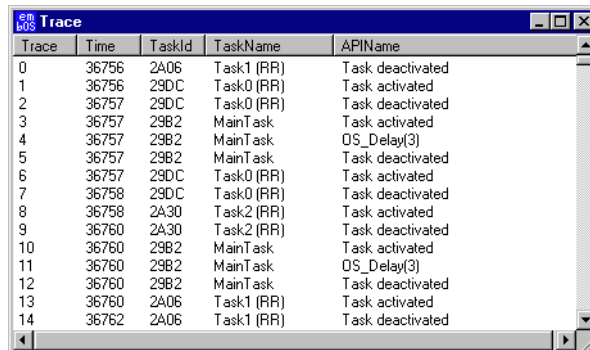
The J-Link communication via Cortex M (memory access) with the current version of embOSView can only be used when the Cortex M vector table of the target application is located at address 0x00.

24.9 Using the API trace

embOS versions 3.06 or higher contain a trace feature for API calls. This requires the use of the trace build libraries in the target application.

The trace build libraries implement a buffer for 100 trace entries. Tracing of API calls can be started and stopped from embOSView via the **Trace menu**, or from within the application by using the functions `OS_TraceEnable()` and `OS_TraceDisable()`. Individual filters may be defined to determine which API calls should be traced for different tasks or from within interrupt or timer routines.

Once the trace is started, the API calls are recorded in the trace buffer, which is periodically read by embOSView. The result is shown in the **Trace window**:

Every entry in the **Trace list** is recorded with the actual system time. In case of calls or events from tasks, the task ID (**TaskId**) and task name (**TaskName**) (limited to 15 characters) are also recorded. Parameters of API calls are recorded if possible, and are shown as part of the **APIName** column. In the example above, this can be seen with `OS_Delay(3)`. Once the trace buffer is full, trace is automatically stopped. The **Trace list** and buffer can be cleared from embOSView.

Setting up trace from embOSView

Three different kinds of trace filters are defined for tracing. These filters can be set up from embOSView via the menu **Options/Setup/Trace**.

Filter 0 is not task-specific and records all specified events regardless of the task. As the Idle loop is not a task, calls from within the idle loop are not traced.

Filter 1 is specific for interrupt service routines, software timers and all calls that occur outside a running task. These calls may come from the idle loop or during startup when no task is running.

Filters 2 to 4 allow trace of API calls from named tasks.
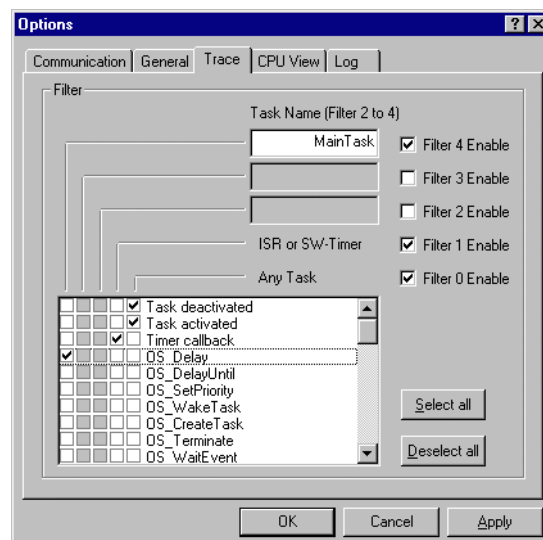
To enable or disable a filter, simply check or uncheck the corresponding checkboxes labeled **Filter 4 Enable** to **Filter 0 Enable**.

For any of these five filters, individual API functions can be enabled or disabled by checking or unchecking the corresponding checkboxes in the list. To speed up the process, there are two buttons available:

- **Select all** - enables trace of all API functions for the currently enabled (checked) filters.
- **Deselect all** - disables trace of all API functions for the currently enabled (checked) filters.

Filter 2, **Filter 3**, and **Filter 4** allow tracing of task-specific API calls. A task name can therefore be specified for each of these filters. In the example above, **Filter 4** is configured to trace calls of `OS_Delay()` from the task called `MainTask`. After the settings are saved (via the **Apply** or **OK** button), the new settings are sent to the target application.

24.10 Trace filter setup functions

Tracing of API or user function calls can be started or stopped from embOSView. By default, trace is initially disabled in an application program. It may be helpful to control recording of trace events directly from the application, using the following functions.

24.11 API functions

Routine	Description	main	Task	ISR	Timer
OS_TraceEnable()	Enables tracing of filtered API calls.	X	X	X	X
OS_TraceDisable()	Disables tracing of API and user function calls.	X	X	X	X
OS_TraceEnableAll()	Sets up Filter 0 (any task), enables tracing of all API calls and then enables the trace function.	X	X	X	X
OS_TraceDisableAll()	Sets up Filter 0 (any task), disables tracing of all API calls and also disables trace.	X	X	X	X
OS_TraceEnableId()	Sets the specified ID value in Filter 0 (any task), thus enabling trace of the specified function, but does not start trace.	X	X	X	X
OS_TraceDisableId()	Resets the specified ID value in Filter 0 (any task), thus disabling trace of the specified function, but does not stop trace.	X	X	X	X
OS_TraceEnableFilterId()	Sets the specified ID value in the specified trace filter, thus enabling trace of the specified function, but does not start trace.	X	X	X	X
OS_TraceDisableFilterId()	Resets the specified ID value in the specified trace filter, thus disabling trace of the specified function, but does not stop trace.	X	X	X	X

Table 24.7: Trace filter API functions

24.11.1 OS_TraceEnable()

Description

Enables tracing of filtered API calls.

Prototype

```
void OS_TraceEnable (void);
```

Additional Information

The trace filter conditions must be set up before calling this function. This functionality is available in trace builds only. In non-trace builds, the API call is removed by the preprocessor.

24.11.2 OS_TraceDisable()

Description

Disables tracing of API and user function calls.

Prototype

```
void OS_TraceDisable (void);
```

Additional Information

This functionality is available in trace builds only. In non-trace builds, the API call is removed by the preprocessor.

24.11.3 OS_TraceEnableAll()

Description

Sets up Filter 0 (any task), enables tracing of all API calls and then enables the trace function.

Prototype

```
void OS_TraceEnableAll (void);
```

Additional Information

The trace filter conditions of all the other trace filters are not affected.
This functionality is available in trace builds only. In non-trace builds, the API call is removed by the preprocessor.

24.11.4 OS_TraceDisableAll()

Description

Sets up Filter 0 (any task), disables tracing of all API calls and also disables trace.

Prototype

```
void OS_TraceDisableAll (void);
```

Additional Information

The trace filter conditions of all the other trace filters are not affected, but tracing is stopped.
This functionality is available in trace builds only. In non-trace builds, the API call is removed by the preprocessor.

24.11.5 OS_TraceEnableId()

Description

Sets the specified ID value in Filter 0 (any task), thus enabling trace of the specified function, but does not start trace.

Prototype

```
void OS_TraceEnableId (OS_U8 Id);
```

Parameter	Description
Id	ID value of API call that should be enabled for trace: 0 <= Id <= 127 Values from 0 to 99 are reserved for embOS.

Table 24.8: OS_TraceEnableId() parameter list

Additional Information

To enable trace of a specific embOS API function, you must use the correct `Id` value. These values are defined as symbolic constants in `RTOS.h`.
This function may also enable trace of your own functions.
This functionality is available in trace builds only. In non-trace builds, the API call is removed by the preprocessor.

24.11.6 OS_TraceDisableId()

Description

Clears the specified ID value in Filter 0 (any task), thus disabling trace of the specified function, but does not stop trace.

Prototype

```
void OS_TraceDisableId (OS_U8 Id);
```

Parameter	Description
Id	ID value of API call that should be enabled for trace: 0 <= Id <= 127 Values from 0 to 99 are reserved for embOS.

