ROSA

Marcus Jansson <mjansson256@yahoo.se>

November 7, 2010

`A tiny`

`Real time Operating System for AVR32`

Contents

1 Description

ROSA is a small cooperative real time kernel for AVR32 UC3A processors. It is aimed to be used on the Atmel EVK1100 platform.

This document is a description of ROSA's support for pseudo parallel execution of user programs. By "pseudo parallel" we mean it "seems" like the programs work in parallel. But as the UC3A processor is a single core processor, only one program at a time can be executed.

A small operating system like ROSA can be used to enhance the structure of a complex program. This is done by breaking down the complex program into several smaller programs.

Compared to other light weight kernels, ROSA is a tiny kernel with very limited functionality.

1.1 Hardware

ROSA runs on the EVK1100 platform. Among other things the hardware features 512 kB flash memory, 64 kB internal RAM memory, a 12 Mhz external crystal, user LEDs, user buttons, serial communication etc.

1.1.1 I/O drivers

ROSAs I/O drivers support the following hardware functions on EVK1100:

- LEDs.
- Buttons.
- Mini-joystick.
- Potentiometer.
- Serial port.

1.2 Software

1.2.1 ROSA source code

The ROSA source code is available in the rosa/src directory which makes it possible to expand ROSA with more services. Examples of expansions that can be done:

- Support for time sharing.
- Support for priority driven scheduling.
- Support for communication mechanisms, semaphores, monitors, mailboxes and rendez-vouz.
- ...

1.2.2 Directory structure

The ROSA software consists of the following directories and files:

- rosa/
  - bin/ - Destination for the binary files.
  - cpu/ - The startup and linker scripts.
  - doc/ - Documentation about ROSA.
  - include/ - The header file directory.
    - drivers/ - Header files for the drivers.
    - kernel/ - Header files for the kernel.
  - src/ - The source file directory.
    - main.c - The main program for ROSA.
    - rosa_config.h - User configuration of ROSA.
    - kernel/ - Kernel source directory.
      - rosa_ker.c - Kernel C source.
      - rosa_ker_asm.S - Kernel assembler source.
      - rosa_scheduler.c - Scheduler specific source.
      - rosa_int.c - Interrupt specific source.
      - rosa_int_asm.S - Interrupt assembler source.
      - rosa_tim.c - Timer specific soruce.
      - rosa_tim_asm.S - Timer assembler source.
    - drivers/
      - button.c - Push button driver.
      - delay.c - Delay functions.
      - gpio.c - GPIO driver.
      - led.c - LED driver.
      - pot.S - Potentiometer driver.
      - usart.c - Serial communication driver.
  - Makefile - Script for the ′make′ program.

1.3 How to compile ROSA

1.3.1 AVR32 Studio

AVR32 Studio can be used to compile ROSA. First the ROSA project must be set up properly. This is done by importing the rosa/ directory into AVR32 Studio. Either from a unpacked source directory or a zip packed file containing the project:

- Select "File/Import..."
- Select "Existing project into workspace"
- Browse for the ROSA directory or a .zip package containing a ROSA project.
- Select the ROSA project.
- Select "Copy project into workspace."
- Click "Finish".

Compiling is done by the normal AVR32 studio compile procedure.

