Contents

Real-Time OS

1. Overview

This lab is a guide to Real-time Operating System (RTOS) in SoC design. This lab is based on µC/OS-II, a compact but complete RTOS shipped with ARM Firmware Suite (AFS). Internal mechanism of µC/OS-II is beyond the scope of this lab. For more detailed information about µC/OS-II, please refer to the book “MicroC/OS-II, the real-time kernel” by Jean J. Labrosse.

2. Background Information

2.1. About µC/OS-II

- Soft Real-time – tasks are performed as fast as possible
- Portable – runs on architectures ranging from 8-bit to 64 bit
- Scalable – features are configurable at compile time
- Multitasking – support 64 tasks simultaneously; including 8 reserved tasks
- Preemptive – preemptive multi-tasking with priority scheduling
- Kernel Services – provides task, time, memory management API; inter-process communication API; task synchronization API
- Nested Interrupt – up to 255 levels of nested interrupt
- Priority Inversion Problem – does not support priority inheritance
- Not using MMU – no well protected memory space like Unix or Win

2.2. Task in µC/OS-II

- Task is a single instance of program
- Task thinks it has all CPU control itself
- Task has its own stack and own set of CPU registers backup in its stack
- Task is assigned a unique priority (highest 0 ~ lowest 63)
- Task is an infinite loop and never returns
- Task has states (see **Figure 1**)
- µC/OS-II saves task records in Task Control Block(TCB)

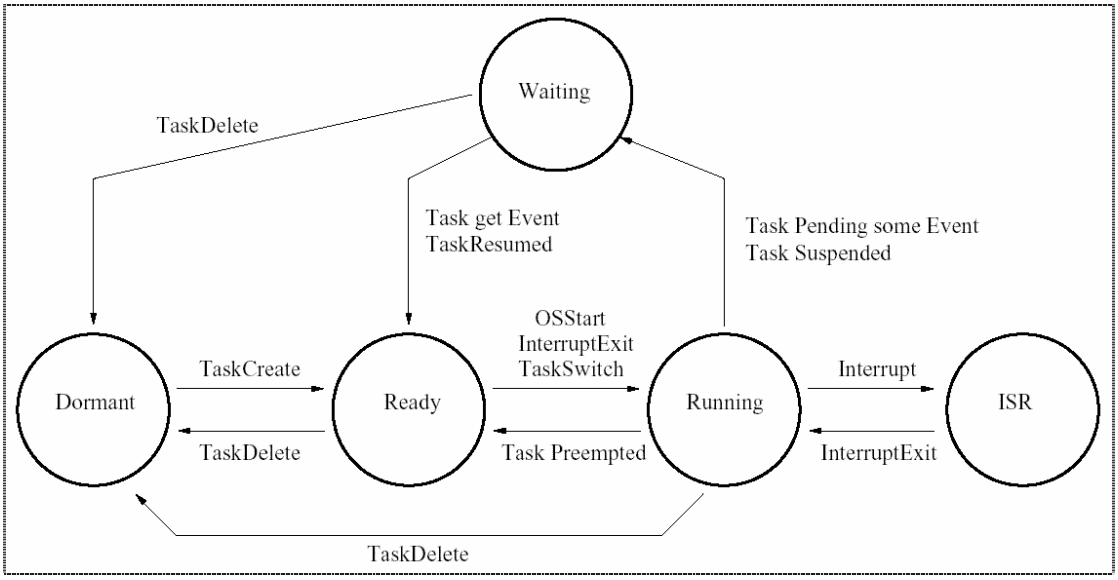

Figure 1 Task states in uC/OS-II

Task States in µC/OS-II:

- ♦ Running – task has control of the processor and executing its job
- ♦ Ready – task is ready to execute but its priority is less than the running task
- ♦ Waiting – task requires the occurrence of an event to continue
- ♦ ISR – task is paused because the processor is handling an interrupt
- ♦ Dormant – task resides in memory, but not seen by the scheduler

