
ARC labs handbook

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CONTENTS:

1	Overview	1
1.1	Introduction	1
1.2	Supported Hardware Platform	1
1.3	Reference	2
2	Getting Started	3
2.1	Software Requirement	3
2.2	Install Software Tools	3
2.3	Final Check	9
2.4	Learn More	9
3	Labs	11
3.1	Overview	11
3.2	Labs	11
4	Appendix	97
4.1	Reference	97
5	Indices and tables	99

OVERVIEW

1.1 Introduction

This is a handbook for ARC labs which is a part of ARC university courses. The handbook is written to help students who attend the ARC university course and anyone who is interested in DesignWare® ARC® processors to get started in DesignWare® ARC® processors development. It describes all the basic elements of ARC labs and how to finish the labs with step-by-step approach.

This handbook can be used as a Lab teaching material for ARC university courses at undergraduate or graduate level with majors in Computer Science, Computer Engineering, Electrical Engineering, or for professional engineers.

This handbook includes 12 labs (more labs are added in the future), which are classified into 3 levels:

- *Level 1: ARC basic*

The labs in this level cover the basic topics about DesignWare® ARC® processors, for example, the installation and usage of hardware and software tools, software or hardware development kits, first hello world example, interrupt handling and internal timers of DesignWare® ARC® processors, and so on.

- *Level 2: ARC advanced*

The labs in this level cover the advanced topics about DesignWare® ARC® processors, for example, Real-Time Operating System (RTOS), customized linkage, compiler optimization, basic applications, DesignWare® ARC® processors DSP feature, and so on.

- *Level 3: ARC exploration*

The labs in this level cover some complex applications about DesignWare® ARC® processors, for example, Internet of Things (IoT) application, embedded machine learning, and so on.

Most of the labs are based on the [embARC Open Software Platform \(OSP\)](#) which is an open software platform to facilitate the development of embedded systems based on DesignWare® ARC® processors.

It is designed to provide a unified platform for DesignWare® ARC® processors users by defining consistent and simple software interfaces to the processor and peripherals together with ports of several well known Free and open-source software (FOSS) embedded software stacks to DesignWare® ARC® processors.

For more details about embARC OSP, see [online docs](#)

1.2 Supported Hardware Platform

The following hardware platforms are supported in this handbook.

- [ARC EM Starter Kit](#)
- [ARC IoT Development Kit](#)

You can click the above links to get the board's data sheet and user manual as a reference.

1.3 Reference

Item	Name
1	ARC EM Databook
2	MetaWare docs
3	ARC EM Starter Kit User Guide
4	ARC GNU docs

GETTING STARTED

Use this guide to get started with your ARC labs development.

2.1 Software Requirement

- **ARC Development Tools** Select **lmwdtl** or **laregnul** from the following list according to your requirement.
 - MetaWare Development Toolkit
 - * **Premium MetaWare Development Toolkit (2018.06)**. The DesignWare ARC MetaWare Development Toolkit builds upon a 25-year legacy of industry-leading compiler and debugger products. It is a complete solution that contains all the components needed to support the development, debugging, and tuning of embedded applications for the DesignWare ARC processors.
 - * **DesignWare ARC MetaWare Toolkit Lite (2018.06)**. A demonstration or evaluation version of the MetaWare Development Toolkit is available for free from the Synopsys website. MetaWare Lite is a functioning demonstration of the MetaWare Development Toolkit with restrictions such as code-size limit of 32 Kilobytes and no runtime library sources. It is available for Microsoft Windows only.
 - GNU Toolchain for ARC Processors
 - * **Open Source ARC GNU IDE (2018.03)**. The GNU Toolchain for ARC Processors offers all of the benefits of open source tools such as complete source code and a large install base. The ARC GNU IDE Installer consists of Eclipse IDE with **ARC GNU plugin for Eclipse**, **ARC GNU prebuilt toolchain**, and **OpenOCD for ARC**
- **Digilent Adept Software** for Digilent JTAG-USB cable driver. All the supported boards are equipped with on board USB-JTAG debugger. One USB cable is required and external debugger is not required.
- **Tera Term** or **PuTTY** for serial terminal connection. The serial configurations are 115200 baud, 8 bits data, 1 stop bit, and no parity (115200-8-N-1) by default.

Note: If using embARC with GNU toolchain on Windows, install **Zadig** to replace FTDI driver with WinUSB driver. See **How to Use OpenOCD on Windows** for more information. If you want to switch back to Metaware toolchain, make sure you switch back the usb-jtag driver from WinUSB to FTDI driver.

2.2 Install Software Tools

2.2.1 Install Metaware Toolkit

Installing MetaWare Development Toolkit (2017.09).

1. Double click the `mw_dekit_arc_i_2017_09_win_install.exe` and click **Next**.



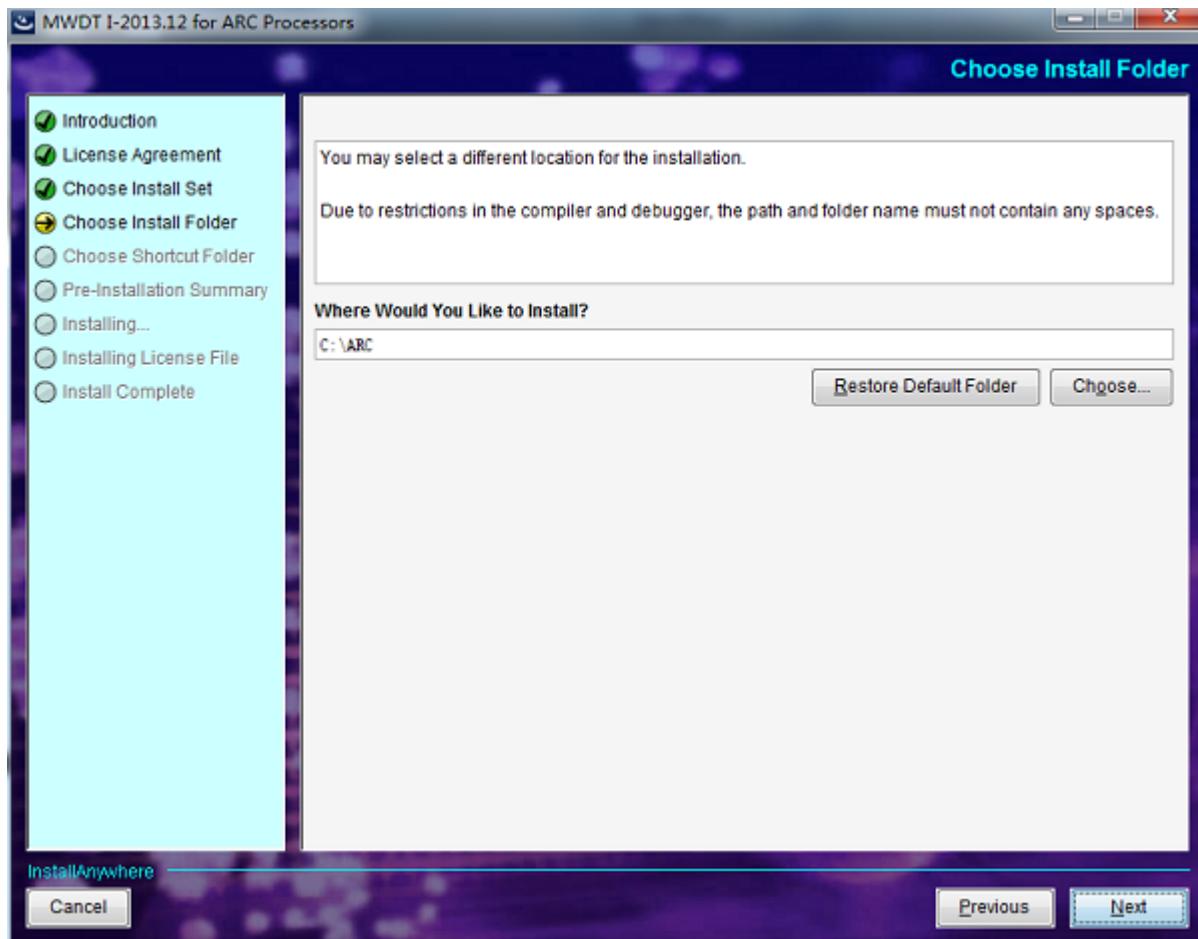
2. Select I accept and click **Next**.



3. Select Typical installation and click **Next**.

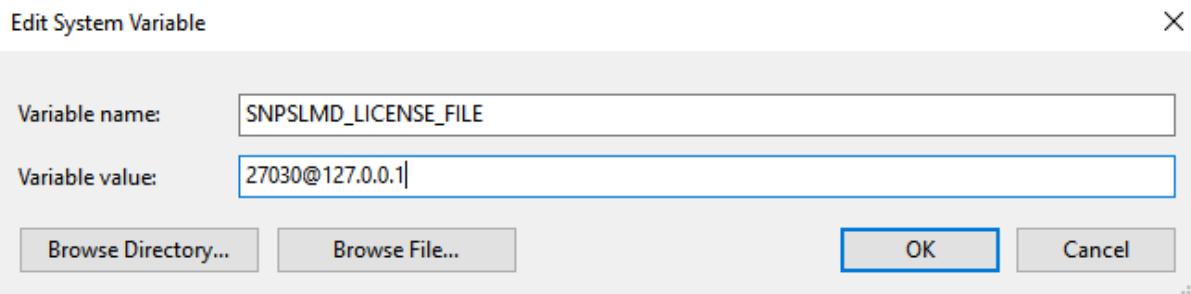


4. Set the install path (make sure you use English letters without any space) and click **Next** until the installation is complete.



5. Set the license file (SNPSLMD_LICENSE_FILE) for MetaWare Development Toolkit. It can be a real file containing license or a license server.

- For Windows, go to **Computer > Properties > Advanced > Environment Variables > System Variables > New.**



- For Linux, add SNPSLMD_LICENSE_FILE into your system variables.

6. Test the MetaWare Development Toolkit and the license

At the command prompt, compile and link in one step.

For example, find the queens.c in the demos folder of MetaWare Development Toolkit installation directory.

```
# On Windows
cd C:\ARC\MetaWare\arc\demos
ccac queens.c
```

If you get the following message without any error, then the MetaWare Development Toolkit is successfully installed.

```
MetaWare C Compiler N-2017.09 (build 005)           Serial 1-799999.  
(c) Copyright 1987-2017, Synopsys, Inc.  
MetaWare ARC Assembler N-2017.09 (build 005)  
(c) Copyright 1996-2017, Synopsys, Inc.  
MetaWare Linker (ELF/ARCompact) N-2017.09 (build 005)  
(c) Copyright 1995-2017, Synopsys, Inc.
```

2.2.2 Install ARC GNU Toolchain

Click (<https://github.com/foss-for-synopsys-dwc-arc-processors/toolchain/releases>) to get the latest version of GNU Toolchain for ARC Processors.

To use and install GNU Toolchain for ARC Processors, see (<http://embarc.org/toolchain/ide/index.html>).

It is recommended to install GNU Toolchain for ARC Processors in the path (windows: C:\arc_gnu\, linux: ~/arc_gnu/) and add arc_gnu/bin into \$PATH variable.

2.2.3 Install embARC OSP

The embARC OSP source code is hosted in a GitHub repository that supports cloning through git. There are scripts in this repo that you are need to set up your development environment, and Git is used to get this repo. If you do not have Git installed, see the beginning of the OS-specific instructions below for help.

Using Git to clone the repository anonymously

```
# On Windows  
cd %userprofile%  
# On Linux  
cd ~  
  
git clone https://github.com/foss-for-synopsys-dwc-arc-processors/embarc_osp.git  
→embarc_osp
```

You have successfully checked out a copy of the source code to your local machine.

2.2.4 Install ARC labs code

The source codes of ARC labs are assumed to work with embARC OSP. You need to use git to clone or download the ARC labs to the root folder of embARC OSP. If the download is successful, the following folder structure is displayed:

```
cd path/to/embarc_osp  
git clone https://github.com/foss-for-synopsys-dwc-arc-processors/arc_labs.git arc_  
→labs
```

```
embarc_osp  
└── arc  
└── board  
└── device  
└── doc  
└── example  
└── arc_labs  
└── inc  
└── library  
└── middleware  
└── options  
└── os
```

2.3 Final Check

Check the following items and set development environment.

- Make sure the paths of MetaWare Development Toolkit or GNU Toolchain for ARC Processors are added to the system variable **PATH** in your environment variables.
- It is recommended to install GNU Toolchain for ARC Processors to default location. Otherwise, you need to make additional changes as described.
 - If running and debugging embARC applications using **arc-elf32-gdb** and **OpenOCD for ARC**, make sure the path of **OpenOCD** is added to the **PATH** in your environment variables and modify **OPENOCD_SCRIPT_ROOT variable** in *<embARC>/options/toolchain/toolchain_gnu.mk* to your **OpenOCD** root path.
 - If running GNU program with using the GNU toolchain on Linux, modify the **OpenOCD** configuration file as Linux format with LF line terminators. **dos2unix** can be used to convert it.

Note: Check the version of your toolchain. The embARC OSP software build system is makefile-based. *make/gmake* is provided in the MetaWare Development Toolkit (*gmake*) and GNU Toolchain for ARC Processors (*make*)

2.4 Learn More

For more details about embARC OSP, see [online docs](#)

3.1 Overview

3.2 Labs

3.2.1 Level 1 Labs

How to Use ARC IDE

MetaWare Development Toolkit

Purpose

- To learn MetaWare Development Toolkit
- To get familiar with the basic usage of the MetaWare Development Toolkit
- To get familiar with the features and usage of the MetaWare Debugger (mdb)

Equipment

The following hardware and tools are required:

- PC host
- MetaWare Development Toolkit
- nSIM simulator or ARC board (EM Starter Kit / IoT Development Kit)
- `embarc_osp/arc_labs/labs/lab1_core_test`

Content

- Create a C project using the MetaWare Development Toolkit
- Import the code `CoreTest.c` from `embarc_osp/arc_labs/labs/lab1_core_test`
- Configure compilation options to compile, and generate executable files.
- Start the debugger of MetaWare Development Toolkit and enter debug mode.

From the different angles of C language and assembly language, use the functions of setting breakpoint, single step execution, full speed execution, and so on combined with observing PC address, register status, global variable status, and profiling performance to analyze the debug target program.

Principles

Use the MetaWare Development Toolkit to create projects and load code. In the engineering unit, configure the compile option to compile code, debug, and analyze the compiled executable file.

Routine code CoreTest.c:

```
////////////////////////////////////////////////////////////////
// This small demo program finds the data point that is the
// minimal distance from x and y [here arbitrarily defined to be (4, 5)]
//
// #define/undefine '_DEBUG' precompiler variable to obtain
// desired functionality. Including _DEBUG will bring in the
// I/O library to print results of the search.
//
// For purposes of simplicity, the data points used in the computations
// are hardcoded into the POINTX and POINTY constant values below
////////////////////////////////////////////////////////////////

#ifndef _DEBUG
#include "stdio.h"
#endif

#define POINTX {1, 2, 3, 4, 5, 6, 7, 8, 9, 10}
#define POINTY {2, 4, 6, 8, 10, 12, 14, 16, 18, 20}
#define POINTS 10

#define GetError(x, y, Px, Py) \
    ( (x-Px)*(x-Px) + (y-Py)*(y-Py) )

int main(int argc, char* argv[]) {
    int pPointX[] = POINTX;
    int pPointY[] = POINTY;

    int x, y;
    int index, error, minindex, minerror;

    x = 4;
    y = 5;

    minerror = GetError(x, y, pPointX[0], pPointY[0]);
    minindex = 0;

    for(index = 1; index < POINTS; index++) {
        error = GetError(x, y, pPointX[index], pPointY[index]);

        if (error < minerror) {
            minerror = error;
            minindex = index;
        }
    }

#ifndef _DEBUG
    printf("minindex = %d, minerror = %d.\n", minindex, minerror);
    printf("The point is (%d, %d).\n", pPointX[minindex], pPointY[minindex]);
    getchar();
#endif

    return 0;
}
```

Steps

- Establishing a project

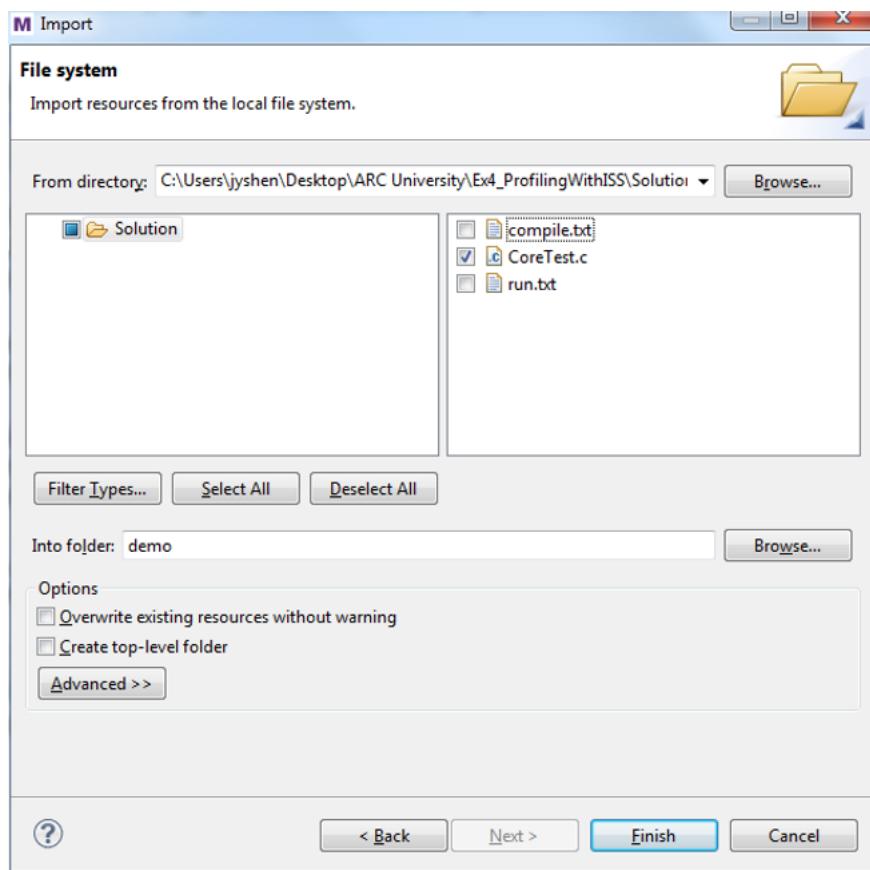
Open the MetaWare Development Toolkit, create an empty project called `demo`, and select the **ARC EM Generic** processor.



- Import the code file `CoreTest.c` to the project `demo`.

In the Project Explorer, click and select **Import**.

Import dialog box is displayed. Select the File System item from the **General** tab, and click **Next**. As shown in the following figure, add the file directory where the source code `CoreTest.c` is located. The dialog box is automatically displays the name of the directory and the file name of the file contained in the directory. Select `CoreTest.c` and click **Finish** to complete the import process.



After the import is complete, you can see the code file `CoreTest.c` you just added in the Project Explorer on the left side of the MetaWare Development Toolkit main interface.

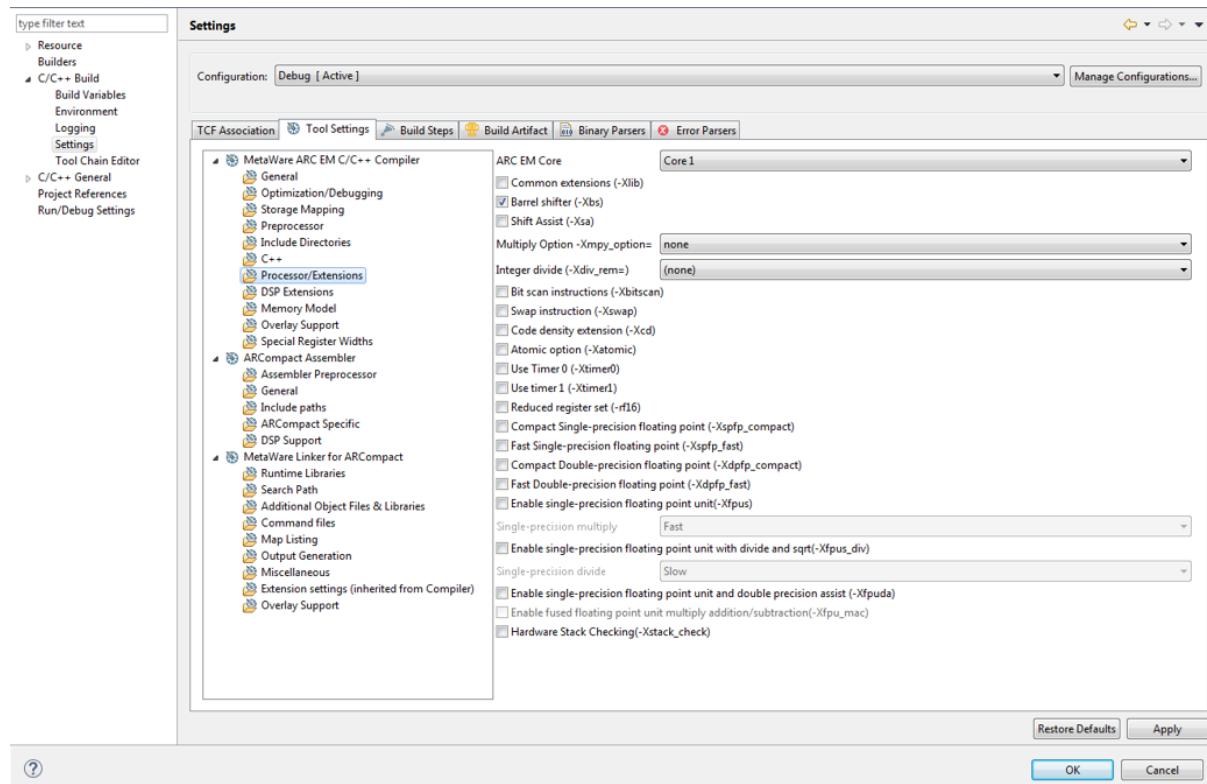
3. Set compilation options

Right-click in the current project demo and select Properties. Click **C/C++ Build > Settings > Tool Settings** to open the compile option settings window.



Select **Optimization/Debugging** to set the compiler optimization and debugging level. For example, set the optimization level to turn off optimization, and set the debugging level to load all debugging information.

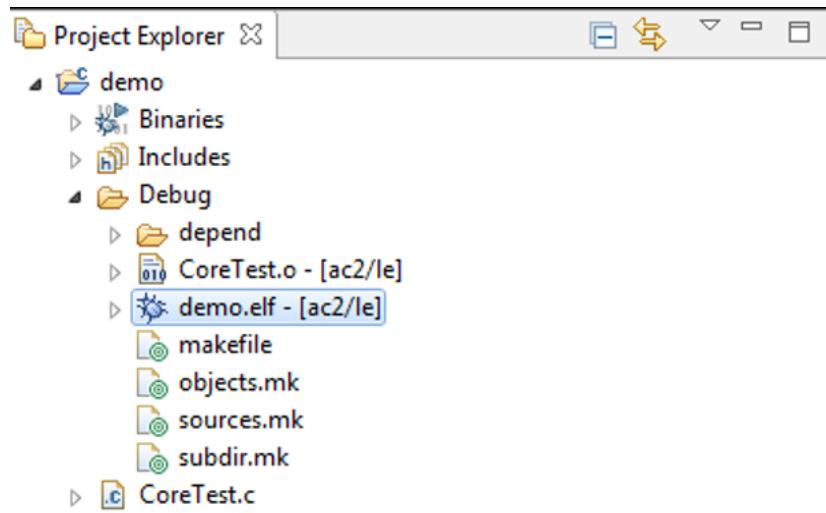
Select Processor/Extensions to set the compile options corresponding to the target processor hardware properties, such as the version of the processor, whether to support extended instructions such as shift, multiplication, floating-point operations, and so on whether to include Timer0/1. As shown in the following figure, this setting indicates that the target processor supports normal extended instructions.



Select **MetaWare ARC EM C/C++** and check the settings compile options and click **OK**.

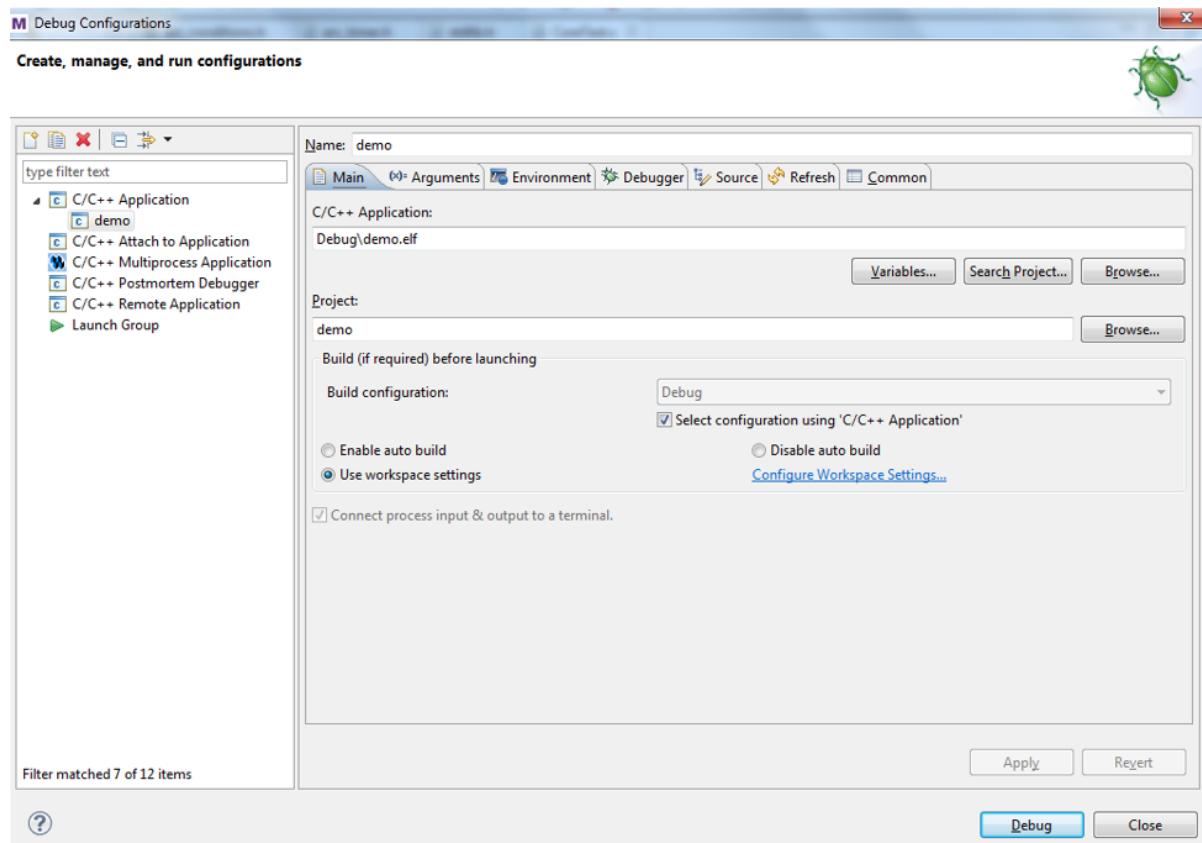
4. Compile project demo

Select Build Project from the Project drop-down menu in the MetaWare Development Toolkit main menu or click the icon . In the MetaWare Development Toolkit main interface, select **Console** to view the logs during compilation. When the message ‘Finished building target: demo.elf’ is displayed, the compilation is successful, and the compiled executable file demo.elf can be seen in the Project Explorer.