Figure 1: Import existing project into workspace

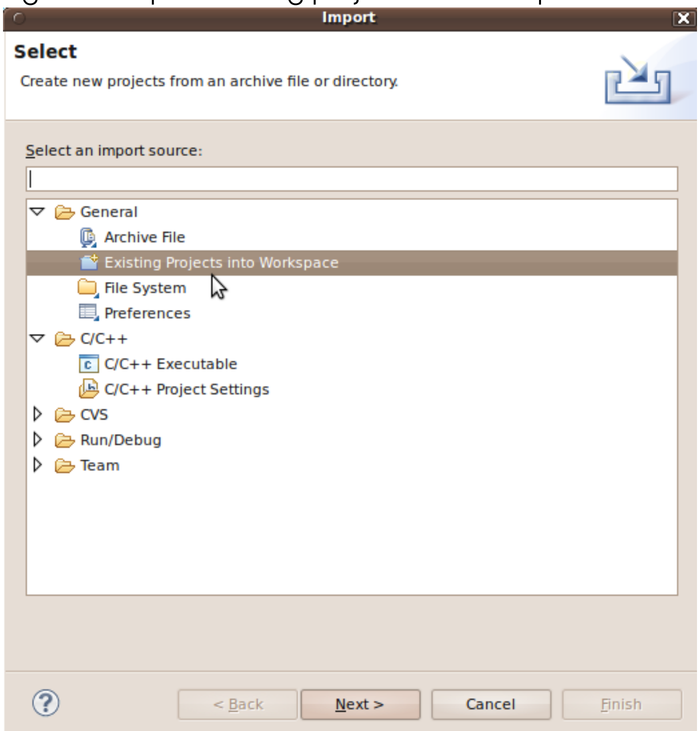
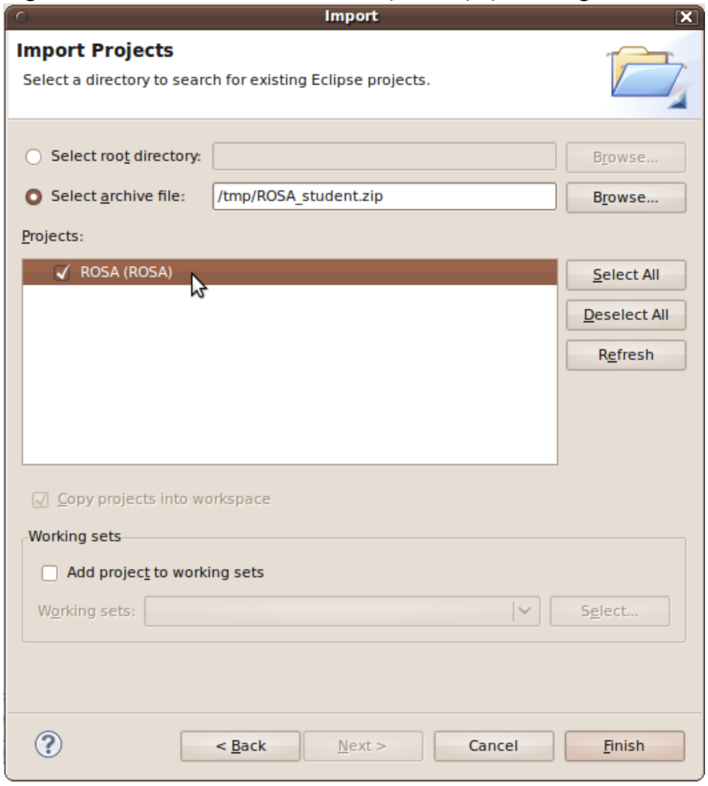


Figure 2: Select ROSA directory or .zip package



1.4 How to program ROSA onto the EVK1100

1.4.1 AVR32 Studio

AVR32 Studio can also be used for programming the MCU flash by the normal AVR32 Studio programming procedure.

2 ROSA kernel functionality

This is a brief description of the kernel functionality.

2.1 Kernel

The ROSA kernel is the controller software and supervisor of the system. As a user of ROSA you create and install "tasks" into the ROSA kernel. When ROSA is started one of the tasks is picked up and execution is turned over to this task.

From time to time the task needs to give up its execution and let other tasks run. The kernel perform a task context switch, thus allowing the next waiting task to run.

2.1.1 Kernel functions

All kernel functions that the user can call are prefixed *ROSA_*, e.g. *ROSA_init()*.

Part of the ROSA kernel is written in assembler. In order to be able to share the same TCB structure from both assemebler and C the kernel utilizes offsets found in the file rosa/src/include/kernel/rosa_off.i. These offsets are used by the assembler routines to access the elements in the TCB block.

2.1.2 Kernel configuration

A few user configurations can be done through the *rosa_config.h* file. For example the timer period and the USART baudrate is defined here. The default is 57600 baud.