2.3. Task Scheduling & Context Switch

In µC/OS-II, task scheduling is performed on following conditions:

- ♦ A task is created/deleted
- ♦ A task changes state
  - – On interrupt exit
  - – On post signal
  - – On pending event
  - – On task suspension

If the scheduler chooses a new task to run, context switch occurs. First, the context (processor registers) of current running task is saved in its stack. Next, the context of the new task is loaded into the processor. Finally, the processor continues execution. (see **Figure 2**)

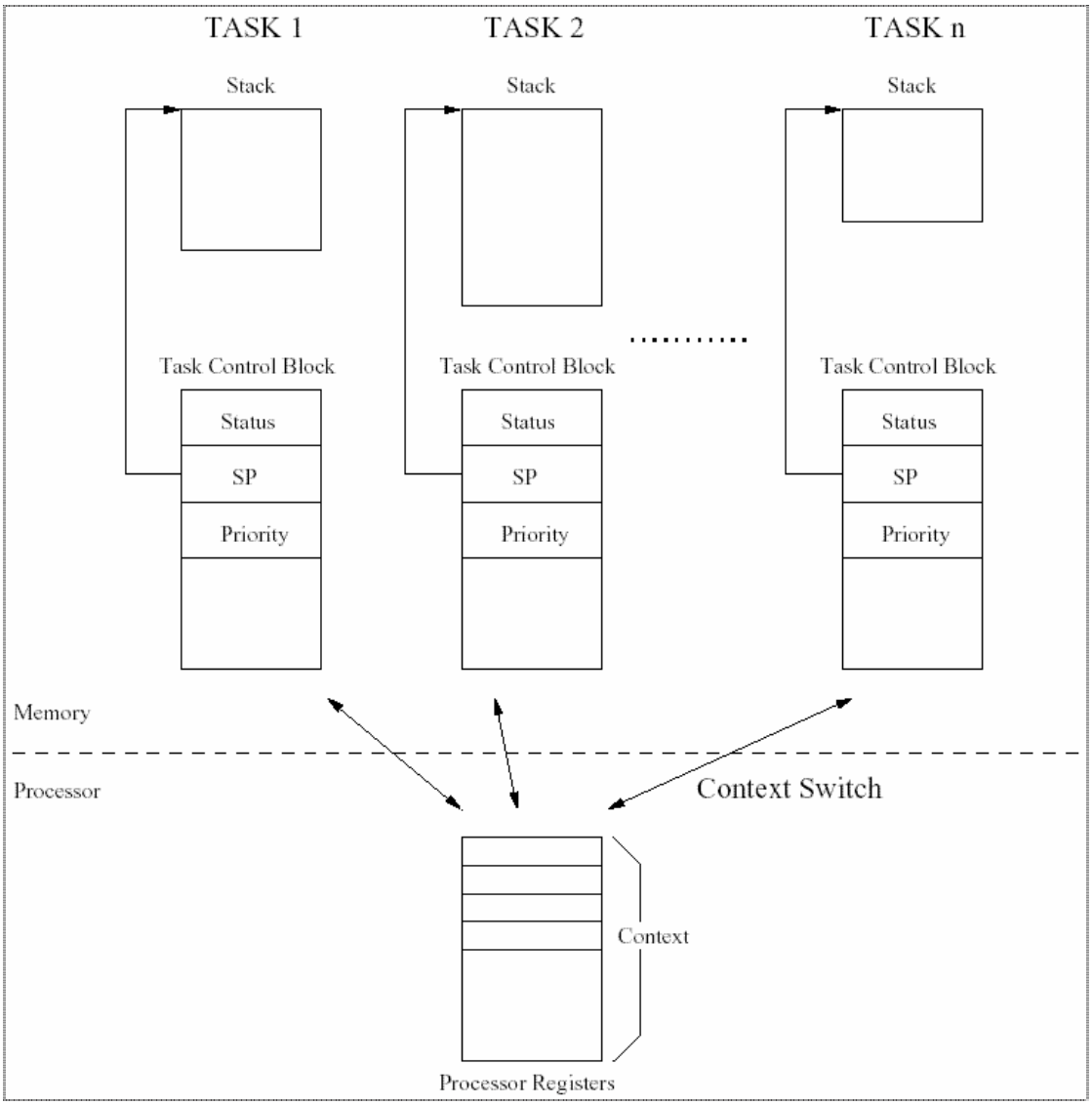

Figure 2 Context switch in uC/OS-II

2.4. Coding Guidelines for Embedded RTOS

Coding for a program to run on embedded RTOS is slightly different from coding for PC. In an embedded application, workloads and available resources are known at design time. Hence, the designer should carefully explore the design space and optimize for short latency, small memory footprint, low power…etc.

When writing programs for µC/OS-II, some rules should be noticed:

- Resources
  - Use µC/OS-II defined data types for consistency & portability
  - Use statically allocated local variables for preemptive multitasking
  - Use semaphore to protect global variables and resources

- Data transfer
  - Inter-task communication can be achieved by mailbox/queue
  - µC/OS-II & user program all run in privileged mode, use share memory with caution!

- Memory allocation
  - Use µC/OS-II Kernel API: OSMemCreate(), OSMemGet()

- Standard C library
  - Many standard routine works in semi-hosting mode but not in stand-alone mode. (e.g. printf, fopen)

2.5. Starting µC/OS-II

µC/OS-II is initialized and started in the main function. The initialization order is important.

1. Initialize ARM target
2. Initialize OS
3. OS create/allocate resources
4. Create an initial task with highest priority
5. Create other user tasks
6. OS start scheduling
7. In the initial task, enable global interrupt
8. the initial task deletes itself
9. Now, all other tasks runs under the control of OS

Note that you must create at least one task before OS start scheduling. Otherwise, you don’t get a chance to start any task and the system remains in idle state.