5. Set debug options

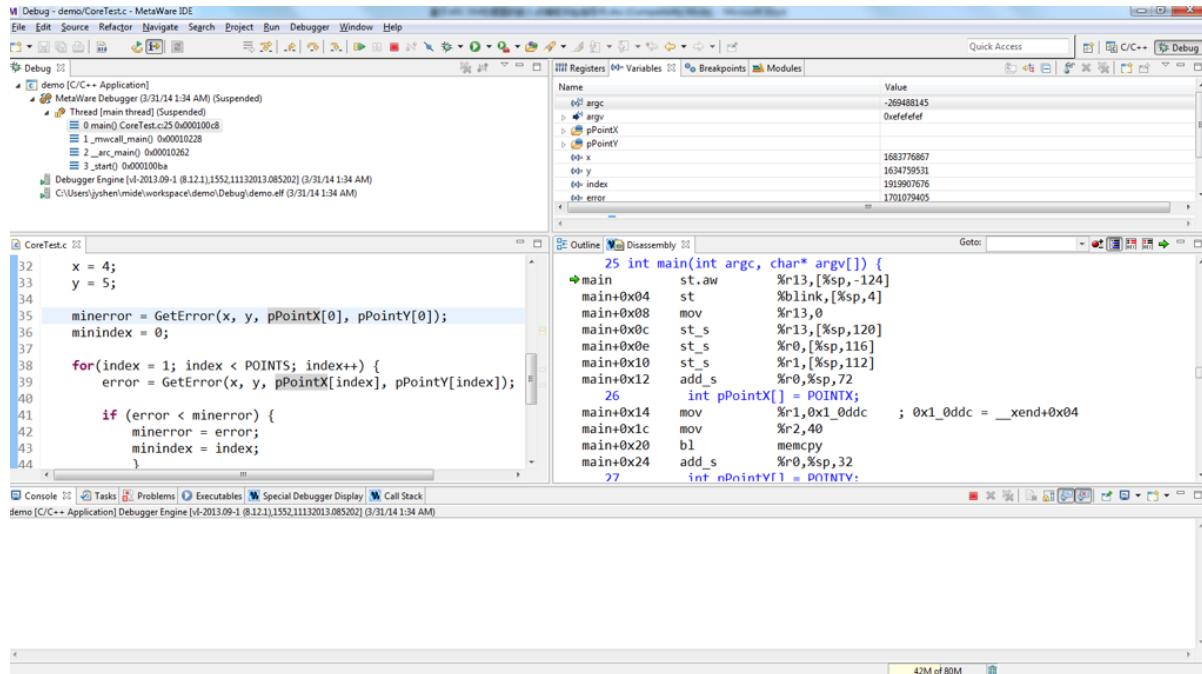
Select Debug Configurations from the **Run** drop-down menu and double-click **C/C++ Application** or right-click **New**



Click **Debugger**. You do not need to make any changes. Check the contents of the Debugger Options, click **Debug** to enter the debugging interface.

6. Debug executable file demo.elf

Select the required debug window from the main menu of the debug interface, such as source code window, assembly code window, register window, global variable window, breakpoint window, function window, and so on.



In the C code window, right-click the code line number on the left side of the window, select **Toggle Breakpoint** or double-click the line number to set a breakpoint on the current line. In the assembly code window, double-click a line of code to set a breakpoint on the current line.

After the breakpoint is set, click to run the program. The program runs directly to the nearest breakpoint. You can observe the current program execution and the relevant status information of the processor through the various windows as described in previous step. If you want to know more about the details of program execution and the instruction behavior of the processor, you can use the following three execution commands to perform single-step debugging. The icon can choose to step through a C language statement or an assembly instruction to match the status information of each window. It can be very convenient for program debugging. If you want to end the current debugging process, click . If you want to return to the main MetaWare Development Toolkit page, click .

7. Code performance analysis using the debugger

Based on the previous project demo, open the **Compile Options** dialog box in step 3 and set the Optimization Level to -O0 in the **Optimization/Debugging** column. Then click to recompile the project, and click to enter the debugging interface. Click **Debugger** in the main menu of the debugging interface, select **Disassembly** from the menu drop-down menu, open the disassembly code window, and you can see that the program is paused at the entrance of the main() function. In the same way, select **Profiling** in the **Debugger** drop-down menu, open the performance analysis window and click .

%	cumulative count	self count	num calls	avg. cnt/call	address	name
20.73	255	255	1	255	00010620	memchr
8.21	356	101	1	101	00010404	_a5_strlen
5.85	428	72	2	36	000108fc	_hl_message_ap
5.04	490	62			00010b16	_ac_pop_nonev
5.04	552	62	1	62	000104a0	memcpy
5.04	614	62	1	62	00010d60	_vsMemcpy
4.88	674	60	2	30	000106f8	_hl_send
4.15	725	51	3	17	00010b84	priority_enq
3.33	766	41	1	41	000101dc	_mwcall_main
3.25	806	40			00010040	_start
1.95	830	24	2	12	00010b54	_ac_mc_va
1.95	854	24			00010a98	_ac_push_13_to_1

The **Profiling** window displays the corresponding of the number of executed instructions of the program with each function under the current debug window. From left to right, the total number of executions of function instructions in the total number of executions of the entire program instruction, the total number of executions of the accumulated instructions, the total number of executions of the functions, the number of times the function is called, the number of including functions, the address of the function, and the name of the function. Through the relationship between the instruction information and the function in the Profiling window, it is very convenient to analyze the program efficiency and find the shortcoming of the program performance.

Use this project as an example to continue to introduce the use of the Profiling window. The program is paused at the entrance of the main() function and the Profiling window opens. The main() function is the main object of performance analysis optimization. The content displayed in the Profiling window is some function information initialized by the processor before the main() function is executed. Click in the Profiling window to clear the current information. If you click , nothing is displayed, and it indicates that the cleaning is successful. Set a breakpoint at the last statement of the main() function (either C statement or assembly statement), and click in the toolbar above the debug interface to let the program execute to the breakpoint. Click in the Profiling window, and only the information related to the main() function is displayed. Therefore, flexible setting of breakpoints, combined with the clear function, can perform performance analysis on the concerned blocks (figure 9).

%	cumulative count	self count	num calls	avg. cnt/call	address	name
83.36	2064	2064	20	103	00010a24	_mw_mpy_32x32y32
13.17	2390	326			000100c8	main
3.47	2476	86	2	43	000104a0	memcpy

It can be seen that the multiplication library function `_mw_mpy_32x32y32` in the `main()` function is called 20 times, and a total of 2064 instructions are executed, while the `main()` function itself executes only 326 instructions, and the `memcpy` function executes 86 instructions. It can be seen that the implementation of the multiplication function of the program consumes a large number of instructions, and the large number of instructions means that the processor spends a large number of computation cycles to perform multiplication operations. Therefore, multiplication is the shortcoming of current program performance. If you want to improve the performance of the program, you should consider how you can use fewer instructions and implement multiplication more efficiently.

Exercises

How can I implement multiplication more efficiently with fewer instructions? Apply this method to the project demo of the fifth part, analyze it with the debugger's Profiling function, observe the total number of instructions consumed by the `main` function, and compare it with the previous Profiling result of Figure 8.

GNU Toolchain for ARC Processors

Purpose

- Learn the GNU Toolchain for ARC Processors
- Familiar with the GNU Toolchain for ARC Processors
- Familiar with the functions and usage of the GNU Toolchain for ARC Processors debugger

Equipment

The following hardware and tools are required:

- PC host
- GNU Toolchain for ARC Processors
- nSIM simulator or ARC board (EM Starter Kit / IoT Development Kit)
- `embarc_osp/arc_labs/labs/lab1_core_test`

Content

- Create a C project using GNU Toolchain for ARC Processors
- Import the code `CoreTest.c` from `embarc_osp/arc_labs/labs/lab1_core_test`
- Configure compilation options to compile, and generate executable files.
- Start the GNU Toolchain for ARC Processors debugger to enter the debug mode

From the C language and assembly language different perspectives, use set breakpoints, single-step execution, full-speed execution and other functions, combined with observation of PC address, register status, global variable status and Profiling Performance analysis window, analysis of the debug target program.

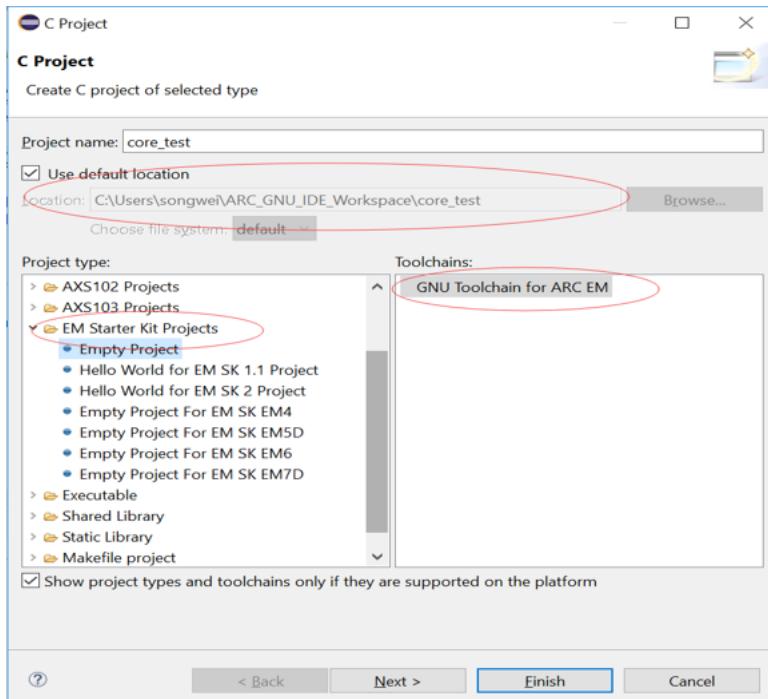
Principles

Use the GNU Toolchain for ARC Processors integrated development environment to create projects and load routine code. In the engineering unit, configure the compile option compilation routine code to debug and analyze the compiled executable file.

Steps

1. Establishing a project

Open the GNU Toolchain for ARC Processors, create an empty project called core_test, and select **ARC EM series processor**.



2. Import the code file CoreTest.c to the project demo

Right-click  **core_test**, and then select **Import**.

Import dialog box is displayed. Select **File System** from the the **General** tab, and click **Next**. As shown in the following figure, add the file directory where the source code CoreTest.c is located. The dialog box automatically displays the name of the directory and the file name of the file contained in the directory. Select the file to be added, CoreTest.c, and click **Finish** to complete the entire import process.



After the import is complete, you can see the code file CoreTest.c that you just added in the Project Explorer.

3. Set compilation options

Right-click in the current project core_test and select **Properties**. Click **C/C++ Build > Settings > Tool Settings** to view the compile option settings page.



Select **Debugging** to set the compiler optimization and debugging level. For example, set the optimization level to off optimization, and the debugging level is to load all debugging information.

Select Processor in the current interface to set the compile options corresponding to the target processor hardware attributes, such as the version of the processor, whether to support extended instructions such as shift, multiplication, floating-point operations, and so on whether to include Timer0/1.

In step 1, you already built the project using the engineering template of EMSK, the corresponding necessary options have been set by default. If there is no special requirement, check the setting compile options in the All options column and click **OK** to close the Properties dialog box.

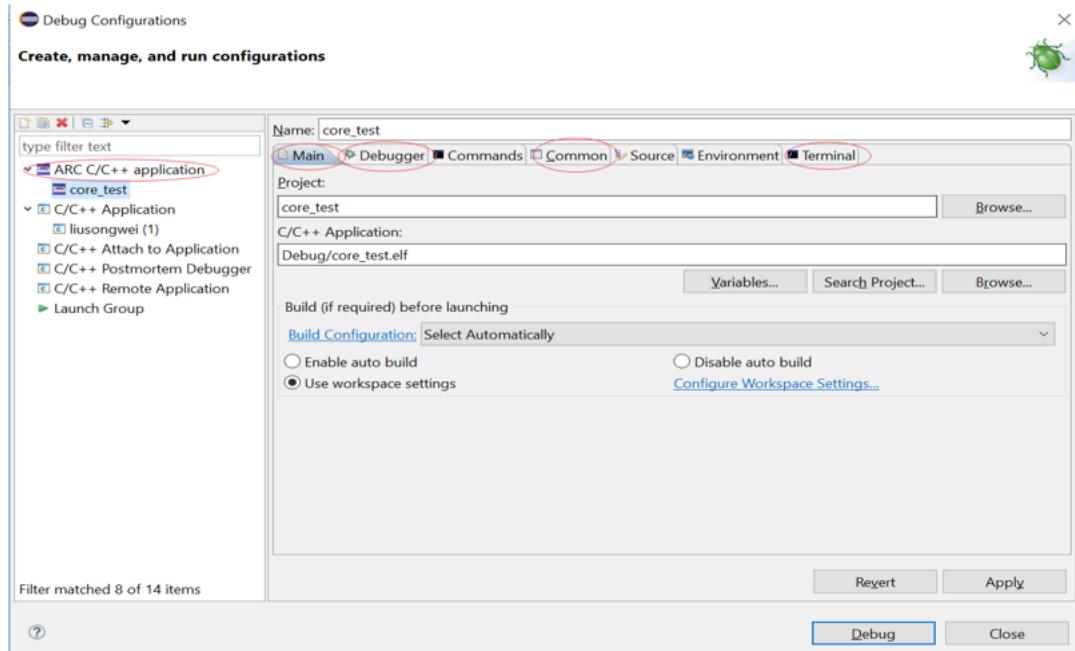
4. Compile the project core_test**

Select **Build Project** from the Project drop-down menu in the GNU Toolchain for ARC Processors main menu or click . In the middle of the GNU Toolchain for ARC Processors main interface, select Console to view the logs during the compilation process. When the message ‘Finished building target: Core_test.elf’ is displayed, the compilation is successful, and the compiled executable file Core_test.elf can be seen in the **Project Explorer** as shown in the following figure.



5. Set debugger options

Select Debug Configurations from the Run drop-down menu in the main menu. Then double-click in C/C++ Application or right-click New to get a dialog box similar to the one shown in the following figure.



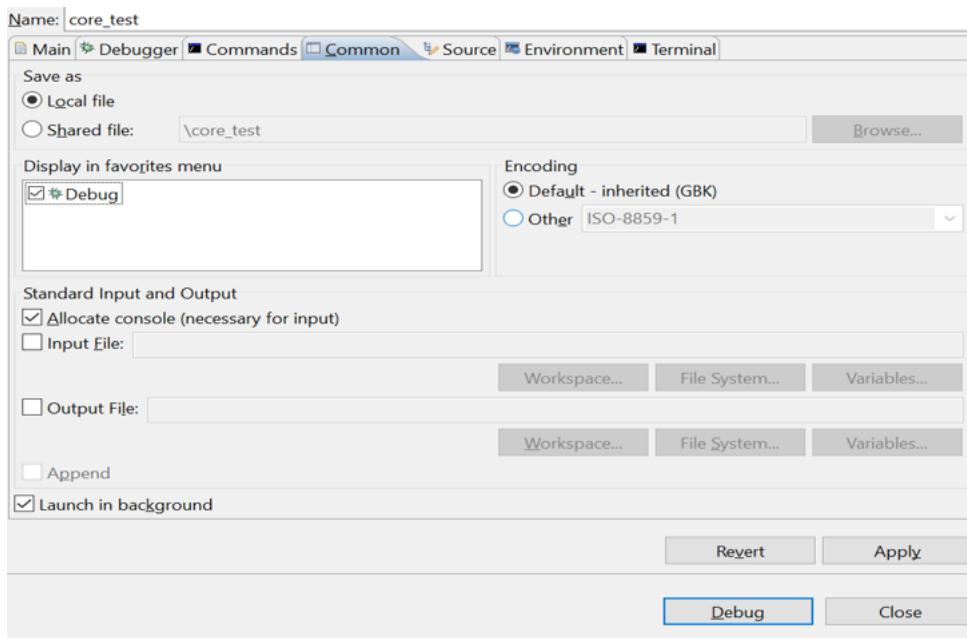
Check if the information in Main is correct. As you use nSIM simulator to simulate EMSK development board, you need to modify the settings of Debugger, Common, and Terminal (this is because nSIM cannot be called directly in GNU IDE. Still need GDB Server for indirect calls). The specific settings are as follows:

- Set Debugger->Gdbserver Settings



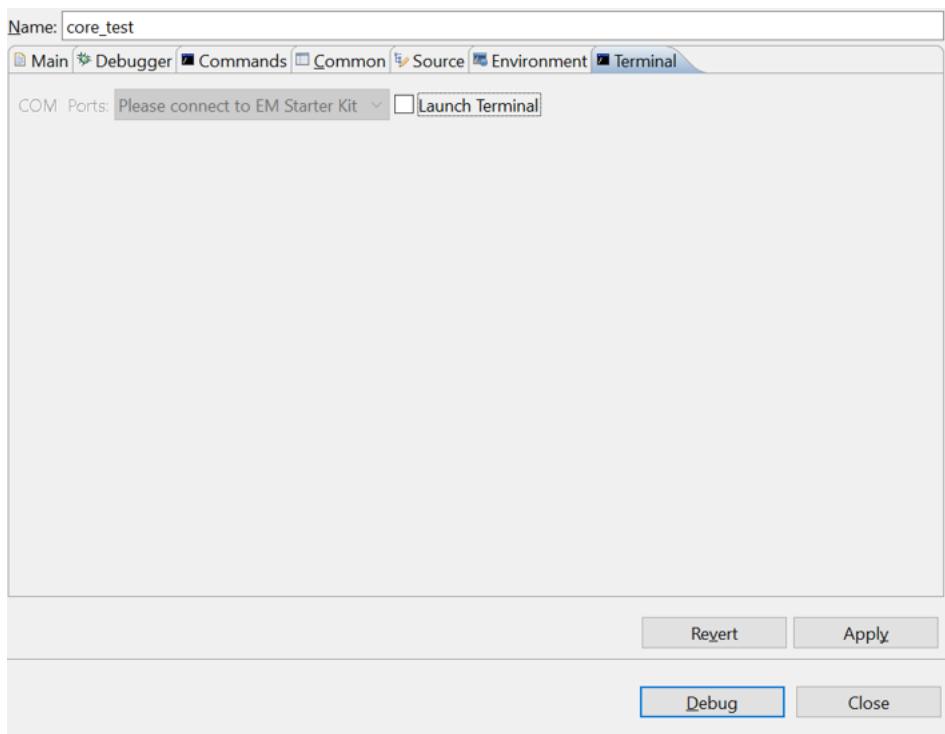
The ARC GDB Server should select nSIM. The port number default setting is 49105. It is important to check the Use TCF. Otherwise, the nSIM cannot work normally. The TCF start file is under *nSIM/nSIM/etc/tcf/templates* (the default installation path). If you have downloaded the MetaWare IDE, the default nSIM path is *C:/ARC/nSIM/nSIM/etc/tcf/templates*, and you can select a TCF file from this folder (depending on the version of the board you are simulating and the kernel model), as shown earlier.

- Pay attention to Debug in Common



- Terminal settings

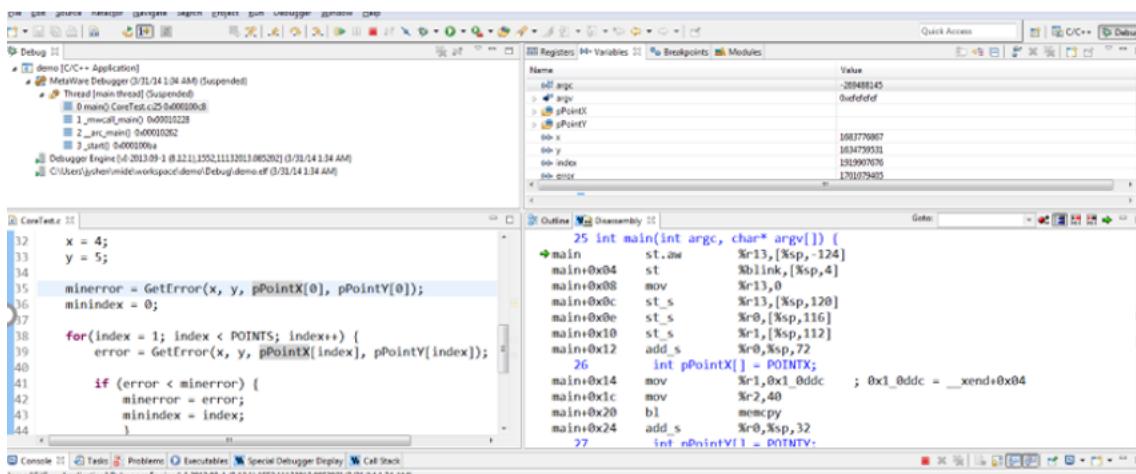
If you are using the EM Starter Kit, the terminal automatically selects the correct port number, and you are using the emulator without a port, uncheck it, as show in the following figure.



After all settings are completed, click **Debug** to enter the debugging interface.

6. Debug executable file core_test.elf

Select the required debug window from the Debugger menu in the main menu of the debug interface, such as source code window, assembly code window, register window, global variable window, breakpoint window, function window, and so on as shown in the following figure.



In the C code window, right-click the code line number on the left side of the window, select **Toggle Breakpoint** or double-click the line number to set a breakpoint on the current line. In the assembly code window, double-click a line of code to set a breakpoint on the current line.

After the breakpoint is set, click to run the program. The program runs directly to the nearest breakpoint. You can observe the current program execution and the relevant status information of the processor through the various windows as described in previous step. If you want to know more about the details of program execution and the instruction behavior of the processor, you can use the following three execution commands | | to perform single-step debugging. The icon can choose to step through a C language statement or an assembly instruction to match the status information of each window. It can be very convenient for program debugging. If you want to end the current debugging process, click . If you want to return to the main MetaWare Development

Toolkit page, click C/C++ | .

7. Code performance analysis using the debugger

Same as the code performance analysis method of MetaWare Development Toolkit. For details, see first part of Lab 1.

For the use of these two IDEs, you can refer to the Help documentation in the respective IDE, or you can view the on-line documentation provided by Synopsys.

How to use embARC OSP

Purpose

- To know what embARC OSP is
- To know how to run examples in embARC OSP
- To know how to debug the examples in embARC OSP
- To know how to create application in embARC OSP

Equipment

The following hardware and tools are required:

- PC host
- GNU Toolchain for ARC Processors / MetaWare Development Toolkit
- ARC board (EM Starter Kit / IoT Development Kit)
- embARC OSP packages

For the detailed tool requirements of embARC OSP, see ‘here <http://embarc.org/embarc_osp/doc/build/html/getting_started/software_requirement.html>’

Content

A brief introduction of embARC OSP, downloading, running, and debugging the provided examples is explained. You can try to create your own embARC applications.

Principles

1. IoT OS/Platform

As more and more devices are connected and become more complex, the tools running in them are becoming more and more complex.

An IoT OS is an operating system that is designed to perform within the constraints that are particular to Internet of Things devices, including restrictions on memory, size, power, and processing capacity. IoT operating systems are a type of embedded OS but by definition are designed to enable data transfer over the Internet and more other features.

2. embARC OSP

The embARC OSP is an open software platform to facilitate the development of embedded systems based on DesignWare® ARC® processors.

It is designed to provide a unified platform for DesignWare® ARC® processors users by defining consistent and simple software interfaces to the processor and peripherals, together with ports of several well known FOSS embedded software stacks to DesignWare® ARC® processors.

For more details, see embARC OSP [online documentation](#)

3. Other platforms

Besides embARC OSP, there are also other IoT platforms:

- Zephyr
- Amazon FreeRTOS

Steps

Get embARC OSP

- git

The embARC OSP source code is hosted in a [GitHub repository](#). The repository consists of scripts and other things to you need to setup your development environment, and use Git to get this repo. If you do not have Git installed, see the beginning of the OS-specific instructions for help.

Using Git to clone the repository anonymously.

```
# On Windows
cd %userprofile%
# On Linux
cd ~

git clone https://github.com/foss-for-synopsys-dwc-arc-processors/embarc_osp.git
→embarc_osp
```

You have checked out a copy of the source code to your local machine.

- http download

You may also try to get the latest release of embARC OSP as a zip from the repository, see [release page](#).

Run the examples

The command-line interface is the default interface to use embARC OSP. After getting the embARC OSP package, you need to open a **cmd** console in Windows / a **terminal** in Linux and change directory to the root of embARC OSP.

