

embOS

Real Time Operating System

CPU & Compiler specifics for
AVR32UC cores using
AVR32 Studio and GNU tool-
chain

Document revision 0

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A product of SEGGER Microcontroller GmbH & Co. KG

www.segger.com

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Software and 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.

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Software	Manual	Date	By	Description
3.82r	0	110131	TS	Chapter "Interrupts" updated.
3.60c	0	080411	TS	Initial Version.

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.
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 microcontrollers, 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:

<http://www.segger.com>

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. Starterkits, eval- and trial-versions are available.



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. The profiling PC tool embOSView is included.



emFile

File system

emFile is an embedded file system with FAT12, FAT16 and FAT32 support. emFile has been optimized for minimum memory consumption in RAM and ROM while maintaining high speed. Various Device drivers, e.g. for NAND and NOR flashes, SD/MMC and CompactFlash cards, are available.



USB-Stack

USB device stack

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

SEGGER TOOLS

Flasher

Flash programmer

Flash Programming tool primarily for microcontrollers.

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

1	Introduction	7
2	Using embOS with AVR32 Studio and GNU toolchain	9
2.1	Installation	10
2.2	First steps	11
2.3	The sample application Main.c	12
2.4	Stepping through the sample application using AVR-JTAGICE-MKII.....	13
3	Build your own application	19
3.1	Required files for an embOS application	20
3.2	Change library mode	21
3.3	Select an other CPU	21
4	AVR32UC specifics.....	23
4.1	CPU modes	24
4.2	Available libraries	24
4.3	Application mode and supervisor mode.....	24
5	Stacks	25
5.1	Task stack for AVR32UC	26
5.2	System stack for AVR32UC	26
5.3	Interrupt stack for AVR32UC	26
5.4	Stack specifics of the AVR32UC family	26
6	Interrupts.....	27
6.1	What happens when an interrupt occurs	28
6.2	Defining interrupt handlers in "C".....	29
6.3	Defining zero latency interrupt handlers.....	30
6.4	OS_ISRInit(): Initialize the interrupt controller	31
6.5	OS_ISRSetGroupPrio(): Set a group priority	32
6.6	OS_SetFastIntPriorityLimit(): Setting the interrupt priority limit.....	33
6.7	Interrupt stack switching	34
7	STOP / WAIT mode	35
7.1	Saving power	36
8	Technical data.....	37
8.1	Memory requirements	38
9	Files shipped with embOS	39
9.1	Files included in embOS.....	40

Chapter 1

Introduction

This guide describes how to use **embOS** Real Time Operating System for the AVR32UC series of microcontrollers using AVR32 Studio and GNU toolchain.

How to use this manual

This manual describes all CPU and compiler specifics of **embOS** using AVR32UC based controllers with AVR32 Studio and GNU toolchain. Before actually using **embOS**, you should read or at least glance through this manual in order to become familiar with the software.

Chapter 2 gives you a step-by-step introduction, how to install and use **embOS** for AVR32UC using AVR32 Studio and GNU toolchain. If you have no experience using **embOS**, you should follow this introduction, because it is the easiest way to learn how to use **embOS** in your application.

Most of the other chapters in this document are intended to provide you with detailed information about functionality and fine-tuning of **embOS** for the AVR32UC based controllers using AVR32 Studio and GNU toolchain.

Chapter 2

Using embOS with AVR32 Studio and GNU toolchain

The following chapter describes how to start with and use **embOS** for AVR32UC and AVR32 Studio and GNU toolchain. You should follow these steps to become familiar with **embOS** for AVR32UC and AVR32 Studio and GNU toolchain.

2.1 Installation

embOS is shipped on CD-ROM or as a zip-file in electronic form.

In order to install it, proceed as follows:

If you received a CD, copy the entire contents to your harddrive into any folder of your choice. When copying, please keep all files in their respective sub directories. Make sure the files are not read only after copying.

If you received a zip-file, please extract it to any folder of your choice, preserving the directory structure of the zip-file.

Assuming that you are using AVR32 Studio and GNU toolchain to develop your application, no further installation steps are required. You will find a prepared sample start application, which you should use and modify to write your application. So follow the instructions of the next heading *First steps* on page 11.

You should do this even if you do not intend to use the AVR32 Studio for your application development in order to become familiar with **embOS**.

If for some reason you will not work with AVR32 Studio, you should:

Copy either all or only the library-file that you need to your work-directory. Also copy the entire CPU specific subdirectory and the **embOS** header file `RTOS.h`. This has the advantage that when you switch to an updated version of **embOS** later in a project, you do not affect older projects that use **embOS** also.

embOS does in no way rely on AVR32 Studio, it may be used without the project manager using batch files or a make utility without any problem.