If an interrupt occurs before OS starts scheduling, the scheduler doesn’t know which tasks to run on interrupt exit and the system crashes. So, we introduce an initial task to

enable global interrupt. This is for safety, but not required.

2.6. Setting up the ARMulator

The ARMulator can function as virtual prototype to various ARM core and development boards. However, the original configuration of ARMulator does not match that of ARM Integrator/AP. To run µC/OS-II on ARMulator, you need to follow the configuration steps in the reference section.

3. Instructions

3.1. Building µC/OS-II

1. Open µC/OS-II project file in **C:/lab08/ucos2/** with Code Warrior.
2. Edit **OS_CFG.H** to customize µC/OS-II.

The configuration of µC/OS-II is done through a number of #define derivatives found in OS_CFG.H. Basically, the default settings in OS_CFG.H work fine. You might want to disable some unused features or decrease some value of settings for more compact memory footprint on final release.

Option	Values	Description
OS_MAX_EVENTS	default: 20 range: >=2	Maximum number of event control block available. The value should be greater than the total number of mailbox, semaphore and queue required by application.
OS_MAX_MEM_PART	default: 10 range: >=2	Maximum partitions to be managed by memory partition manager. Note that OS_MEM_EN must be set to 1 first.
OS_MAX_QS	default: 5 range: >=2	Maximum number of queue available in system.
OS_MAX_TASKS	default: 62 range: 62~2	Maximum number of task can exist at a time. Note that although µC/OS-II can handle 64 tasks but it reserves 2 tasks for itself.
OS_LOWEST_PRIO	default: 63 range: 63~1	Specifies the lowest task priority (i.e., highest number) that you intend to use.
OS_TASK_IDLE_STK_SIZE	default: 512	Stack size (in 16-bit entries) for IDLE_TASK. The minimum stack size depends on processor type and deepest interrupt level allowed. It's better to use default setting.
OS_TASK_STAT_EN	default: 0	Statistic task computes CPU usage once every second. The priority of statistic task is always set to OS_LOWEST_PRIO-1.
OS_TASK_STAT_STK_SIZE	default: 512	Stack size (in 16-bit entries) for STAT_TASK. It is suggested to use default value.
OS_CPU_HOOKS_EN	default: 1	This setting indicates whether hook functions