Use the **blinky** as an example.

1. Go to the **blinky** example folder

```
cd example\baremetal\blinky
```

2. Connect your board to PC host, and open the UART terminal with putty/tera term/minicom

3. Build and run it with command, here ARC GNU toolchain is selected

```
# For EMSK 2.3
make TOOLCHAIN=gnu BOARD=emsk BD_VER=23 CUR_CORE=arcem11d run
# For EMSK 2.2
make TOOLCHAIN=gnu BOARD=emsk BD_VER=22 CUR_CORE=arcem7d run
# For IoTDK
make TOOLCHAIN=gnu BOARD=iotdk run
```

Note: for EM Starter Kit, make sure the board version (BD_VER) and core configuration (CUR_CORE) match your hardware. You could press configure button (located above the letter “C” of the ARC logo) when bit 3 and

bit 4 of SW1 switch is off to run a self-test. By doing so, board information is sent by UART and displayed on your UART terminal.

4. Get the results

- For EMSK, you can see the on-board LEDs start to blink when the download is successful.
- For IoTDK, as it does not have usable LEDs except some status LEDs, the following output log is displayed through UART.

```
led out: ff, ff
led out: ff00, ff
led out: ff, ff
.....
```

Debug the examples

Use the **blink** as example, to debug it, you need to run the following commands:

```
# For emsk 2.3
make TOOLCHAIN=gnu BOARD=emsk BD_VER=23 CUR_CORE=arcem11d gui
# For emsk 2.2
make TOOLCHAIN=gnu BOARD=emsk BD_VER=22 CUR_CORE=arcem7d gui
# For IoTDK
make TOOLCHAIN=gnu BOARD=iotdk gui
```

For MetaWare Development Toolkit, the mdb (MetaWare debugger) is used and it is a GUI interface. You can refer the MetaWare toolchain user manual for details.

For GNU Toolchain for ARC Processors, the command-line based gdb is used. You need to have some basic knowledge of gdb debug.

Create your own application

Create your own application in embARC OSP.

- Goals
 - Bare-metal application based on embARC OSP
 - Hardware: EMSK 2.2 - ARC EM7D Configuration / IoTDK
 - Print “Hello world from embARC” through UART at 115200 bps
 - Use GNU toolchain to running and debugging in the command line
1. Create a folder named `hello_world` under `embarc/example/baremetal`.
 2. Copy the makefile template `example/example.makefile` and `main.c.tpl` into `hello_world` folder and rename `example.makefile` to `makefile`, rename `main.c.tpl` to `main.c`.

3. Change the configurations in makefile according to your hardware configuration and application.
 - Change the application name: change the value of APPL to helloworld.
 - Change the board name: change the value of BOARD to emsk / iotdk. This option can also be given in command-line. If not specified, the default value is emsk
 - Change the board version: change the value of BD_VER to 22 (for emsk) or 10 (for iotdk). This option can also be given in command-line. If not specified, the default value is 22 for board emsk.
 - Change the core configuration: change the value of CUR_CORE to arcem7d This option can also be given in command-line. If not specified, the default is arcem7d for board emsk and version 22. For iotdk, CUR_CORE can be bypassed as iotdk only has one core configuration.
 - Change the embARC OSP root: change the value of EMBARC_ROOT to ../../... EMBARC_ROOT can be relative path or an absolute path.
 - Add the middleware that you need for this application: Change the value of MID_SEL.
 - The value of MID_SEL must be the folder name in <embARC>/middleware, such as common or lwip.
 - If using lwip, ntshell, fatfs, and common, set MID_SEL to lwip ntshell fatfs common.
 - Set it to common in the “HelloWorld” application.
 - Change your toolchain: change the value of TOOLCHAIN to gnu.
 - Update source folders and include folder settings.
 - Update the C code folder settings: change the value of APPL_CSRC_DIR to .. APPL_CSRC_DIR is the C code relative path to the application folder
 - Update the assembly source-folder settings: change the value of APPL_ASMSRC_DIR.
 - Update the include-folders settings: change the value of APPL_INC_DIR which is the application include path to the application folder (-I).
 - If more than one directory is needed, use whitespace between the folder paths.
 - Set your application defined macros: Change the value of APPL_DEFINES.
 - For example, if define APPLICATION=1, set APPL_DEFINES to -DAPPLICATION=1.

Then makefile for hello world application will be like this

```
## embARC application makefile template ##
### You can copy this file to your application folder
### and rename it to makefile.
##

##
# Application name
##
APPL ?= helloworld

##
# Extended device list
##
EXT_DEV_LIST +=

# Optimization level
# Please refer to toolchain_xxx.mk for this option
OLEVEL ?= O2

##
# Current board and core (for emsk)
```

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```
##  
BOARD ?= emsk  
BD_VER ?= 22  
CUR_CORE ?= arcem7d  
  
##  
# Current board and core (for iotdk)  
BOARD ?= iotdk  
BD_VER ?= 10  
  
##  
# Debugging JTAG  
##  
JTAG ?= usb  
  
##  
# Toolchain  
##  
TOOLCHAIN ?= gnu  
  
##  
# Uncomment following options  
# if you want to set your own heap and stack size  
# Default settings see options.mk  
##  
#HEAPSZ ?= 8192  
#STACKSZ ?= 8192  
  
##  
# Uncomment following options  
# if you want to add your own library into link process  
# For example:  
# If you want link math lib for gnu toolchain,  
# you need to set the option to -lm  
##  
#APPL_LIBS ?=  
  
##  
# Root path of embARC  
##  
EMBARC_ROOT = ../../..  
  
##  
# Middleware  
##  
MID_SEL = common  
  
##  
# Application source path  
##  
APPL_CSRC_DIR = .  
APPL_ASMSRC_DIR = .  
  
##  
# Application include path  
##  
APPL_INC_DIR = .  
  
##  
# Application defines
```

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```

##  

APPL_DEFINES =  

##  

# Include current project makefile  

##  

COMMON_COMPILE_PREREQUISITES += makefile  

### Options above must be added before include options.mk ###  

# Include key embARC build system makefile  

override EMBARC_ROOT := $(strip $(subst \,/, $(EMBARC_ROOT)))  

include $(EMBARC_ROOT)/options/options.mk

```

4. Run

- Set your EM Starter Kit 2.2 hardware configuration to ARC EM7D (no need to set to IoT Development Kit), and connect it to your PC. Open PuTTY or Tera-term, and connect to the right COM port. Set the baud rate to **115200 bps**.
- Enter `make run` in the command-line to run this application.

Exercises

Create your application which is different with **blinky** and **hello_world** in embARC OSP.

ARC features: timer and auxiliary registers

Purpose

- To know about internal timer of DesignWare® ARC® processors
- To learn how to program auxiliary registers to control the timer
- Read the count value of the timer, and implement a time clock by the timer

Equipment

The following hardware and tools are required:

- PC host
- GNU Toolchain for ARC Processors / MetaWare Development Toolkit
- ARC board (EM Starter Kit / IoT Development Kit)
- `embarc_osp/arc_labs/labs/lab3_timer`

Content

- Read the auxiliary registers of DesignWare® ARC® processors to get the version and other setting information of the timer resource.
- As all DesignWare® ARC® processors have **Timer0**, the **Timer0** is used in this lab, and write the auxiliary registers to initialize, start and stop the timer.
- By reading the count value of the timer, the execution time of a code block is calculated with the count value and the clock frequency.

Principles

Introduction of internal Timer and Auxiliary registers

Timers in DesignWare® ARC® processors

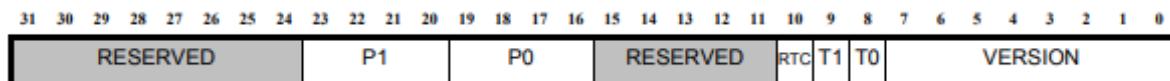
- Two 32-bits programmable timers **Timer0** and **Timer1**
- One 64-bits **RTC** (Real-Time Counter)

All the times are configurable, for example, there are four DesignWare® ARC® processors cores in **ARC_EMSK1.1**, the configuration information is as followed.

Timer	EM4	EM4_16CR	EM4	EM4_16CR
HAS_TIMER0	1	1	1	1
HAS_TIMER1	1	0	1	0
RTC_OPTION	0	0	0	0

The auxiliary register Timer BCR stores the timer resource information of an ARC EM processor core, the register address of **TIMER_BUILD** is *0x75*.

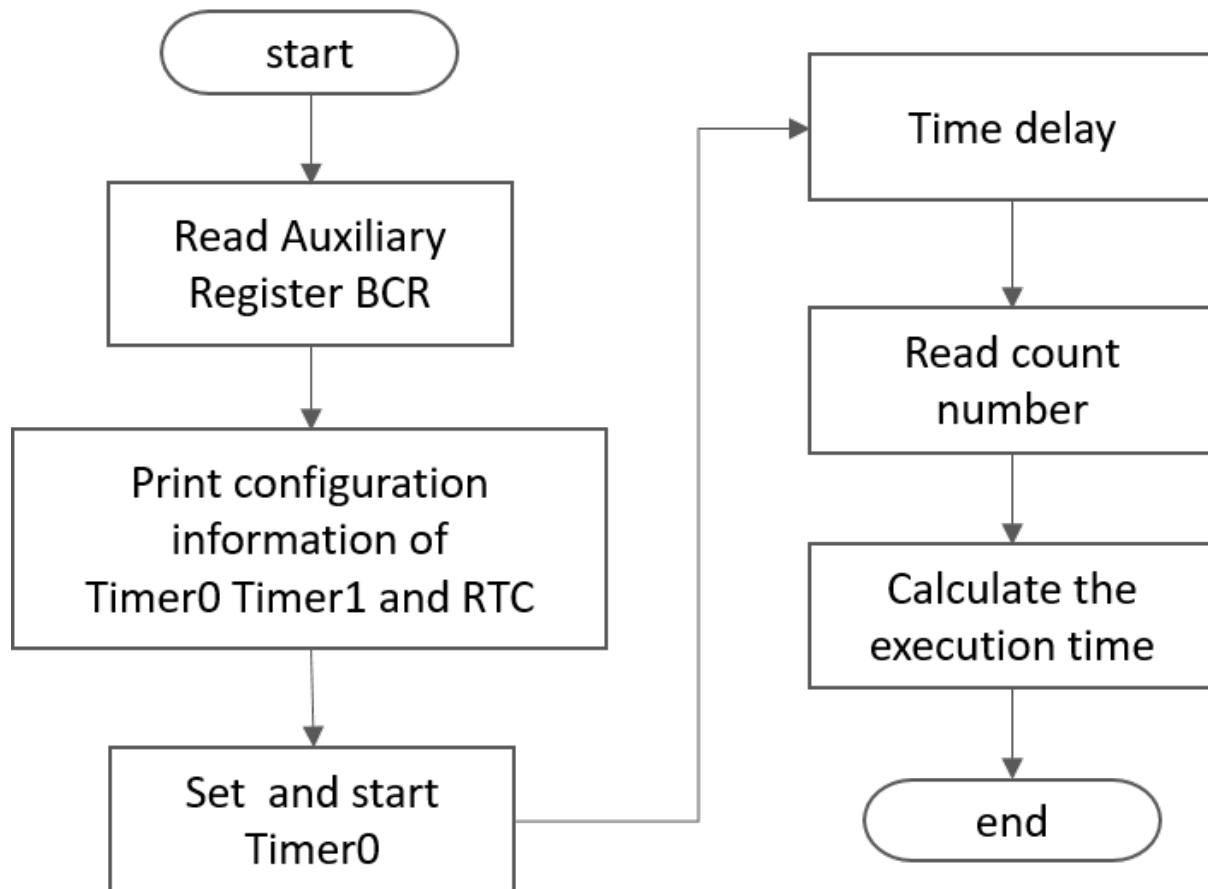
TIMER_BUILD



As described earlier, the timer resources in the ARC EM processor can be configured, the timer's configuration information and controlling of the timers can be done by writing and reading the auxiliary register of that timer. For example, the following table shows the related auxiliary registers of the **Timer0**.

Auxiliary Register	Name	Permission	Description
0x21	COUNT0	RW	Processor timer 0 count value
0x22	CONTROL0	RW	Processor timer 0 control value
0x23	LIMIT0	RW	Processor timer 0 limit value

Program flow chart



Steps

Makefile configuration

There are two ways to configure the internal timers.

First, configure by compiling command, for example:

```
make BOARD=iotdk BD_VER=10 CUR_CORE=arcem9d -j4 TOOLCHAIN=gnu run
```

Second, configured by modifying the makefile. Here, the compile command is simple, for example:

```
make -j4 run
```

Open the folder `embarc_osp/arc_labs/labs/lab3_timer`, and open the `makefile`, here is the default configuration.

```
# Application name
API ?= lab3_timer

##
# Current Board And Core
##
BOARD ?= iotdk
BD_VER ?= 10
CUR_CORE ?= arcem9d
```

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```
##  
# Set toolchain  
##  
TOOLCHAIN ?= gnu  
  
#  
# root dir of embARC  
#  
EMBARC_ROOT = ../../..  
  
MID_SEL = common  
  
# application source dirs  
APPL_CSRC_DIR = .  
APPL_ASMSRC_DIR = .  
  
# application include dirs  
APPL_INC_DIR = .
```

- Reconfigure **BOARD** and **CUR_CORE**, in this lab, the launch board *iotdk* is used.

```
##  
# Current Board And Core  
##  
BOARD ?= iotdk  
BD_VER ?= 10  
CUR_CORE ?= arcem9d
```

- Reconfigure **TOOLCHAIN**, select the toolchain *gnu* or *metaware* you used

```
##  
# Set toolchain  
##  
TOOLCHAIN ?= gnu
```

- Reconfigure **EMBARC_ROOT**, make sure the relative path between *embARC OSP* root folder and the *timer* folder is correct.

```
#  
# root dir of embARC  
#  
EMBARC_ROOT = ../../..
```

Main code

Read auxiliary register **BCR_BUILD**

The function `_arc_aux_read()` can be used to read the auxiliary register for the timer resource information.

Read auxiliary register **TIMER_BUILD**. In the register **TIMER_BUILD**, the lower 8 bits indicate the core version information, the bit 9 indicate the **Timer0**, the bit 10 indicate the **Timer1**, and the bit 11 indicate the **RTC**. Here is the code:

```
uint32_t bcr = _arc_aux_read(AUX_BCR_TIMERS);  
int timer0_flag=(bcr >> 8) & 1;  
int timer1_flag=(bcr >> 9) & 1;  
int RTC_flag=(bcr >> 10) & 1;
```

Read timer related auxiliary registers, for example, the **Timer0**. Here is the code:

```
EMBARC_PRINTF("Does this timer0 exist? YES\r\n");
/*Read auxiliary register configuration information*/
EMBARC_PRINTF("timer0's operating mode:0x%08x\r\n",_arc_aux_read(AUX_TIMER0_CTRL));
EMBARC_PRINTF("timer0's limit value :0x%08x\r\n",_arc_aux_read(AUX_TIMER0_LIMIT));
EMBARC_PRINTF("timer0's current cnt_number:0x%08x\r\n",_arc_aux_read(AUX_TIMER0_
↪CNT));
```

Stop-Set-Start the Timer0

The function `_arc_aux_write()` can be used to write the auxiliary register.

To control **Timer0** with the related auxiliary registers.

- **COUNT0**: write this register to set the initial value of the **Timer0**. It increases from the set value at anytime you write this register.
- **CONTROL0**: write this register to update the control modes of the **Timer0**.
- **LIMIT0**: write this register to set the limit value of the **Timer0**, the limit value is the value after which an interrupt or a reset must be generated.

In this lab, timer should be stopped before setting and starting it, the function `timer_stop()` is already encapsulated in embARC OSP, you can use this function or directly write the register. Set the timer work mode, enable interrupt or not, set the limit value, and then start the timer. Here is the code:

```
/* Stop it first since it might be enabled before */
_arc_aux_write(AUX_TIMER0_CTRL, 0);
_arc_aux_write(AUX_TIMER0_LIMIT,0);
_arc_aux_write(AUX_TIMER0_CNT, 0);
/* This is a example about timer0's timer function. */
uint32_t mode = TIMER_CTRL_NH; /*Timing without triggering interruption.*/
uint32_t val = MAX_COUNT;
_arc_aux_write(AUX_TIMER0_CNT, 0);
_arc_aux_write(AUX_TIMER0_LIMIT,val);
/* start the specific timer */
_arc_aux_write(AUX_TIMER0_CTRL,mode);
```

When the timer is running, the count value of the timer can be read and calculate the execution time of a code block. Here is the code:

```
uint32_t start_cnt=_arc_aux_read(AUX_TIMER0_CNT);
/**
 * code block
 */
uint32_t end_cnt=_arc_aux_read(AUX_TIMER0_CNT);
uint32_t time=(end_cnt-start_cnt) / (BOARD_CPU_CLOCK/1000);
```

Compile and debug

- Compile and download

Open cmd from the folder `embarc_osp/arc_labs/labs/lab3_timer`, input the compile command:

```
make -j4 run
```

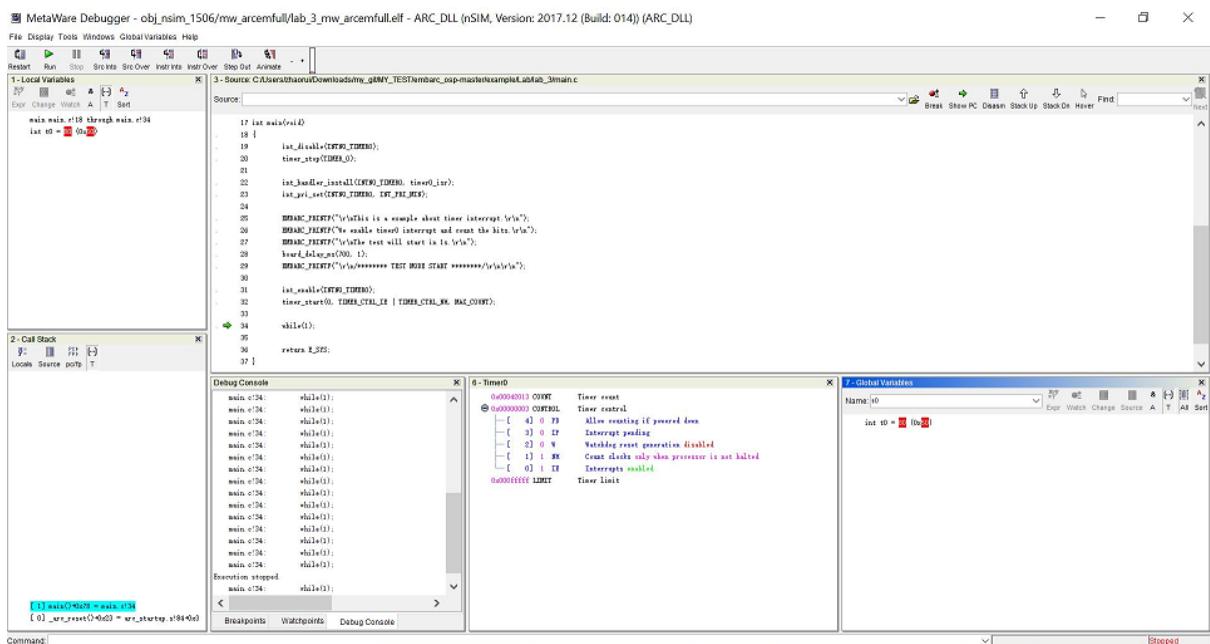
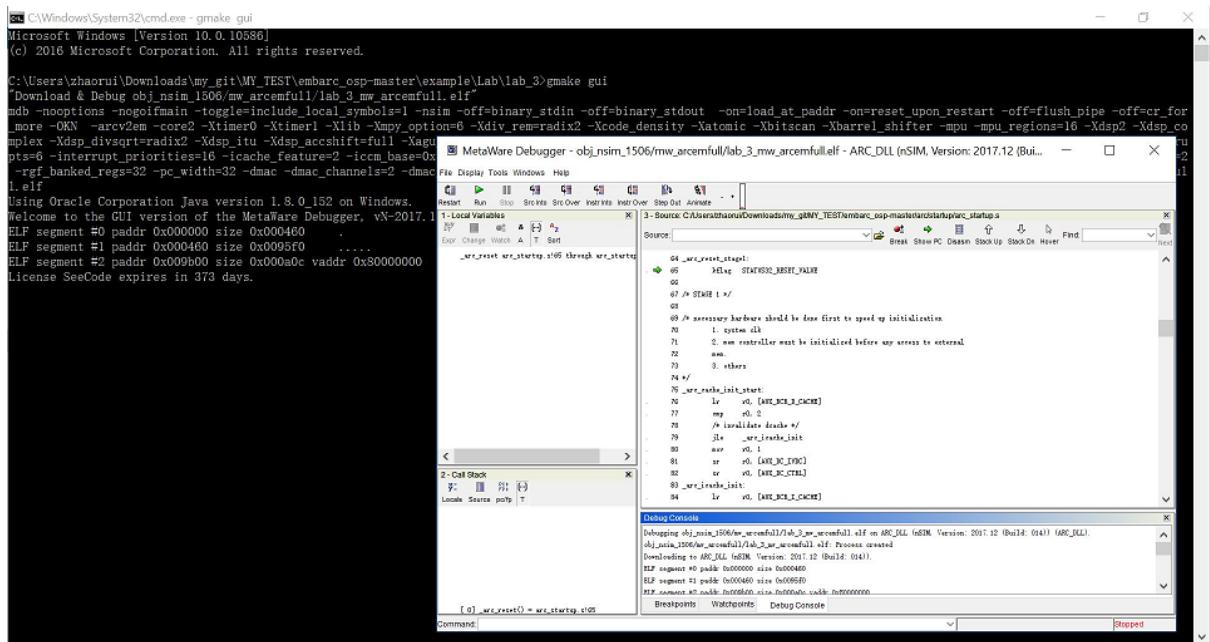
Note: If your toolchain is WetaWare, you should use gmake. If you do not use core configuration specified in makefile, you need to pass all the make options to trigger make command

- Output

- Debug

Open cmd from the folder *embarc_osp/arc_labs/labs/lab3_timer*, input the command:

make qui



The debug view pops up automatically, the variables and registers can be seen.

Exercises

In the debug view, observe and understand the contents of the interrupt vector table.

Note: Click the Memory button in the debug view Debugger drop-down menu to see the contents of the memory in real time.

ARC features: interrupts

Purpose

- To introduce the interrupt handling of DesignWare® ARC® processors
- To know how to use the interrupt and timer APIs already defined in embARC OSP

Equipment

The following hardware and tools are required:

- PC host
- GNU Toolchain for ARC Processors / MetaWare Development Toolkit
- ARC board (EM Starter Kit / IoT Development Kit)
- `embarc_osp/arc_labs/labs/lab4_interrupt`

Content

This lab and lab 3 are both introductions to the internal characteristics of the ARC processor. Lab 3 introduces the timer. This lab aims to introduce the interrupt of embARC through `embarc_osp/arc_labs/labs/lab4_interrupt` in the embARC OSP package. The two routines gives you a preliminary understanding of the ARC interrupt resources.

Principles

The ARC EM processor uses vector interrupts to handle interrupt events. When the interrupt occurs, the processor stops the execution of the current program, and queries the corresponding interrupt vector in the predefined interrupt vector table according to the current interrupt type. In other words, to find the entry address of the interrupt service program. Then program jumps to the address to execute the interrupt service routine. After the execution is completed, returns to the interrupted program and complete the response of the interrupt event.

In embARC OSP, the `int_handler_install()` function is used to bind our interrupt function name to the interrupt vector of the corresponding interrupt, and then the above functions are achieved.

Steps

Open and browse lab one

Go to the `embarc_osp/arc_labs/labs/lab4_interrupt`.

The `lab_4_1` is more fundamental compared to `lab_4_2`. Go to folder `lab_4_1` in which the precise timing function is implemented through the timer interrupt.

Open `main.c` and browse the entire program.

```
#include "embARC.h"
#include "embARC_debug.h"

#define COUNT (BOARD_CPU_CLOCK/1000)

volatile static int t0 = 0;
volatile static int second = 0;

/** arc timer 0 interrupt routine */
```

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```

static void timer0_isr(void *ptr)
{
    timer_int_clear(TIMER_0);
    t0++;
}

/** arc timer 0 interrupt delay */
void timer0_delay_ms(int ms)
{
    t0 = 0;
    while(t0<ms);
}

/** main entry for testing arc fiq interrupt */
int main(void)
{
    int_disable(INTNO_TIMER0);
    timer_stop(TIMER_0);

    int_handler_install(INTNO_TIMER0, timer0_isr);
    int_pri_set(INTNO_TIMER0, INT_PRI_MIN);

    EMBARC_PRINTF("\r\nThis is a example about timer interrupt.\r\n");
    EMBARC_PRINTF("\r\n***** TEST MODE START *****\r\n\r\n");

    int_enable(INTNO_TIMER0);
    timer_start(TIMER_0, TIMER_CTRL_IE | TIMER_CTRL_NH, COUNT);

    while(1)
    {
        timer0_delay_ms(1000);
        EMBARC_PRINTF("\r\n %ds.\r\n", second);
        second++;
    }
    return E_SYS;
}

```

Sub-module Analysis Lab One Code

The code can be roughly divided into three parts: interrupt service function, main function, and delay function.

Each part is analyzed:

- Interrupt service function:

```

static void timer0_isr(void *ptr)
{
    timer_int_clear(TIMER_0);
    t0++;
}

```

This code is a standard example of an interrupt service routine: enters the service function, clears the interrupt flag bit, and then performs the processing that needs to be done in the interrupt service function. Other interrupt service functions can also be written using this template.

In this function, the count variable t0 is incremented by one.

