ARC labs handbook

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CHAPTER

ONE

OVERVIEW

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

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

This handbook includes 12 labs currently (more labs will be added in the future), which can be classified into 3 levels:

- Level1: ARC basic

The labs in this level cover the basic topics about DesignWare® ARC® processors, e.g., the installation of tools, hello world, interrupts, timers and so on.

- Level2: ARC advance

The labs in this level cover the advanced topics about DesignWare® ARC® processors, e.g., RTOS, customized linkage, ARC DSP and so on.

- Level3: ARC exploration

The labs in this level will cover some complex applications, e.g., IoT application, embedded machine learning and so on.

Most of labs are based on the embARC Open Software Platform (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 about embARC OSP, please refer its online docs

1.1 Supported Hardware Platform

The following hardare platforms are supported in this handbook:

- ARC EM Starter Kit
- ARC IoT Development Kit

You can go to the specific link to get the board's data sheet and user manual

1.2 Reference

Here is reference for this hand book.

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

CHAPTER

TWO

GETTING STARTED

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

2.1 Software Requirement

- **ARC Development Tools** Choose **MetaWare Toolkit** and/or **ARC GNU Toolchain** from the following list according to your requirement.
  - MetaWare 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/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, but has a number of restrictions, including a code-size limit of 32 Kilobytes and no runtime library sources. It is available for Microsoft Windows only.
  - ARC GNU Toolchain
    - Open Source ARC GNU IDE (2018.03) The ARC GNU Toolchain offers all of the benefits of open source tools, including 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, so just one USB cable is required, no need for external debugger.
- Tera Term or PuTTY for serial terminal connection, 115200 baud, 8 bits data, 1 stop bit and no parity (115200-8-N-1) by default.

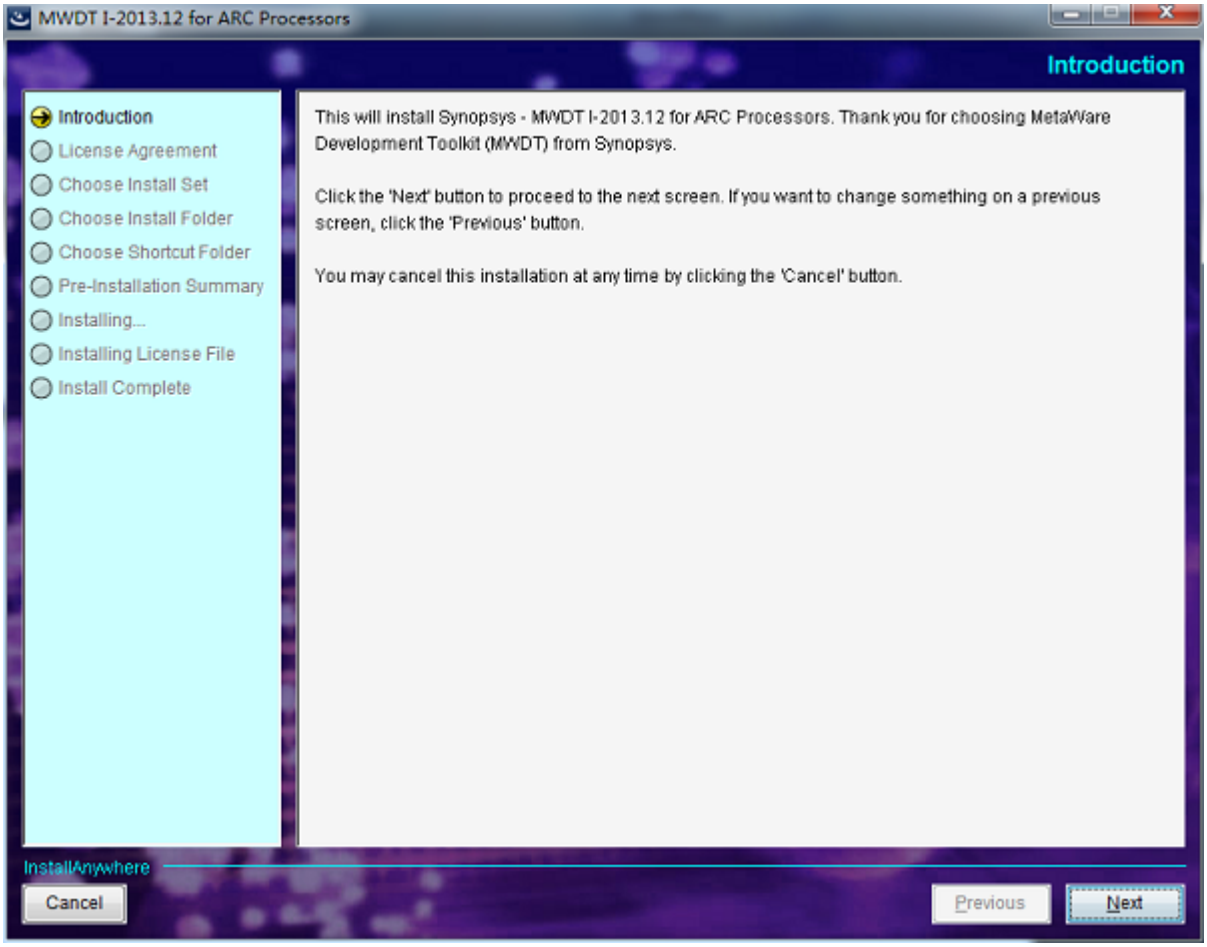
Note: If using embARC with GNU toolchain on Windows, install Zadig to replace FTDI driver with WinUSB driver. See How to Use OpenOCD on Windows for more information.