2.2 First steps

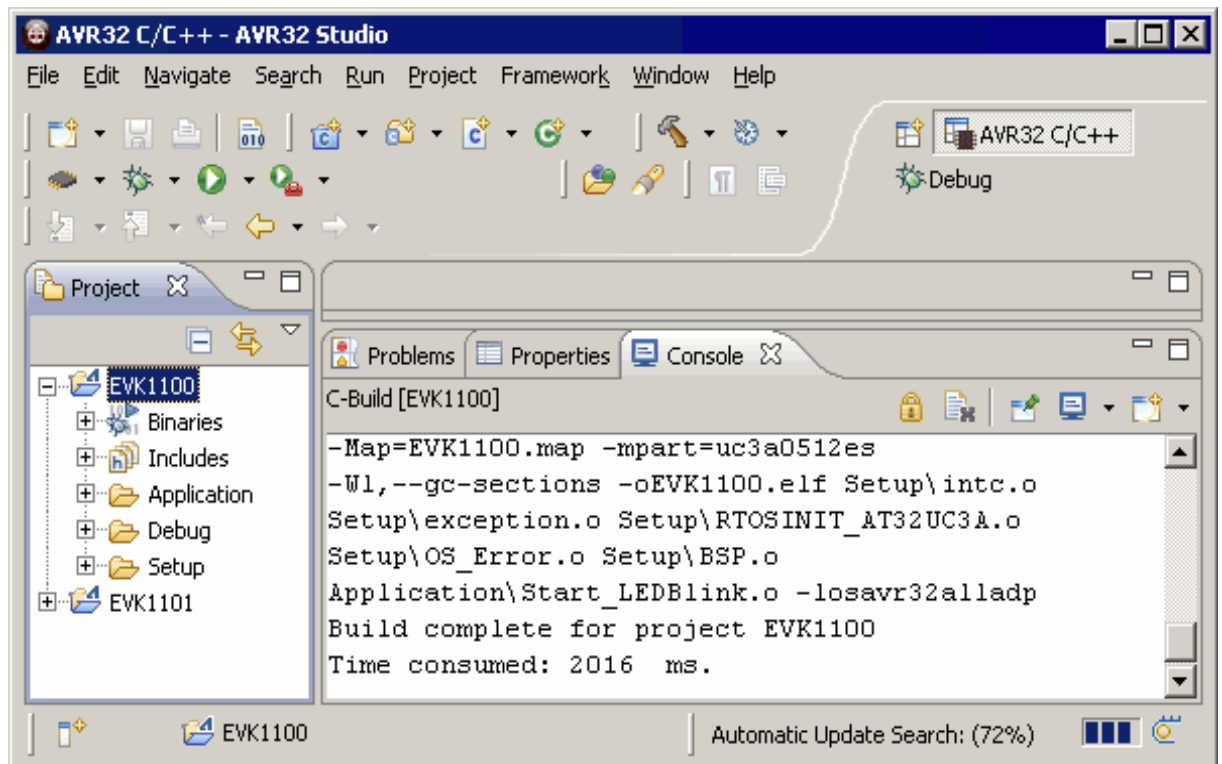
After installation of **embOS** (See "Installation" on page 10.) you are able to create your first multitasking application. You received a ready to go sample start workspaces and projects and every other files needed in the subfolder "Start". It is a good idea to use one of them as a starting point for all of your applications.

The subfolder "BoardSupport" contains the workspaces and projects which are located in manufacturer- and CPU-specific subfolders:

To get your first multitasking application running, you should proceed as follows:

- Create a work directory for your application, for example C:\Work
- Copy the whole folder "Start" which is part of your **embOS** distribution into your work directory
- Clear the read only attribute of all files in the new "Start" folder
- Start AVR32 Studio and switch your workspace directory to "Start\BoardSupport\Atmel\"
- Open one of the projects and refresh the folders.
- Build the project.

After building the start project your screen should look like follows:



For additional information you should open the `ReadMe.txt` file which is part of every specific project.

The ReadMe file describes the different configurations of the project and gives additional information about specific hardware settings of the supported evalboards, if required.

2.3 The sample application Main.c

The following is a printout of the sample application `main.c`. It is a good startingpoint for your application. (Please note that the file actually shipped with your port of **embOS** may look slightly different from this one)

What happens is easy to see:

After initialization of **embOS**; two tasks are created and started.

The two tasks are activated and execute until they run into the delay, then suspend for the specified time and continue execution.

```

/*****
*           SEGGER MICROCONTROLLER GmbH & Co. KG           *
* Solutions for real time microcontroller applications *
*****
File      : Main.c
Purpose  : Skeleton program for OS
-----END-OF-HEADER-----*/
#include "RTOS.H"

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

void HPTask(void) {
    while (1) {
        OS_Delay (10);
    }
}

void LPTask(void) {
    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;
}

```

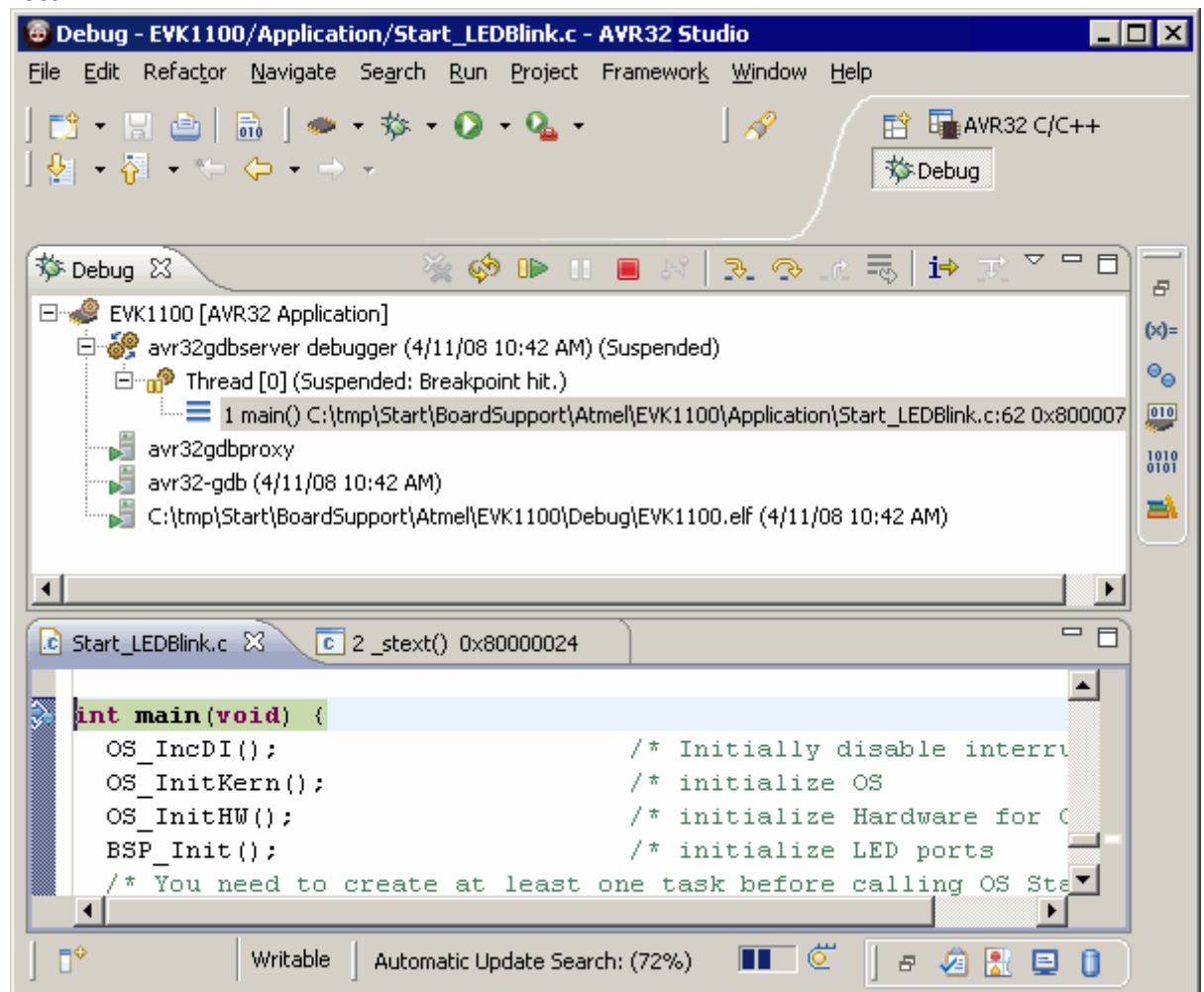
2.4 Stepping through the sample application using AVR-JTAGICE-MKII