2.2 Task

A task is a program running under the kernels supervision. A task consists of:

- A TCB.
- A data area.
- Program code.

2.2.1 TCB

The TCB contain information and/or space for:

- Task identification (id/name).
- Address to the next TCB in the TCB-list.
- The start address of the task.
- Where the data area is located and its size.
- The current state, which is described by the return address and the status register (SR).
- All necessary CPU registers.

The exact definition of the TCB is found in the file rosa/src/include/kernel/rosa_def.h.

2.2.2 Data area

The data area is the private stack for the task. The data area contains temporary data etc. for the task. The stack size must be suitable to hold all temporary data.

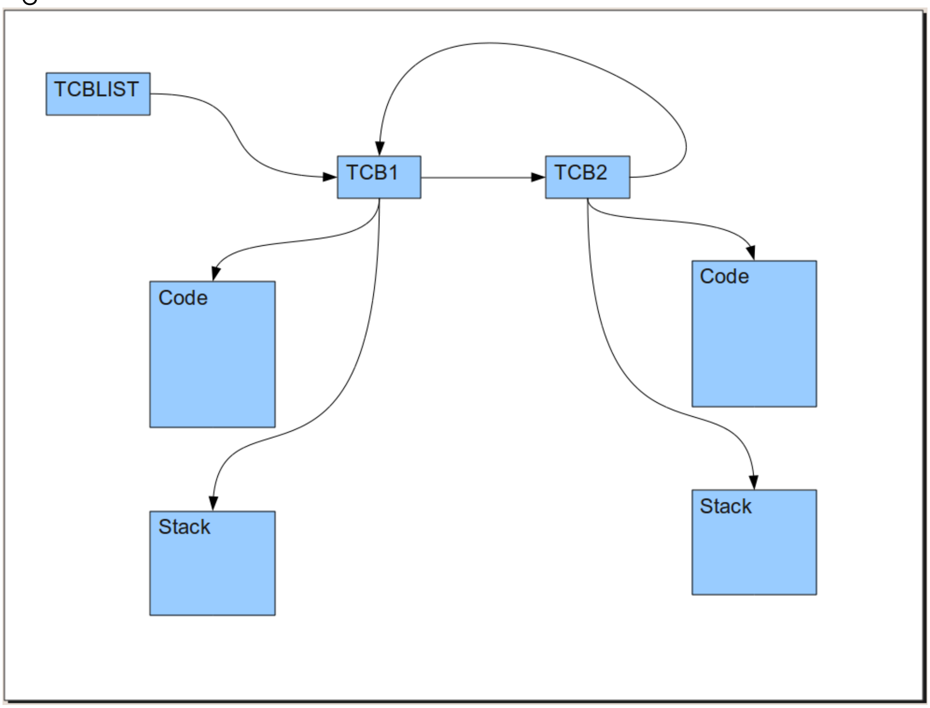
2.2.3 Program code

One of the important parts in a task is the program code. When the kernel does a context switch the task program code starts to run. The program code is executed in a never ending loop. From time to time the program code call the kernel context switch function in order to allow other tasks to run.

2.3 TCBLIST

The ROSA kernel utilizes a variable TCBLIST which contain a link to the TCBs in the kernel. See Figure3. Another variable EXECTASK contains the TCB of the current executing task.

Figure 3: TCBLIST is a circular linked list.



3 The internal structure of ROSA

This is a more detailed description of the internal structure of ROSA.

The first thing to note about ROSA is that kernel functions execute in supervisor mode and the tasks execute in user mode. Mode switching is done by ROSA.

3.1 Creating and installing tasks

All TCB's are linked together by the variable TCBLIST. When a task have been created by *ROSA_tcbCreate()* and installed in the kernel by *ROSA_tcbInstall()*, the TCBLIST will contain a reference to the first TCB created.

When more tasks are created and installed, each TCB is linked into the TCBLIST and the correct information is filled into the TCB.

These are the necessary informations that need to be initialized in the TCB:

- How to find the next TCB.
- Start and return address, the address the task will start execute at.
- The status register (SR) is set to work in user mode.
- The user stack pointer (USP), which the task will use.
- All CPU registers are saved into the TCB in order to not be destroyed by a context switch.