Table 24.9: OS_TraceDisabledId() parameter list

Additional Information

To disable trace of a specific embOS API function, you must use the correct `Id` value. These values are defined as symbolic constants in `RTOS.h`.
This function may also be used for disabling trace of your own functions.
This functionality is available in trace builds only. In non-trace builds, the API call is removed by the preprocessor.

24.11.7 OS_TraceEnableFilterId()

Description

Sets the specified ID value in the specified trace filter, thus enabling trace of the specified function, but does not start trace.

Prototype

```
void OS_TraceEnableFilterId (OS_U8 FilterIndex,
                             OS_U8 Id)
```

Parameter	Description
FilterIndex	Index of the filter that should be affected: 0 <= FilterIndex <= 4 0 affects Filter 0 (any task) and so on.
Id	ID value of API call that should be enabled for trace: 0 <= Id <= 127 Values from 0 to 99 are reserved for embOS.

Table 24.10: OS_TraceEnabledFilterId() parameter list

Additional Information

To enable trace of a specific embOS API function, you must use the correct Id value. These values are defined as symbolic constants in RTOS.h.
This function may also be used for enabling trace of your own functions.
This functionality is available in trace builds only. In non-trace builds, the API call is removed by the preprocessor.

24.11.8 OS_TraceDisableFilterId()

Description

Clears the specified ID value in the specified trace filter, thus disabling trace of the specified function, but does not stop trace.

Prototype

```
void OS_TraceDisableFilterId (OS_U8 FilterIndex,
                              OS_U8 Id)
```

Parameter	Description
FilterIndex	Index of the filter that should be affected: 0 <= FilterIndex <= 4 0 affects Filter 0 (any task) and so on.
Id	ID value of API call that should be enabled for trace: 0 <= Id <= 127 Values from 0 to 99 are reserved for embOS.

Table 24.11: OS_TraceDisableFilterId() parameter list

Additional Information

To disable trace of a specific embOS API function, you must use the correct Id value. These values are defined as symbolic constants in RTOS.h.
This function may also be used for disabling trace of your own functions.
This functionality is available in trace builds only. In non-trace builds, the API call is removed by the preprocessor.

24.12 Trace record functions

The following functions write data into the trace buffer. As long as only embOS API calls should be recorded, these functions are used internally by the trace build libraries. If, for some reason, you want to trace your own functions with your own parameters, you may call one of these routines.

All of these functions have the following points in common:

*   To record data, trace must be enabled.
*   An ID value in the range 100 to 127 must be used as the ID parameter. ID values from 0 to 99 are internally reserved for embOS.
*   The events specified as ID must be enabled in trace filters.
*   Active system time and the current task are automatically recorded together with the specified event.

24.13 API functions

Routine	Description	main	Task	ISR	Timer
OS_TraceVoid()	Writes an entry identified only by its ID into the trace buffer.	X	X	X	X
OS_TracePtr()	Writes an entry with ID and a pointer as parameter into the trace buffer.	X	X	X	X
OS_TraceData()	Writes an entry with ID and an integer as parameter into the trace buffer.	X	X	X	X
OS_TraceDataPtr()	Writes an entry with ID, an integer, and a pointer as parameter into the trace buffer.	X	X	X	X
OS_TraceU32Ptr()	Writes an entry with ID, a 32 bit unsigned integer, and a pointer as parameter into the trace buffer.	X	X	X	X

Table 24.12: Trace record API functions

24.13.1 OS_TraceVoid()

Description

Writes an entry identified only by its ID into the trace buffer.

Prototype

```
void OS_TraceVoid (OS_U8 Id);
```

Parameter	Description
Id	ID value of API call that should be enabled for trace: 0 <= Id <= 127 Values from 0 to 99 are reserved for embOS.

Table 24.13: OS_TraceVoid() parameter list

Additional Information

This functionality is available in trace builds only, and the API call is not removed by the preprocessor.

24.13.2 OS_TracePtr()

Description

Writes an entry with ID and a pointer as parameter into the trace buffer.

Prototype

```
void OS_TracePtr (OS_U8 Id,
                  void* p);
```

Parameter	Description
Id	ID value of API call that should be enabled for trace: 0 <= Id <= 127 Values from 0 to 99 are reserved for embOS.
p	Any void pointer that should be recorded as parameter.

Table 24.14: OS_TracePtr() parameter list

Additional Information

The pointer passed as parameter will be displayed in the trace list window of embOSView. This functionality is available in trace builds only. In non-trace builds, the API call is removed by the preprocessor.

24.13.3 OS_TraceData()

Description

Writes an entry with ID and an integer as parameter into the trace buffer.

Prototype

```
void OS_TraceData (OS_U8 Id,
                   int   v);
```

Parameter	Description
Id	ID value of API call that should be enabled for trace: 0 <= Id <= 127 Values from 0 to 99 are reserved for embOS.
v	Any integer value that should be recorded as parameter.

Table 24.15: OS_TraceData() parameter list

Additional Information

The value passed as parameter will be displayed in the trace list window of embOSView.This functionality is available in trace builds only. In non-trace builds, the API call is removed by the preprocessor.

24.13.4 OS_TraceDataPtr()

Description

Writes an entry with ID, an integer, and a pointer as parameter into the trace buffer.

Prototype

```
void OS_TraceDataPtr (OS_U8 Id,
                      int   v,
                      void* p);
```

Parameter	Description
Id	ID value of API call that should be enabled for trace: 0 <= Id <= 127 Values from 0 to 99 are reserved for embOS.
v	Any integer value that should be recorded as parameter.
p	Any void pointer that should be recorded as parameter.

Table 24.16: OS_TraceDataPtr() parameter list

Additional Information

The values passed as parameters will be displayed in the trace list window of embOS-View. This functionality is available in trace builds only. In non-trace builds, the API call is removed by the preprocessor.

24.13.5 OS_TraceU32Ptr()

Description

Writes an entry with ID, a 32 bit unsigned integer, and a pointer as parameter into the trace buffer.

Prototype

```
void OS_TraceU32Ptr (OS_U8  Id,
                     OS_U32 p0,
                     void*  p1);
```

Parameter	Description
Id	ID value of API call that should be enabled for trace: 0 <= Id <= 127 Values from 0 to 99 are reserved for embOS.
p0	Any unsigned 32 bit value that should be recorded as parameter.
p1	Any void pointer that should be recorded as parameter.

Table 24.17: OS_TraceU32Ptr() parameter list

Additional Information

This function may be used for recording two pointers. The values passed as parameters will be displayed in the trace list window of embOSView. This functionality is available in trace builds only. In non-trace builds, the API call is removed by the preprocessor.

24.14 Application-controlled trace example

As described in the previous section, the user application can enable and set up the trace conditions without a connection or command from embOSView. The trace record functions can also be called from any user function to write data into the trace buffer, using ID numbers from 100 to 127.

Controlling trace from the application can be useful for tracing API and user functions just after starting the application, when the communication to embOSView is not yet available or when the embOSView setup is not complete.

The example below shows how a trace filter can be set up by the application. The function `OS_TraceEnableID()` sets trace filter 0 which affects calls from any running task. Therefore, the first call to `SetState()` in the example would not be traced because there is no task running at that moment. The additional filter setup routine `OS_TraceEnableFilterId()` is called with filter 1, which results in tracing calls from outside running tasks.