		should be included or not. hook functions are declared in OS_CPU_C.C.
OS_MBOX_EN	default: 1	This enables or disables code generation of message mailbox service.
OS_MEM_EN	default: 0	This enables or disables code generation of memory partition manager and its associated data structures.
OS_Q_EN	default: 1	This enables or disables code generation of message queue service.
OS_SEM_EN	default: 1	This enables or disables code generation of semaphore manager.
OS_TASK_CHANGE_PRIO_EN	default: 0	This indicates whether tasks can change priority at runtime.
OS_TASK_CREATE_EN	default: 1	This enables support for standard task creation function. You can choose either standard or extended version of task creation function. If you wish, you can use both.
OS_TASK_CREATE_EXT_EN	default: 0	This enables support for extended task creation function. Extended version delivers more powerful control over task.
OS_TASK_DEL_EN	default: 0	This enables or disables task deletion capability.
OS_TASK_SUSPEND_EN	default: 1	This enables or disables task suspension capability
OS_TICKS_PER_SEC	default: 200	This constant specifies the rate at which OSTimeTick() is called. Better leave this untouched.

Table 1 uC/OS-II configuration options in OS_CFG.H

3. In **target settings dialog**, turn to **Language Settings > ARM C Compiler > Preprocessor**. Add **INTEGRATOR** to List of #DEFINEs to generate specific code for Integrator. (see **Figure 3**)

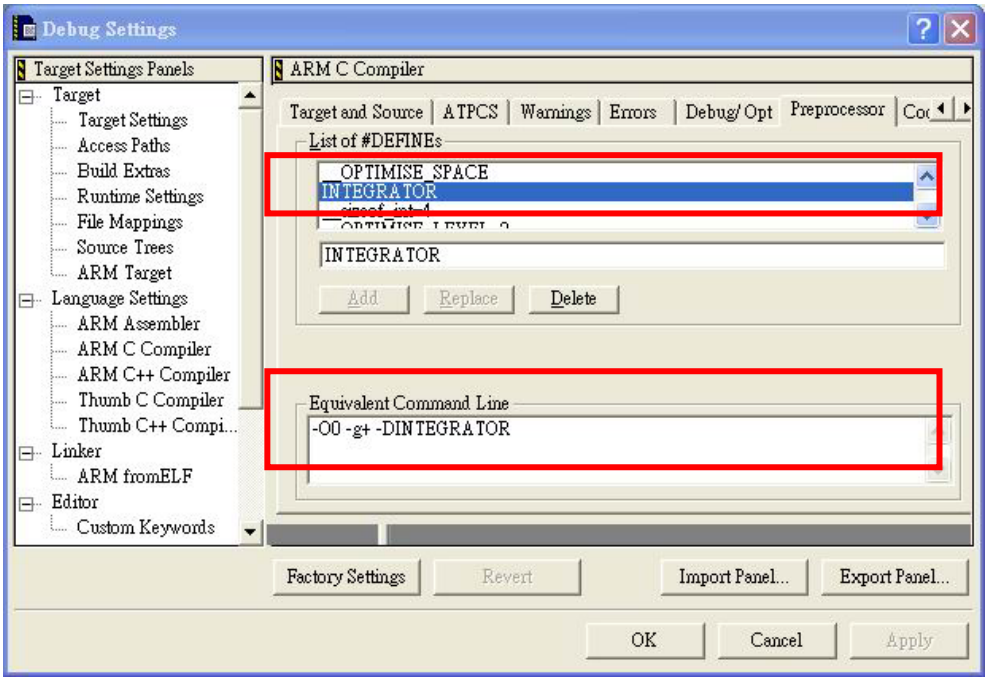

Figure 3 Define INTEGRATOR to generate specific code

4. At last, add 2 directories to the Access Path so header files could be found. In target settings dialog, select **Target > Access Paths**. Add ${AFS_ROOT}/AFSv1_4/Source/uHAL/h/ and ${AFS_ROOT}/AFSv1_4/Source/uHAL/Boards/INTEGRATOR/ as shown in **Figure 4**.