When starting the debugger, you will usually see the main function (very similar to the screenshot below). In some debuggers, you may look at the startup code and have to set a breakpoint at main. Now you can step through the program. `OS_IncDI()` initially disables interrupts.

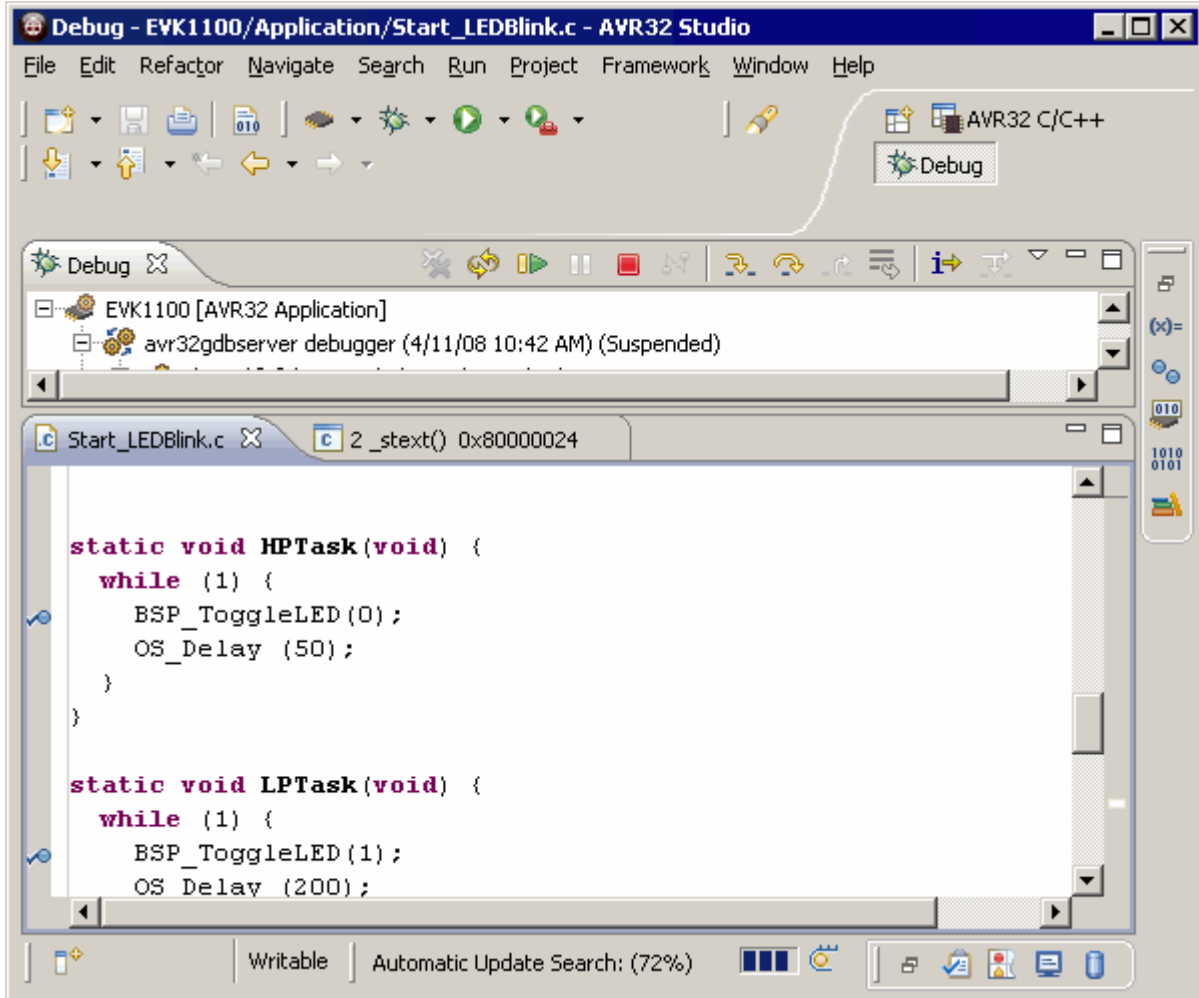
`OS_InitKern()` is part of the *embOS* library; you can therefore only step into it in disassembly mode. It initializes the relevant OS-Variables. Because of the previous call of `OS_IncDI()`, interrupts are not enabled during execution of `OS_InitKern()`.