Example code

```
#include "RTOS.h"

#ifndef OS_TRACE_FROM_START
  #define OS_TRACE_FROM_START 1
#endif

/*  Application specific trace id numbers   */
#define APP_TRACE_ID_SETSTATE  100

char MainState;

/*  Sample of application routine with trace   */

void SetState(char* pState, char Value) {
  #if OS_TRACE
    OS_TraceDataPtr(APP_TRACE_ID_SETSTATE, Value, pState);
  #endif
  * pState = Value;
}

/* Sample main routine, that enables and setup API and function call trace
   from start   */
void main(void) {
  OS_InitKern();
  OS_InitHW();
  #if (OS_TRACE && OS_TRACE_FROM_START)
    /* OS_TRACE is defined in trace builds of the library          */
    OS_TraceDisableAll();           /*  Disable all API trace calls      */
    OS_TraceEnableId(APP_TRACE_ID_SETSTATE);          /*  User trace  */
    OS_TraceEnableFilterId(0, APP_TRACE_ID_SETSTATE);  /*  User trace  */
    OS_TraceEnable();
  #endif

  /* Application specific initialization */
  SetState(&MainState, 1);
  OS_CREATETASK(&TCBMain, "MainTask", MainTask, PRIO_MAIN, MainStack);
  OS_Start();  /* Start multitasking  -> MainTask() */
}
```

By default, embOSView lists all user function traces in the trace list window as Routine, followed by the specified ID and two parameters as hexadecimal values. The example above would result in the following:

```
Routine100(0xabcd, 0x01)
```

where `0xabcd` is the pointer address and `0x01` is the parameter recorded from `OS_TraceDataPtr()`.

24.15 User-defined functions

To use the built-in trace (available in trace builds of embOS) for application program user functions, embOSView can be customized. This customization is done in the setup file `embOS.ini`.

This setup file is parsed at the startup of embOSView. It is optional; you will not see an error message if it cannot be found.

To enable trace setup for user functions, embOSView needs to know an ID number, the function name and the type of two optional parameters that can be traced. The format is explained in the following sample `embOS.ini` file:

Example code

```
# File: embOS.ini
#
# embOSView Setup file
#
# embOSView loads this file at startup. It must reside in the same
# directory as the executable itself.
#
# Note: The file is not required to run embOSView. You will not get
# an error message if it is not found. However, you will get an error message
# if the contents of the file are invalid.


#
# Define add. API functions.
# Syntax: API( <Index>, <Routinename> [parameters])
# Index: Integer, between 100 and 127
# Routinename: Identifier for the routine. Should be no more than 32 characters
# parameters: Optional paramters. A max. of 2 parameters can be specified.
#             Valid parameters are:
#                 int
#                 ptr
#           Every parameter must be placed after a colon.
#
API( 100, "Routine100")
API( 101, "Routine101", int)
API( 102, "Routine102", int, ptr)
```

Chapter 25

Performance and resource usage

This chapter covers the performance and resource usage of embOS. It explains how to benchmark embOS and contains information about the memory requirements in typical systems which can be used to obtain sufficient estimates for most target systems.

25.1   Introduction

High performance combined with low resource usage has always been a major design consideration. embOS runs on 8/16/32 bit CPUs. Depending on which features are being used, even single-chip systems with less than 2 Kbytes ROM and 1 Kbyte RAM can be supported by embOS. The actual performance and resource usage depends on many factors (CPU, compiler, memory model, optimization, configuration, etc.).

25.2 Memory requirements

The memory requirements of embOS (RAM and ROM) differs depending on the used features of the library. The following table shows the memory requirements for the different modules. These values are typical values for a 32 bit CPU and depend on CPU, compiler, and library model used.

Module	Memory type	Memory requirements
embOS kernel	ROM	1700 bytes
embOS kernel	RAM	51 bytes
Mailbox	RAM	24 bytes
Semaphore	RAM	8 bytes
Resource semaphore	RAM	16 bytes
Software timer	RAM	20 bytes
Task event	RAM	0 bytes

Table 25.1: embOS memory requirements

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25.3 Performance

The following section shows how to benchmark embOS with the supplied example programs.

25.4 Benchmarking

embOS is designed to perform fast context switches. This section describes two different methods to calculate the execution time of a context switch from a task with lower priority to a task with a higher priority.

The first method uses port pins and requires an oscilloscope. The second method uses the high-resolution measurement functions. Example programs for both methods are supplied in the \Sample directory of your embOS shipment.

Segger uses these programs to benchmark embOS performance. You can use these examples to evaluate the benchmark results. Note that the actual performance depends on many factors (CPU, clock speed, toolchain, memory model, optimization, configuration, etc.).

Please be aware that the number of cycles are not equal to the number of instructions. Many instructions on ARM need two or three cycles even at zero waitstates, e.g. LDR needs 3 cycles.

The following table gives an overview about the variations of the context switch time depending on the memory type and the CPU mode:

Target	Memory	Time / Cycles
ST STM32F4 @ 168Mhz	Flash	1.6us / 284
Renesas RZ @ 400Mhz	RAM	0.6us / 240

Table 25.2: embOS context switch times

All named example performance values in the following section are determined with the following system configuration:

All sources are compiled with IAR Embedded Workbench version 6.40.5, XR library and high optimization level. embOS version 4.14 has been used; values may differ for different builds.

25.4.1 Measurement with port pins and oscilloscope

The example file `OS_MeasureCST_Scope.c` uses the `BSP.c` module to set and clear a port pin. This allows measuring the context switch time with an oscilloscope.

The following source code is excerpt from `OS_MeasureCST_Scope.c`:

```c
#include "RTOS.h"
#include "BSP.h"

static OS_STACKPTR int StackHP[128], StackLP[128];  // Task stacks
static OS_TASK TCBHP, TCBLP;                         // Task-control-blocks

/**********************************************************************
*
*       HPTask
*/
static void HPTask(void) {
  while (1) {
    OS_Suspend(NULL);    // Suspend high priority task
    BSP_ClrLED(0);       // Stop measurement
  }
}

/**********************************************************************
*
*       LPTask
*/
static void LPTask(void) {
  while (1) {
    OS_Delay(100);       // Synchronize to tick to avoid jitter
    //
    // Display measurement overhead
    //
    BSP_SetLED(0);
    BSP_ClrLED(0);
    //
    // Perform measurement
    //
    BSP_SetLED(0);       // Start measurement
    OS_Resume(&TCBHP);   // Resume high priority task to force task switch
  }
}

/**********************************************************************
*
*       main
*/
int main(void) {
  OS_IncDI();                      // Initially disable interrupts
  OS_InitKern();                   // Initialize OS
  OS_InitHW();                     // Initialize Hardware for OS
  BSP_Init();                      // Initialize LED ports
  OS_CREATETASK(&TCBHP, "HP Task", HPTask, 100, StackHP);
  OS_CREATETASK(&TCBLP, "LP Task", LPTask,  99, StackLP);
  OS_Start();                      // Start multitasking
  return 0;
}
```

25.4.1.1 Oscilloscope analysis

The context switch time is the time between switching the LED on and off. If the LED is switched on with an active high signal, the context switch time is the time between the rising and the falling edge of the signal. If the LED is switched on with an active low signal, the signal polarity is reversed.

The real context switch time is shorter, because the signal also contains the overhead of switching the LED on and off. The time of this overhead is also displayed on the oscilloscope as a small peak right before the task switch time display and must be subtracted from the displayed context switch time. The picture below shows a simplified oscilloscope signal with an active-low LED signal (low means LED is illuminated). There are switching points to determine:

• A = LED is switched on for overhead measurement
• B = LED is switched off for overhead measurement
• C = LED is switched on right before context switch in low-prio task
• D = LED is switched off right after context switch in high-prio task

The time needed to switch the LED on and off in subroutines is marked as time t_{AB}.

The time needed for a complete context switch including the time needed to switch the LED on and off in subroutines is marked as time t_{CD}.