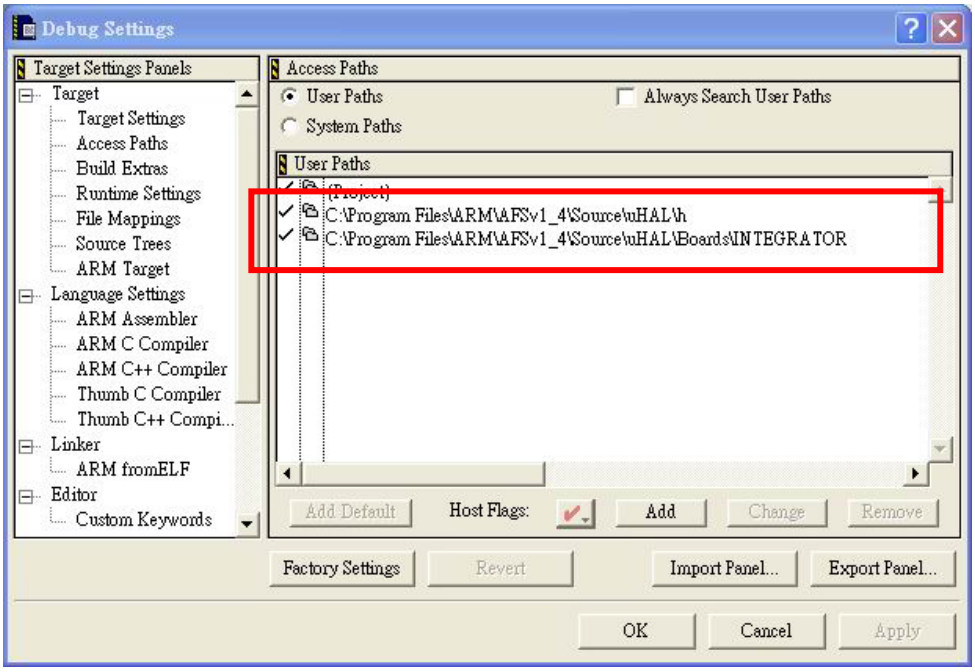

Figure 4 Adding access path for ARM uHAL library

5. Press the **Make** button, µC/OS-II library should be built successfully. A static library **ucos2.a** is created. Check the file in your working directory.

3.2. Porting Program to µC/OS-II

1. Open the project "**eg1**" at **C:/lab08/eg1/** with CodeWorrior.

2. The original code of eg1.c is listed in **Figure 5**. This program asks user for name and age, then it prints greeting message.

```
1     #include <stdio.h>
2
3     int main(void)
4     {
5        char name[64];
6        int age;
7
8        printf("please enter your name: ");
9        scanf("%s", name);
10
11       do
12        {
13            printf("please enter your age: ");
14          scanf("%d", &age);
15        }while(age < 0);
16
17        printf("Hello, %s. Nice to meet you!\nYour age is %d.\n", name, age);
18
19        return(0);
20    }
```

Figure 5 Original code of eg1.c

3. In order to port the program to µC/OS-II, include "**includes.h**" in eg1.c. The header file is an interface for µC/OS-II. (see **Figure 6**)

```
1     #include    "includes.h"          /* uC/OS-II interface */
2
3     #include <stdio.h>
```

Figure 6 Including µC/OS-II interface in your code

4. Change the function name from **main()** to **Task1()** as shown in **Figure 7**. In addition, change the return type from **int** to **void** because a task never returns. Remove the return statements, too.

```
1     void Task1(void *pdata)
2     {
3     …
4     …
5     return(0); <= remove this!
6     }
```

Figure 7 Changes from Main() to Task1()