`OS_InitHW()` is part of `RTOSInit_*.c` and therefore part of your application. Its primary purpose is to initialize the hardware required to generate the timer-tick-interrupt for *embOS*. Step through it to see what is done.

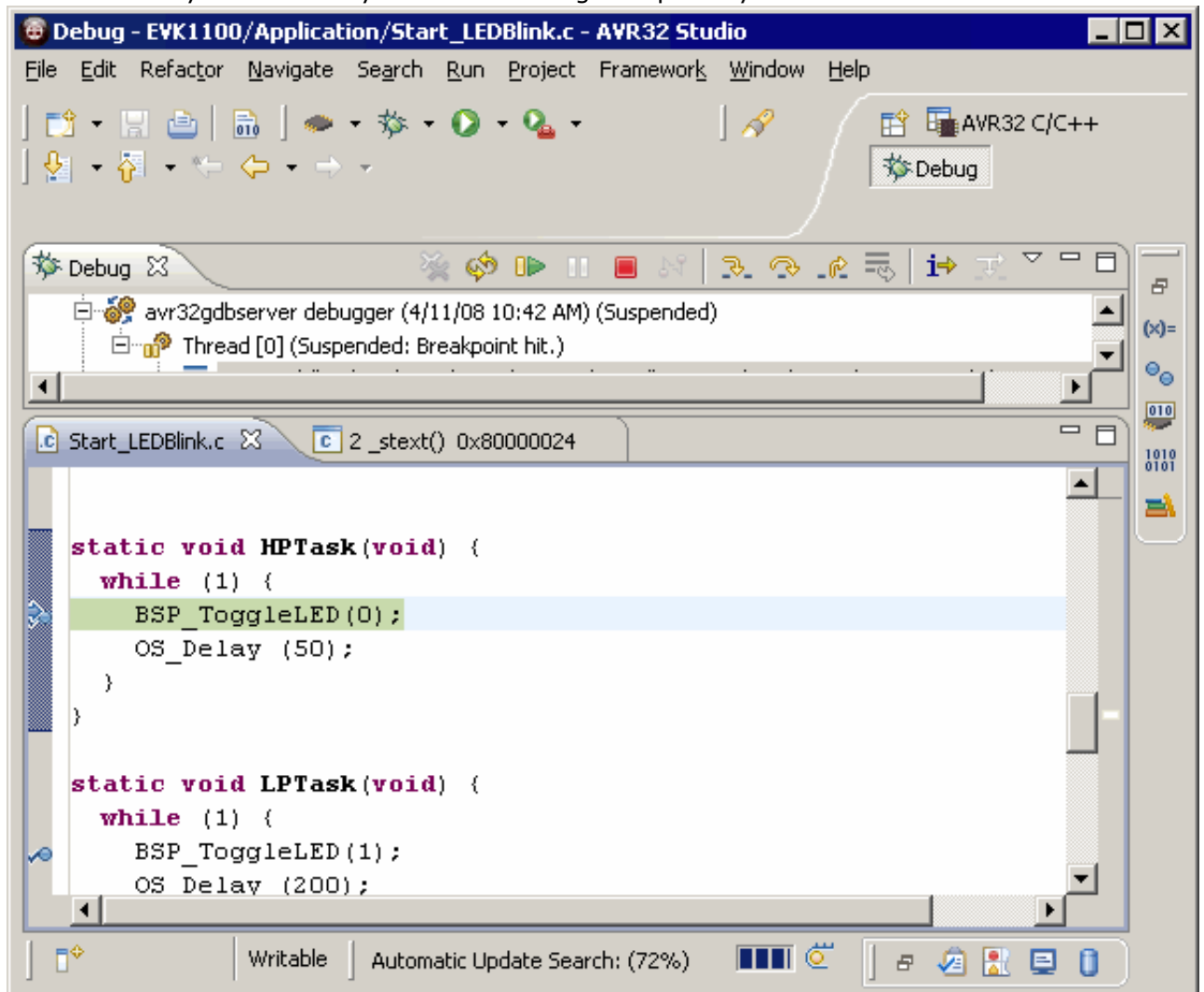
`OS_Start()` should be the last line in main, since it starts multitasking and does not return.