Part of this needs to be done in assembler, due to the low level nature of e.g. saving specific CPU registers. This is handled by the *contextInit()* call last in *ROSA_tcbCreate()*.

3.2 Starting the ROSA kernel

When *ROSA_start()* is called the first task in TCBLIST will start to execute. In order to activate the first task we must load the correct value for the user stack pointer (USP), and set the correct value of the status register (SR). This needs to be done from assembler.

To start task execution the task start address, STADDR, is loaded from the TCB and a jump is done to STADDR.

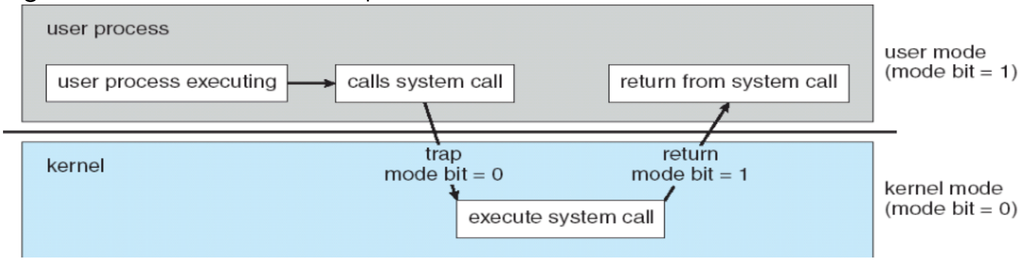
3.3 Context switching

When a task have finished its execution during a period, *ROSA_yield()* is called. The functionperforms the following sequence:

- The context of the CPU is stored to the TCB.
- The scheduler function, *scheduler()*, is called and a new TCB is written into EXECTASK.
- The context of the new TCB is restored by a call to *contextRestore()*.

The *ROSA_yield()* utilizes the supervisor mode which is entered by the '*scall*' system call instruction. This instruction jumps to the *_handle_Supervisor_Call* vector and effectively runs the context switch routines in supervisor mode.

Figure 4: The context switch procedure



3.3.1 Context save

contextSave() does the following operations:

- Fetch the TCB of the current executing task.
- Saves temporary work registers.
- Saves the status register, SR.
- Saves the CPU registers.
- Saves the return address.
- Saves the correct user stack pointer, USP.

3.3.2 Scheduling

The *scheduler()* function fetch the next task to execute. The currently running TCB, referenced to by the variable EXECTASK, is changed to another TCB from the TCBLIST. A reference to the new task TCB is put in the EXECTASK variable.

3.3.3 Context restore

contextRestore() practically does the reverse of the context save:

- Fetch the TCB from the EXECTASK.
- Restores the USP.
- Restores return address.
- Restores CPU registers.
- Restores SR.
- Restores work registers.
- Return from supervisor mode.

This sequence makes the CPU start executing the new task.

4 How to use ROSA from C

We will look at how ROSA can be used. The following code contains two simple tasks and initialization of ROSA. Each task will control LED1 and LED2 on the EVK1100.

4.1 Simple source code walk through

This is a description on how to set up the main.c file and start running the ROSA kernel. A more detailed walk through of the kernel is found in section 5 on page 13

4.1.1 Headers

We start in the main.c by including the necessary header files.

```
//Kernel includes
#include "kernel/rosa_ker.h"

//I/O driver includes
#include "drivers/led.h"
#include "drivers/delay.h"

//Include configuration
#include "rosa_config.h"
```

4.1.2 Tasks

Now we define our tasks; task1 and task2. Note that the tasks consist of a *while(1)*-loop, which basically will make the task run forever.

The next thing to note is the *ledOn()/Off()* scheme, task1 will light up LED1 of the EVK1100. Task2 will light up LED2. Pay attention to the inconsistency between the labeling of the LEDs on EVK1100 and the defined LEDx_GPIO numbers.