5. A task must receive an argument of type **(void*)**, so change argument list from **void** to void ***pdata** as in **Figure 7**. The purpose of this pointer is to pass initialization value to task.

```
1     void Task1(void *pata)
2     {
3        //local variable declaration
4
5        for(;;)
6        {
7            // user code
8            …
9             OSTimeDly(100);
10        }
11    }
```

Figure 8 Warp task body with an infinite loop

6. A task is an infinite loop, so wrap the codes with a for loop (see **Figure 8**). Remember, all task should call at least one kernel service in its code body. Otherwise, the multitasking mechanism of µC/OS-II will not work. You can call **OSTimeDly()** service to pause for a while after each round of processing, allowing lower priority task to execute.

7. Insert a new main function as shown in **Figure 10** at the bottom of eg1.c. In the main function, create an instance for Task1.

```
OSTaskCreate(void (*task)(void* pd), void *pdata, OS_STK *ptos, INTU8 prio)

Arguments:

*task   ⇨  pointer to the task's code
*pdata  ⇨  pointer for passing arguments
*ptos   ⇨  pointer to top of stack
prio    ⇨  unique priority for each task. smaller number means higher priority
```

Figure 9 Syntax for OSTaskCreate()

```
1    int main(int argc, char *argv[])
2    {
3        /* do target (uHAL based ARM system) initialization */
4        ARMTargetInit();
5
6        /* needed by uC/OS */
7        OSInit();
8
9        /* create the tasks in uC/OS */
10       OSTaskCreate(Task1, (void *)0, (void*)&Stack1[STACKSIZE - 1], 3);
11
12       /* Start the (uHAL based ARM system) system running */
13       ARMTargetStart();
14
15       /* start the game */
16       OSStart();
17
18       /* never reached */
19       return(0);
20   }
```

Figure 10 Code for main() that creates an instance of Task1()

8. Insert the following code near the top of eg1.c to create a stack for Task1. Each task must have its own stack. The actual stack size needed depends on processor type, depth of interrupt allowed and the work your task is running…etc. System crashes on stack overflow. So, it's better to allocate a bigger stack first than try to decrease the value. (see **Figure 11**)

```
1     /* allocate memory for tasks' stacks */
2     #ifdef SEMIHOSTED
3       #define    STACKSIZE    (64+SEMIHOSTED_STACK_NEEDS)
4     #else
5       #define    STACKSIZE    64
6     #endif
7
8     OS_STK Stack1[STACKSIZE];
```

Figure 11 Define stack size and create resources for task

9. Finally, eg1.c is an executable program at µC/OS-II.

3.3. Building Program with µC/OS-II

1. Open the project "**eg1**" at **C:/lab08/eg1/** with CodeWorrior.

2. Add **µC/OS-II** as a sub-project. This enables automatic rebuilt of sub-project whenever necessary. This approach is more flexible than add the pre-compiled ucos2.a library file. (see **Figure 12**)

------ Note ------
When adding sub-projects, a popup message might appear indicating that some Access Path is added. This is ok.
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3. Add ARM **uHAL** library as a sub-project. The project file is located in ${AFS_ROOT}\Source\uHAL\Build\Integrator.b\uHALlibrary.mcp. (see **Figure 12**)

------ Note ------
The uHAL library is board specific. Choose the project file that matches your development board. We choose "**Integrator.b**" for Integrator/AP.

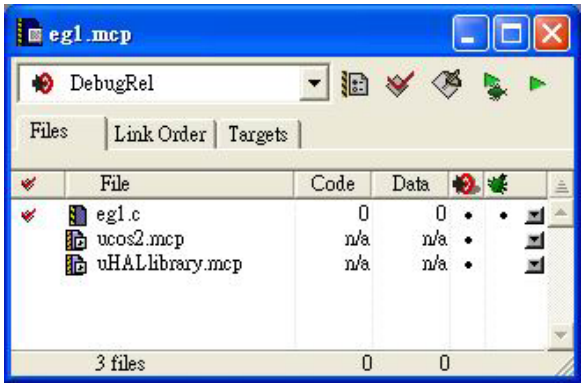


Figure 12 Adding uC/OS-II and uHAL as sub-projects

4. Now, specify which target to build and link. In project window, click the **Target** tab to display the Targets view for the project. Then, click the **plus** sign next to a build target containing the subproject to expand the hierarchy. Each build target in the subproject is listed in the hierarchy (see **Figure 13**).