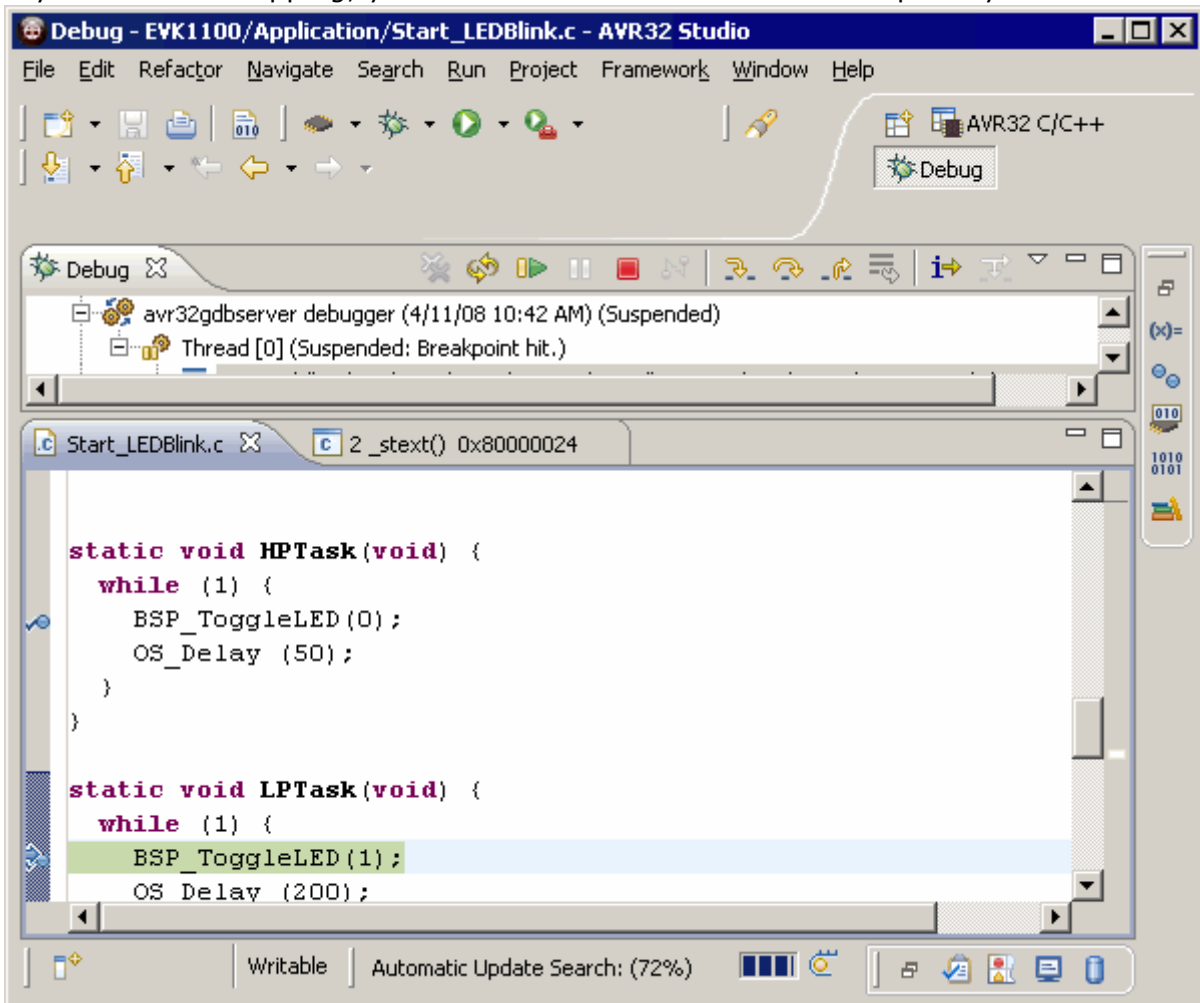
Before you step into `OS_Start()`, you should set two break points in the two tasks as shown below.



As `OS_Start()` is part of the **embOS** library, you can step through it in disassembly mode only. You may press **GO**, step over `OS_Start()`, or step into `OS_Start()` in disassembly mode until you reach the highest priority task.

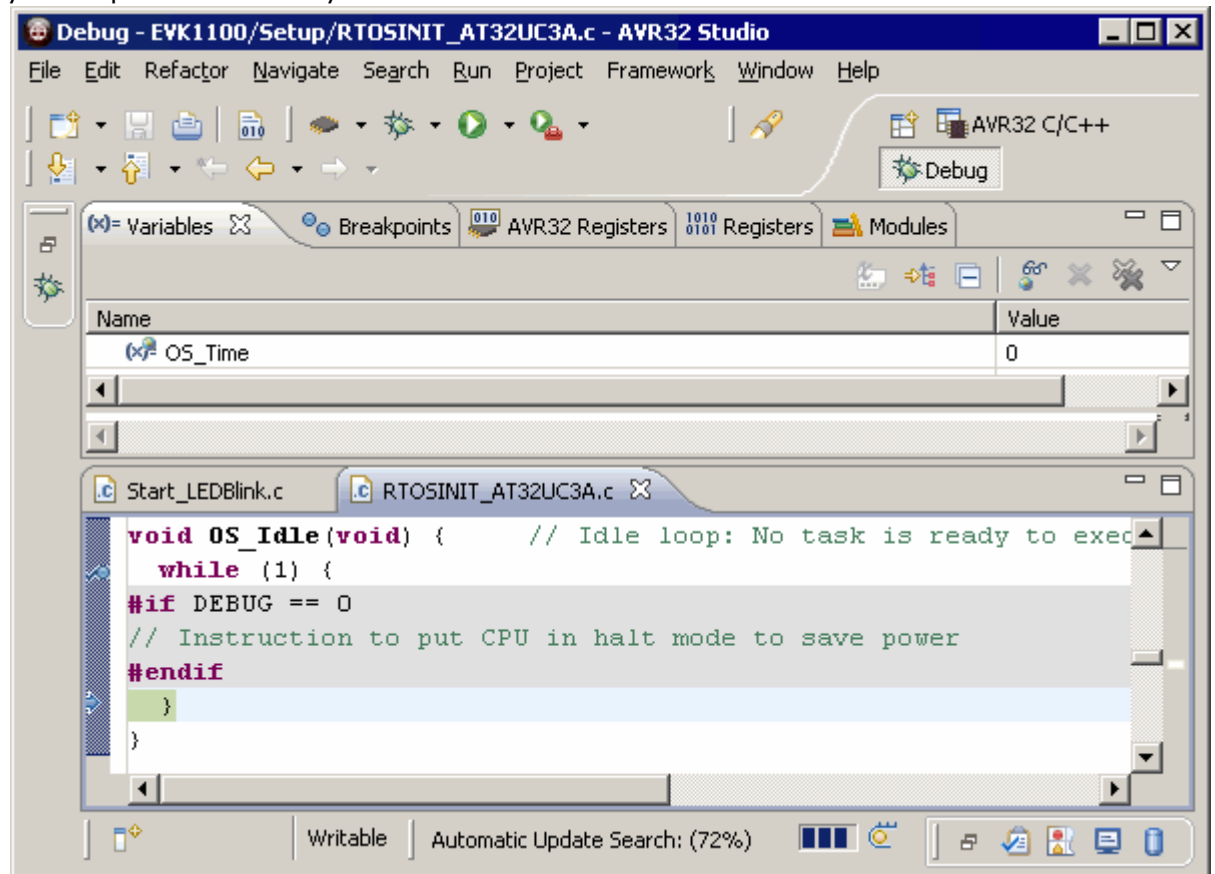


If you continue stepping, you will arrive in the task with lower priority:



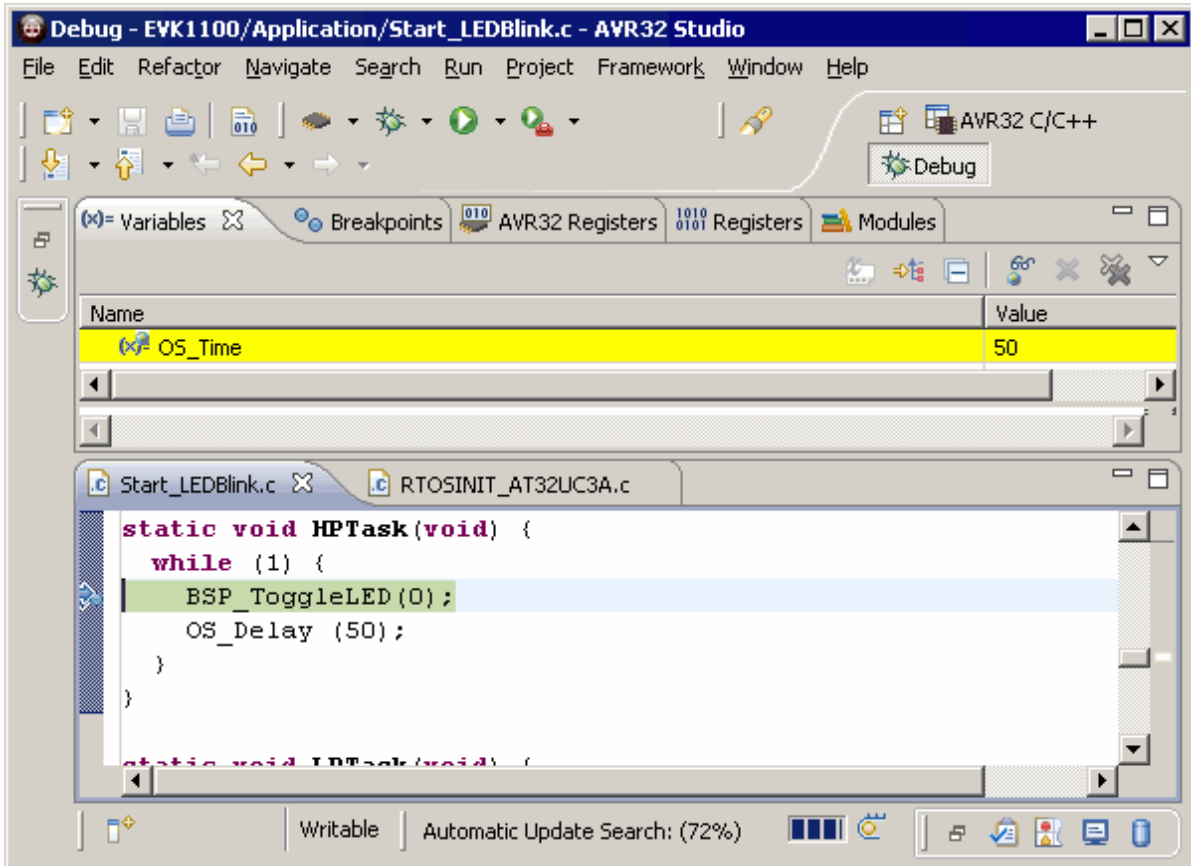
Continuing to step through the program, there is no other task ready for execution. **embOS** will therefore start the idle-loop, which is an endless loop which is always executed if there is nothing else to do (no task is ready, no interrupt routine or timer executing).

You will arrive there when you step into the `OS_Delay()` function in disassembly mode. `OS_Idle()` is part of `RTOSInit*.c`. You may also set a breakpoint there before you step over the delay in `LPTask`.



If you set a breakpoint in one or both of our tasks, you will see that they continue execution after the given delay.

As can be seen by the value of **embOS** timer variable `OS_Time`, shown in the watch window, HPTask continues operation after expiration of the 50 ms delay.



Chapter 3

Build your own application

To build your own application, you should always start with a copy of the sample start workspace and project. Therefore copy the entire folder "Start" from your **embOS** distribution into a working folder of your choice and then modify the start project there. This has the advantage, that all necessary files are included and all settings for the project are already done.

3.1 Required files for an embOS application

To build an application using *embOS*, the following files from your *embOS* distribution are required and have to be included in your project:

- **RTOS.h** from subfolder `Inc\`
This header file declares all *embOS* API functions and data types and has to be included in any source file using *embOS* functions.
- **RTOSInit_*.c** from one target specific `"BoardSupport*\\"-subfolder`.
It contains the hardware dependent initialization code for the specific CPU, the *embOS* timer and optional UART for `embOSView`.
- **RTOSVect.c** and **RTOSVect.h** from one target specific `"BoardSupport*\\"-subfolder`. It contains the interrupt vector definitions.
- **exception.s** from one target specific `"BoardSupport*\\"-subfolder`. It contains the low level interrupt handler.
- **crt0.x** from one target specific `"BoardSupport*\\"-subfolder`. It contains the startup code.
- One *embOS* library from the `"Lib\"-subfolder`.
- **OS_Error.c** from one target specific `"BoardSupport*\\"-subfolder`.
The error handler is used if any *embOS* library other than the Release build library is used in your project.