ROSA_yield() is the function which performs a context switch, allowing both tasks to run in pseudo parallel, despite the forever *while(1)*-loop.

```
//TASK1
//--------------
//LED1 lights up
//LED2 goes dark
void task1(void)
{
    while(1) {
        ledOn(LED0_GPIO);   //EVK1100 LED1!
        ledOff(LED1_GPIO);
        ROSA_yield();
    }
}
```

```
//TASK2
//--------------
//LED2 lights up
//LED1 goes dark
void task2(void)
{
	while(1) {
		ledOff(LED0_GPIO);
		ledOn(LED1_GPIO);
		ROSA_yield();
	}
}
```

4.1.3 TCB and stack declaration

We declare our TCB and stack for the two tasks we are going to create. The first thing we do is to reserve stack space by defining a global array with appropriate size. Space for the TCB is also reserved by the tcb struct.

```
//Data blocks for the tasks
#define T1_STACK_SIZE 0x40
static int t1_stack[T1_STACK_SIZE];
static tcb t1_tcb;

#define T2_STACK_SIZE 0x40
static int t2_stack[T2_STACK_SIZE];
static tcb t2_tcb;
```

4.1.4 More TCB and TCBLIST

So far so good, but ROSA does not know where to find the tasks we want to run, and neither are the TCBs of the tasks set up correctly yet. This is done by calling *ROSA_tcbCreate()* and *ROSA_tcbInstall().* This must be done before starting ROSA with the *ROSA_start()* call. Execution control is now in the hands of ROSA and will not return to this point.

Below is an example of how it is done from the *main()*-function:

```
int main(void)
{
	//Initialize ROSA
	ROSA_init();

	//Create tasks, set up the TCB correctly
	ROSA_tcbCreate(&t1_tcb, "tsk1", task1, t1_stack,
		T1_STACK_SIZE);
	ROSA_tcbCreate(&t2_tcb, "tsk2", task2, t2_stack,
		T2_STACK_SIZE);
```

```
    //Install the TCBs into the TCBLIST.
    ROSA_tcbInstall(&t1_tcb);
    ROSA_tcbInstall(&t2_tcb);

    //Start the ROSA kernel
    ROSA_start();
    /* Execution will never return here */
}
```

5 Kernel source code walk through

This is a closer look at the ROSA kernel.

In the *main()* function, as shown previously, the first kernel function to be called is *ROSA_init()*. This function sets the TCBLIST and EXECTASK to NULL. This is done since no task have been added yet. Also I/O is initialized by this function call.

```
void ROSA_init(void)
{
    //No tasks yet.
    TCBLIST = NULL;
    EXECTASK = NULL;

    //Do initialization of I/O drivers
    ledInit();                      //LEDs
    buttonInit();                   //Buttons
    joystickInit();                 //Joystick
    potInit();                      //Potentiometer
    usartInit(USART, &usart_options, FOSC0);//Serial
}
```

Next the TCB's of two tasks are created by function call to *ROSA_tcbCreate()*.

```
ROSA_tcbCreate(&t1_tcb, "tsk1", task1, t1_stack, T1_STACK_SIZE);
ROSA_tcbCreate(&t2_tcb, "tsk2", task2, t2_stack, T2_STACK_SIZE);
```

These calls fill in the necessary information into the TCB as shown below. First the task id/name is copied into the TCB.

```
void ROSA_tcbCreate(tcb * tcbTask, char tcbName[NAMESIZE],
    void *tcbFunction, int * tcbStack, int tcbStackSize)
{
    int i;
```

```
//Initialize the tcb with the correct values
for(i = 0; i < NAMESIZE; i++) {
    //Copy the id/name
    tcbTask->id[i] = tcbName[i];
}
```

The link to the next TCB is set to NULL as this TCB block have not been installed into the ROSA kernel yet.

```
//Dont link this TCB anywhere yet
tcbTask->nexttcb = NULL;
```

The start and return addresses are set up to point to the beginning of the task function. The stack and its size are set up, and the USP is set to point to the data area. An initial value of the SR is set. This give us a known initial state of the task.

```
//Set the task function start and return address
tcbTask->staddr = tcbFunction;
tcbTask->retaddr = (int)tcbFunction;

//Set up the stack
tcbTask->datasize = tcbStackSize;
tcbTask->dataarea = tcbStack + tcbStackSize;
tcbTask->saveusp = tcbTask->dataarea;

//Set the initial SR
tcbTask->savesr = ROSA_INITIALSR;
```