The context switching time t_{CS} is calculated as follows:

$t_{CS} = t_{CD} - t_{AB}$

Voltage [V]
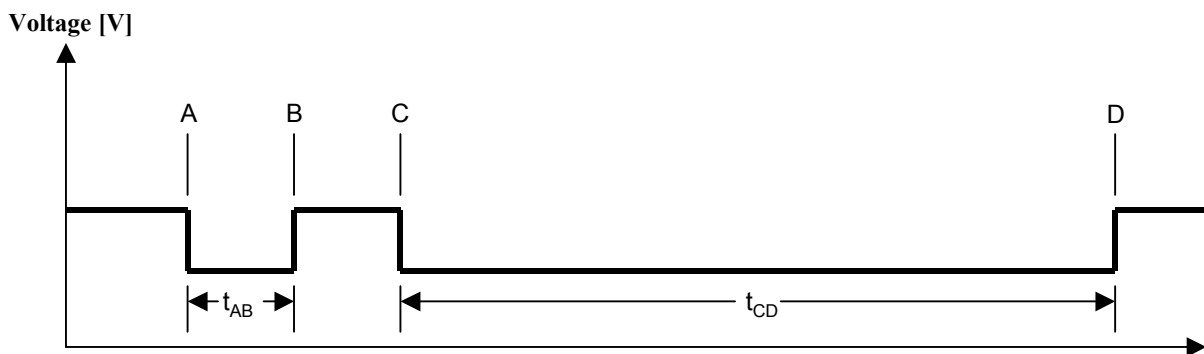
25.4.1.2 Example measurements Renesas RZ, Thumb2 code in RAM

Task switching time has been measured with the parameters listed below:

embOS Version V4.14
Application program: `OS_MeasureCST_Scope.c`
`Hardware:` Renesas RZ processor with 399MHz
Program is executing in RAM
Thumb2 mode is used
Compiler used: SEGGER Embedded Studio V2.10B (GCC)
CPU frequency (f_{CPU}): `399.0MHz`
CPU clock cycle (t_{Cycle}): t_{Cycle} = 1 / f_{CPU} = 1 / 399.0MHz = 2.506ns

Measuring t_{AB} and t_{CD}

t_{AB} is measured as 480ns.
The number of cycles calculates as follows:
$Cycles_{AB}$ = t_{AB} / t_{Cycle}
=480ns / 2.506ns
= 191.54 Cycles
=> 192 Cycles
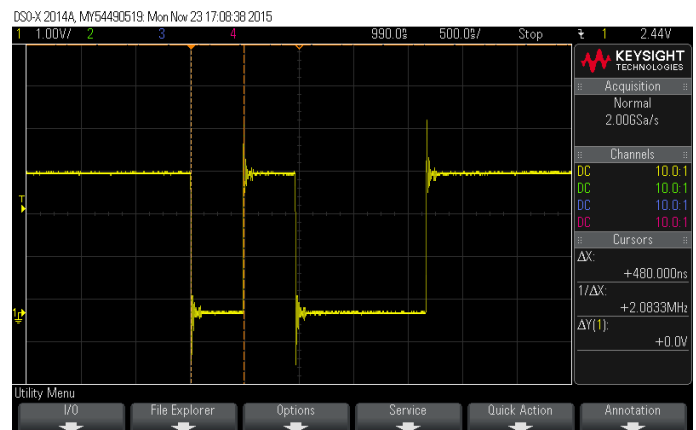
t_{CD} is measured as 1200.0ns.
The number of cycles calculates as follows:
$Cycles_{CD}$ = t_{CD} / t_{Cycle}
= 1200.0ns / 2.506ns
= 478.85 Cycles
=> 479 Cycles
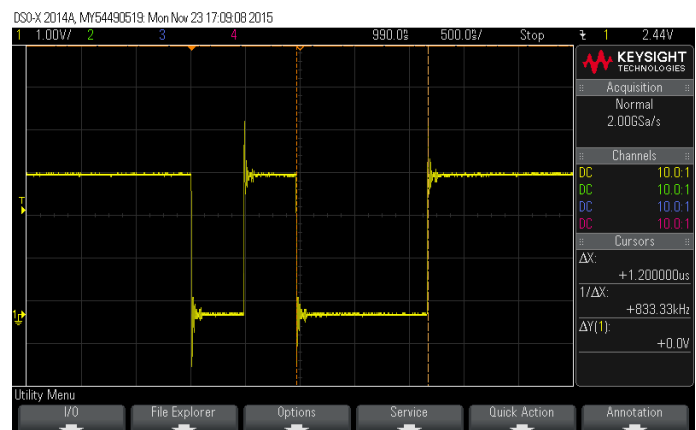
Resulting context switching time and number of cycles

The time which is required for the pure context switch is:
t_{CS} = t_{CD} - t_{AB} = 479 ycles - 192 Cycles = 287 Cycles
=> **287 Cycles (0.72us @399 MHz)**.

25.4.1.3 Measurement with high-resolution timer

The context switch time may be measured with the high-resolution timer. Refer to section *High-resolution measurement* on page 301 for detailed information about the embOS high-resolution measurement.

The example OS_MeasureCST_HRTimer_embOSView.c uses a high resolution timer to measure the context switch time from a low priority task to a high priority task and displays the results on embOSView.

```
#include "RTOS.h"
#include "stdio.h"

static OS_STACKPTR int StackHP[128], StackLP[128];  // Task stacks
static OS_TASK TCBHP, TCBLP;                          // Task-control-blocks
static OS_U32  Time;                                  // Timer values

/***********************************************************************
*
*       HPTask
*/
static void HPTask(void) {
  while (1) {
    OS_Suspend(NULL);                  // Suspend high priority task
    OS_Timing_End(&_Time);             // Stop measurement
  }
}

/***********************************************************************
*
*       LPTask
*/
static void LPTask(void) {
  char   acBuffer[100];                // Output buffer
  OS_U32 MeasureOverhead;              // Time for Measure Overhead
  OS_U32 v;

  //
  // Measure Overhead for time measurement so we can take
  // this into account by subtracting it
  //
  OS_Timing_Start(&MeasureOverhead);
  OS_Timing_End(&MeasureOverhead);
  //
  // Perform measurements in endless loop
  //
  while (1) {
    OS_Delay(100);                     // Sync. to tick to avoid jitter
    OS_Timing_Start(&_Time);           // Start measurement
    OS_Resume(&TCBHP);                 // Resume high priority task to force task switch
    v  = OS_Timing_GetCycles(&_Time);
    v -= OS_Timing_GetCycles(&MeasureOverhead);
    v = OS_ConvertCycles2us(1000 * v);  // Convert cycles to nano-seconds
    sprintf(acBuffer, "Context switch time: %1u.%.31u usec\r",
                   v / 1000uL, v % 1000uL);
    OS_SendString(acBuffer);
  }
}
```

The example program calculates and subtracts the measurement overhead. The results will be transmitted to embOSView, so the example runs on every target that supports UART communication to embOSView.

The example program OS_MeasureCST_HRTimer_Printf.c is identical to the example program OS_MeasureCST_HRTimer_embOSView.c but displays the results with the printf() function for those debuggers which support terminal output emulation.

Chapter 26

Debugging

26.1 Runtime errors

Some error conditions can be detected during runtime. These are:

- Usage of uninitialized data structures
- Invalid pointers
- Unused resource that has not been used by this task before
- `OS_LeaveRegion()` called more often than `OS_EnterRegion()`
- Stack overflow (this feature is not available for some processors)

Which runtime errors that can be detected depend on how much checking is performed. Unfortunately, additional checking costs memory and performance (it is not that significant, but there is a difference). If embOS detects a runtime error, it calls the following routine:

```
void OS_Error(int ErrCode);
```

This routine is shipped as source code as part of the module `OS_Error.c`. It simply disables further task switches and then, after re-enabling interrupts, loops forever as follows:

Example

```
/*
   Run time error reaction
*/
void OS_Error(int ErrCode) {
  OS_EnterRegion();        /* Avoid further task switches */
  OS_DICnt =0;             /* Allow interrupts so we can communicate */
  OS_EI();
  OS_Status = ErrCode;
  while (OS_Status);
}
```

If you are using embOSView, you can see the value and meaning of `OS_Status` in the system variable window.

When using an emulator, you should set a breakpoint at the beginning of this routine or simply stop the program after a failure. The error code is passed to the function as a parameter.

You can modify the routine to accommodate your own hardware; this could mean that your target hardware sets an error-indicating LED or shows a small message on the display.