- Main function

```

int main(void)
{
}

```

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```

int_disable(INTNO_TIMER0);
timer_stop(TIMER_0);

int_handler_install(INTNO_TIMER0, timer0_isr);
int_pri_set(INTNO_TIMER0, INT_PRI_MIN);

EMBARC_PRINTF("\r\nThis is a example about timer interrupt.\r\n");
EMBARC_PRINTF("\r\n***** TEST MODE START *****\r\n\r\n");

int_enable(INTNO_TIMER0);
timer_start(TIMER_0, TIMER_CTRL_IE | TIMER_CTRL_NH, COUNT);

while(1)
{
    timer0_delay_ms(1000);
    EMBARC_PRINTF("\r\n %ds.\r\n", second);
    second++;
}
return E_SYS;
}

```

The EMBARC_PRINTF function in this code is only used to send information to the computer, which can be ignored during analysis.

This code is divided into two parts: initialization and looping.

In the initialization section, the timer and timer interrupts are configured.

Unlike Lab 3, this code uses the embARC OSP API to program **Timer0**. In fact, in essence, these two methods are the same. The API just encapsulates the read and write operations of the auxiliary registers for convenience.

First, in order to configure **Timer0** and its interrupts, turn them off first. This work is done by the functions `int_disable` and `timer_stop`.

Then configure the interrupt service function and priority for our interrupts. This work is done by the functions `int_handler_install` and `int_pri_set`.

Finally, after the interrupt configuration is complete, enable the **Timer0** and interrupts that are previously turned off. This work is done by the functions `int_enable` and `timer_start`. The implementation of the `timer_start` function is the same as the reading and writing of the auxiliary registers in our lab_3. Interested students can view them in the file `arc_timer.c`. One point to note in this step is the configuration of `timer_limit` (the last parameter of `timer_start`). Configure the interrupt time to 1ms, do a simple calculation (the formula is the expression after COUNT).

In this example, the loop body only serves as an effect display. Our own delay function in the loop body to print the time per second is called.

Note: Since nSIM is only simulated by computer, there may be time inaccuracy when using this function. Interested students can use the EMSK to program the program in the development board. In this case, the time is much higher than that in nSIM.

- Delay function

```

static void timer0_isr(void *ptr)
{
    t0 = 0;
    while(t0<ms);
}

```

This code is very simple and the idea is clear. When the function entered, clear the global variable `t0`. The interrupt interval is set to 1ms in the above `timer_start`, assume that every time `t0` is incremented, the time has passed 1ms.

Wait through the while(t0<ms) sentence, so that the full ms delay with higher precision is received.

Lab one output

After the lab one program is successfully downloaded, the serial output is as follows:

```
embARC Build Time: Mar 16 2018, 09:58:46
Compiler Version: Metaware, 4.2.1 Compatible Clang 4.0.1

This is an example about timer interrupt
/*****TEST MODE START*****/
0s

1s

2s

3s

4s

5s

...
```

Open and browse the lab two

Enter lab_4_2, which shows the working state of priority and interrupt nesting.

Open main.c and browse through the entire program.

```
#include "embARC.h"
#include "embARC_debug.h"

#define MAX_COUNT 0xfffffff

volatile static uint8_t timer_flag = 0;
volatile static uint8_t hits = 0;

volatile static uint8_t nesting_flag = 1;

/** arc timer 0 interrupt routine */
static void timer0_isr(void *ptr)
{
    timer_int_clear(TIMER_0);

    timer_flag = 0;

    board_delay_ms(10, 1);

    if(timer_flag)
    {
        EMBARC_PRINTF("Interrupt nesting!\r\n");
    }
    else
    {
        EMBARC_PRINTF("Interrupt\r\n");
    }

    hits++;
}
```

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```

}

/** arc timer 1 interrupt routine */
static void timer1_isr(void *ptr)
{
    timer_int_clear(TIMER_1);

    timer_flag = 1;
}

/** main entry for testing arc fiq interrupt */
int main(void)
{
    timer_stop(TIMER_0);
    timer_stop(TIMER_1);

    int_disable(INTNO_TIMER0);
    int_disable(INTNO_TIMER1);

    int_handler_install(INTNO_TIMER0, timer0_isr);
    int_pri_set(INTNO_TIMER0, INT_PRI_MAX);

    int_handler_install(INTNO_TIMER1, timer1_isr);
    int_pri_set(INTNO_TIMER1, INT_PRI_MIN);

EMBARC_PRINTF("\r\nThe test will start in 1s.\r\n");
EMBARC_PRINTF("\r\n***** TEST MODE START *****\r\n\r\n");

    int_enable(INTNO_TIMER0);
    int_enable(INTNO_TIMER1);

    timer_start(TIMER_0, TIMER_CTRL_IE | TIMER_CTRL_NH, MAX_COUNT);
    timer_start(TIMER_1, TIMER_CTRL_IE | TIMER_CTRL_NH, MAX_COUNT/100);

    while(1)
    {
        if((hits >= 5)&&(nesting_flag == 1))
        {
            timer_stop(TIMER_0);
            timer_stop(TIMER_1);

            int_disable(INTNO_TIMER0);
            int_disable(INTNO_TIMER1);

            int_pri_set(INTNO_TIMER0, INT_PRI_MIN);
            int_pri_set(INTNO_TIMER1, INT_PRI_MAX);

            nesting_flag = 0;

            int_enable(INTNO_TIMER0);
            int_enable(INTNO_TIMER1);

            timer_start(TIMER_0, TIMER_CTRL_IE | TIMER_CTRL_NH, MAX_COUNT);
            timer_start(TIMER_1, TIMER_CTRL_IE | TIMER_CTRL_NH, MAX_COUNT/
→100);
        }
        else if((hits >= 10)&&(nesting_flag == 0))
        {
            timer_stop(TIMER_0);
            timer_stop(TIMER_1);
    }
}

```

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```

        int_disable(INTNO_TIMER0);
        int_disable(INTNO_TIMER1);

        int_pri_set(INTNO_TIMER0, INT_PRI_MAX);
        int_pri_set(INTNO_TIMER1, INT_PRI_MIN);

        hits = 0;
        nesting_flag = 1;

        int_enable(INTNO_TIMER0);
        int_enable(INTNO_TIMER1);

        timer_start(TIMER_0, TIMER_CTRL_IE | TIMER_CTRL_NH, MAX_COUNT);
        timer_start(TIMER_1, TIMER_CTRL_IE | TIMER_CTRL_NH, MAX_COUNT/
↪100);
    }
}

return E_SYS;
}

```

Sub-module analysis lab two code

Lab two seems complicated, but it is very simple. The code for Lab two only needs to be divided into two parts: the interrupt service routine and the main function.

- Interrupt service function

```

static void timer0_isr(void *ptr)
{
    timer_int_clear(TIMER_0);

    timer_flag = 0;

    board_delay_ms(10, 1);

    if(timer_flag)
    {
        EMBARC_PRINTF("Interrupt nesting!\r\n");
    }
    else
    {
        EMBARC_PRINTF("Interrupt\r\n");
    }

    hits++;
}

static void timer1_isr(void *ptr)
{
    timer_int_clear(TIMER_1);

    timer_flag = 1;
}

```

First, in order to analyze the code, ignore the extraneous parts (such as EMBARC_PRINTF, delay, and hits in if).

In this case, we can find that for the interrupt service function timer0_isr, it is impossible to have the timer_flag of 1 only when it is itself. The only way to do this is to have another higher priority interrupt between timer_flag=0 and if statement set it.

Following this line of thought, see timer1_isr.

Regarding EMBARC_PRINTF, it is used to indicate the status.

Regarding the delay, its role is to lengthen this period of time, making nesting more likely.

Regarding hits, it is mentioned in the main function module.

- main function

```
int main(void)
{
    timer_stop(TIMER_0);
    timer_stop(TIMER_1);

    int_disable(INTNO_TIMER0);
    int_disable(INTNO_TIMER1);

    int_handler_install(INTNO_TIMER0, timer0_isr);
    int_pri_set(INTNO_TIMER0, INT_PRI_MAX);

    int_handler_install(INTNO_TIMER1, timer1_isr);
    int_pri_set(INTNO_TIMER1, INT_PRI_MIN);

    EMBARC_PRINTF("\r\nThe test will start in 1s.\r\n");
    EMBARC_PRINTF("\r\n***** TEST MODE START *****\r\n\r\n");

    int_enable(INTNO_TIMER0);
    int_enable(INTNO_TIMER1);

    timer_start(TIMER_0, TIMER_CTRL_IE | TIMER_CTRL_NH, MAX_COUNT);
    timer_start(TIMER_1, TIMER_CTRL_IE | TIMER_CTRL_NH, MAX_COUNT/100);

    while(1)
    {
        if((hits >= 5) && (nesting_flag == 1))
        {
            timer_stop(TIMER_0);
            timer_stop(TIMER_1);

            int_disable(INTNO_TIMER0);
            int_disable(INTNO_TIMER1);

            int_pri_set(INTNO_TIMER0, INT_PRI_MIN);
            int_pri_set(INTNO_TIMER1, INT_PRI_MAX);

            nesting_flag = 0;

            int_enable(INTNO_TIMER0);
            int_enable(INTNO_TIMER1);

            timer_start(TIMER_0, TIMER_CTRL_IE | TIMER_CTRL_NH, MAX_COUNT);
            timer_start(TIMER_1, TIMER_CTRL_IE | TIMER_CTRL_NH, MAX_COUNT/100);
        }
        else if((hits >= 10) && (nesting_flag == 0))
        {
            timer_stop(TIMER_0);
            timer_stop(TIMER_1);

            int_disable(INTNO_TIMER0);
            int_disable(INTNO_TIMER1);

            int_pri_set(INTNO_TIMER0, INT_PRI_MAX);
            int_pri_set(INTNO_TIMER1, INT_PRI_MIN);

            hits = 0;
        }
    }
}
```

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```

nesting_flag = 1;

int_enable(INTNO_TIMER0);
int_enable(INTNO_TIMER1);

timer_start(TIMER_0, TIMER_CTRL_IE | TIMER_CTRL_NH, MAX_COUNT);
timer_start(TIMER_1, TIMER_CTRL_IE | TIMER_CTRL_NH, MAX_COUNT/100);

}

}

return E_SYS;
}

```

The main function looks very long, there is a considerable part of it that is repetitive (you can also build a small function to make the code look more concise).

In the first lab, the configuration of the timer and the creation of the interrupt is discussed and it is not repeated here.

The main function is simple: when the interrupt of **Timer0** occurs 5 times, change the priority relationship of the two interrupts. The hits mentioned earlier are count variables in the above functions.

Lab two output

The label phenomenon of Lab two is shown in the following figure.

“Interrupt nesting!” indicates that interrupt nesting has occurred, and “Interrupt” indicates that it has not occurred.

For a better understanding, go back and look at the priority settings in the main function.

It is easy to see that when **Timer0** interrupt priority is low (INT_PRI_MAX is low priority, a larger number means a lower priority in ARC), **Timer1** interrupt can preempt **Timer0** interrupt; when **Timer0** interrupt priority is higher, **Timer1** interrupt cannot interrupt/preempt its ISR execution.

To summarize, high-priority interrupts can interrupt low-priority interrupts, and low-priority interrupts can be preempted by high-priority interrupts.

```

embARC Build Time: Mar 16 2018, 09:58:46
Compiler Version: Metaware, 4.2.1 Compatible Clang 4.0.1

This test will start in 1s.

*****TEST MODE START*****

Interrupt nesting!
Interrupt nesting!
Interrupt nesting!
Interrupt nesting!
Interrupt nesting!
Interrupt nesting!
Interrupt
Interrupt
Interrupt
Interrupt
Interrupt
Interrupt
Interrupt nesting!
Interrupt nesting!
Interrupt nesting!
Interrupt nesting!
Interrupt nesting!
Interrupt nesting!
Interrupt
Interrupt
Interrupt

```

Exercises

Try using an interrupt other than a timer to write a small program. (For example, try to implement a button controlled LED using GPIO interrupt)

How to use ARC board

Purpose

1. To get familiar with ARC board and on-board peripheral
2. To how to use ARC board and on-board peripherals
3. To how to debug the ARC board and on-board peripherals

Equipment

- PC host
- GNU Toolchain for ARC Processors / MetaWare Development Toolkit
- ARC board (EM Starter Kit / IoT Development Kit)
- `embarc_osp/arc_labs/labs/lab5_emsk` / `embarc_osp/arc_labs/lab5_iotdk`

Content

1. Board introduction.

Through the user manual, get a brief knowLEDge of ARC board and what peripherals are on it.

2. Board programming.

Based on embARC OSP, program the on board peripherals.

Principles

1. EM Starter Kit

For the basic introduction of EM Starter Kit, please go [here](#)

There are on board LEDs, DIP switch and button on EM Starter Kit, this lab will show how to program theses on-board peripherals of EM Starter Kit.

The code for EM Starter Kit is located in `embarc_osp/arc_labs/labs/lab5_emsk`. In the code, the button and DIP switch values of EM Starter Kit are read and LED blinks periodically.

2. IoT Development Kit

For the basic introduction of IoT Development Kit, please go [here](#)

As there are no easy-to-use on board peripherals like LEDs on EM Starter Kit, this lab will show how to control a LED through the arduino interface of IoT Development Kit.

Steps

EM Starter Kit

1. Connect EM Starter Kit to PC, select **em7d** configuration and open UART terminal.

2. Compile and run the `embarc_osp/arc_labs/lab5_emsk` example with the following cmds.

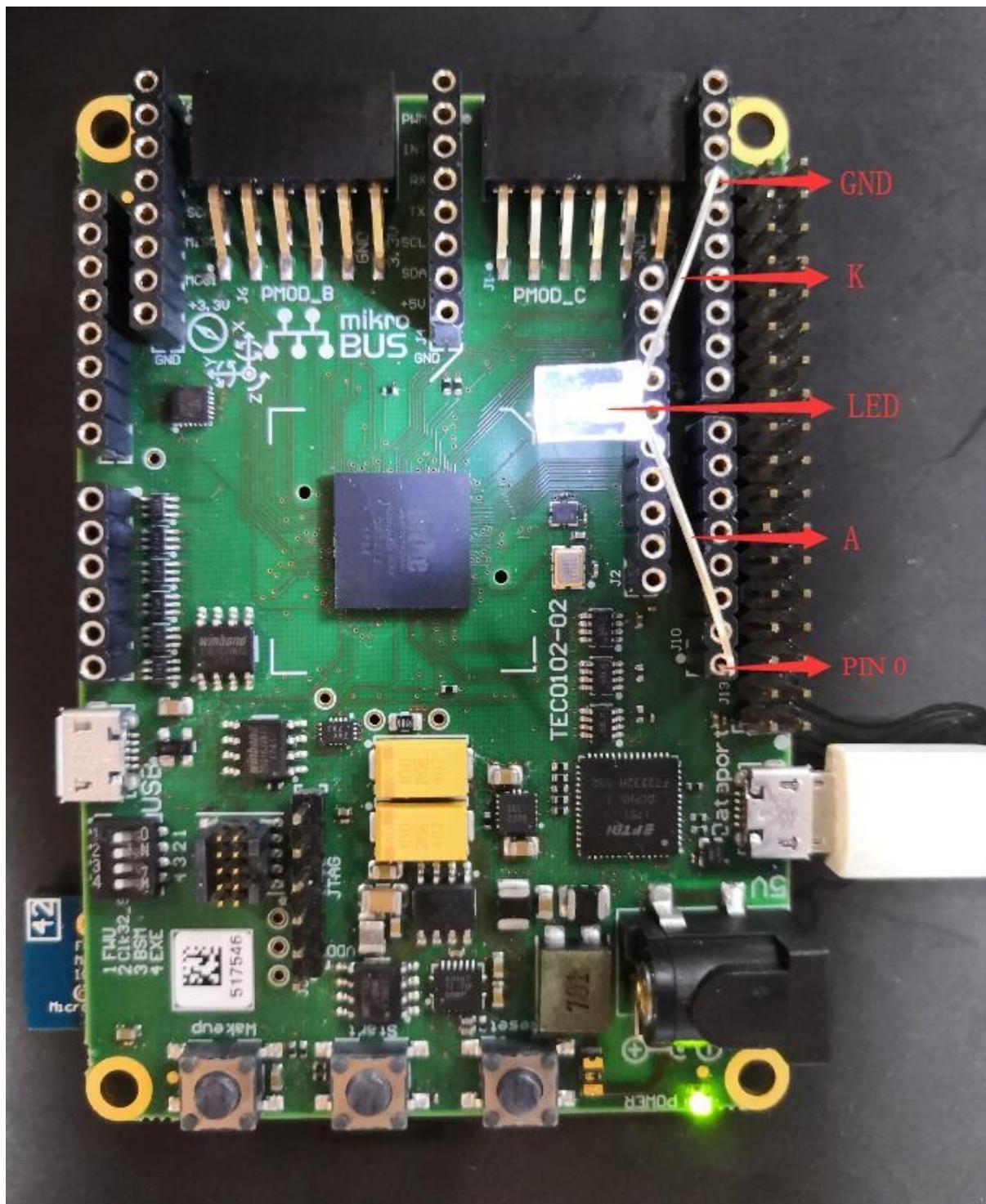
```
cd /arc_labs/lab5_emsk  
make TOOLCHAIN=gnu BOARD=emsk BD_VER=22 CUR_CORE=em7d run
```

3. Watch the changes of LED, press the button or operate the DIP switch, then watch the result in UART terminal.

IoT Development Kit

IoT Development Kit has a arduino interface, here select arduino digital pinout ARDUINO_PIN_0(iotdk_gpio4b_2[0]) to control LED.

1. find a LED, connect the LED anode pin to ARDUINO_PIN_0, connect the LED cathode pin to GND of IoT Development Kit.
2. compile and run the `embarc_osp/arc_labs/lab5_iotdk` example.



Note: the connect between LED and IoT Development Kit is just for test. a $1k\Omega$ resistor should be added to limited the current.

Exercises

Try to create you own application to program the peripherals of ARC board

A simple bootloader

Purpose

- Understand the memory map of ARC boards
- Understand the principles of bootloader and self-booting
- Understand the usage of shell commands in cmd
- Create a self-booting application

Equipment

The following hardware and tools are required:

- PC host
- GNU Toolchain for ARC Processors / MetaWare Development Toolkit
- ARC board (EM Starter Kit / IoT Development Kit)
- SD card
- `example/baremetal/bootloader`

Simple Bootloader

This simple bootloader is designed to work as a secondary/simple bootloader for embARC OSP, it loads `boot.hex` or `boot.bin` on SD Card and run that program. The example can be used as ntshell application.

The following features are provided in this simple bootloader:

- Boot application from SD card
- File operations on SD card
- UART Y-modem protocol to update application
- Operations on ARC processors

Content

1. Build and run the `example/baremetal/bootloader`
2. Download the generated `bootloader.bin` into flash
3. Build a self-boot application and boot it from SD card
4. Use the ntshell commands

Principles

Memory Map of ARC board

EM Starter Kit

The available memory regions of EM Starter Kit are shown below.

Table 1: Memory Map of EM Starter Kit

Name	Start address	Size
on-chip ICCM	0x00000000	256/128 KB
on-chip DCCM	0x80000000	128 KB
on-board DDR RAM	0x10000000	128 MB

In this lab, the last 1 MB of DDR (starting from 0x17f00000) is reserved for the simple bootloader, other memory regions are available for application.

IoT Development Kit

The available memory regions of IoT Development Kit are shown in the following table:

Table 2: Memory Map of IoT Development Kit

Name	Start address	Size
on-chip eflash	0x00000000	256 KB
external boot SPI flash	0x10000000	2 MB
on-chip ICCM	0x20000000	256 KB
on-chip SRAM	0x30000000	128 KB
on-chip DCCM	0x80000000	128 KB
on-chip XCCM	0xC0000000	32 KB
on-chip YCCM	0xE0000000	32 KB

In this lab, on-chip eflash and on-chip SRAM are reserved for the simple bootloader, CCMs are reserved for application.

Boot of ARC board

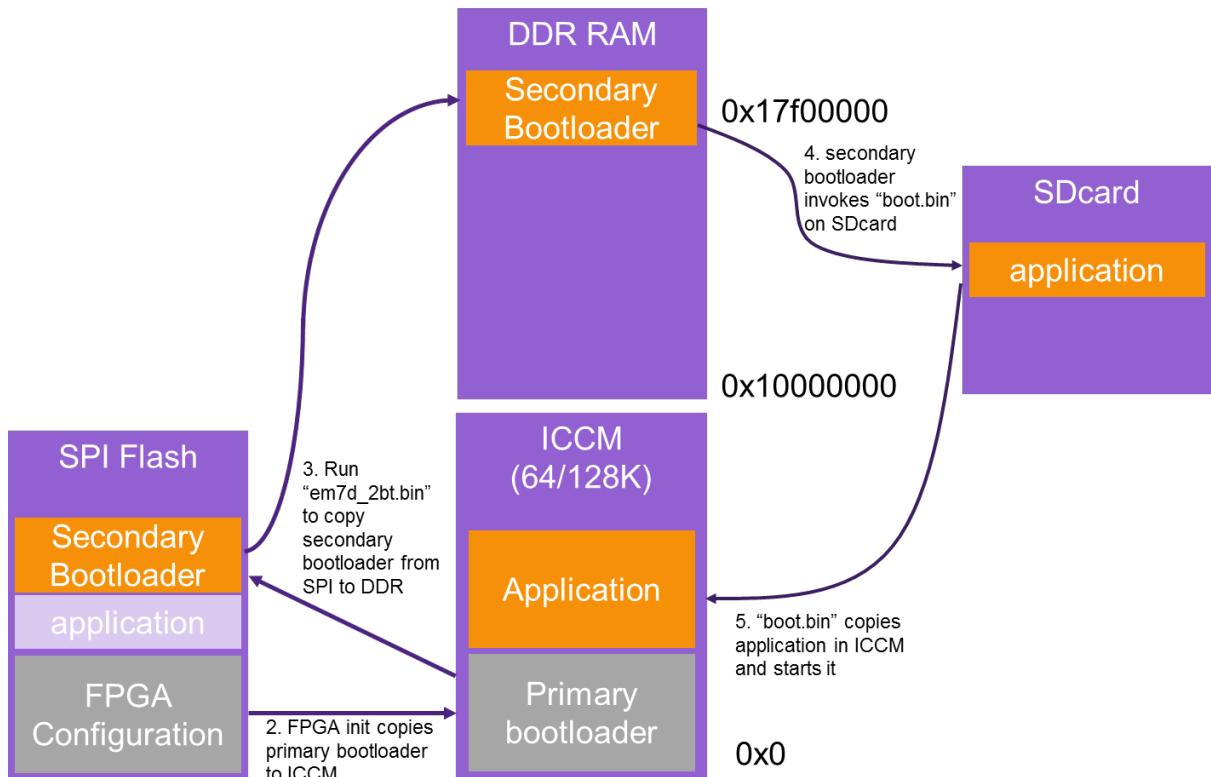
EM Starter Kit

The EM Starter Kit uses a Xilinx SPARTAN-6 FPGA part which can be configured to run different members of the AR Cv2 EM Processor family. The EMSK includes a SPI flash pre-programmed with four FPGA configurations of ARC EM cores.

When a “power on” or reset/configure is issued, the FPGA auto-loads one of the pre-installed FPGA configurations from SPI flash. After the FPGA configuration is loaded from the SPI flash, a simple primary bootloader is loaded in ICCM. Through the primary bootloader, an application can be loaded from SPI Flash into ICCM or external DDR memory.

Considering that the SPI Flash is used to store FPGA images, the secondary bootloader is designed based on the primary bootloader to load an application from an SD card since it can be read and written easily. The startup sequence is listed below:

1. Power on or reset event.
2. Load FPGA configuration from the SPI flash.
3. Run primary bootloader, which loads the secondary bootloader from the SPI Flash into main memory (DDR).
4. Run secondary bootloader from main memory to load application from the SD card into ICCM/DDR memory.
5. Run the application from ICCM/DDR memory.



IoT Development Kit

IoT Development Kit can boot from on-chip eflash and extern boot SPI flash, which is decided by the FWU switch of IOTDK. When this switch is set to “off”, the processor starts executing the program stored in on-chip eflash; When this switch is set to “on”, the processor starts executing the program stored in external boot SPI eflash. The simple bootloader can be written to both flash to load an application from the TF card. The startup sequence for IoT Development Kit is listed below:

1. Power on or reset event
2. Boot from on-chip eflash or extern boot SPI flash decided by the FWU switch
3. Run simple bootloader to load application from the TF card into ICCM.
4. Run the application from ICCM memory.

How to flash the ARC board

EM Starter Kit

- Generate a secondary bootloader binary file

```
$ cd <embarc_root>/example/baremetal/bootloader
$ gmake BOARD=emsk BD_VER=22 CUR_CORE=arcem7d TOOLCHAIN=mw bin
```

- Program generated secondary bootloader binary file into SPIFlash

- Insert SD card to your PC, and copy the binary file obj_emsk_23/gnu_arcem7d/ emsk_bootloader_gnu_arcem7d.bin to SD card root folder, and rename it to em7d_2bt.bin

- Insert the SD card to EMSK Board, choose the right core configuration, build and run the <embARC>/example/baremetal/bootloader example, then press any button to stop auto boot process, and enter to ntshell command mode.
- Use ntshell command **spirw** to program the **em7d_2bt.bin** into spiflash.
 - * Run **spirw** to show help
 - * Run **spirw -i** to check SPIFlash ID, it should be **Device ID = ef4018**
 - * Run **spirw -w em7d_2bt.bin 0x17f00000 0x17f00004** to program spiflash
 - * Check the output message to see if it was programmed successfully.

The screenshot shows a terminal window titled "COM3:115200baud - Tera Term VT". The window displays a command-line interface for the ntshell command. The user enters "spirw -i" which outputs the SPI Flash Command Done, usage information, and the Device ID as "ef4018". The user then enters "spirw -w em7d_2bt.bin 0x17f00000 0x17f00004" which starts writing the file to the SPI flash at address 0x17f00000. The progress bar shows the write operation is 100% complete. Finally, the user enters "spirw" which outputs the SPI Flash Command Done again, along with the boot image header details: head: 0x8656164, cpu: 0x0, start: 0xd8001c, size: 0x246f0, ram addr: 0x17f00000, start: 0x17f00004, checksum: 0xf5015c. A red box highlights the "Device ID = ef4018" line, another highlights the "spirw -i" command, and a third highlights the "boot image header" details.