The last thing to do during TCB creation is to set up the task context registers to a known state. This is done in assembler by the *context-Init()* call.

```
    //Initialize context
    contextInit(tcbTask);
}
```

The assembler routine initialize the lr register (task activation record) to point to the start address, STADDR, of the task program code. The registers in the TCB, TCB.SAVEREG.R0 - TCB.SAVEREG.R12, are set to zero.

```
contextInit:
    //Initialize lr in the savereg area
    ld.w r0,r12[TCB.STADDR]
    st.w r12[TCB.SAVEREG.LR],r0

    //Initialize regs to zero
    mov r0,0x0
    st.w r12[TCB.SAVEREG.R0],r0
    st.w r12[TCB.SAVEREG.R1],r0
    st.w r12[TCB.SAVEREG.R2],r0
    ...
    st.w r12[TCB.SAVEREG.R12],r0
    mov pc,lr
```

Now the TCB have been properly created and it is time to install the TCB into the ROSA kernel.

```
    //Install TCB into the TCBLIST.
    ROSA_tcbInstall(t1_tcb);
    ROSA_tcbInstall(t2_tcb);
}
```

This function call checks to see if the TCBLIST is empty, which is the case when t1_tcb is installed. The TCB (t1_tcb) is installed at the first position of the list.

If the TCBLIST is not empty, which will be the case when t2_tcb is installed, the TCB will be attached to the last position in the list.

The TCBLIST is circular, which mean the last element will always point to the first element.

```
void ROSA_tcbInstall(tcb * tcbTask)
{
    tcb * tcbTmp;
    // Is this the first tcb installed?
    if(TCBLIST == NULL) {
        TCBLIST = tcbTask;

        //Install the first tcb
        TCBLIST->nexttcb = tcbTask;

        //Make the list circular
        tcbTask->nexttcb = TCBLIST;
    }
    else {
        //Find last tcb in the list
        tcbTmp = TCBLIST;
        while(tcbTmp->nexttcb != TCBLIST) {
            tcbTmp = tcbTmp->nexttcb;
        }
```

```
        //Install tcb last in the list
        tcbTmp->nexttcb = tcbTask;

        //Make the list circular
        tcbTask->nexttcb = TCBLIST;
    }
}
```

Finally the ROSA kernel can be started:

```
    //Start the ROSA kernel
    ROSA_start();
    /* Execution will never return to here */
```

In effect this is the initial context switch. This is an assembler routine that sets EXECTASK to be the first task in the TCBLIST. The routine loads information (USP, SR, STADDR, registers etc.) from EXECTASK and puts it directly onto the processor.

Loading lr with STADDR means that we are going to continue execution at the task program code when this routine is finished.

```
ROSA_start:
    //Put the first task from TCBLIST into EXECTASK
    lda.w r12,TCBLIST
    lda.w r11,EXECTASK
    ld.w r12,r12[0x0]
    st.w r11[0x0],r12

    //Set up start USP
    ld.w r0,r12[TCB.SAVEUSP]
    st.w --sp,r0
    ldmts sp,sp
    ld.w r0,sp++

    //Load start lr, execution will jump here later
    ld.w lr,r12[TCB.STADDR]

    //Set up start SR, enter user mode
    ld.w r0,r12[TCB.SAVESR]
    mtsr 0x0,r0

    //Load start registers R0-R12
    ld.w r0,r12[TCB.SAVEREG.R0]
    ld.w r1,r12[TCB.SAVEREG.R1]
    ld.w r2,r12[TCB.SAVEREG.R2]
    ...
    ld.w r12,r12[TCB.SAVEREG.R12]
    mov pc,lr
```