Note: When modifying the OS_Error() routine, the first statement needs to be the disabling of scheduler via OS_EnterRegion(); the last statement needs to be the infinite loop.

If you look at the `OS_Error()` routine, you will see that it is more complicated than necessary. The actual error code is assigned to the global variable `OS_Status`. The program then waits for this variable to be reset. Simply reset this variable to 0 using your in circuit-emulator, and you can easily step back to the program sequence causing the problem. Most of the time, looking at this part of the program will make the problem clear.

26.1.1 OS_DEBUG_LEVEL

The preprocessor symbol OS_DEBUG_LEVEL defines the embOS debug level. The default value is 1. With higher debug levels more debug code is included.

26.2 List of error codes

Value	Define	Explanation
100	OS_ERR_ISR_INDEX	Index value out of bounds during interrupt controller initialization or interrupt installation.
101	OS_ERR_ISR_VECTOR	Default interrupt handler called, but interrupt vector not initialized.
102	OS_ERR_ISR_PRIO	Wrong interrupt priority
103	OS_ERR_WRONG_STACK	Wrong stack used before main()
104	OS_ERR_ISR_NO_HANDLER	No interrupt handler was defined for this interrupt
105	OS_ERR_TLS_INIT	OS_TLS_Init() called multiple times for one task. (Port specific error message)
106	OS_ERR_MB_BUFFER_SIZE	The maximum buffer size of 64KB for one mailbox buffer is exceed by call of OS_CreateMB(). This limit exists on 8 and 16bit CPUs only.
116	OS_ERR_EXTEND_CONTEXT	OS_ExtendTaskContext called multiple times from one task
117	OS_ERR_TIMESLICE	An illegal time slice value of zero was used when calling OS_CreateTask(), OS_CreateTaskEx() or OS_SetTimeSlice(). Since version 3.86f of embOS, a time slice of zero is legal (as described in chapter 4). The error is not generated when a task is created with a time slice value of zero.
118	OS_ERR_INTERNAL	OS_ChangeTask called without RegionCnt set (or other internal error)
119	OS_ERR_IDLE_RETURNS	Idle loop should not return
120	OS_ERR_STACK	Stack overflow or invalid stack.
121	OS_ERR_CSEMA_OVERFLOW	Counting semaphore overflow.
122	OS_ERR_POWER_OVER	Counter overflows when calling OS_POWER_UsageInc()
123	OS_ERR_POWER_UNDER	Counter underflows when calling OS_POWER_UsageDec()
124	OS_ERR_POWER_INDEX	Index to high, exceeds (OS_POWER_NUM_COUNTERS - 1)
125	OS_ERR_SYS_STACK	System stack overflow
126	OS_ERR_INT_STACK	Interrupt stack overflow
128	OS_ERR_INV_TASK	Task control block invalid, not initialized or overwritten.
129	OS_ERR_INV_TIMER	Timer control block invalid, not initialized or overwritten.
130	OS_ERR_INV_MAILBOX	Mailbox control block invalid, not initialized or overwritten.
132	OS_ERR_INV_CSEMA	Control block for counting semaphore invalid, not initialized or overwritten.

Table 26.1: Error code list

Value	Define	Explanation
133	OS_ERR_INV_RSEMA	Control block for resource sema-phore invalid, not initialized or over-written.
135	OS_ERR_MAILBOX_NOT1	One of the following 1-byte mailbox functions has been used on a multi-byte mailbox: OS_PutMail1() OS_PutMailCond1() OS_GetMail1() OS_GetMailCond1().
136	OS_ERR_MAILBOX_DELETE	OS_DeleteMB() was called on a mail-box with waiting tasks.
137	OS_ERR_CSEMA_DELETE	OS_DeleteCSema() was called on a counting semaphore with waiting tasks.
138	OS_ERR_RSEMA_DELETE	OS_DeleteRSema() was called on a resource semaphore which is claimed by a task.
140	OS_ERR_MAILBOX_NOT_IN_LIST	The mailbox is not in the list of mail-boxes as expected. Possible reasons may be that one mailbox data struc-ture was overwritten.
142	OS_ERR_TASKLIST_CORRUPT	The OS internal task list is destroyed.
143	OS_ERR_QUEUE_INUSE	Queue in use
144	OS_ERR_QUEUE_NOT_INUSE	Queue not in use
145	OS_ERR_QUEUE_INVALID	Queue invalid
146	OS_ERR_QUEUE_DELETE	A queue was deleted by a call of OS_Q_Delete() while tasks are wait-ing at the queue.
147	OS_ERR_MB_INUSE	Mailbox in use
148	OS_ERR_MB_NOT_INUSE	Mailbox not in use
150	OS_ERR_UNUSE_BEFORE_USE	OS_Unuse() has been called before OS_Use().
151	OS_ERR_LEAVEREGION_BEFORE_ENTERR EGION	OS_LeaveRegion() has been called before OS_EnterRegion().
152	OS_ERR_LEAVEINT	Error in OS_LeaveInterrupt().
153	OS_ERR_DICNT	The interrupt disable counter (OS_DICnt) is out of range (0-15). The counter is affected by the follow-ing API calls: OS_IncDI() OS_DecRI() OS_EnterInterrupt() OS_LeaveInterrupt()
154	OS_ERR_INTERRUPT_DISABLED	OS_Delay() or OS_DelayUntil() called from inside a critical region with interrupts disabled.
155	OS_ERR_TASK_ENDS_WITHOUT_TERMINA TE	Task routine returns without 0S_TerminateTask()
156	OS_ERR_RESOURCE_OWNER	OS_Unuse() has been called from a task which does not own the resource.
157	OS_ERR_REGIONCNT	The Region counter overflows (>255)

Table 26.1: Error code list (Continued)

Value	Define	Explanation
160	OS_ERR_ILLEGAL_IN_ISR	Illegal function call in an interrupt service routine: A routine that must not be called from within an ISR has been called from within an ISR.
161	OS_ERR_ILLEGAL_IN_TIMER	Illegal function call in an interrupt service routine: A routine that must not be called from within a software timer has been called from within a timer.
162	OS_ERR_ILLEGAL_OUT_ISR	embOS timer tick handler or UART handler for embOSView was called without a call of OS_EnterInterrupt().
163	OS_ERR_NOT_IN_ISR	OS_EnterInterrupt() has been called, but CPU is not in ISR state
164	OS_ERR_IN_ISR	OS_EnterInterrupt() has not been called, but CPU is in ISR stat
165	OS_ERR_INIT_NOT_CALLED	OS_InitKern() was not called
166	OS_ERR_CPU_STATE_ISR_ILLEGAL	OS-function called from ISR with high priority
167	OS_ERR_CPU_STATE_ILLEGAL	CPU runs in illegal mode
168	OS_ERR_CPU_STATE_UNKNOWN	CPU runs in unknown mode or mode could not be read
170	OS_ERR_2USE_TASK	Task control block has been initialized by calling a create function twice.
171	OS_ERR_2USE_TIMER	Timer control block has been initialized by calling a create function twice.
172	OS_ERR_2USE_MAILBOX	Mailbox control block has been initialized by calling a create function twice.
174	OS_ERR_2USE_CSEMA	Counting semaphore has been initialized by calling a create function twice.
175	OS_ERR_2USE_RSEMA	Resource semaphore has been initialized by calling a create function twice.
176	OS_ERR_2USE_MEMF	Fixed size memory pool has been initialized by calling a create function twice.
180	OS_ERR_NESTED_RX_INT	OS_Rx interrupt handler for embOS-View is nested. Disable nestable interrupts.
185	OS_ERR_SPINLOCK_INV_CORE	Invalid core ID specified for accessing a OS_SPINLOCK_SW struct.
190	OS_ERR_MEMF_INV	Fixed size memory block control structure not created before use.
191	OS_ERR_MEMF_INV_PTR	Pointer to memory block does not belong to memory pool on Release
192	OS_ERR_MEMF_PTR_FREE	Pointer to memory block is already free when calling OS_MEMF_Release(). Possibly, same pointer was released twice.