Successfully programmed to spiflash

```

COM3:115200baud - Tera Term VT
File Edit Setup Control Window Help
ntshell command load(load .bin file from SD card to ram at specified address) was registered!
ntshell command go(run the program at the specified address) was registered!
NTShell Task StartUp
COM1>spirw -h
usage: spirw <-opt>
--Option Available--
-h/-?                      show help
-i read Device ID
-r filename                 read image from spi to file on host, address and size have been taken
   from header in spi flash
-w file ram_addr start_addr write binary [file] to spi flash, the image will be loaded to ram_addr
r and run from start_addr
*****
SPI Flash Command Done
COM1>spirw
usage: spirw <-opt>
--Option Available--
-h/-?                      show help
-i read Device ID
-r filename                 read image from spi to file on host, address and size have been taken
   from header in spi flash
-w file ram_addr start_addr write binary [file] to spi flash, the image will be loaded to ram_addr
r and run from start_addr
COM1>spirw -i
Device ID = ef4018
*****
SPI Flash Command Done
COM1:spirw -w em7d_2bt.bin 0x17f00000 0x17f00004
** Writing file em7d_2bt.bin; to address 0x17f00000 start at 0x17f00004
Erase 37 sectors from 0xd80000 to 0xda4fff

** Writing SPI flash **
- data
write 0xd8001c - 0xd8101c check_sum:57126
write 0xd8101c - 0xd8201c check_sum:ac3a2
write 0xd8201c - 0xd8301c check_sum:102aac
write 0xd8301c - 0xd8401c check_sum:1575b3
write 0xd8401c - 0xd8501c check_sum:1a91ea
write 0xd8501c - 0xd8601c check_sum:e1b504
write 0xda301c - 0xda401c check_sum:f43f00
write 0xda401c - 0xda470c check_sum:f5015c
Written 149260 bytes: header=28 and image=149232 image from 0xd80000 to 0xda470b

** Boot image header **
head: 0x8656164
cpu: 0x0
start: 0xd8001c
size: 0x246f0
ram addr: 0x17f00000
start: 0x17f00004
checksum: 0xf5015c
*****
SPI Flash Command Done

```

- If programmed successfully, when the board is reset, make sure Bit 4 of the on-board DIP switch is ON to enable secondary bootloader run.
- If the SD card already contains the *boot.bin* in it, the bootloader automatically loads it from SD card, if not, it enters to ntshell mode.
- You can goto the next step to generate the *boot.bin* for proper application you want to be auto-loaded in SD card.



COM22:115200baud - Tera Term VT

```

File Edit Setup Control Window Help
Firmware Feb 22 2017, v2.3
Bootloader Feb 22 2017, v1.1
ARC EM7D, core configuration #1

ARC IDENTITY = 0x43
RF_BUILD = 0x2
TIMER_BUILD = 0x1010b05
ICCM_BUILD = 0xa05
DCCM_BUILD = 0x10905
I_CACHE_BUILD = 0x225105
D_CACHE_BUILD = 0x215105

SelfTest PASSED

Boot image has been found
    start = 0xd8001c
    size = 0x4030c
    ram addressss = 0x17f00000
    start address = 0x17f00004

Reload cfg button pressed(C)
*****
**      Synopsys, Inc.      **
**      ARC EM Starter kit   **
**      **
**      Comprehensive software stacks **
**      available from embARC.org   **
**      **
*****
```

Bit 4 of DIP switch is off, then bootloader is not loaded and start to run

```

Firmware Feb 22 2017, v2.3
Bootloader Feb 22 2017, v1.1
ARC EM7D, core configuration #1

ARC IDENTITY = 0x43
RF_BUILD = 0x2
TIMER_BUILD = 0x1010b05
ICCM_BUILD = 0xa05
DCCM_BUILD = 0x10905
I_CACHE_BUILD = 0x225105
D_CACHE_BUILD = 0x215105

SelfTest PASSED

Boot image has been found
    start = 0xd8001c
    size = 0x4030c
    ram addressss = 0x17f00000
    start address = 0x17f00004

Loading 262924 bytes from SPI: 0xd8001c to RAM: 0x17f00000 - completed
Bit 4 of DIP switch is on, then bootloader is loaded
```

Starting application from RAM/flash
embARC Build Time: Mar 16 2017, 17:34 Secondary bootloader on spiflash
Compiler Version: ARC GNU, 6.2.1 20160824
FatFS initialized successfully!
boot.json open error. use default bootloader

Press any button on board to stop auto boot in 5 s

- Generate boot.bin using any embARC example which ram start address should be 0x10000000 and use bootloader to run it

- Known Issues

- Boot rom of EMSK1.x is not able to load secondary bootloader on SPIFlash, you need a modified EMSK1.x mcs file to enable this function, send request in forum about this mcs file.

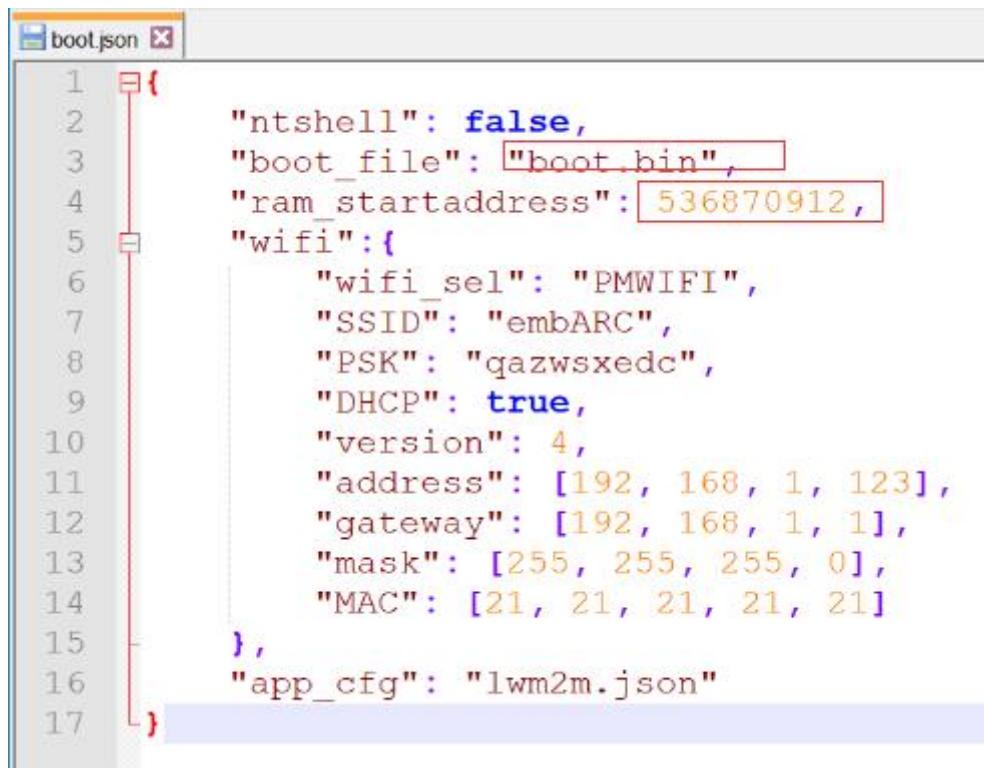
IoT Development Kit

- Generate a secondary bootloader binary file

```
$ cd <embarc_root>/example/baremetal/bootloader
$ gmake BOARD=iotdk BD_VER=10 CUR_CORE=arcem9d TOOLCHAIN=mw LOCATION=eflash bin
```

- Program generated secondary bootloader binary file into SPIFlash

- Insert SD card to your PC, and copy the binary file obj_iotdk_10/mw_arcem9d/simple_bootloader_mw_arcem9d.bin to SD card Root, and rename it to simple_bootloader.bin
- copy the file example/bootloader/boot.json to SD card root, and change the boot_file value to boot.bin, and change the ram_startaddress to 536870912(0x20000000).



- Insert the SD card to iotdk Board, build and run the <embARC>/example/baremetal/bootloader example, and enter to ntshell command mode.

```
$ cd <embarc_root>/example/baremetal/bootloader
$ gmake distclean
$ gmake BOARD=iotdk BD_VER=10 CUR_CORE=arcem9d TOOLCHAIN=mw run
```

- Use ntshell command **flash** to program the **simple_bootloader.bin** into both flash.

- * Run **flash -h** to show help.
- * Run **flash -eflash simple_bootloader.bin** to program eflash.
- * Run **flash -bootspi simple_bootloader.bin** to program bootspi flash.
- * Check the output message to see if it was programmed successfully.

COM1>flash -h
Usage: flash [OPTION]...
Write bin file to flash(eflash or bootspi flash)
-h/H/? Show the help information
Examples:
flash -eflash test.bin Write bin file to eflash
flash -bootspi test.bin Write bin file to bootspi flash
flash -h Show the help information
COM1>flash -eflash simple_bootloader.bin
COM1>flash -bootspi simple_bootloader.bin
COM1>

- If the SD card already contains the `boot.bin` and `boot.json` in it, the bootloader automatically loads it from SD card, if not, it enters to ntshell mode.
- You can goto the next step to generate the `boot.bin` for proper application you want to be auto-loaded in SD card.

```
embARC Build Time: Oct 10 2018, 10:03:54
Compiler Version: Metaware, 4.2.1 Compatible Clang 4.0.1 (branches/release_40)
FatFS initialized successfully!
boot_file:boot.bin
app_cfg:lwm2m.json
ram:0x20000000
ntshell:0
Start loading boot.bin from sdcard to 0x20000000 and run...
led out: f, ff
led out: f0, ff
led-----
[REDACTED]
[REDACTED]
-----
embARC Build Time: Sep 28 2018, 09:18:00
Compiler Version: Metaware, 4.2.1 Compatible Clang 4.0.1 (branches/release_40)
ed out: 0, 0
led out: ffff, 0
led out: 0, 0
led out: ffff, 0
led out: 0, 0
```

- Generate `boot.bin` using any embARC example which ram start address should be `0x20000000` and use bootloader to run it

Exercises

1. Create and build a different self-boot embARC application
2. Use the ntshell commands

3. Use the UART-ymodem to load your application

3.2.2 Level 2 Labs

Compiler Optimizations

Part 1. Prerequisites

Before starting to use the ARC DSP, the following prerequisites are required:

- Make sure that the MetaWare tools for Windows is installed
https://www.synopsys.com/dw/ipdir.php?ds=sw_metaware
- Learn how to create, edit, build, and debug projects in MetaWare IDE
- Make sure that the IoT Development Kit and Digilent USB drivers (Digilent Adept 2) installed and tested
<http://store.digilentinc.com/digilent-addept-2-download-only>
- IoT Development Kit board is EM9D based

The following needs to be tested before starting this lab:

- Connecting IoT Development Kit to computer
- Connecting serial console (PuTTY) to IoT Development Kit COM port (For information on how to do initial board setup and configuration, see *Getting Started* chapter of *ARC IOT Design Kit User Guide*).

Part 2. Lab Objectives

Use MetaWare compiler options to optimize regular C code employing DSP extensions. Try direct usage of DSP extensions through intrinsic.

Part 3. Lab principle and method

This section describes compiler options in MetaWare used in this lab.

To optimize code to use DSP extensions two sets of compiler options are used throughout the lab, DSP Extensions options and optimization level.

DSP Extensions Options

Use embARC OSP build system to build tool. The details can be found in embARC OSP document page. Here is the example command. You can pass extra compiler/liner options by ADT_COPT/ADT_LOPT.

```
gmake BOARD=emsk BD_VER=23 CUR_CORE=arcem9d TOOLCHAIN=mw gui ADT_COPT="-Hfxapi -  
→Xdsp2" OLEVEL=O2
```

Options that are used in the lab are:

- **-Xdsp[1/2]:**
Enable DSP instructions
- **-Xdsp_complex, -Xdsp_divsqrt:**
Enable complex arithmetic DSP, divide, and sqrt instructions
- **-Xdsp_ctrl[=up|convergent,noguard|guard, preshift|postshift]:**
Fine-tune the compiler's assumptions about the rounding, guard-bit, and fractional product shift behavior

- **-Hdsplib:** Link in the DSP library
For programming ARC fixed-point DSP in C and C++
Contains functions to carry out DSP algorithms such as filtering and transforms
- **-Hfxapi:** Use the Fixed Point API support library
Used with **-Xdsp**. Provides low level intrinsic support for ARC EM DSP instructions.
Programs written using this API execute natively on an ARC EM processor with DSP extensions and can also be emulated on x86 Windows hosts.
- **-Xxy:** Specifies that XY memory is available
Used with **-Xdsp2**. Enables optimization for XY memory
- **-Xagu_small, -Xagu_medium, -Xagu_large:**
Enables AGU, and specifies its size. Note, IOTDK has small AGU

Note: Because ARC is configurable processor, different cores can contain different extensions on hardware level. Therefore, options set for compiler should match underlying hardware. On the other hand, if specific hardware feature is present in the core but compiler option is not set, it cannot be used effectively, if used at all. IOTDK Core default options are presented in Appendix A.

Optimization level

MetaWare compiler has different optimization levels, which enables or disables various optimization techniques included in the compiler. You can pass the optimization option to gmake by “OLEVEL=O2”.

The lowest level is the default **-O0**, which does little optimization to the compiled assembly code, which can be used for debugging, because in un-optimized assembly code all source code commands have 1:1 representation. On the other hand, **-O3** highest level optimization highly modifies output assembly code to make it smaller and fast, but debugging such a code is harder, because it is not close match with source code. Also, high level of optimization requires longer compilation time, which for large project can be significant, if many compilation iterations are to be made.

Optimization for DSP extensions

A regular code without direct usage of DSP extensions can be optimized to use DSP extensions wherever applicable, which compiler can do automatically with DSP extension options corresponding to hardware are set and high-level of optimization is selected.

Checking options

Options are specified in the makefile or command line, as shown in the previous section.

Part 4. Optimizing code

An example code below contains a function “test” which contains a 20 step for loop and a multiply accumulate operation done manually.

```
#include <stdio.h>

short test(short *a, short *b) {
    int i;
```

(continues on next page)

(continued from previous page)

```

long acc = 0;
for(i = 0; i < 10; i++)
    acc += ( ((long) (*a++)) * *b++) <<1 ;

return (short) (acc);
}

short a[] = {1,2,3,4,5, 6,7,8,9,10};
short b[] = {11,12,13,14,15, 16,17,18,19,20};

int main(int argc, char *argv[]) {
    short c = test(a,b);

    printf("result=%d",c);

    return 0;
}

```

Step 1. Compiling without DSP extensions

Set optimization level “-O0”, and no DSP extensions (unchecked -Xdsp1, -Xdsp2).

After compilation, open disassembly window and check assembly code for function “test”.

Below is the list of options used when launching gmake:

```
OLEVEL=O0 ADT_COPT="-arcv2em -core1 -Xlib -Xtimer0 -Xtimer1"
```

You can use the following command to generate disassembly code:

```
elfdump -T -S <your_working_directory>/obj_iotdk_10/mw_arcem9d/
dsp_lab1_mw_arcem9d.elf
```

Notice assembly code in the disassembled output. See how many assembly instruction are used for each lin. For example, for loop spends several instruction to calculate loop variable value and check whether to stop.

```

29 short test(short *a, short *b) {
test      sub_s      %sp,%sp,16
test+0x02 st_s       %r0,[%sp,12]
test+0x04 st_s       %r1,[%sp,8]
32      long acc = 0;
test+0x06 mov_s      %r0,0
test+0x08 st_s       %r0,[%sp]
test+0x0a st_s       %r0,[%sp,4]
33      for(i = 0; i < 10; i++)
test+0x0c ld_s       %r0,[%sp,4]
33      for(i = 0; i < 10; i++)
test+0x0e cmp_s      %r0,9
test+0x10 bgt_s      0xdc = test+0x34 = basic.c!36
34      acc += ((long)(*a++) * *b++) << 1;
test+0x12 ld_s       %r0,[%sp,12]
test+0x14 add_s      %r1,%r0,2
test+0x16 st_s       %r1,[%sp,12]
test+0x18 ldh_s.x   %r0,[%r0]
test+0x1a ld_s       %r1,[%sp,8]
test+0x1c add_s      %r2,%r1,2
test+0x1e st_s       %r2,[%sp,8]
test+0x20 ldh_s.x   %r1,[%r1]
test+0x22 mpy_s      %r0,%r0,%r1
test+0x24 asl_s      %r0,%r0
test+0x26 ld_s       %r1,[%sp]
test+0x28 add_s      %r0,%r0,%r1
test+0x2a st_s       %r0,[%sp]
test+0x2c ld_s       %r0,[%sp,4]
test+0x2e add_s      %r0,%r0,1
test+0x30 st_s       %r0,[%sp,4]
test+0x32 b_s        0xb4 = test+0x0c = basic.c!33

```

Step 2. Compiling without DSP extensions, with -O2

Compile with:

```
OLEVEL=O2 ADT_COPT="-arcv2em -core1 -Xlib -Xtimer0 -Xtimer1"
```

Adding optimization level -O2, optimizes out many of the instructions:

```

29 short test(short *a, short *b) {
test      mov_s      %r2,0
test+0x02 mov        %lp_count,10
test+0x06 lp         0xbe = test+0x16 = basic.c!36
34      acc += ((long)(*a++) * *b++) << 1;
test+0x0a ldh.x.ab  %r3,[%r1,2]
test+0x0e ldh.x.ab  %r12,[%r0,2]
test+0x12 mpyw_s    %r3,%r3,%r12
test+0x14 add1_s    %r2,%r2,%r3
36      return (short) ((acc+0x8000)>>16);
test+0x16 add        %r0,%r2,0x8000
test+0x1e j_s.d     [%blink]
test+0x20 asr_s     %r0,%r0,16
.0+0x2c nop_s
47      return 0;
→main      j_s.d     [%blink] ; _mwcall_main+0x6e

```

In this code it is easy to find zero-delay loop ("lp" command) which acts as for loop. Note that multiply-accumulate is done with separate "mpyw_s" and "add1_s" instructions.

Step 3. Compiling with DSP extensions

Compile with:

```
OLEVEL=O3 ADT_COPT="-arcv2em -core1 -Xlib -Xtimer0 -Xtimer1 -Xdsp1"
```

Adding -Xdsp1 (optimization level changed to -O3) helps compiler to optimize away “mpyw_s” and “add1_s” instructions and replace them with hardware dual-16bit SIMD multiplication “vmpy2h”. Notice the loop count is now 5.

```
3: short test(short *a, short *b) {           %lp_count,5
 13c: 244a7140      mov    %lp_count,5
 140: 244a1000      mov    %r12,0
 4:     int i;
 5:
 6:     long acc = 0;
 7:     for(i = 0; i < 10; i++)
 144: 20a80300      lp     0x15c = test+0x20
 8:         acc += ( ((long)(*a++)) * *b++) << 1 ;
 148: 11040402      ld.ab  %r2,[%r1,4]
 14c: 10040403      ld.ab  %r3,[%r0,4]
 150: 2b1c0084      vmpy2h %r4,%r3,%r2
 154: 24141102      addl   %r2,%r12,%r4
 158: 2214014c      addl   %r12,%r2,%r5
 9:
10:     return (short) (acc);
15c: 7fe0            j_s.d  [%blink]
15e: 788e            sexh_s %r0,%r12
main:
13: short a[] = {1,2,3,4,5, 6,7,8,9,10};
14: short b[] = {11,12,13,14,15, 16,17,18,19,20};
15:
16: int main(int argc, char *argv[]) {
```

Note: Assignment: Remove “<<1” from test function and see changes in the output instructions.

Appendix A. IOTDK Default Core Configurations

ARC_EM5D

This is an ARC EM core with 32 bits address space, 128 KB of code memory (ICCM) and 256 KB of data memory (DCCM).

```
-arcv2em -core1 -HL -Xcode_density -Xswap -Xnorm -Xmpy16 -Xmpy -Xmpyd  
-Xshift_assist -Xbarrel_shifter -Xdsp2 -Xdsp_complex -Xtimer0 -Xtimer1
```

ARC_EM7D

This is an ARC EM core with 32 bits address space, 256 KB of code memory (ICCM) and 128 KB of data memory (DCCM). Corresponding MetaWare compiler options for this configuration are:

```
-arcv2em -core2 -HL -Xcode_density -Xdiv_rem=radix2 -Xswap  
-Xbitscan -Xmpy_option=mpyd -Xshift_assist -Xbarrel_shifter  
-Xdsp2 -Xdsp_complex -Xdsp_divsqrt=radix2 -Xdsp_accshift=limited -Xtimer0  
-Xtimer1 -Xstack_check -Hccm -Xdmac
```

ARC_EM9D

This is an ARC EM core with 32 bits address space, 256 KB of code memory (ICCM) and 128 KB of data memory (DCCM). The corresponding MetaWare compiler options for this configuration are:

```
-arcv2em -core2 -Hrgf_banked_regs=32 -HL -Xcode_density  
-Xdiv_rem=radix2 -Xswap -Xbitscan -Xmpy_option=mpyd
```

```
-Xshift_assist -Xbarrel_shifter -Xdsp2 -Xdsp_complex
-Xdsp_divsqrt=radix2 -Xdsp_itu-Xdsp_accshift=full -Xagu_large
-Xxy -Xbitstream -Xfpus_div -Xfpu_mac -Xfpus_mpy_slow
-Xfpus_div_slow -Xtimer0 -Xtimer1 -Xstack_check -Hccm -Xdmac
```

ARC_EM11D Configuration

This is an ARC EM core with 32 bits address space, 64 KB of code memory (ICCM) and 64 KB of data memory (DCCM). Corresponding MetaWare compiler options for this configuration are:

```
-arcv2em -core2 -Hrgf_banked_regs=32 -HL -Xcode_density
-Xdiv_rem=radix2 -Xswap -Xbitscan -Xmpy_option=mpyd
-Xshift_assist -Xbarrel_shifter -Xdsp2 -Xdsp_complex -Xdsp_divsqrt=radix2
-Xdsp_itu -Xdsp_accshift=full -Xagu_large -Xxy -Xbitstream -Xfpus_div
-Xfpu_mac -Xfpuda -Xfpus_mpy_slow -Xfpus_div_slow -Xtimer0 -Xtimer1
-Xstack_check -Hccm -Xdmac
```

Programming ARC DSP Using FXAPI

Part 1. Prerequisites

Before starting to use the ARC DSP, the following prerequisites are required:

- Make sure that the MetaWare tools for Windows installed
https://www.synopsys.com/dw/ipdir.php?ds=sw_metaware
- Learn how to create, edit, build, and debug projects in MetaWare IDE
- Make sure that the IoT Development Kit and Digilent USB drivers (Digilent Adept 2) installed and tested
<http://store.digilentinc.com/digilent-addept-2-download-only>
- IoT Development Kit is based on DSP-enabled core configuration EM9D

The following procedures need to be tested before this lab:

- Connecting IoT Development Kit to computer
- Connecting serial console (PuTTY) to IoT Development Kit COM port (For information on how to do initial board setup and configuration, see *Getting Started* chapter of *ARC IOT Design Kit User Guide*).

Part 2. Lab Objectives

Use FXAPI and compare program run speed with and without FXAPI, i.e. DSP extension usage.

Part 3. Lab principle and method

This lab uses complex number multiplication as an example where using just compiler optimization options cannot gain the same effect as calling DSP instructions manually through FXAPI.

In this lab two implementations of complex multiplication are shown with and without FXAPI.

Complex number multiplication

Multiplication of two complex numbers $a (R_a + I_a i)$ and $b (R_b + I_b i)$

Is done using formula:

$$ab = (R_a + I_a i)(R_b + I_b i) = (R_a R_b - I_a I_b) + (R_a I_b + R_b I_a)i$$

In this lab example multiplication and accumulation of two arrays of complex numbers are used as a way to compare performance of ARC DSP extensions when used effectively.

The sum of element wise products of two arrays of complex numbers is calculated according to the following formula:

$$\text{result} = \sum_{i=0}^N a_i + b_i$$

where a and b are arrays of N complex numbers.

Implementation without DSP

In order to calculate element wise products of two arrays of complex numbers, a struct can be defined that stores real and imaginary parts of the complex number. Therefore, the calculation process receives an array of structures and works on it. The code is shown below:

```
typedef struct { short real; short imag; } complex_short;

complex_short short_complex_array_mult (complex_short *a, complex_short *b, int
→size) {
    complex_short result = {0,0};
    int acci=0;
    int accr=0;

    for (int i=0; i < size; i++) {
        accr += (int) ( a[i].real * b[i].real );
        accr -= (int) ( a[i].imag * b[i].imag );

        acci += (int) ( a[i].real * b[i].imag );
        acci += (int) ( a[i].imag * b[i].real );
    }

    result.real = (short) accr;
    result.imag = (short) acci;

    return result;
}
```

The example keeps real and imaginary values in variables of type “short”, while multiplication results are kept in “int” integer to avoid truncation. Final result is casted to short to return complex number as a result.

Implementation with FXAPI

FXAPI makes it possible to directly access complex number instructions (like MAC) available in ARC DSP Extensions. This is done through complex number type cq15_t, and various fx_* functions. Here fx_v2a40_cmac_cq15 FXAPI function is called which performs MAC of two cq15_t complex numbers.

```
cq15_t fx_complex_array_mult(cq15_t *a, cq15_t *b, int size) {
    v2accum40_t acc = { 0, 0 };
```

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```

for (int i=0; i < size; i++) {
    acc = fx_v2a40_cmac_cq15(acc, *a++, *b++);
}

return fx_cq15_cast_v2a40( acc );
}

```

As with previous implementation q15_t is of similar size as short type, therefore, multiplication result needs larger storage. Here 40b vector accumulator is used directly to store intermediate results of MAC, and is casted to cq15_t on return.

Using IoT Development Kit board for performance comparison

To compare performance of these two functions a simple ESMK application is created that performs complex array multiplication using either of the implementations above. The program initializes two arrays of complex numbers with random values and calls functions above in a loop (1 000 000-10 000 000 times) to make calculation delay measurable in seconds. This is done 8 times, and after each loop a LED on board turns-on. In the result, LED strip on board works as a “progress bar” showing the process of looped multiplications.

The main performance check loop is shown in the following example. The outer loop runs 8 times (number of LEDs on LED strip), the inner loop makes “LOOPS/8” calls to complex multiplication function. LOOPS variable is configurable to change the total delay. The following example uses DSP types, and can be changed to use short-based struct type.