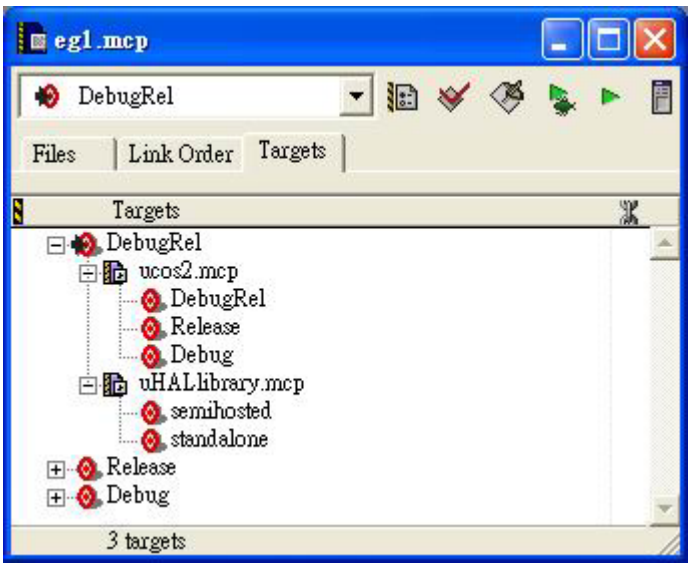


Figure 13 build target hierarchy view

5. Click on the **Target** icon next to the subproject build targets you want to build along with the main project. The CodeWarrior IDE displays an arrow and target icon for selected build targets (see **Figure 14**).

6. Click in the **Link Column** next to the subproject build targets. Select the target you want to link with the main project (see **Figure 14**).

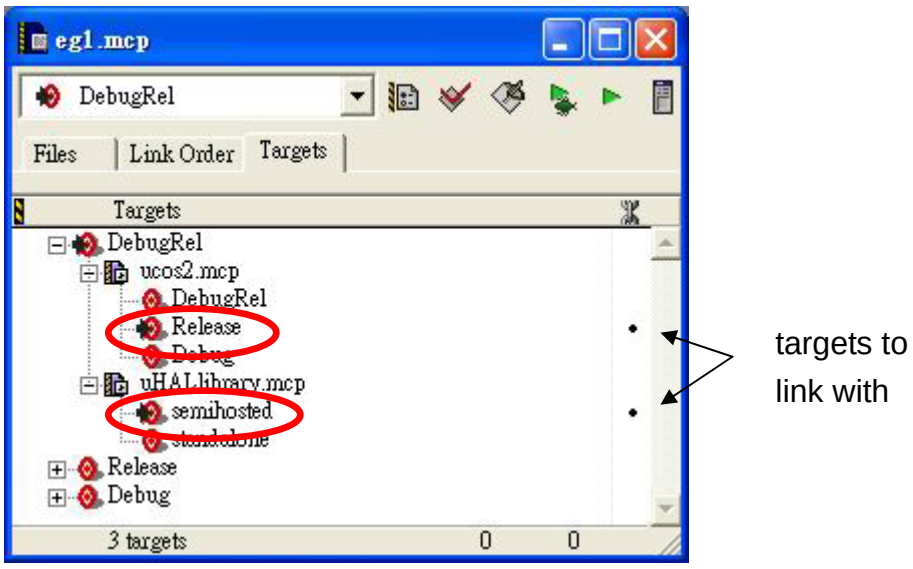


Figure 14 Select target to build and link with

------ Note ------
You are free to create link dependencies to any of the build targets in a subproject. However, semi-hosted target must be selected for uHAL in order to support debugging with AXD.