When you decide to write your own startup code ensure that non initialized variables are initialized with zero, according to "C" standard. This is required for some *embOS* internal variables. Also ensure, that the EVBA register is initialized.

Your `main()` function has to initialize *embOS* by call of `OS_InitKern()` and `OS_InitHW()` prior any other *embOS* functions except `OS_IncDI()` are called.

You should then modify or replace the `main.c` source file in one target specific `"BoardSupport*\\"-subfolder`.

3.2 Change library mode

For your application you may wish to choose an other library. For debugging and program development you should use an **embOS**-debug library. For your final application you may wish to use an **embOS**-release library or a stack check library.

Therefore you have to select or replace the **embOS** library in your project or target:

- If your wished library is already contained in your project, just select the appropriate configuration.
- To add a library, change the project settings accordingly.
- Check and set the appropriate `OS_LIBMODE_*` define which you would like to use for debug and release builds and modify the `OS_Config.h` file accordingly.

3.3 Select an other CPU

embOS for AVR32UC and AVR32 Studio and GNU toolchain contains CPU specific code for various AVR32UC CPUs. Manufacturer- and CPU specific sample start workspaces and projects are located in the subfolders of the "BoardSupport" folder.

To select a CPU which is already supported, just select the appropriate project from a CPU specific folder.

If your CPU is currently not supported, examine all RTOSInit files in the CPU specific subfolders and select one which almost fits your CPU. You may have to modify `OS_InitHW()`, `OS_COM_Init()`, the interrupt service routines for **embOS** timer tick and communication to `embOSView`.

Chapter 4

AVR32UC specifics

4.1 CPU modes

embOS supports nearly all memory and code model combinations that GNU's C-Compiler supports.

4.2 Available libraries

embOS for GNU compiler comes with 7 different libraries, one for each library mode. The libraries are named as follows:

`libosAVR32UC<LibMode>.a`

Parameter	Meaning	Values
LibMode	Library mode	XR: Extreme release
		R: Release
		S: Stack check
		D: Debug
		SP: Stack check + profiling
		DP: Debug + profiling
		DT: Debug + trace

Example:

`libosAVR32UC_DP.a` is the library for a project using AVR32UC core and debug and profiling features of *embOS*.

4.3 Application mode and supervisor mode

All *embOS* tasks run in application mode while interrupts and *embOS* system run in supervisor mode. Interrupts require only space on the supervisor stack. Therefore no extra space for interrupts on the task stacks is needed.

Chapter 5

Stacks

5.1 Task stack for AVR32UC

All *embOS* tasks execute in application mode. Every *embOS* task has its own individual stack which can be located in any memory area. The required stacksize for a task is the sum of the stack size used by all functions for local variables and parameter passing, plus basic stack size.

The basic stack size is the size of memory required to store the registers of the CPU plus the stack size required by *embOS*-routines.

For the AVR32UC, this minimum basic task stack size is about 44 bytes.

5.2 System stack for AVR32UC

The *embOS* system executes in supervisor mode. The minimum system stack size required by *embOS* is about 144 bytes (stack check & profiling build). However, since the system stack is also used by the application before the start of multitasking (the call to `OS_Start()`), and because software-timers and "C"-level interrupt handlers also use the systemstack, the actual stack requirements depend on the application.

5.3 Interrupt stack for AVR32UC

If a normal hardware exception occurs, the AVR32UC core switches to IRQ mode, which uses the supervisor stack pointer. As a result, only scratch registers are saved onto the IRQ stack. Every interrupt requires 80 bytes on the interrupt stack.

The maximum supervisor stack size required by the application can be calculated as maximum interrupt nesting level * 80 bytes.

5.4 Stack specifics of the AVR32UC family

Interrupts require space on the supervisor stack. The supervisor stack is used to store contents of scratch registers, the ISR itself uses supervisor stack. The Supervisor stack is also used during startup, `main()`, *embOS* internal functions and software timers.

All other stacks are not initialized and not used by *embOS*. If required by the application, the startup function and linker command files have to be modified to initialize the stacks.

Chapter 6

Interrupts

6.1 What happens when an interrupt occurs

- The CPU-core receives an interrupt request
- If the interrupt is not masked the interrupt is accepted
- The hardware automatically sets the mask bits in the status register
- The Status Register, Program Counter, LR and R8-R12 are stored on the supervisor stack
- One of the low level interrupt handler is called, which calls OS_CallISR()/OS_CallNestableISR.
- OS_CallISR()/OS_CallNestableISR calls OS_ISRHandler()
- OS_ISRHandler() calls the user defined interrupt handler.
- Return from interrupt.
- For details, please refer to the AVR32UC user manual

6.2 Defining interrupt handlers in "C"

Interrupt handlers called from the embOS interrupt handler in RTOSInit*.c are just normal C-functions which do not take parameters and do not return any value. **embOS** provides support for each of the four interrupt levels.

embOS interrupt handler are normal C functions and have to be used for interrupt sources running at all priorities up to the user definable interrupt priority level limit for zero latency interrupts.

Example of an embOS interrupt handler

Simple interrupt routine:

```
void OS_Systick(void) {
    OS_SetCompare(OS_TIMER_RELOAD);
    OS_TICK_Handle();
}
```

The default user definable interrupt priority level limit is 1, which means, that interrupts with priority level 0 and 1 are disabled by embOS while interrupts running at priority level 2 and 3 are never disabled by embOS.

The vector table is located in RTOSVect.c. Please insert your user interrupt handler there.

Example

```
/******
 *
 *      Exception vector table
 */
const OS_ISR_HANDLER* vector_table[] = {
    //(const OS_ISR_HANDLER*) COMPARE_IRQHandler, // Group 0 Line 0 SYSBLOCK
    (const OS_ISR_HANDLER*) OS_Systick,
    ...
    ...
}
```

When no user interrupt handler is defined the default interrupt handler `_IllegalException()` is called.