```

#include "fxarc.h"
#define LOOPS 10000000
int main(int argc, char *argv[]) {
    unsigned int led_status = 0x40 ;
    DWCREG_PTR pctr =
        (DWCREG_PTR) (DWC_GPIO_0 | PERIPHERAL_BASE);
    DWCREG_PTR uart =
        (DWCREG_PTR) (DWC_UART_CONSOLE | PERIPHERAL_BASE);

    gpio_init(pctr);
    uart_initDevice(uart, UART_CFG_BAUDRATE_115200,
                    UART_CFG_DATA_8BITS,
                    UART_CFG_1STOP, UART_CFG_PARITY_NONE);

    cq15_t cq15_a[20] = {{0x2000,10},{0x100,20},{4,30}};
    cq15_t cq15_b[20] = {{0x2000,11},{0x100,21},{5,31}};
    cq15_t res;

    uart_print(uart, "*** Start ***\n\r");

    led_status = 0x7F;

    for (int i =0; i< 8; i++) {
        gpio_set_leds(pctr, led_status);
        for (int j = 1; j < LOOPS/8; j++ ) {
            res = fx_complex_array_mult(cq15_a, cq15_b, 2);
        };

        led_status = led_status >> 1;
    }

    gpio_set_leds(pctr, 0x01ff);
    uart_print(uart, "*** End ***\n\r");
    return 0;
}

```

Part 4. Test

To test the following example, some modification of the code is required to have two loops with and without DSP. You must re-build libraries for this particular configuration of IOTDK:

```
buildlib my_dsp -tcf=<IOTDK tcf file> -bd . -f
```

IoT Development Kit tcf file can be found in `embarc_osp/board/iotdk/configs/10/tcf/arcem9d.tcf`

Both examples are to be compiled with DSP extensions, with the following options set:

```
gmake BOARD=iotdk BD_VER=10 CUR_CORE=arcem9d TOOLCHAIN=mw gui  
ADT_COPT="-Hdsplib -Xdsp2 -tcf=./arcem9d.tcf -Xdsp_complex"  
ADTLOPT="-Hdsplib -Xdsp2 -tcf=./arcem9d.tcf -Hlib=./my_dsp"
```

With high optimization level functions using “short” type is compiled to use DSP MAC operation, enabling significant speedup.

```
158 complex_short short_complex_array_mult(complex_short *a, complex_short *b, int size) {  
short_complex_array_mult    mov_s          %r11,%r0  
163      for (int i=0; i < size; i++) {  
.1+0x02      brlt.d        %r3,1,0xe4 = .1+0x3c = cmplx_mul.c!164+0xe  
.1+0x06      mov_s          %r8,0  
.1+0x08      mov             %lp_count,%r3  
.1+0x0c      mov_s          %r9,0  
.1+0x0e      lp              0xe0 = .1+0x38 = cmplx_mul.c!164+0xa  
.1+0x12      ldh.x.ab     %r6,[%r2,4]  
.1+0x16      ldh.s.x     %r12,[%r1,2]  
168      acci += (int) ( a[i].imag * b[i].real );  
.1+0x18      mov             %acc1,%r9  
.1+0x1c      ldh.x.ab     %r0,[%r1,4]  
.1+0x20      mac             0,%r12,%r6  
.1+0x24      ldh.x        %r3,[%r2,-2]  
167      acci += (int) ( a[i].real * b[i].imag );  
.1+0x28      mac             %r9,%r3,%r0  
165      accr -= (int) ( a[i].imag * b[i].imag );  
.1+0x2c      mpyw_s        %r12,%r12,%r3  
164      accr += (int) ( a[i].real * b[i].real );  
.1+0x2e      mpyw            %r0,%r6,%r0  
.1+0x32      add_s          %r0,%r0,%r8  
.1+0x34      sub             %r8,%r0,%r12  
.1+0x38      nop_s           
.1+0x3a      b_s             0xe6 = .1+0x3e = cmplx_mul.c!174  
.1+0x3c      mov_s          %r9,0  
174      return result;  
.1+0x3e      sth             %r8,[%r11]  
.1+0x42      j_s.d         [%blink]  
.1+0x44      sth             %r9,[%r11,2]
```

However, using FXAPI enables compiler to directly use complex MAC instruction “cmachfr”.

```
186 cq15_t fx_complex_aray_mult(cq15_t *a, cq15_t *b, int size) {  
fx_complex_aray_mult    mov_s          %r10,0  
189      for (int i=0; i < size; i++) {  
.0+0x02      setacc          0,%r10,0x201 ; 0x201 = uart_initDevice+0x01 = uart.c!32+0x1  
.0+0x0a      setacc          0,%r10,0x101 ; 0x101 = main+0x11 = cmplx_mul.c!59+0x11  
.0+0x12      brlt.d        %r3,1,0xbe = .0+0x2a = cmplx_mul.c!193  
.0+0x16      mov             %lp_count,%r3  
.0+0x1a      lp              0xbe = .0+0x2a = cmplx_mul.c!193  
190      acc = fx_v2a40_cmac_cq15(acc, *a++, *b++);  
.0+0x1e      ld.ab           %r3,[%r2,4]  
.0+0x22      ld.ab           %r12,[%r1,4]  
.0+0x26      cmachfr        0,%r12,%r3  
193      return fx_cq15_cast_v2a40( acc );  
.0+0x2a      getacc          %r1,0xf00 ; 0xf00 = __EH_FRAME_END+0x70  
.0+0x32      j_s.d         [%blink]  
.0+0x34      st s            %r1,%r0
```

ARC DSP Using DSP Library

Part 1. Prerequisites

Before starting to use the ARC DSP, the following prerequisites are required:

- Make sure that the MetaWare tools for Windows installed

https://www.synopsys.com/dw/ipdir.php?ds=sw_metaware

- Learn how to create, edit, build and debug projects in MetaWare IDE
- Make sure that the IoT Development Kit and Digilent USB drivers (Digilent Adept 2) installed and tested
<http://store.digilentinc.com/digilent-addept-2-download-only>
- IoT Development Kit configured with DSP-enabled core configuration EM9D

The following procedures need to be tested before starting this lab:

- Connecting IoT Development Kit to computer
- Configuring IoT Development Kit to use ARC core with DSP extensions (these labs use EM5D core configuration)
- Connecting serial console (PuTTY) to IoT Development Kit COM port (For information on how to do initial board setup and configuration please refer to *Getting Started* chapter of *ARC IOT Design Kit User Guide* that came along with IOTDK board).

Part 2. Lab Objectives

Use DSP Library and compare program run speed with and without DSP library, that is, DSP extension usage.

Part 3. Lab principle and method

This lab uses matrix multiplication as an example where DSP library helps to efficiently use DSP extensions with shorter code.

In this lab two implementations of matrix multiplication are shown: implemented manually and with the use of DSP library.

Matrix multiplication

Multiplication of two matrices A and B of sizes [M*N] and [N*K] respectively is implemented using the following formula:

$$c_{ij} = \sum_{k=0}^{N-1} a_{ik} b_{kj}$$

Where i= 0...(M-1) and j = 0..(K-1) are row and column indexes of output matrix, with size [M*K].

Implementation without DSP

The following example shows the implementation of matrix multiplication of two matrices containing “short” values. By convention, matrices here are implemented as 1D arrays with row-first indexing, where element a_{ik} is indexed as a_{ik} . Build with the command:

```
gmake BOARD=iotdk BD_VER=10 CUR_CORE=arcem9d TOOLCHAIN=mw gui
ADT_COPT="-Hdsplib -Xdsp2 -tcf=./arcem9d.tcf -Xdsp_complex"
ADTLOPT="-Hdsplib -Xdsp2 -tcf=./arcem9d.tcf -Hlib=./my_DSP"
```

```
#include "embARC.h"
#include "embARC_debug.h"
#include <stdlib.h>

#define MATRIX_SIZE 20
```

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```

#define MAX_NUM 1000
#define LOOPS 100000

/* **** */
/* Matrix manipulation functions */

/* randomize matrix with values up to 'max_value' */
void rand_sq_mat(short x[][][MATRIX_SIZE], int SIZE, int max_value) ;

/* multiply two square matrices of same size*/
void mul_sq_mat(short x[][][MATRIX_SIZE], short y[][][MATRIX_SIZE], short z[][][MATRIX_
→SIZE], int size) ;

/* print square matrix through UART*/
void print_sq_mat(short x[][][MATRIX_SIZE], int SIZE);

/* **** */

int main(int argc, char *argv[]) {

    short a[MATRIX_SIZE][MATRIX_SIZE];
    short b[MATRIX_SIZE][MATRIX_SIZE];
    short c[MATRIX_SIZE][MATRIX_SIZE];
    int n = MATRIX_SIZE;

    rand_sq_mat(a, n, MAX_NUM);
    rand_sq_mat(b, n, MAX_NUM);

    print_sq_mat(a, n);
    print_sq_mat(b, n);

    unsigned int led_status = 0x40 ;
    led_status = 0x7F;

    EMBARC_PRINTF("*** Start ***\n\r");

    for (int i =0; i< 8; i++) {
        for (int j = 1; j < LOOPS/8; j++ ) {
            mul_sq_mat(a,b,c,n);
        };
        led_write(led_status, BOARD_LED_MASK);
        led_status = led_status >> 1;
    }

    print_sq_mat(c, n);

    EMBARC_PRINTF("*** Exit ***\n\r");

    return 0;
}

void rand_sq_mat(short x[][][MATRIX_SIZE], int SIZE, int max_value) {
    for (int i=0;i<SIZE;i++) {
        for(int j=0;j<SIZE;j++) {
            x[i][j] = 1 + (rand() % max_value); //plus 1 to avoid zeros
        }
    }
}

```

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```

void mul_sq_mat(short x[] [MATRIX_SIZE], short y[] [MATRIX_SIZE], short z[] [MATRIX_
→SIZE], int size) {
    for (int i=0; i<size; i++) {
        for(int j=0;j<size;j++) {
            z[i][j]=0;
            for(int k=0;k<size;k++) {
                z[i][j] += x[i][k]*y[k][j];
            }
        }
    }
}

void print_sq_mat(short x[MATRIX_SIZE] [MATRIX_SIZE], int SIZE){

    EMBARC_PRINTF("-----\n\r");

    for(int j = 0; j < SIZE; j++ ) {
        for(int i = 0; i < SIZE; i ++){
            EMBARC_PRINTF("%d\t", x[j][i]);
        }
        EMBARC_PRINTF("\n\r");
    }

    EMBARC_PRINTF("-----\n\r");
}

```

Implementation with DSPLIB

DSP library contains matrix multiplication function, implementing matrix multiplication using DSP library requires initialization of matrix arrays (1D) and call to `dsp_mat_mult_q15`. The overall code is 4 lines, as highlighted in the following code. Note that `dsplib.h` must be included, and matrix `a`, `b`, and `c` must be declared as global variable. As the numbers are in q15 type, it is better to make elements of `a` and `b` between 32767 (~0.99) and 16384 (0.5), or 32768(-1) and 49152 (-0.5) that the result in `c` is not rounded to zero. Note as IOTDK is configured to have small AGU, the DSP library routine is not significantly faster.

```

#include "embARC.h"
#include "embARC_debug.h"
#include <stdlib.h>
#include "dsplib.h"

#define MATRIX_SIZE 20
#define MAX_NUM 1000
#define LOOPS 100000

/* **** */
/* Matrix manipulation functions */

/* randomize matrix with values up to 'max_value' */
//void rand_sq_mat(short x[] [MATRIX_SIZE], int SIZE, int max_value);

/* multiply two square matrices of same size*/
void mul_sq_mat(short x[] [MATRIX_SIZE], short y[] [MATRIX_SIZE], short z[] [MATRIX_
→SIZE], int size) ;

/* print square matrix through UART*/
void print_sq_mat(short* x, int SIZE);

```

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```

/*
 ****
 __xy q15_t a[MATRIX_SIZE*MATRIX_SIZE];
 __xy q15_t b[MATRIX_SIZE*MATRIX_SIZE];
 __xy q15_t c[MATRIX_SIZE*MATRIX_SIZE];

int main(int argc, char *argv[]) {

    int n =MATRIX_SIZE;
matrix_q15_t matA, matB, matC;

    //rand_sq_mat(a,n, MAX_NUM);
    //rand_sq_mat(b,n, MAX_NUM);
    for (int i =0; i< MATRIX_SIZE*MATRIX_SIZE; i++) { a[i]=16384; }
    for (int i =0; i< MATRIX_SIZE*MATRIX_SIZE; i++) { b[i]=16383; }

    print_sq_mat(a,n);
    print_sq_mat(b,n);

dsp_mat_init_q15(&matA, MATRIX_SIZE, MATRIX_SIZE, a);
dsp_mat_init_q15(&matB, MATRIX_SIZE, MATRIX_SIZE, b);
dsp_mat_init_q15(&matC, MATRIX_SIZE, MATRIX_SIZE, c);
dsp_status status;

unsigned int led_status = 0x40 ;
led_status = 0x7F;

EMBARC_PRINTF("*** Start ***\n\r");

for (int i =0; i< 8; i++) {
    for (int j = 1; j < LOOPS/8; j++ ) {
        status = dsp_mat_mult_q15(&matA, &matB, &matC);
    };
    led_write(led_status, BOARD_LED_MASK);
    led_status = led_status >> 1;
}

if ( status == DSP_ERR_OK ) EMBARC_PRINTF("done\n");
else EMBARC_PRINTF("something wrong");
print_sq_mat(c,n);

EMBARC_PRINTF("*** Exit ***\n\r");

return 0;
}

//void rand_sq_mat(short x[][][MATRIX_SIZE], int SIZE, int max_value) {
//    for (int i=0;i<SIZE;i++) {
//        for(int j=0;j<SIZE;j++) {
//            x[i][j] = 1 + (rand() % max_value); //plus 1 to avoid zeros
//        }
//    }
//}

//void mul_sq_mat(short x[][][MATRIX_SIZE],short y[][][MATRIX_SIZE], short z[][][MATRIX_
→SIZE], int size) {
//    for (int i=0; i<size; i++) {
//        for(int j=0;j<size;j++) {
//            z[i][j]=0;
}

```

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```

//           for(int k=0;k<size;k++) {
//             z[i][j] += x[i][k]*y[k][j];
//           }
//         }
// }

void print_sq_mat(short* x, int SIZE) {

  EMBARC_PRINTF("-----\n\r");

  for(int j = 0; j < SIZE; j++ ) {
    for(int i = 0; i < SIZE; i ++){
      EMBARC_PRINTF("%d\t", x[i+j*SIZE]);
    }
    EMBARC_PRINTF("\n\r" );
  }

  EMBARC_PRINTF("-----\n\r");
}

```

Note: **Assignment 1:** Use example in previous lab to create an IoT Development Kit application that uses LED strip as progress bar for large number of matrix multiplications with and without DSP library. Adjust number of loops made to achieve measurable delay.

Part 4. Test

To test the example below, an example program needs to be created that has two loops of matrix multiplications with and without DSP library.

Both examples are to be compiled with DSP extensions, with the following options set:

-O2 -arcv2em -core1 -Xlib -Xtimer0 -Xtimer1 -Xdsp1 -Hdsplib

Note: **Assignment 2:** Run the example and compare computational delay with and without DSPLIB

Note: Note that DSPLIB is statically linked with the project when -Hdsplib is set, and as the DSPLIB itself is pre-compiled with high level of optimization, changing optimization option for example program does not affect DSPLIB performance. On the other hand, even with highest optimization level a function utilizing simple instructions on “short” type (even converted to MACs if possible) is less efficient than direct use of DSPLIB.

A WiFi temperature monitor

ESPB266 WIFI module

Purpose

- To learn how to build a wireless sensor terminal based on the embARC OSP package
- To know how to use ESP8266 module and AT commands
- To learn more about the usage of FreeRTOS operating system

Equipment

The following hardware and tools are required:

- PC host
- GNU Toolchain for ARC Processors / MetaWare Development Toolkit
- ARC board (EM Starter Kit / IoT Development Kit)
- embARC OSP package
- `embarc_osp/arc_labs/labs/lab10_esp8266_wifi`

Content

Through this lab, you get a preliminary understanding of ESP8266 WIFI module and the AT command.

The lab is based on the embARC OSP package and on the supports of the popular WIFI module, ESP8266. During the lab, you will first use the AT command to set the ESP8266 to the server mode. Then you can use your laptop or mobile phone to access ESP8266 by IP address. You will get a static webpage transmitted via TCP protocol.

Principles

ESP8266

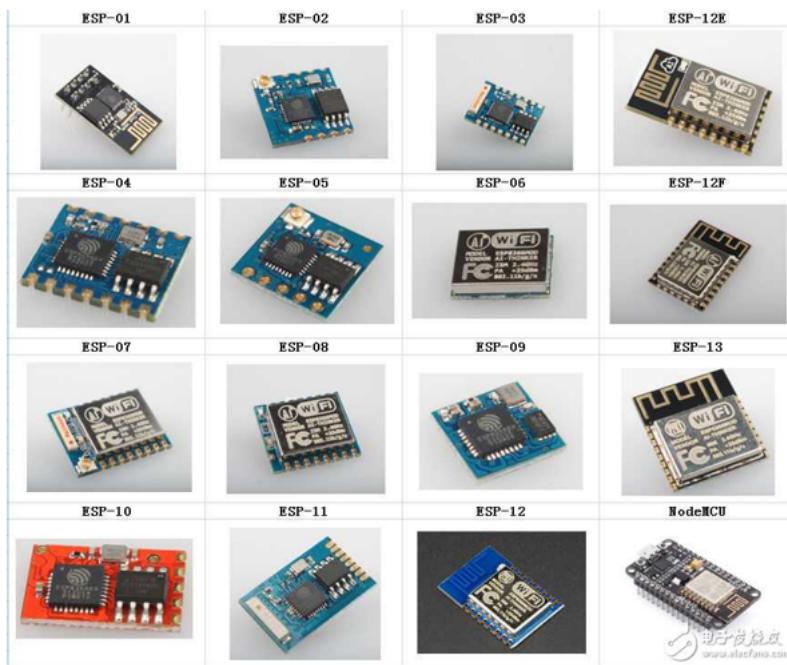
The ESP8266 is an ultra-low-power WIFI chip with industry-leading package size and ultra-low power technology. It is designed for mobile devices and IoT applications, facilitating the connection between user devices to IoT environments.

The ESP8266 is available with various encapsulations. On-board PCB antenna, IPEX interface, and stamp hole interface are supported.

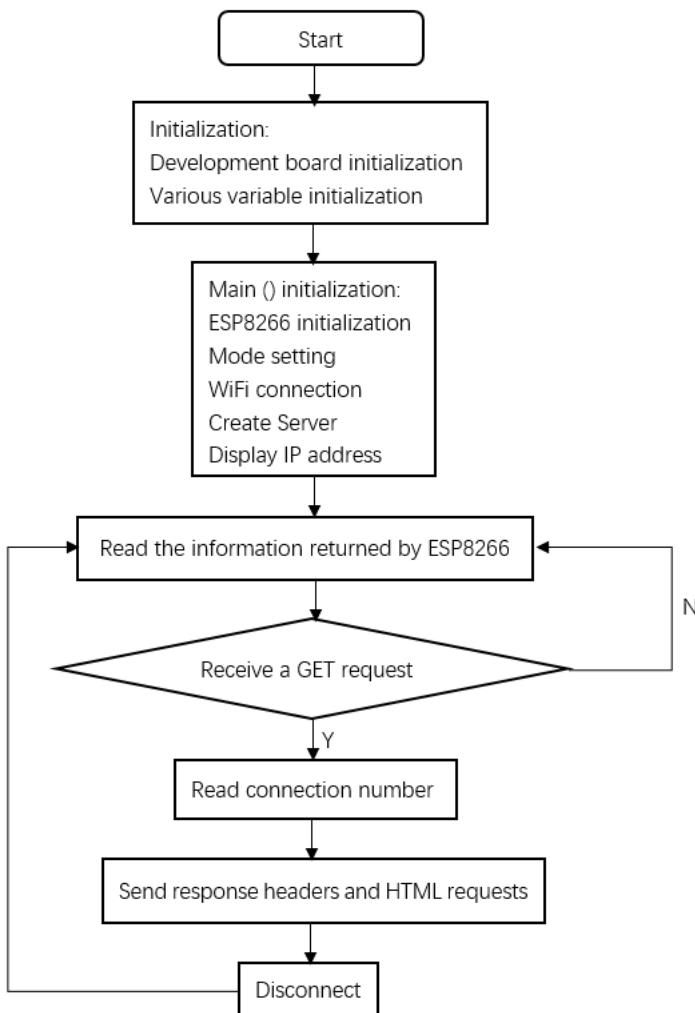
ESP8266 can be widely used in smart grid, intelligent transportation, smart furniture, handheld devices, industrial control, and other IoT fields.

Ai-Thinker company has developed several WIFI modules based on ESP8266, including ESP01 and ESP01S which will be used in this lab.

Note: See [embARC doc](#) to learn how to connect it with your board.



Program structure is shown below



Code is shown below

```

#include "embARC.h"
#include "embARC_debug.h"

#include "board.h"
//#include "dev_uart.h"
#include "esp8266.h"

#include <stdio.h>
#include <string.h>

#define WIFI_SSID      "\\"embARC\\\""
#define WIFI_PWD       "\\"12345678\\\""

static char http_get[] = "GET /";
static char http_IDP[] = "+IPD,";
static char http_html_header[] = "HTTP/1.x 200 OK\r\nContent-type: text/
˓→html\r\n\r\n";
static char http_html_body_1[] = "<html><head><title>ESP8266_AT_HttpServer</title>
˓→</head><body><h1>Welcome to this Website</h1>";
static char http_html_body_2[] = "<p>This Website is used to test the AT command_
˓→about HttpServer of ESP8266.</p></body></html>";

int main(void)
{
    char *conn_buf;
    char scan_result[1024];

    //ESP8266 Init
    EMBARC_PRINTF("===== Init
˓→=====\\n");

    ESP8266_DEFINE(esp8266);
    esp8266_init(esp8266, UART_BAUDRATE_115200);
    at_test(esp8266->p_at);
    board_delay_ms(100, 1);

    //Set Mode
    EMBARC_PRINTF("===== Set Mode
˓→=====\\n");

    esp8266_wifi_mode_get(esp8266, false);
    board_delay_ms(100, 1);
    esp8266_wifi_mode_set(esp8266, 3, false);
    board_delay_ms(100, 1);

    //Connect WiFi
    EMBARC_PRINTF("===== Connect WiFi
˓→=====\\n");

    do
    {
        esp8266_wifi_scan(esp8266, scan_result);
        EMBARC_PRINTF("Searching for WIFI %s .....\\n", WIFI_SSID);
        board_delay_ms(100, 1);
    }
    while (strstr(scan_result, WIFI_SSID) == NULL);

    EMBARC_PRINTF("WIFI %s found! Try to connect\\n", WIFI_SSID);

    while(esp8266_wifi_connect(esp8266, WIFI_SSID, WIFI_PWD, false)!=AT_OK)
    {
        EMBARC_PRINTF("WIFI %s connect failed\\n", WIFI_SSID);
    }
}

```

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```

        board_delay_ms(100, 1);

    }

EMBARC_PRINTF("WIFI %s connect succeed\n", WIFI_SSID);

//Create Server
EMBARC_PRINTF("===== Connect Server\n");
===== \n");

esp8266_tcp_server_open(esp8266, 80);

//Show IP
EMBARC_PRINTF("===== Show IP\n");
===== \n");

esp8266_address_get(esp8266);
board_delay_ms(1000, 1);

EMBARC_PRINTF("===== while\n");
===== \n");

while (1)
{
    memset(scan_result, 0, sizeof(scan_result));
    at_read(esp8266->p_at, scan_result, 1000);
    board_delay_ms(200, 1);
    //EMBARC_PRINTF("Alive\n");

    if(strstr(scan_result, http_get) != NULL)
    {

        EMBARC_PRINTF("===== send\n");
===== \n");

        EMBARC_PRINTF("\nThe message is:\n%s\n", scan_result);

        conn_buf = strstr(scan_result, http_IDP) + 5;
        *(conn_buf+1) = 0;

        EMBARC_PRINTF("Send Start\n");
        board_delay_ms(10, 1);

        esp8266_connect_write(esp8266, http_html_header, conn_buf,
===== sizeof(http_html_header)-1));
        board_delay_ms(100, 1);

        esp8266_connect_write(esp8266, http_html_body_1, conn_buf,
===== sizeof(http_html_body_1)-1));
        board_delay_ms(300, 1);

        esp8266_connect_write(esp8266, http_html_body_2, conn_buf,
===== sizeof(http_html_body_2)-1));
        board_delay_ms(300, 1);

        esp8266_CIPCLOSE(esp8266, conn_buf);

        EMBARC_PRINTF("Send Finish\n");
    }
}

return E_OK;