Table 26.1: Error code list (Continued)

Value	Define	Explanation
193	OS_ERR_MEMF_RELEASE	OS_MEMF_Release() was called for a memory pool, that had no memory block allocated (all available blocks were already free before).
194	OS_ERR_POOLADDR	OS_MEMF_Create() was called with a memory pool base address which is not located at a word aligned base address
195	OS_ERR_BLOCKSIZE	OS_MEMF_Create() was called with a data block size which is not a multiple of processors word size.
200	OS_ERR_SUSPEND_TOO_OFTEN	Nested call of OS_Suspend() exceeded OS_MAX_SUSPEND_CNT
201	OS_ERR_RESUME_BEFORE_SUSPEND	OS_Resume() called on a task that was not suspended.
202	OS_ERR_TASK_PRIORITY	OS_CreateTask() was called with a task priority which is already assigned to another task. This error can only occur when embOS was compiled without round robin support.
203	OS_ERR_TASK_PRIORITY_INVALID	The value 0 was used as task priority.
210	OS_ERR_EVENT_INVALID	An OS_EVENT object was used before it was created.
211	OS_ERR_2USE_EVENTOBJ	An OS_EVENT object was created twice. This error should not be reported. Contact Segger support.
212	OS_ERR_EVENT_DELETE	An OS_EVENT object was deleted with waiting tasks
223	OS_ERR_TICKHOOK_INVALID	Invalid tick hook.
224	OS_ERR_TICKHOOK_FUNC_INVALID	Invalid tick hook function
225	OS_ERR_NOT_IN_REGION	A function was called without declaring the necessary critical region.
230	OS_ERR_NON_ALIGNED_INVALIDATE	Cache invalidation needs to be cache line aligned
235	OS_ERR_NON_TIMERCYCLES_FUNC	Callback function for timer counter value has not been set. Required by OS_GetTime_us().
236	OS_ERR_NON_TIMERINTPENDING_FUNC	Callback function for timer interrupt pending flag has not been set. Required by OS_GetTime_us().
240	OS_ERR_MPU_NOT_PRESENT	MPU unit not present in the device
241	OS_ERR_MPU_INVALID_REGION	Invalid MPU region index number
242	OS_ERR_MPU_INVALID_SIZE	Invalid MPU region size
243	OS_ERR_MPU_INVALID_PERMISSION	Invalid MPU region permission
244	OS_ERR_MPU_INVALID_ALIGNMENT	Invalid MPU region alignment
245	OS_ERR_MPU_INVALID_OBJECT	OS object is directly accessible from the task which is not allowed
254	OS_ERR_TRIAL_LIMIT	Trial time limit reached

Table 26.1: Error code list (Continued)

The latest version of the defined error table is part of the comment just before the OS_Error() function declaration in the source file OS_Error.c.

26.3 Application defined error codes

The embOS error codes begin at 100. The range 1 - 99 can be used for application defined error codes. With it you can call `OS_Error()` with your own defined error code from your application.

Example

```
#define OS_ERR_APPL         0x02

void UserAppFunc(void) {
  int r;
  r = DoSomething()
  if (r == 0) {
    OS_Error(OS_ERR_APPL)
  }
}
```

Chapter 27

System variables

The system variables are described here for a deeper understanding of how the OS works and to make debugging easier.

27.1 Introduction

Note: Do not change the value of system variables.

These variables are accessible and are not declared constant, but they should only be altered by functions of embOS. However, some of these variables can be very useful, especially the time variables.

27.2   Time variables

27.2.1   OS_Global

OS_Global is a structure which includes embOS internal variables. The following variables OS_Global.Time and OS_Global.TimeDex are part of OS_Global. Any other part of OS_Global is not explained here as they are not required to use embOS.

27.2.2   OS_Global.Time

Description

This is the time variable which contains the current system time in ticks (usually equivalent to ms).

Additional Information

The time variable has a resolution of one time unit, which is normally 1/1000 sec (1 ms) and is normally the time between two successive calls to the embOS timer interrupt handler. Instead of accessing this variable directly, use `OS_GetTime()` or `OS_GetTime32()` as explained in the Chapter *Time measurement* on page 295.

27.2.3   OS_Global.TimeDex

For internal use only. Contains the time at which the next task switch or timer activation is due. If `((int)(OS_Global.Time - OS_Global.TimeDex)) >= 0`, the task list and timer list will be checked for a task or timer to activate. After activation, `OS_Global.TimeDex` will be assigned the time stamp of the next task or timer to be activated.

Note that the value of `OS_Global.TimeDex` may be invalid during task execution. It contains correct values during execution of `OS_Idle()` and when used internally in the embOS scheduler. The value of `OS_Global.TimeDex` should not be used by the application.

If you need any information about the next time-scheduled action from embOS, the function `OS_GetNumIdleTicks()` can be used to get the number of ticks spent idle.

27.3 OS internal variables and data-structures

embOS internal variables are not explained here as they are not required to use embOS. Your application should not rely on any of the internal variables, as only the documented API functions are guaranteed to remain unchanged in future versions of embOS.

Important

Do not alter any system variables.

27.4 OS information routines

API functions

Routine	Description	main	Task	ISR	Timer
OS_GetCPU()	Returns the CPU name.	X	X	X	X
OS_GetLibMode()	Returns the library mode name.	X	X	X	X
OS_GetModel()	Returns the memory model name.	X	X	X	X
OS_GetLibName()	Returns the complete library name.	X	X	X	X
OS_GetVersion()	Returns the OS version.	X	X	X	X

27.4.1 OS_GetCPU()

Description

Returns a pointer to the CPU name string.

Prototype

```
const char* OS_GetCPU(void);
```

Return value

A pointer to the CPU name string.

27.4.2 OS_GetLibMode()

Description

Returns a pointer to the embOS library mode name string.

Prototype

```
const char* OS_GetLibMode(void);
```

Return value

A pointer to the embOS library mode name string including the trial prefix in case of an embOS trial library, e.g. "DP", "R" or "(Trial)SP".

27.4.3 OS_GetModel()

Description

Returns a pointer to the memory model name string.

Prototype

```
const char* OS_GetModel(void);
```

Return value

A pointer to the embOS memory model string, e.g. "v7vL".

27.4.4 OS_GetLibName()

Description

Returns a pointer to the complete embOS library name string including trial prefix, memory model and library mode.

Prototype

```
const char* OS_GetLibName(void);
```

Return value

A pointer to the complete embOS library name including the trial prefix, memory model and library mode, e.g. (Trial)v7vLDP.

27.4.5 OS_GetVersion()

Description

Returns the embOS version number.

Prototype

```
OSUINT OS_GetVersion(void);
```

Return value

Returns the embOS version number, e.g. "41203" for embOS version 4.12c.

Chapter 28

Supported development tools

28.1 Overview

embOS has been developed with and for a specific C compiler version for the selected target processor. Check the file *RELEASE.HTML* for details. It works with the specified C compiler only, because other compilers may use different calling conventions (incompatible object file formats) and therefore might be incompatible. However, if you prefer to use a different C compiler, contact us and we will do our best to satisfy your needs in the shortest possible time.

Reentrance

All routines that can be used from different tasks at the same time must be fully reentrant. A routine is in use from the moment it is called until it returns or the task that has called it is terminated.

All routines supplied with your real-time operating system are fully reentrant. If for some reason you need to have non-reentrant routines in your program that can be used from more than one task, it is recommended to use a resource semaphore to avoid this kind of problem.

C routines and reentrance

Normally, the C compiler generates code that is fully reentrant. However, the compiler may have options that force it to generate non-reentrant code. It is recommended not to use these options, although it is possible to do so in certain circumstances.

Assembly routines and reentrance

As long as assembly functions access local variables and parameters only, they are fully reentrant. Everything else needs to be thought about carefully.