Now task1 starts to execute. It will light LED1, turn LED2 off and then immediately do a context switch.

```
void task1(void)
{
    while(1) {
        ledOn(LED0_GPIO);   //EVK1100 LED1!
        ledOff(LED1_GPIO);
        ROSA_yield();
    }
}
```

The context switch routine consists of switching to supervisor mode and three calls to *contextSave(), scheduler()* and *contextRestore()*. When a call is done the return address is written to the lr register. The lr register will be overwritten by consecutive calls. Pushing the lr register to the stack is essential as this contain the return address to the yielding task and needs to be saved into the TCB.SAVEREG.LR in the *contextSave* routine.

```
ROSA_yield:
    pushm lr
    lda.w lr,_yield
    //Enter supervisor mode
    scall
_yield:
    call contextSave
    call scheduler
    call contextRestore
    //Execution will not return to here!
```

The *contextSave()* routine saves the context from the processor into the TCB of EXECTASK.

```
contextSave:
    pushm r12
    //Fetch the current executing task
    lda.w r12,EXECTASK
    ld.w r12,r12[0x0]

    //Save work registers to TCB
    st.w r12[TCB.SAVER0],r0
    st.w r12[TCB.SAVER1],r1
    ld.w r0,sp++                //Use r0 to save r12
    st.w r12[TCB.SAVEREG.R12],r0

    //Save task SR to TCB
    ld.w r0,sp[SF_SR]
    st.w r12[TCB.SAVESR],r0
```

```
    //Save task registers r0-r11 to TCB
    mov r0,TCB.SAVEREG.R11
    add r0,r12
    stmts r0,r0-r11

    //Get the address of the USP
    mov r0,sp
    st.w --sp,r0
    stmts sp,sp
    ld.w r1,sp++    //USP in r1

    //Save RETADDR to TCB
    ld.w r0,r1[SF_LR_TASK]

    //Get from user stack, return to task,
    //not to ROSA_yield
    st.w r12[TCB.RETADDR],r0

    //Save LR_task
    st.w r12[TCB.SAVEREG.LR],r0

    //Save USP
    sub r1,-0x04
    st.w r12[TCB.SAVEUSP],r1

    mov pc,lr
```

When the scheduler is done a new task TCB is present in the EXECTASK. Now *contextRestore()* will do the final part of the context switch, i.e. turning execution over to the next task. Register values are fetched from the TCB and written directly to the processor or on the stack for retrieval when exiting supervisor mode.

```
contextRestore:
    //Fetch the current executing task
    lda.w r12,EXECTASK
    ld.w r12,r12[0x0]

    //Restore USP
    ld.w r1,r12[TCB.SAVEUSP]
    st.w --sp,r1
    ldmts sp,sp
    ld.w r1,sp++

    //Restore LR = retaddr
    ld.w lr,r12[TCB.SAVEREG.LR]

    //Restore RETADDR
    ld.w r0,r12[TCB.RETADDR]
    st.w sp[SF_PC],r0

    //Restore registers
    mov r0,TCB.SAVEREG.R11
    add r0,r12
```

```
    ldmts r0,r0-r11

    //Restore r7
    ld.w r7,r12[TCB.SAVEREG.R7]

    //Restore SR
    ld.w r0,r12[TCB.SAVESR]
    st.w sp[SF_SR],r0           //Put SR on the stack for later
         fetch

    //Restore work registers
    ld.w r0,r12[TCB.SAVER0]
    ld.w r1,r12[TCB.SAVER1]
    ld.w r12,r12[TCB.SAVEREG.R12]

    //We are done, exit from supervisor mode
    rets
```

Now execution is at task2, which will run until the *ROSA_yield()* turn over execution to the next task, which in this case is task1.

```
void task2(void)
{
    while(1) {
        ledOff(LED0_GPIO);  //EVK1100 LED1!
        ledOn(LED1_GPIO);
        ROSA_yield();
    }
}
```

The two tasks will continue to execute in this fashion, taking turn to run their program code on the processor one loop at a time before leaving execution over to the other task by the *ROSA_yield()* call.

6 Summary

We now know what parts are necessary to a small cooperative realtime kernel. We have seen in detail how a simple system execute on the ROSA kernel.