```

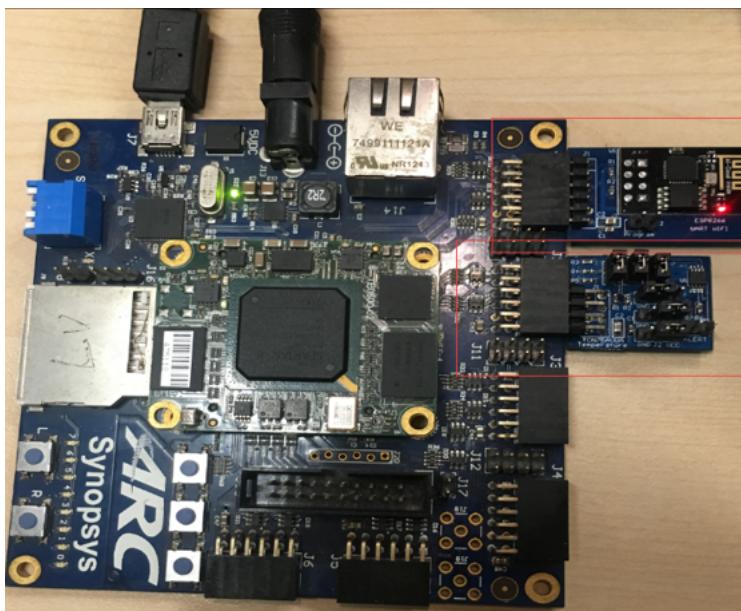
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{}

Steps

Hardware connection (as shown below)



Compile and download

Compile and download the program, after downloading successfully, the relevant download information is displayed in the command window(as shown in the following example).

```
0x00000004 in ?? ()
Loading section .init, size 0x1b0 lma 0x10000000
Loading section .vector, size 0x400 lma 0x10000400
Loading section .text, size 0x1446c lma 0x10000800
Loading section .rodata, size 0x1cb4 lma 0x10014c6c
Loading section .data, size 0xc2c lma 0x10016920
Start address 0x10000004, load size 94972
Transfer rate: 602 KB/sec, 9497 bytes/write.
Continuing.
```

At this point, feedback information will be shown on your serial port console, representing the process of the board establishing connection with http server with AT command (showing below).

```
embARC Build Time: Mar 21 2018, 17:53:27
Compiler Version: ARC GNU, 7.1.1 20170710
===== Init =====
[at_parser_init]56: obj->psio 0x1006ba30 -> 0x10057948

.....
OK" (9)
===== Set Mode =====
[at_send_cmd]117: at_out: "AT+CWMODE_CUR?
" (16)

.....
```

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```

OK" (24)
===== Connect WiFi =====
[at_send_cmd]117: at_out: "AT+CWLAP
" (10)

.....
OK" (24)
[at_send_cmd]117: at_out: "AT+CWJAP_CUR="embARC_test", "123456789"

.....
WIFI "embARC_test" connect succeed
===== Connect Server =====
[at_send_cmd]117: at_out: "AT+CIPMUX=1
" (13)

.....
OK" (26)
===== Show IP =====
[at_send_cmd]117: at_out: "AT+CIFSR
" (10)
[at_get_reply]137: "
AT+CIFSR
+CIFSR:STAIP,"192.168.137.81"
+CIFSR:STAMAC,"5c:cf:7f:0b:5c:d1"

OK" (83)
===== while =====
.....
===== send =====
.....
Send Start
Send Finish

```

Access server

The serial port feedback information above shows that the board has successfully connected to the target WIFI through ESP8266. It is set to the server mode by using the AT command, and the IP address of the server is also given.

At this point, use a PC or mobile phone to connect to the same WIFI, open a browser, and enter the IP address 192.168.137.81 to see the static HTTP page. Notice the IP address that you enter should be the same IP address shown in *Show IP* section at your serial port console.

Exercises

Referring to the embARC documents, using ESP8266 and TCN75 temperature sensor to build http server to make the page display the sensor temperature in real time.

BLE Communication

Purpose

- Familiar with the wireless communication in IoT
- Familiar with the usage of RN4020 BLE module on IoT Development Kit

- Learn to use the API of RN4020 driver in embARC OSP

Equipment

The following hardware and tools are required:

- PC host
- ARC GNU toolchain/MetaWare Development Toolkit
- ARC board (IoT Development Kit)
- embARC OSP package
- `embarc_osp/arc_labs/labs/lab6_ble_rn4020`

Content

Complete the communication between smartphone and IoTDK board through RN4020 BLE module.

- Setup RN4020 BLE module by using API of RN4020 driver.
- Connect mobile phone and RN4020 by BLE, and check the data send by IoTDK in smartphone.
- Send data from smartphone to IoTDK board, and print this data value in terminal.

Principles

RN4020 BLE module is controlled by the user through input/output lines (that is physical device pins) and an UART interface. The UART Interface supports ASCII commands to control/configure the RN4020 modules for any specific requirement based on the application.

Setup

Before connecting an RN4020 module to a smartphone device, you might need to set up the RN4020 module as follows.

1. Configure UART which is connected to RN4020 with these parameters: **Baud rate - 115200, Data bits - 8, Parity - None, Stop bits - 1**
2. Set the **WAKE_SW** pin high to enter command mode
3. Run the command **SF, 1** to reset to the factory default configuration
4. Run the command **SN, IoT DK** to set the device name to be “IoT DK”
5. Run the command **SS, C0000001** to enable support of the Device Information, Battery Service, and User-Defined Private Service
6. Run the command **SR, 00002000** to set the RN4020 module as a server
7. Run the command **PZ** to clear all settings of the private service and the private characteristics
8. Run the command **PS, 11223344556677889900AABBCCDDEEFF** to set the UUID of user-defined private service to be `0x11223344556677889900AABBCCDDEEFF`
9. Run the command **PC, 010203040506070809000A0B0C0D0E0F, 18, 06** to add private characteristic `0x010203040506070809000A0B0C0D0E0F` to current private service. The property of this characteristic is `0x18` (writable and could notify) and has a maximum data size of 6 bytes.
10. Run the command **R, 1** to reboot the RN4020 module and to make the new settings effective
11. Run the command **LS** to display the services

The source code using the API of RN4020 driver in embARC OSP as follows.

```

rn4020_setup(rn4020_ble);
rn4020_reset_to_factory(rn4020_ble);

/* Set device Name */
rn4020_set_dev_name(rn4020_ble, "IoT DK");

/* Set device services */
rn4020_set_services(rn4020_ble, RN4020_SERVICE_DEVICE_INFORMATION |
                     RN4020_SERVICE_BATTERY |
                     RN4020_SERVICE_USER_DEFINED);

rn4020_set_features(rn4020_ble, RN4020_FEATURE_SERVER_ONLY);
rn4020_clear_private(rn4020_ble);

/* Set private service UUID and private characteristic */
rn4020_set_prv_uuid(rn4020_ble, RN4020_PRV_SERV_HIGH_UUID, RN4020_PRV_SERV_LOW_
                     ↪UUID);
rn4020_set_prv_char(rn4020_ble, RN4020_PRV_CHAR_HIGH_UUID, RN4020_PRV_CHAR_LOW_
                     ↪UUID, 0x18, 0x06, RN4020_PRIVATE_CHAR_SEC_NONE);

/* Reboot RN4020 to make changes effective */
rn4020_reset(rn4020_ble);

rn4020_refresh_handle_uuid_table(rn4020_ble);

```

Advertise

Run the command **A** to start advertisement. The source code using the API of RN4020 driver in embARC OSP as follows.

```
rn4020_advertise(rn4020_ble);
```

Send data

Run the command **SUW, 2A19, value** to set the level of Battery. The source code using the API of RN4020 driver in embARC OSP as follows.

```

while (1) {

    rn4020_battery_set_level(rn4020_ble, battery--);

    board_delay_ms(1000, 0);
    if (battery < 30) {
        battery = 100;
    }
}

```

Note: About detailed usage of RN4020 BLE module, see RN4020 Bluetooth Low Energy Module User's Guide

Steps

Run project

Open the serial terminal emulator in PC (for example, Tera Term), set as **115200 baud, 8 bits data, 1 stop bit and no parity**, and connect to the IoT DK board.

Open cmd from the folder `embarc_ospf[arc_labs]labs/lab6_ble_rn4020`, input the command as follow

make run

POWERED BY
embARC

Then the output is displayed in the serial terminal.

Connection

Open the BLE browser APP in smartphone (for example, LightBlue in IOS), and scan for BLE peripherals, connect the “IoT DK” device. Then the output is displayed in the serial terminal.

```
embARC Build Time: Sep 20 2018, 09:55:07
Compiler Version: Metaware, 4.2.1 Compatible Clang 4.0.1 (branches/release_40)
rn4020 test application
connected
```

And the device information is displayed BLE browser APP.

[Back](#) [Peripheral](#) [Clone](#)

IoT DK

UUID: 4CF706AF-2D72-EC22-3E7C-E100A7B2C831

Connected

ADVERTISEMENT DATA [Show](#)

Device Information

Serial Number String 001EC06BA93C	>
Hardware Revision String 4.1	>
Firmware Revision String 1.33BEC	>
Software Revision String 1.33BEC	>
Manufacturer Name String Microchip	>
Model Number String RN4020	>

[Info](#)  [Log](#)

Communication

Read the data of Battery services in BLE browser APP. Check whether the data decreases gradually.

The screenshot shows the IoT DK BLE browser interface. At the top, there are three tabs: 'IoT DK' (selected), 'Battery Level', and 'Hex'. Below the tabs, the device name 'IoT DK' is displayed. Under 'Battery Level', the UUID '2A19' and status 'Connected' are shown. A section titled 'READ/NOTIFIED VALUES' contains a table with the following data:

0x5F	14:48:41.259
0x60	14:48:40.179
0x62	14:48:39.099
0x63	14:48:37.869
0x64	14:48:36.699

A red box highlights the first row of the table. Below the table, there is a 'Cloud Connect' section with an info icon and a toggle switch. A 'DESCRIPTORS' section shows a count of 0. At the bottom, there are three buttons: 'Info' (selected), 'Log' (disabled), and a Log icon.

Write data in BLE browser APP. Check the received data in PC serial terminal.

The screenshot shows the IoT DK configuration interface. At the top, it displays the device identifier: IoT DK 0x01020304-0506-0708-... Hex. Below this, the device name is IoT DK, the UUID is 01020304-0506-0708-0900-0A0B0C0D0E0F, and the status is Connected. A section titled NOTIFIED VALUES contains a button labeled "Listen for notifications". Below this, there are two entries: "Cloud Connect" with a toggle switch set to off, and two other entries both labeled "No value". Under the WRITTEN VALUES section, a red box highlights the "Write new value" button. Below it, two entries are listed: 0xDB9584 (14:49:09.559) and 0xEB20 (14:49:02.421). At the bottom, there are tabs for Info, Log, and a blue refresh icon.

```

embARC Build Time: Sep 20 2018, 09:55:07
Compiler Version: Metaware, 4.2.1 Compatible Clang 4.0.1 (branches/release_40)
rn4020 test application
connected
write: 0x001B:EB20. write: 0x001B:DB9584.

```

Exercises

Try to use the received data in IoTDK board, and do some control by using GPIO. (for example, LED on/off)

Memory map and linker

Purpose

- To get familiar with memory layout in compilation process
- To learn how to use linker

Equipment

The following hardware and tools are required:

- PC host
- ARC GNU toolchain/MetaWare Development Toolkit
- nSIM simulator
- `embarc_osp/arc_labs/labs/lab8_linker`

Content

- Customizing your program with **compiler pragmas**.
- Using “pragma code” to specify a new name of section in which the code or function reside.
- Mapping this code section into specified memory location with linker.
- Checking the location of this code section after build process.

Principles

By default, compiler-generated code is placed in the `.text` section. The default code section name can be overridden by using the `code pragma`. After compile process, the linker automatically maps all input sections from object files to output sections in executable files. If you want to customize the mapping, you can change the default linker mapping by invoking a linker command file.

Steps

Create a project and overriding code section name

Open MetaWare IDE, create an empty C project called `lab_linker` and select ARC EM series processor. Import the `main.c` and `link.cmd` files from the `embarc_osp/arc_labs/labs/lab8_linker` directory into the project.

Open `main.c` file in MetaWare IDE, use “pragma code” to change the section in which function `modify` reside from `.text` to a new name “`modify_seg`”.

```
#pragma Code ("modify_seg")
void modify(int list[], int size) {
    int out, in, temp;

    for(out=0; out<size; out++)
        for(in=out+1; in<size; in++)
            if(list[out] > list[in]) {
                temp = list[in];
                list[in] = list[out];
                list[out] = temp;
            }
}
```

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```
}
```

```
#pragma Code ()
```

Pragma code has two forms that must be used in pairs to bracket the affected function definitions:

```
#pragma code(Section_name)
/* ----- Affected function definitions go here ---- */
#pragma code() /* No parameters here */
```

Section_name is a constant string expression that denotes the name of the section

Note: About detailed usage of the compiler pragmas, see MetaWare C/C++ Programmer's Guide for the ccac Compiler

Edit the linker command file

Open link.cmd file, there are two parts, one is for memory blocks location, the other is for sections mapping. Add one new block named “MyBlock” in MEMORY, the start address is 0x00002000, and the size is 32KB. Add one new GROUP in SECTIONS, and mapping section “modify_seg” into MyBlock.

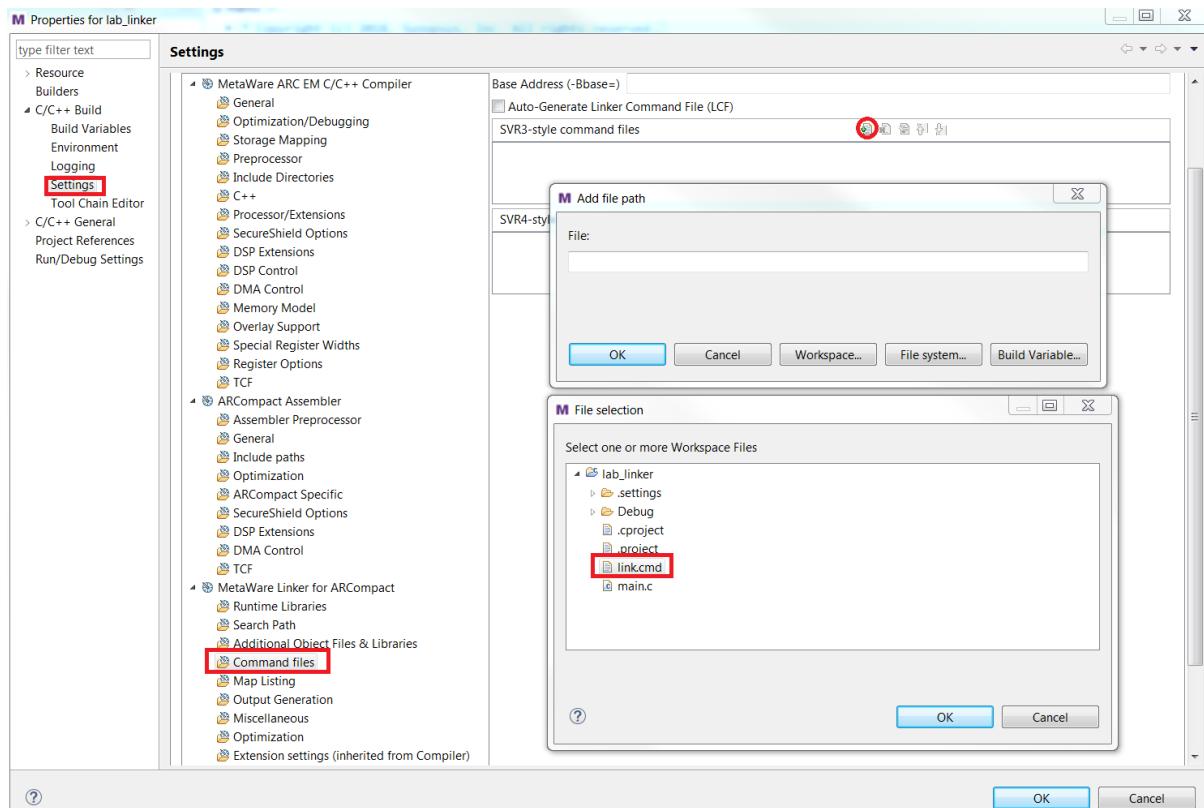
```
MEMORY {
    // Note: overlap of code and data spaces is not recommended since it makes
    //        Address validity checking impossible with the debugger and simulator
    MyBlock: ORIGIN = 0x00002000, LENGTH = 32K
    MEMORY_BLOCK1: ORIGIN = 0x0010000, LENGTH = 64K
    MEMORY_BLOCK2: ORIGIN = 0x0020000, LENGTH = 128K
}

SECTIONS {
    GROUP: {
        modify_seg: {}
    }>MyBlock
.....
```

Note: About format and syntax of the linker command file, please refer to the document “MetaWare ELF Linker and Utilities User's Guide”

Add the linker command file into the project

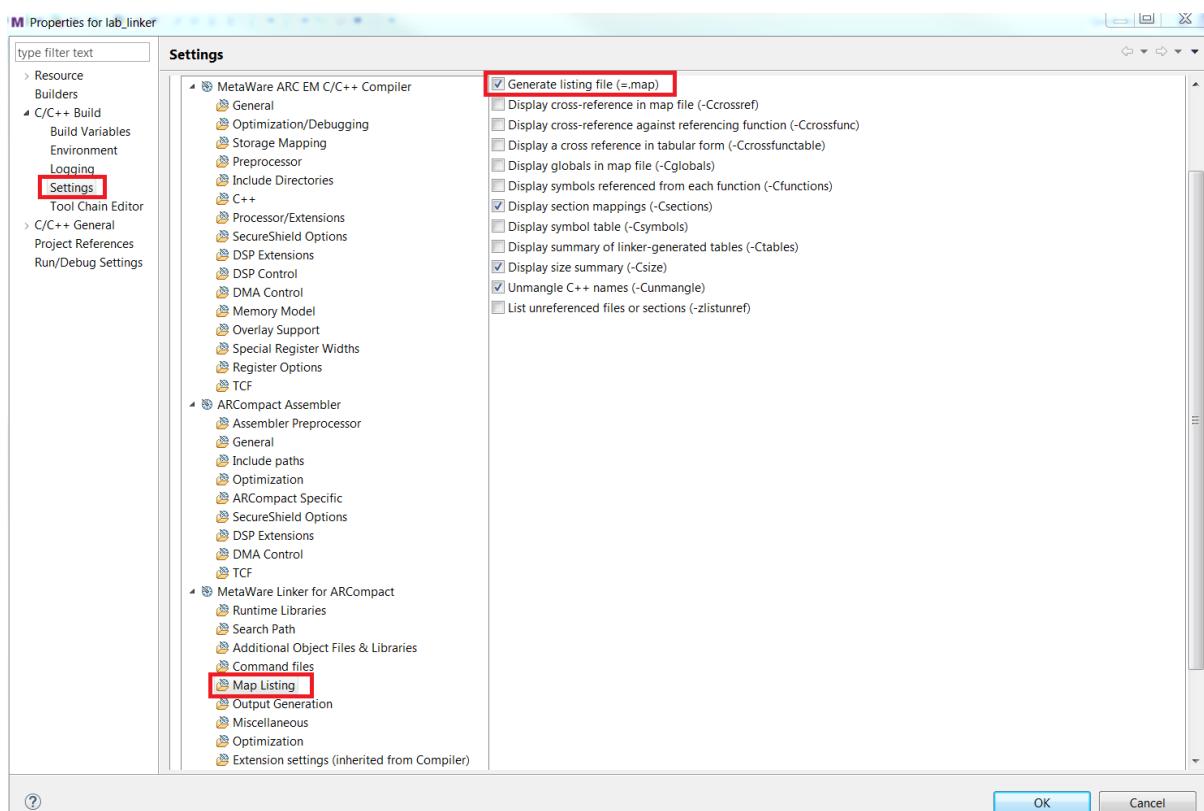
Right click the current project lab_linker and select Properties. Click **C/C++ build > Settings > Tool Settings** to open the linker option settings page.



Select Command files to add linker.cmd file into this project.

Check the result

In the linker option settings window, select Map listing to check Generate listing file(=.map)



Build the lab_linker project, then open the lab_linker.map file.

SECTION SUMMARY

OUTPUT/ INPUT SECTION	TYPE	START ADDRESS	END ADDRESS	LENGTH
modify_seg	text	00002000	00002039	0000003a
.fini	text	00010000	00010005	00000006
.init	text	00010008	0001000d	00000006
.text	text	00010010	0001013d	0000012e
.vectors	text	00010140	0001017f	00000040
.sdata	bss	00020000	0001ffff	00000000
.data	data	00020000	0002001f	00000020
.stack	bss	00020020	0003001f	00010000

Search SECTIONS SUMMARY, then you can check the size and location of *modify_seg* section, it resides in *MyBlock*, similar to you setting in the linker command file.

Exercises

Check the memory mapping info of *modify_seg* section by using elfdump tool.

How to use FreeRTOS

Purpose

- To learn how to implement tasks in FreeRTOS operating system
- To learn how to register tasks in FreeRTOS
- To get familiar with inter-task communication of FreeRTOS

Equipment

The following hardware and tools are required:

- PC host
- GNU Toolchain for ARC Processors / MetaWare Development Toolkit
- ARC board (EM Starter Kit / IoT Development Kit)
- embARC OSP package
- [embarc_osp/arc_labs/labs/lab9_freertos](#)

Content

This lab utilizes FreeRTOS v9.0.0, and creates 3 tasks based on embARC OSP. You should apply inter-task communicating methods such as semaphore and message queue in order to get running LEDs result. You should know the basic functions of FreeRTOS.

Principles

Background

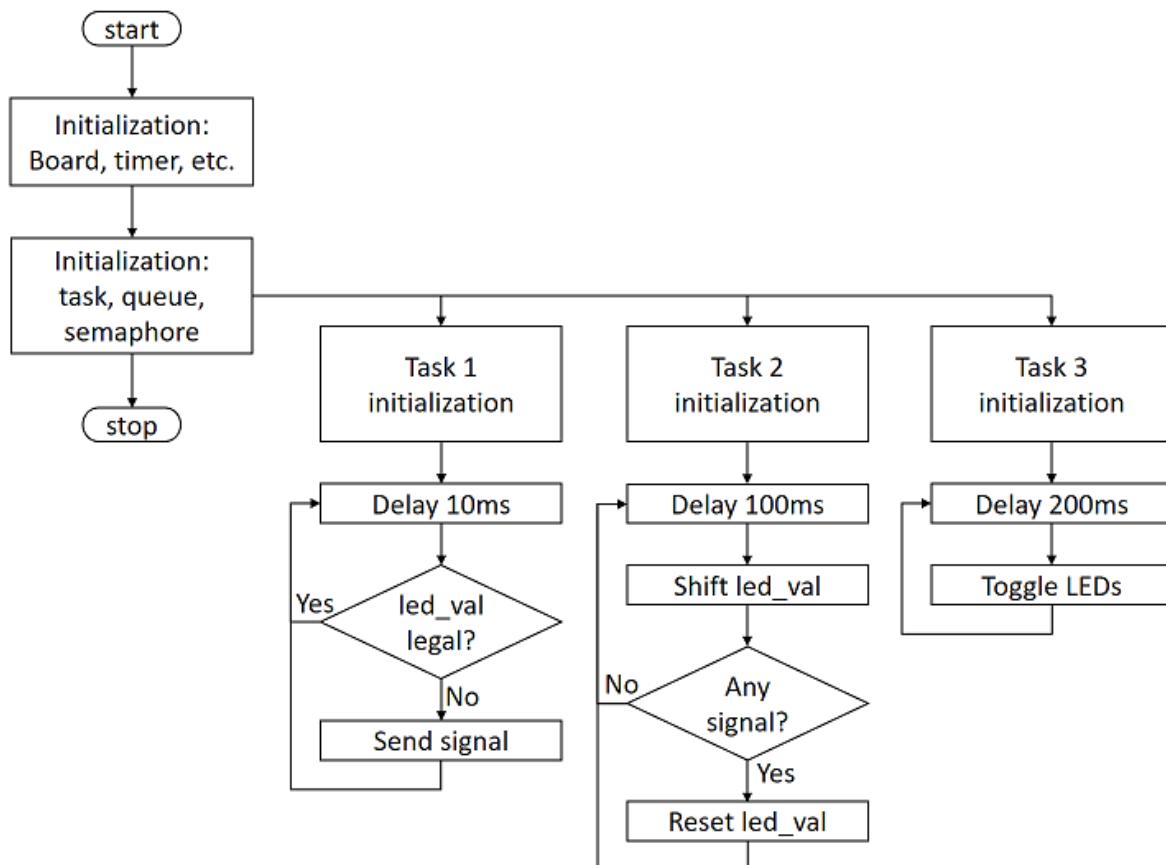
A Real Time Operating System (RTOS) is an operating system intended to serve real-time applications that process data in within a predefined time period.

As resources becoming abundant for modern micro processors, the cost to run RTOS is become increasingly insignificant. RTOS also provides event-driven mode for better utilization of CPU with efficiency. Among RTOSs for micro processors, FreeRTOS stands out as a free for use, open-sourced RTOS with complete documents. This is why FreeRTOS is selected.

Design

This lab implements a running LED light with 3 tasks on FreeRTOS. Despite using 3 tasks overkill for a running LED, but it is beneficial for the understanding of FreeRTOS itself and inter-task communication as well.