Chapter 29

Source code of kernel and library

29.1 Introduction

embOS is available in two versions:

1. Object version: Object code + hardware initialization source.
2. Full source version: Complete source code.

Because this document describes the object version, the internal data structures are not explained in detail. The object version offers the full functionality of embOS including all supported memory models of the compiler, the debug libraries as described and the source code for idle task and hardware initialization. However, the object version does not allow source-level debugging of the library routines and the kernel.

The full source version gives you complete flexibility: embOS can be recompiled for different data sizes; different compile options give you full control of the generated code, making it possible to optimize the system for versatility or minimum memory requirements. You can debug the entire system and even modify it for new memory models or other CPUs.

The source code distribution of embOS contains the following additional files:

- The `CPU` folder contains all CPU and compiler-specific source code and header files used for building the embOS libraries. It also contains the sample start project, workspace, and source files for the embOS demo project delivered in the Start folder. Generally, you should not modify any of the files in the `CPU` folder.
- The `GenOSSrc` folder contains all embOS sources and a batch file used for compiling all of them in batch mode as described in the following section.

29.2 Building embOS libraries

The embOS libraries can only be built if you have purchased a source code version of embOS.

In the root path of embOS, you will find a DOS batch file `PREP.BAT`, which needs to be modified to match the installation directory of your C compiler. Once this is done, you can call the batch file `M.BAT` to build all embOS libraries for your CPU.

Note: Rebuilding the embOS libraries using the M.bat file will delete and rebuild the entire Start folder. If you made any modifications or built own projects in the Start folder, make a copy of your start folder before rebuilding embOS.

The build process should run without any error or warning message. If the build process reports any problem, check the following:

- Are you using the same compiler version as mentioned in the file `RELEASE.HTML`?
- Can you compile a simple test file after running `PREP.BAT` and does it really use the compiler version you have specified?
- Is there anything mentioned about possible compiler warnings in the *RELEASE.HTML*?

If you still have a problem, let us know.

The whole build process is controlled with a small number of batch files which are located in the root directory of your source code distribution:

- `Prep.bat`: Sets up the environment for the compiler, assembler, and linker. Ensure that this file sets the path and additional include directories which are needed for your compiler. This batch file is the only one which might require modifications to build the embOS libraries. This file is called from `M.bat` during the build process of all libraries.
- `Clean.bat`: Deletes the entire output of the embOS library build process. It is called during the build process, before new libraries are generated. It deletes the `Start` folder. Therefore, be careful not to call this batch file accidentally. This file is called initially by `M.bat` during the build process of all libraries.
- `cc.bat`: This batch file calls the compiler and is used for compiling one embOS source file without debug information output. Most compiler options are defined in this file and generally should not be modified. For your purposes, you might activate debug output and may also modify the optimization level. All modifications should be done with care. This file is called from the embOS internal batch file `CC_OS.bat` and cannot be called directly.
- `ccd.bat`: This batch file calls the compiler and is used for compiling `OS_Global.c` which contains all global variables. All compiler settings are identical to those used in `cc.bat`, except debug output is activated to enable debugging of global variables when using embOS libraries. This file is called from the embOS internal batch file `CC_OS.bat` and cannot be called directly.
- `asm.bat`: This batch file calls the assembler and is used for assembling the assembly part of embOS which contains the task switch functionality. This file is called from the embOS internal batch file `CC_OS.bat` and cannot be called directly.
- `MakeH.bat`: Builds the embOS header file `RTOS.h` which is composed from the CPU/compiler-specific part `OS_Chip.h` and the generic part `OS_RAW.h`. `RTOS.h` is output in the subfolder `Start\Inc`.
- `M1.bat`: This batch file is called from `M.bat` and is used for building one specific embOS library, it cannot be called directly.
- `M.bat`: This batch file must be called to generate all embOS libraries. It initially calls `Clean.bat` and therefore deletes the entire `Start` folder. The generated libraries are then placed in a new `Start` folder, which contains start projects, libraries, header, and sample start programs.

29.3 Major compile time switches

Many features of embOS may be modified using compile-time switches. With each embOS distribution, these switches are preconfigured to appropiate values for each embOS library mode. In case a configuration set is desired that was not covered by the shipped embOS libraries, the compile-time switches may be modified accordingly to create customized configurations on your own authority. According modifications must be done to `OS_RAW.h` and, subsequently, the embOS sources must be recompiled and `RTOS.h` rebuilt to account for the modified switches. Alternatively, compile-time switches may also be passed as parameters during build. In case of doubt, please contact the embOS support for assistance.

29.4 Source code project

All embOS start projects use the embOS libraries instead of the embOS source code. Even the embOS source shipment does not include a project which uses embOS sources.

It can be useful to have the embOS sources instead of the embOS library in a project, e.g. for easier debugging. To do so you just have to exclude or delete the embOS library from your project and add the embOS sources as described below.

The embOS sources consists of the files in the folder *GenOSSrc*, *CPU* and *CPU\OSSrc-CPU*. These files can be found in the embOS source shipment.

Folder	Description
GenOSSrc	embOS generic sources
CPU	RTOS assembler file
CPU\OSScrCPU	CPU and compiler-specific files

Please add all C and assembler files from these folders to your project and add include paths to these folders to your project settings. For some embOS ports it might be necessary to add additional defines to your preprocessor settings. If necessary you will find more information about it in the CPU and compiler-specific embOS manual.

Chapter 30

embOS shipment

This chapter describes the different embOS shipment variants.

30.1 General information

embOS is shipped as a zip file in three different versions: Object code, source code and trial version.

Version	Description
Object code	embOS libraries
Source code	embOS libraries + embOS source code
Trial	embOS trial libraries

30.1.1 Object code shipment

Directory	File	Description
Start\BoardSupport		embOS BSP files and start projects in manufacturer specific subfolders
Start\Inc	RTOS.h BSP.h OS_Config.h	Include files for embOS
Start\Lib		embOS libraries
	embOSView.exe	PC utility for runtime analysis
	Release_embOS.html	embOS release history
	Release_embOS_Generic.html	embOS generic release history
	UM010xx_embOS_CPU_Compiler.pdf	embOS CPU and compiler-specific manual
	UM01001_embOS_Generic.pdf	embOS generic manual

30.1.2 Source code shipment

The source code shipment is the same as the object code shipment plus the embOS sources and batch files to rebuild the embOS libraries.
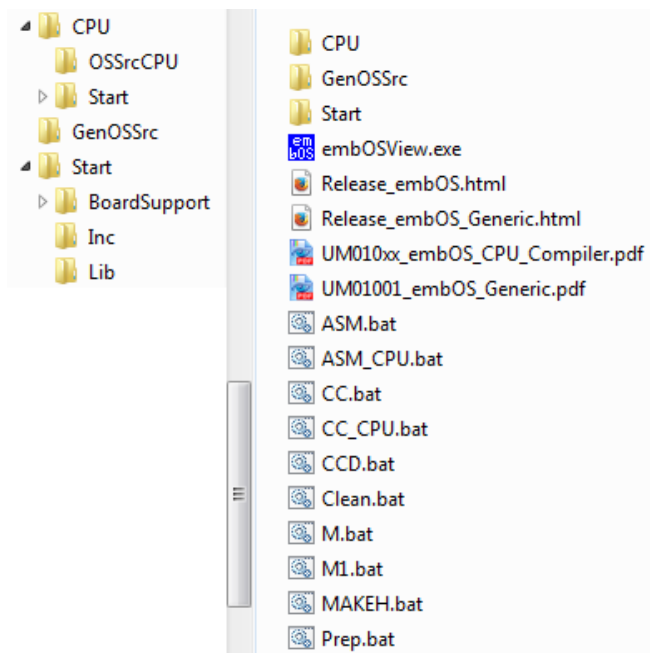
Directory	File	Description
CPU	OSCHIP.h, OS_Priv.h, RTOS.asm	CPU and compiler-specific files
CPU\OSSrcCPU		Additional CPU and compiler-specific source files
Start\BoardSupport		embOS BSP files and start projects in manufacturer specific subfolders
Start\Inc	RTOS.h BSP.h OS_Config.h	Include files for embOS
Start\Lib		embOS libraries
	embOSView.exe	PC utility for runtime analysis
	Release_embOS.html	embOS release history
	Release_embOS_Generic. html	embOS generic release history
	UM010xx_embOS_CPU_Comp iler.pdf	embOS CPU and compiler-specific manual
	UM01001_embOS_Generic. pdf	embOS generic manual
	*.bat	Batch files to rebuild the embOS libraries

30.1.3 Trial shipment

The trial shipment is exactly the same as the object code shipment. The only difference is a 12 hour embOS trial limitation when creating more than three tasks.