------ Note ------
The µC/OS-II shipped with AFS has been tested, so you can select Release target for to focus on debugging user application only.
----

7. Define **SEMIHOSTED** for programs to run in semi-hosted mode. In semi-hosted mode, an extra space of 1K bytes is needed for stack.

8. Build the main project. An executable file that contains both user application and operating system will be created.

9. Press **Run** button, you can see programs running on µC/OS-II in AXD console window. (see **Figure 15**)

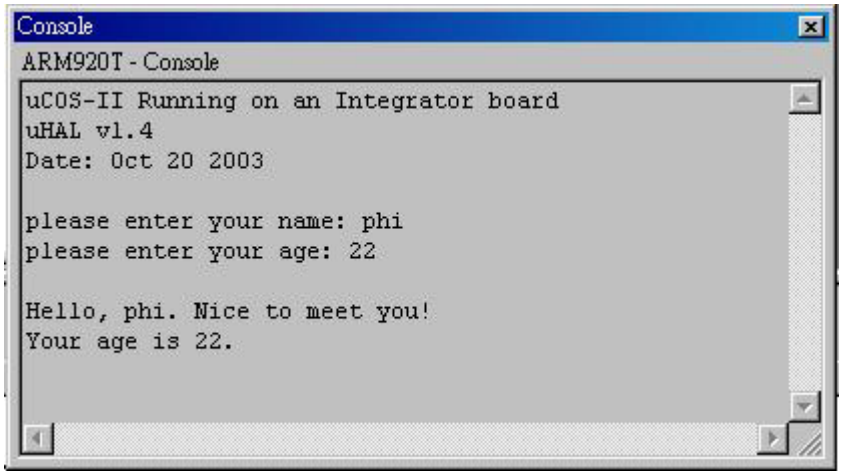


Figure 15 Application running in AXD console

4. Exercise

Write an ID checking engine. The checking rule is in the reference section.

User input:
- The ID numbers

Program output:

- The ID number
- Check result

Example:

Please Enter ID : A123456789
======= check result =======
A123456789 valid

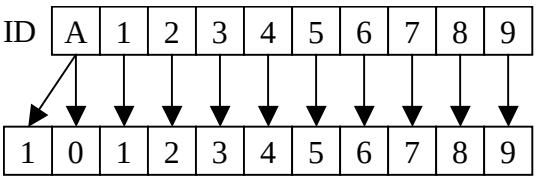
5. References

Information about µC/OS-II

- http://www.ucos-ii.com/
- “MicroC/OS-II, the real-time kernel” (ISBN: 0-87930-543-6)

ID Checking Rules

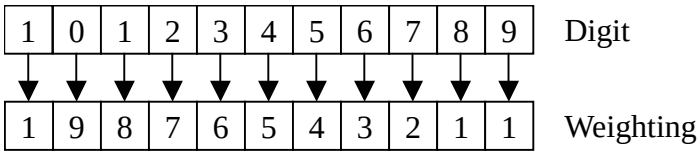
- ID number comes in a 10-digit set. The ID starts with an alphabet, followed by 9 digits of numeral.
- Check the first numeral, it should be either “1” or “2”.
- Transform the alphabet into 2 digits. Use **Figure 16** for transformation.



A	B	C	D	E	F	G	H	I	J	K	L	M
10	11	12	13	14	15	16	17	34	18	19	20	21
N	O	P	Q	R	S	T	U	V	W	X	Y	Z
22	35	23	24	25	26	27	28	29	30	31	32	33

Figure 16 Transform table for alphabet

- Multiply each digit with its weighting and sum them up.



$$(1\times1+0\times9+1\times8+2\times7+3\times6+4\times5+5\times4+6\times3+7\times2+8\times1+9\times1)=130$$

- The summation of a valid ID should be devisable by 10.

130 mod 10 = 0 ⇨ valid