The following is the flow chart of the program:



Realization

The following is the example code of system , including various initialization and task time delay.

```
#include "embARC.h"
#include "embARC_debug.h"
#include <stdlib.h>
```

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```

static void task1(void *par);
static void task2(void *par);
static void task3(void *par);

#define TSK_PRIOR_1          (configMAX_PRIORITIES-1)
#define TSK_PRIOR_2          (configMAX_PRIORITIES-2)
#define TSK_PRIOR_3          (configMAX_PRIORITIES-3)

// Semaphores
static SemaphoreHandle_t sem1_id;

// Queues
static QueueHandle_t dtql1_id;

// Task IDs
static TaskHandle_t task1_handle = NULL;
static TaskHandle_t task2_handle = NULL;
static TaskHandle_t task3_handle = NULL;

int main(void)
{
    vTaskSuspendAll();

    // Create Tasks
    if (xTaskCreate(task1, "task1", 128, (void *)1, TSK_PRIOR_1, &task1_
→handle) != pdPASS) {
        /*!< FreeRTOS xTaskCreate() API function */
        EMBARC_PRINTF("Create task1 Failed\r\n");
        return -1;
    } else {
        EMBARC_PRINTF("Create task1 Successfully\r\n");
    }

    if (xTaskCreate(task2, "task2", 128, (void *)2, TSK_PRIOR_2, &task2_
→handle) != pdPASS) {
        /*!< FreeRTOS xTaskCreate() API function */
        EMBARC_PRINTF("Create task2 Failed\r\n");
        return -1;
    } else {
        EMBARC_PRINTF("Create task2 Successfully\r\n");
    }

    if (xTaskCreate(task3, "task3", 128, (void *)3, TSK_PRIOR_3, &task3_
→handle) != pdPASS) {
        /*!< FreeRTOS xTaskCreate() API function */
        EMBARC_PRINTF("Create task3 Failed\r\n");
        return -1;
    } else {
        EMBARC_PRINTF("Create task3 Successfully\r\n");
    }

    // Create Semaphores
    sem1_id = xSemaphoreCreateBinary();
    xSemaphoreGive(sem1_id);

    // Create Queues
    dtql1_id = xQueueCreate(8, sizeof(uint32_t));

    xTaskResumeAll();
    vTaskSuspend(NULL);
}

```

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```

        return 0;
    }

static void task1(void *par)
{
    uint32_t led_val = 0;

    static portTickType xLastWakeTime;
    const portTickType xFrequency = pdMS_TO_TICKS(10);

    // Use current time to init xLastWakeTime, mind the difference with
    →vTaskDelay()
    xLastWakeTime = xTaskGetTickCount();

    while (1) {
        /* call Freertos system function for 10ms delay */
        vTaskDelayUntil( &xLastWakeTime, xFrequency );

        //####Insert code here####
    }
}

static void task2(void *par)
{
    uint32_t led_val = 0x0001;

    static portTickType xLastWakeTime;
    const portTickType xFrequency = pdMS_TO_TICKS(100);

    // Use current time to init xLastWakeTime, mind the difference with
    →vTaskDelay()
    xLastWakeTime = xTaskGetTickCount();

    while (1) {
        /* call Freertos system function for 100ms delay */
        vTaskDelayUntil( &xLastWakeTime, xFrequency );

        //####Insert code here####
    }
}

static void task3(void *par)
{
    uint32_t led_val = 0;

    static portTickType xLastWakeTime;
    const portTickType xFrequency = pdMS_TO_TICKS(200);

    // Use current time to init xLastWakeTime, mind the difference with
    →vTaskDelay()
    xLastWakeTime = xTaskGetTickCount();

    while (1) {
        /* call Freertos system function for 100ms delay */
        vTaskDelayUntil( &xLastWakeTime, xFrequency );

        //####Insert code here####
    }
}

```

Steps

Build and run the uncompleted code

The code is at `embarc_osp/arc_labs/labs/lab9_freertos`, uses an UART terminal console and run the code, the following message from program is displayed:

```
embARC Build Time: Mar 9 2018, 17:57:50
Compiler Version: Metaware, 4.2.1 Compatible Clang 4.0.1 (branches/release_40)
Create task1 Successfully
Create task2 Successfully
Create task3 Successfully
```

This message implies that three tasks are working correctly.

Implement task 3

It is required for task 3 to retrieve new value from the queue and assign the value to `led_val`. The LED controls are already implemented in previous labs, the new function to learn is `xQueueReceive()`. This is a FreeRTOS API to pop and read an item from queue. See FreeRTOS documentation and complete the code for this task. (An example is in ‘complete’ folder)

Implement task 1

It is required for task 1 to check if value from queue is legal. If not, a reset signal is needed to be sent.

Two new functions might be helpful for this task: `xSemaphoreGive()` for release a signal and `xQueuePeek()` for read item but not pop from a queue. See FreeRTOS documentation and complete the code for this task. (An example is in ‘complete’ folder)

Do notice the difference between `xQueueReceive()` and `xQueuePeek()`.

Implement task 2

There are two different works for task 2 to complete: to shift `led_val` and queue it, and to reset both `led_val` and queue when illegal `led_val` is detected.

Three functions can be helpful: `xQueueSend()`, `xSemaphoreTake()`, `xQueueReset()`. See FreeRTOS documentation and complete the code for this task. (An example is in ‘complete’ folder)

Build and run the completed code

BUILD the completed program and debug it to fulfill all requirements. (8-digit running LEDs are used in example code)

Exercises

The problem of philosophers having meal:

Five philosophers sitting at a round dining table. Suppose they are either thinking or eating, but they cannot do these two things at same time. So each time when they are having food, they stop thinking and vice versa. There are five forks on the table for eating noodle, each fork is placed between two adjacent philosophers. It is hard to eat noodle with one fork, so all philosophers need two forks in order to eat.

Write a program with proper console output to simulate this process.

3.2.3 Level 3 Labs

AWS IoT Smarthome

Purpose

- Show the smart home solution based on ARC and AWS IoT Cloud
- Learn how to use the AWS IoT Cloud
- Learn how to use the EMSK Board peripheral modules and on-board resources

Equipment

Required Hardware

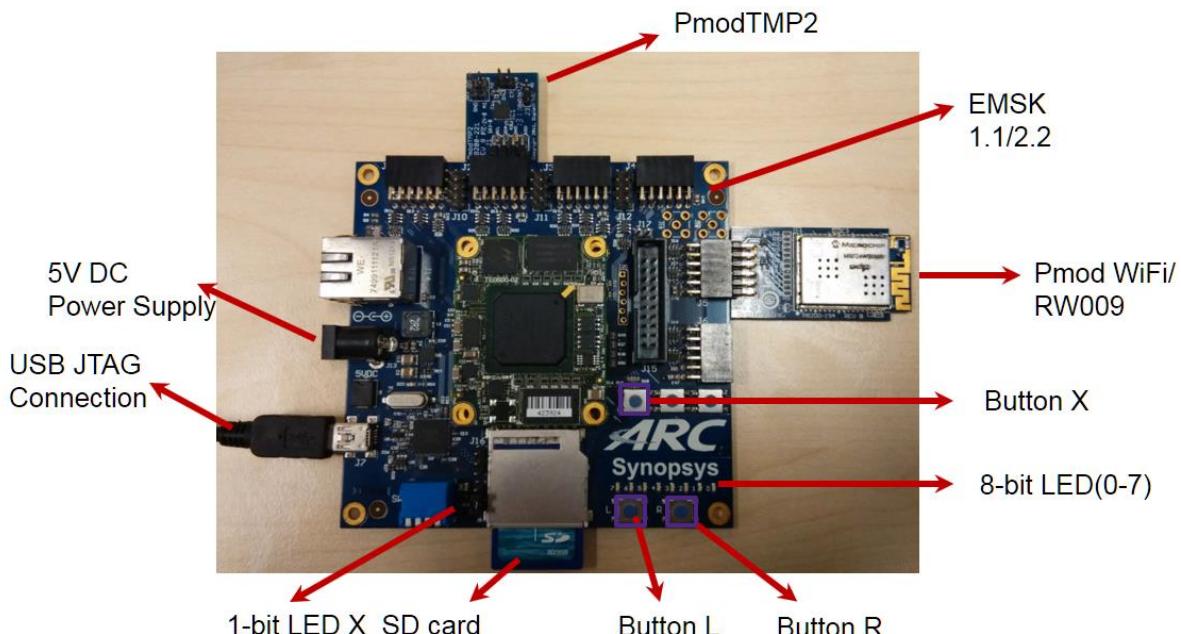
- [DesignWare ARC EM Starter Kit (EMSK)]
- [Digilent PMOD WiFi (MRF24WG0MA)]
- [Digilent PMOD TMP2]
- SD Card
- WiFi Hotspot (default SSID: **embARC**, Password: **qazwsxedc**, WPA/WPA2 encrypted)

Required Software

- MetaWare or ARC GNU Toolchain
- Serial port terminal (e.g. Putty, Tera-term or Minicom)

Hardware Connection (EMSK Board)

- Connect PMOD WiFi to J5, connect PMOD TMP2 to J2.



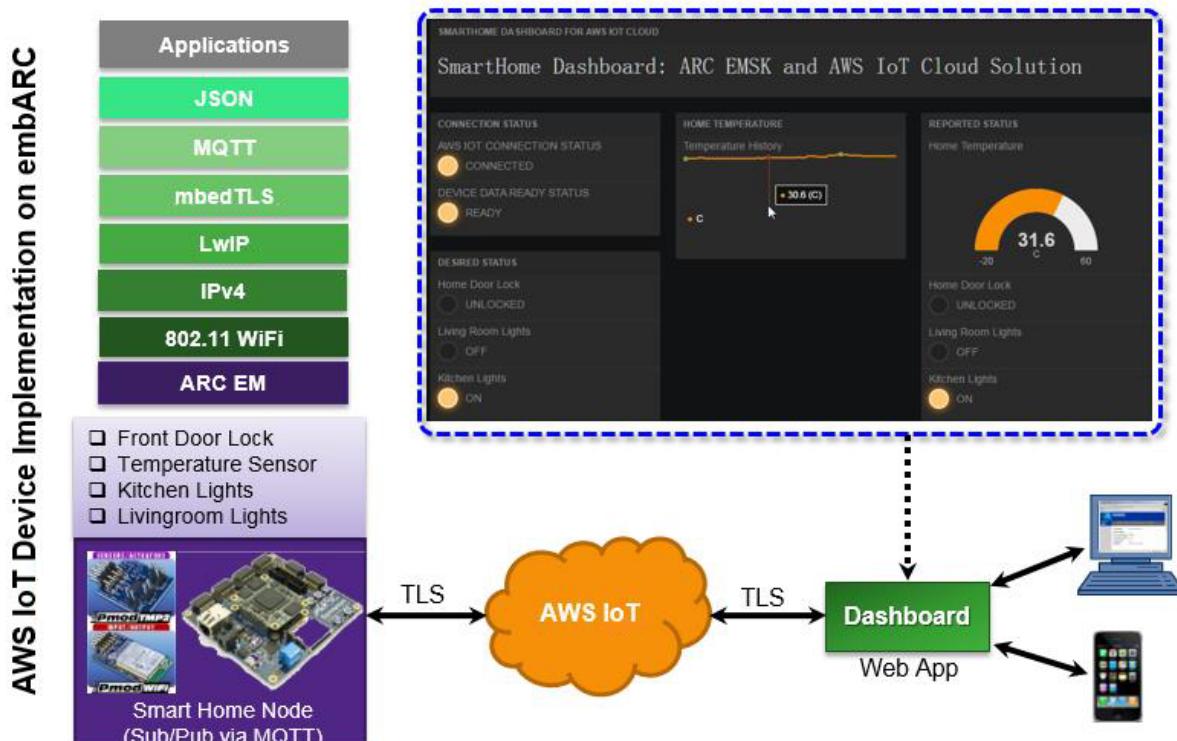
- Configure your hardware with proper core configuration.

- The hardware resources are described at the table below.

Hardware Resources	Represent
BUTTON R	Livingroom Lights Control
LED 0-1	Livingroom Lights Status (On or Off)
BUTTON L	Kitchen Lights Control
LED 2-3	Kitchen Lights Status (On or Off)
BUTTON X	Front Door Lock Control
LED 4-5	Front Door Lock Status (On or Off)
LED 7	WiFi Connection Status (On for connected, Off for not)
LED X	Node Working Status (toggling in 2s period if working well)
PMOD TMP2	Temperature Sensor
PMOD WiFi	Provide WiFi Connection

Content

This lab provides instructions on how to establish connection between the EMSK and Amazon Web Services Internet of Things (AWS IoT) cloud with a simulated smart home application. With the help of AWS IoT as a cloud platform, devices can securely interact with cloud applications and other devices. AWS IoT also supports MQ Telemetry Transport (MQTT) and provides authentication and end-to-end encryption.



This application is designed to show how to connect only 1 EMSK and AWS IoT Cloud using embARC. The connection between EMSK and AWS IoT Cloud is secured by TLS.

Principles

This lab demonstrates the smart home solution based on EMSK by establishing the connection between EMSK Board and AWS IoT Cloud. The AWS IoT Device C SDK for the embedded platform has been optimized and ported for embARC.

In this lab application, the peripheral modules and on-board resources of EMSK board are used to simulate the objects which are controlled and monitored in smart home scenario. The AWS IoT Cloud is used as the cloud host

and a controlling platform that communicates with the EMSK Board with MQTT protocol. A HTML5 Web APP is designed to provide a dash board in order to monitor and control smart home nodes.

Steps

Creating and setting smart home node

1. Create an AWS account at [\[Amazon AWS Website\]](#). Amazon offers various account levels, including a free tier for AWS IoT.
2. Login AWS console and choose AWS IoT.

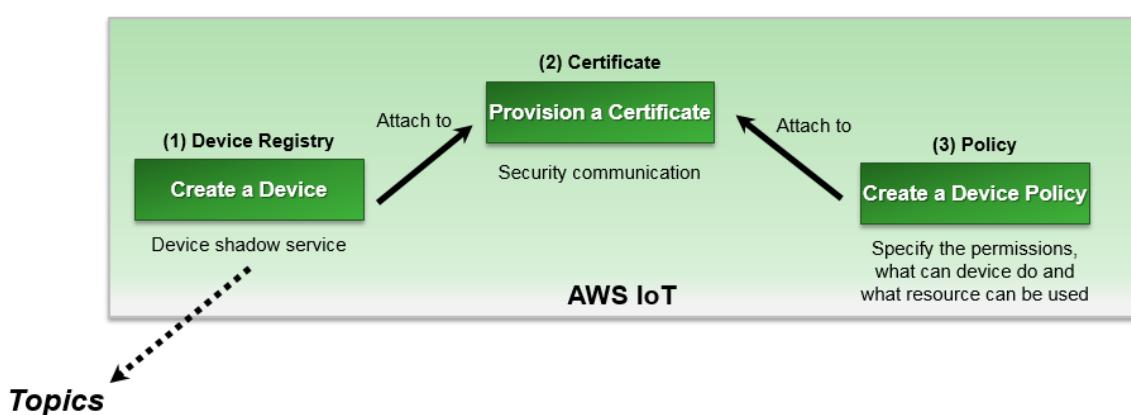


3. Choose an appropriate IoT server in the top right corner of the AWS IoT console page. As an example we choose US East (N. Virginia) server, you may choose other server as you see fit.

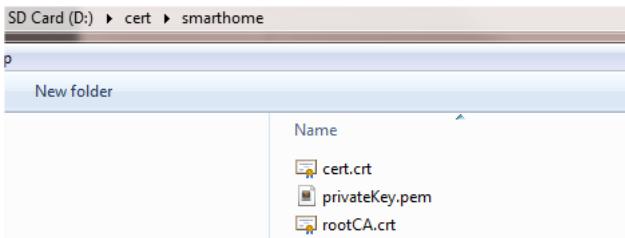


4. Create your smart home node in the thing registry and generate X.509 certificate for the node. Create an AWS IoT policy. Then attach your smart home node and policy to the X.509 certificate.

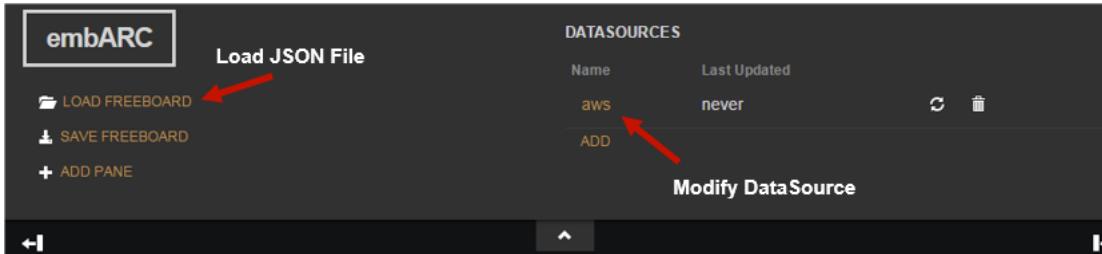
Note: for more details, see [\[Using a Smart Home IoT Application with EMSK\]](#)



5. Download the root CA certificate from [\[here\]](#). Rename it *rootCA.crt*. Copy the certificate files *cert.crt*, *privateKey.pem* and *rootCA.crt* to folder *cert/smarthouse*. Insert the SD card to your PC, and copy the certificate folder cert to the SD Card root.



6. Open the [Web App] in a web browser and load the configuration file dashboard-smarthomesinglething.json obtained from [embARC/example/freertos/iot/aws/smarthome_demo]. The dashboard can be loaded automatically



7. Click "ADD" to go to DATASOURCE page and fill the forms.

- a) TYPE: Choose AWS IoT.
- b) NAME: Name is aws.

The image shows the 'DATASOURCE' configuration form for AWS IoT. It has the following fields:

- TYPE:** AWS IoT (selected)
- NAME:** aws
- AWS IOT ENDPOINT:** input_your_own_endpoint (instructions: Your AWS account-specific AWS IoT endpoint. You can use the AWS IoT CLI describe-endpoint command to find this endpoint)
- REGION:** input_your_own_region (instructions: The AWS region of your AWS account)
- CLIENT ID:** (empty field, instructions: MQTT client ID should be unique for every device)
- ACCESS KEY:** input_your_own_accesskey (instructions: Access Key of AWS IAM)
- SECRET KEY:** input_your_own_secretKey (instructions: Secret Key of AWS IAM)
- THINGS:** Thing
SmartHome (instructions: AWS IoT Thing Name of the Shadow this device is associated with)
ADD

At the bottom right are 'SAVE' and 'CANCEL' buttons.

- c) AWS IOT ENDPOINT: Go to AWS IoT console and click your smart home node "SmartHome". Copy the content XXXXXXXXXXXXXXXXX.iot.us-east-1.amazonaws.com in REST API endpoint to AWS IOT ENDPOINT.

The screenshot shows the AWS IoT Resources page. On the left, there's a list of resources: 'Smart Home' (selected), '9ce7e d7884 6nh ACTIV E'. At the top right, there's a detailed view of the 'Smart Home' resource. A red arrow points from the text 'AWS IOT ENDPOINT' to the 'REST API endpoint' section in the details view.

- d) REGION: Copy the AWS region of your smart home node in REST API endpoint to REGION. For example, <https://XXXXXXXXXXXXXX.iot.us-east1.amazonaws.com/things/SmartHome/shadow>. REGION is us-east-1.
- e) CLIENT ID: Leave it blank as default.
- f) ACCESS KEY and SECRET KEY: Go to AWS Services page and click "IAM".

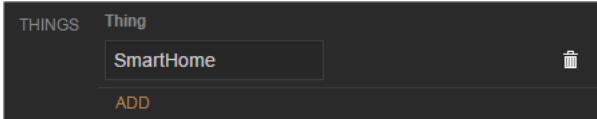
The screenshot shows the AWS Services page. The 'IAM' link under the 'Identity & Access Management' section is highlighted with a red arrow. Other services listed include History, All AWS Services, Inspector, Certificate Manager, Console Home, Compute, Storage & Content Delivery, Database, Networking, Developer Tools, Management Tools, Security & Identity, Analytics, Internet of Things, Mobile Services, Application Services, Enterprise Applications, and Game Development.

Go to User page and click “Create New Users”. Enter User Names “AWSIoTUser”. Then download user security credentials, Access Key ID and Secret Access Key. Copy Access Key ID to ACCESS KEY and Secret Access Key to SECRET KEY.

The screenshot shows the AWS IAM User creation process.
 (1) On the left sidebar, 'Users' is selected.
 (2) In the main area, a new user 'AWSIoTUser' is being created.
 (3) A success message states: 'Your 1 User(s) have been created successfully. This is the last time these User security credentials will be available for download. You can manage and recreate these credentials any time.'
 (4) On the right, the user 'AWSIoTUser' is shown in the 'Summary' tab, and the 'Permissions' tab is selected, showing the attached policy 'AWSIoTDataAccess'.

Go to user page and click “AWSIoTUser”. Click “Attach Policy” to attach “AWSIoTDataAccess” to “AWSIoTUser”.

- g) THINGS: AWS IoT thing name “SmartHome”.



- h) Click **Save** to finish the setting.

Building and Running AWS IoT Smart Home Example

1. The AWS IoT thing SDK for C has been ported to embARC. Check the above steps in order for your IoT application to work smoothly. Go to *embARC/example/freertos/iot/aws/smarthome_demo*. Modify `aws_iot_config.h` to match your AWS IoT configuration. The macro **AWS_IOT_MQTT_HOST** can be copied from the REST API endpoint in AWS IoT console. For example, `https://XXXXXXXXXXXXXX.iot.us-east-1.amazonaws.com/things/SmartHome/shadow`. **AWS_IOT_MQTT_HOST** should be `XXXXXXXXXXXXXX.iot.us-east-1.amazonaws.com`.

```
// Get from console
// =====
#define AWS_IOT_MQTT_HOST      "XXXXXXXXXXXXXX.iot.us-east-1.amazonaws.com" // < Custom
#define AWS_IOT_MQTT_PORT       8883 // < default port for MQTT/S
#define AWS_IOT_MQTT_CLIENT_ID  "csdk-SH" // < MQTT client ID should be unique for every device
#define AWS_IOT_MY_THING_NAME   "SmartHome" // < Thing Name of the Shadow this device
#define AWS_IOT_ROOT_CA_FILENAME "rootCA.crt" // < Root CA file name
#define AWS_IOT_CERTIFICATE_FILENAME "cert.crt" // < device signed certificate file name
#define AWS_IOT_PRIVATE_KEY_FILENAME "privateKey.pem" // < Device private key filename
// =====
```

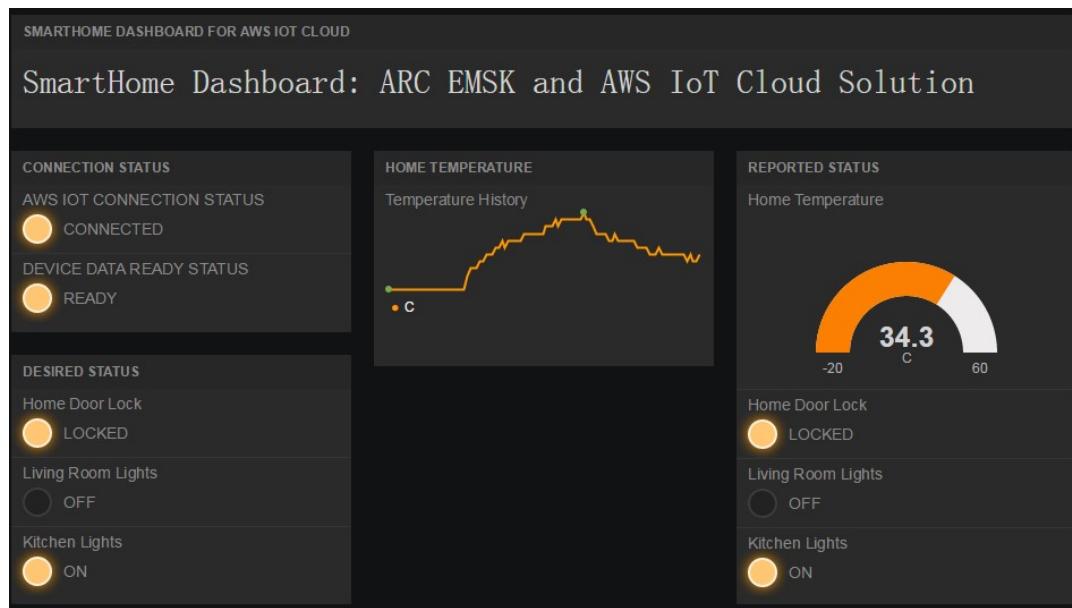
2. Use USB cable to connect the EMSK board. Set the baud rate of the terminal emulator to 115200.
3. Insert the SD Card into the EMSK board SD Card slot. Run the AWS IoT application using JTAG. Go to *embARC/example/freertos/iot/aws/smarthome_demo* in command-line, run the following command:

```
make TOOLCHAIN=gnu BD_VER=22 CUR_CORE=arcem7d run
```

4. FreeRTOS-based runtime environment can be loaded automatically. Wait for WiFi initialization and connection establishment (30 seconds or less) until the “WiFi connected” message is shown in the terminal emulator. “Network is ok” is shown after the certificate files cert.crt, privateKey.pem, and rootCA.crt are validated. The information in “reported”: {} is the state of the EMSK-based smart home node. “Updated Accepted !!” means the connection works between the smart home node and AWS IoT cloud.

```
Shadow Init
Shadow Connect
Frontdoor is open
Turn off Kitchenlights
Turn off LivingRoomLights
Update shadow: {"state":{"reported":{"temperature":29.6,"DoorLocked":false,"KitchenLights":false,"LivingRoomLights":false}}, "clientToken":"csdk-SH-0"}
*****
Delta - FrontDoor state changed to 1
FrontDoor is locked
Delta - KitchenLights light state changed to 1
Turn on KitchenLights
Update Accepted !
Update shadow: {"state":{"reported":{"temperature":29.6,"DoorLocked":true,"KitchenLights":true,"LivingRoomLights":false}}, "clientToken":"csdk-SH-1"}
*****
Update Accepted !!
Update shadow: {"state":{"reported":{"temperature":29.6,"DoorLocked":true,"KitchenLights":true,"LivingRoomLights":false}}, "clientToken":"csdk-SH-2"}
*****
```

5. Try out functions of EMSK and Dashboard. You can press the button L/R/X to see LED toggling on board, and the status of LEDs also changes on dashboard web app. You can also click the lights of **DESIRED STATUS** pane on the dashboard app, and check the reactions of LEDs status on board and dashboard web app.



Exercises

This application is designed to show how to connect only 1 EMSK and AWS IoT Cloud using embARC. Try to add more nodes and implement a Multi-nodes AWS IoT Smarthome Demo.

Note: You could find related demo codes [\[here\]](#)

**CHAPTER
FOUR**

APPENDIX

4.1 Reference

1. [online docs](#)
2. [ARC EM Starter Kit Webpage](#)
3. [ARC IoT Development Kit Webpage](#)
4. [Github Repository of embARC Open Software Platform \(OSP\)](#)

**CHAPTER
FIVE**

INDICES AND TABLES

- genindex
- search