The low level assembler interrupt handler in exception.s calls `OS_CallISR()` or `OS_CallNestableISR()`.

Differences between `OS_CallISR()` and `OS_CallNestableISR()`

`OS_CallISR()` should be used as 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 "zero latency" interrupt priority level, thus locking any other embOS interrupt, Zero latency interrupts are never disabled.

`OS_CallNestableISR()` should be used as 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.

6.3 Defining zero latency interrupt handlers

Zero latency interrupt handler have to be used for interrupt sources running at priorities above the user definable interrupt priority limit.

The rules for a *Zero latency interrupt* handler are as follows:

- Local variables may be used.
- Other functions may be called.
- **embOS** functions must not be called, nor direct, neither indirect.
- The priority of the interrupt has to be above the user definable priority limit for fast interrupts.

Zero latency interrupt handler functions can be just normal C-functions or also assembler functions which are called from of one the low level interrupt handler in exception.s.

Example of an embOS zero latency interrupt handler

```
void UserZeroLatencyFunc() {  
    ...  
}  
  
_int3:  
    mov     r12, 3  
    call   UserZeroLatencyFunc  
    rete
```

The default zero latency priority limit is 1, which means, that interrupts running at priority level 2 and 3 are never disabled by embOS.

6.4 OS_ISRInit(): Initialize the interrupt controller

Description

OS_ISRInit() is used to initialize the interrupt handling.

Prototype

```
void OS_ISRInit(void)
```

Additional Information

To initialize the interrupt controller and the embOS interrupt handling ensure that this function is called before the start of embOS. It sets all interrupt group priority register to interrupt priority 0 and low level interrupt handler for interrupt priority 0.

6.5 OS_ISRSetGroupPrio(): Set a group priority

Description

OS_ISRSetGroupPrio() is used to set an interrupt priority for a interrupt group.

Prototype

```
void OS_ISRSetGroupPrio(OS_U32 ISRGroup, OS_U32 Prio);
```

Parameter	Description
ISRGroup	Index of the interrupt group.
Prio	Interrupt priority, $0 \leq \text{Prio} \leq 3$

Table 6.1: OS_ISRSetGroupPrio() parameter list

Additional Information

Each interrupt group has its own interrupt priority. The default group interrupt priority is 0.

6.6 OS_SetFastIntPriorityLimit(): Setting the interrupt priority limit

The interrupt priority limit for zero latency interrupts is set to 1 by default. This means, all interrupts with higher priority from 2 to 3 will never be disabled by **embOS**.

Description

OS_SetFastIntPriorityLimit() is used to set the interrupt priority limit between zero latency interrupts and lower priority **embOS** interrupts.

Prototype

```
void OS_SetFastIntPriorityLimit(unsigned int Prio)
```

Parameter	Description
Prio	The highest value useable as priority for embOS interrupts. All interrupts with higher priority are never disabled by embOS . Valid range: 0 < Priority <= 3

Table 6.2: OS_ARM_EnableISRSource() parameter list

Additional Information

To disable zero latency interrupts at all, the priority limit may be set to 3 which is the highest interrupt priority for interrupts. To modify the default priority limit, OS_SetFastIntPriorityLimit() should be called before **embOS** was started.

6.7 Interrupt stack switching

Since AVR32UC core based controllers have a separate stack pointer for interrupts, there is no need for explicit stack-switching in an interrupt routine. The routines `OS_EnterIntStack()` and `OS_LeaveIntStack()` are supplied for source compatibility to other processors only and have no functionality. The AVR32UC supervisor stack is used for interrupt handler.

Chapter 7

STOP / WAIT mode

7.1 Saving power

In case your controller does support some kind of power saving mode, it should be possible to use it also with **embOS**, as long as the timer keeps working and timer interrupts are processed. To enter that mode, you usually have to implement some special sequence in function `OS_Idle()`, which you can find in **embOS** module `RTOSInit_*.c`.

Chapter 8

Technical data

8.1 Memory requirements

These values are neither precise nor guaranteed but they give you a good idea of the memory-requirements. They vary depending on the current version of **embOS**. Using AVR32UC mode, the minimum ROM requirement for the kernel itself is about 2.500 bytes. In the table below, you find the minimum RAM size for **embOS** resources. The sizes depend on selected **embOS** library mode; the table below is for a release build.

embOS resource	RAM [bytes]
Task control block	36
Resource semaphore	16
Counting semaphore	8
Mailbox	24
Software timer	20

Chapter 9

Files shipped with embOS

9.1 Files included in embOS

Directory	File	Explanation
root	*.pdf	Generic API and target specific documentation
root	embOSView.exe	Utility for runtime analysis, described in generic documentation
root	Release.html	Version control document
.metadata	*.*	AVR32 Studio workbench files
Start\Inc	RTOS.h	Include file for embOS , to be included in every "C"-file using embOS -functions
Start\Lib	osavr32*.r82	embOS libraries
Start\Setup	OS_Error.c	embOS runtime error handler used in stack check or debug builds
Start\Setup	exception.s	Low level interrupt handler and vector table
Start\Setup	RTOSVect.c	Interrupt handler functions
Start\Setup	RTOSVect.h	Interrupt defines
Start\Setup	crt0.x	Startup code
Start\Setup	RtosInit*.c	CPU specific hardware routines
Start\Application	*.c	Sample frame program to serve as a start

Any additional files shipped serve as example.

Index

I

Installation	10
Interrupt stack	26, 34
IRQ_STACK	26

M

Memory models	24
Memory requirements	38

O

OS_ARM_InstallISRHandler()	32
----------------------------------	----

S

Stacks	25
CSTACK	26
Interrupt stack	26
System stack	26
STOP / WAIT mode	35
Syntax, conventions used	3
System stack	26