Directory	File	Description
Start\BoardSupport		embOS BSP files and start projects in manufacturer specific subfolders
Start\Inc	RTOS.h BSP.h OS_Config.h	Include files for embOS
Start\Lib		embOS libraries
	embOSView.exe	PC utility for runtime analysis
	License.txt	License information
	ReadMe.txt	General trial version information
	Release_embOS.html	embOS release history
	Release_embOS_Generic.html	embOS generic release history
	UM010xx_embOS_CPU_Compiler.pdf	embOS CPU and compiler-specific manual
	UM01001_embOS_Generic.pdf	embOS generic manual

Chapter 31

Update

This chapter describes how to update an existing project with a newer embOS version.

31.1 Introduction

embOS ports are availabe for different CPUs and compiler. Each embOS port has an own version number.

SEGGER updates embOS ports to a newer software version for different reasons. This is done to fix problems or to include the newest embOS features.

Customers which have a valid support and update agreement will be automatically informed about a new version by email. The email includes a download link to the latest version. The version information and complete release history is available for each embOS port at *segger.com*. The latest embOS port version is available as a trial version at *segger.com*.

31.2 How to update an existing project

If an existing project should be updated to a newer embOS version just files have to be replaced.
Please don't use embOS files from different embOS versions in your project!

You should have received the embOS update as a zip file. Unzip this file to the location of your choice and replace all embOS files in your project with the newer files from the embOS update shipment. We recommend to don't modify the embOS files. If you need to modify an embOS file you will have to merge this file with the newer version of the file. Otherwise your modifications will be lost.

In general the following files have to be updated:

File	Location	Description
embOS libraries	Start\Lib	embOS object code libraries
RTOS.h	Start\Inc	embOS header file
OS_Config.h	Start\Inc	embOS config header file
BSP.h	Start\Inc	Board support header file
RTOSInit.c	Start\BoardSupport\...\Setup	Hardware related routines
OS_Error.c	Start\BoardSupport\...\Setup	embOS error routine
Additional files	Start\BoardSupport\...\Setup	CPU and compiler-specific files

31.2.1 My project does not work anymore. What did I do wrong?

The most common mistake is that only the embOS library was updated but not the RTOS.h. Please ensure that the embOS library and the RTOS.h belongs the the same embOS port version. Please also ensure that you also updated other embOS files like OS_Error.c and RTOSInit.c. If you are still having problems don't hesitate to contact SEGGER.

Chapter 32

Support

This chapter should help if any problem occurs. This could be a problem with the tool chain, with the hardware or the use of the embOS functions and it describes how to contact the embOS support.

32.1 Contacting support

If you are a registered embOS user and you need to contact the embOS support please send the following information via email to **support_embos@segger.com**:

- Which embOS do you use? (CPU, compiler).
- The embOS version.
- Your embOS registration number.
- If you are unsure about the above information you can also use the name of the embOS zip file (which contains the above information).
- A detailed description of the problem.
- Optionally a project with which we can reproduce the problem.

Please also take a few moments to help us to improve our service by providing a short feedback when your support case has been solved.

Chapter 33

FAQ (frequently asked questions)

Q: Can I implement different priority scheduling algorithms?
A: Yes, the system is fully dynamic, which means that task priorities can be changed while the system is running (using `OS_SetPriority()`). This feature can be used for changing priorities in a way so that basically every desired algorithm can be implemented. One way would be to have a task control task with a priority higher than that of all other tasks that dynamically changes priorities. Normally, the priority-controlled round-robin algorithm is perfect for real-time applications.

Q: Can I use a different interrupt source for embOS?
A: Yes, any periodic signal can be used, that is any internal timer, but it could also be an external signal.

Q: What interrupt priorities can I use for the interrupts my program uses?
A: Any.

Chapter 34

Glossary

Cooperative multi-tasking	A scheduling system in which each task is allowed to run until it gives up the CPU; an ISR can make a higher priority task ready, but the interrupted task will be returned to and finished first.
Counting semaphore	A type of semaphore that keeps track of multiple resources. Used when a task must wait for something that can be signaled more than once.
CPU	Central Processing Unit. The "brain" of a microcontroller; the part of a processor that carries out instructions.
Critical region	A section of code which must be executed without interruption.
Event	A message sent to a single, specified task that something has occurred. The task then becomes ready.
Interrupt Handler	Interrupt Service Routine. The routine is called by the processor when an interrupt is acknowledged. ISRs must preserve the entire context of a task (all registers).
ISR	Interrupt Service Routine. The routine is called by the processor when an interrupt is acknowledged. ISRs must preserve the entire context of a task (all registers).
Mailbox	A data buffer managed by an RTOS, used for sending messages to a task or interrupt handler.
Message	An item of data (sent to a mailbox, queue, or other container for data).
Multitasking	The execution of multiple software routines independently of one another. The OS divides the processor's time so that the different routines (tasks) appear to be happening simultaneously.
NMI	Non-Maskable Interrupt. An interrupt that cannot be masked (disabled) by software. Example: Watchdog timer interrupt.
Preemptive multi-tasking	A scheduling system in which the highest priority task that is ready will always be executed. If an ISR makes a higher priority task ready, that task will be executed before the interrupted task is returned to.
Process	Processes are tasks with their own memory layout. Two processes cannot normally access the same memory locations. Different processes typically have different access rights and (in case of MMUs) different translation tables.
Processor	Short for microprocessor. The CPU core of a controller

Priority	The relative importance of one task to another. Every task in an RTOS has a priority.
Priority inversion	A situation in which a high priority task is delayed while it waits for access to a shared resource which is in use by a lower priority task. A task with medium priority in the ready state may run, instead of the high priority task. embOS avoids this situation by priority inheritance.
Queue	Like a mailbox, but used for sending larger messages, or messages of individual size, to a task or an interrupt handler.
Ready	Any task that is in "ready state" will be activated when no other task with higher priority is in "ready state".
Resource	Anything in the computer system with limited availability (for example memory, timers, computation time). Essentially, anything used by a task.
Resource semaphore	A type of semaphore used for managing resources by ensuring that only one task has access to a resource at a time.
RTOS	Real-time Operating System.
Running task	Only one task can execute at any given time. The task that is currently executing is called the running task.
Scheduler	The program section of an RTOS that selects the active task, based on which tasks are ready to run, their relative priorities, and the scheduling system being used.
Semaphore	A data structure used for synchronizing tasks.
Software timer	A data structure which calls a user-specified routine after a specified delay.
Stack	An area of memory with LIFO storage of parameters, automatic variables, return addresses, and other information that needs to be maintained across function calls. In multitasking systems, each task normally has its own stack.
Superloop	A program that runs in an infinite loop and uses no real-time kernel. ISRs are used for real-time parts of the software.
Task	A program running on a processor. A multitasking system allows multiple tasks to execute independently from one another.
Thread	Threads are tasks which share the same memory layout. Two threads can access the same memory locations. If virtual memory is used, the same virtual to physical translation and access rights are used (c.f. Thread, Process)

Tick   The OS timer interrupt. Usually equals 1 ms.

Time slice   The time (number of ticks) for which a task will be executed
                        until a round-robin task change may occur.

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