2.2 Install Software Tools

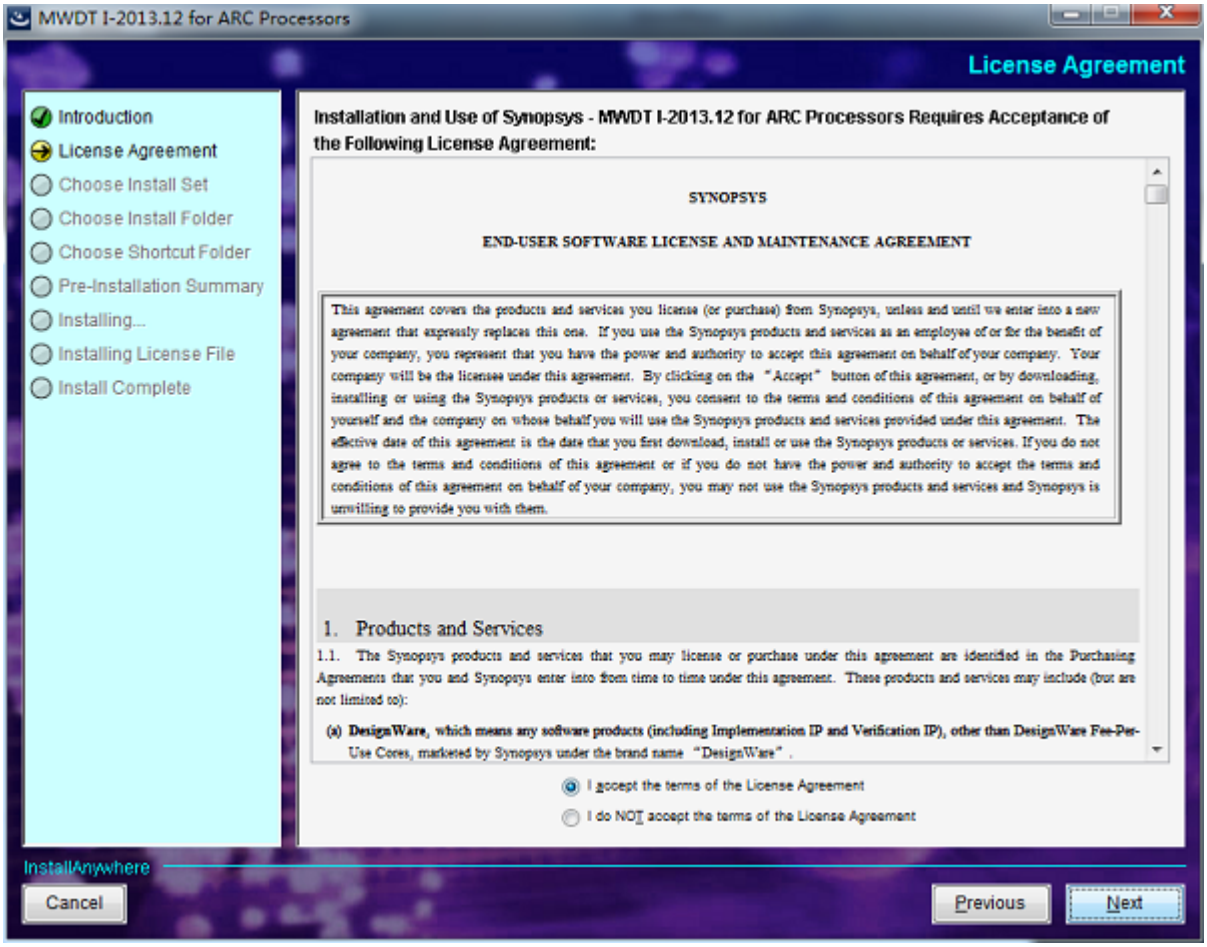
2.2.1 Install Metaware Toolkit

Here we will start install MetaWare Development Toolkit (2017.09).

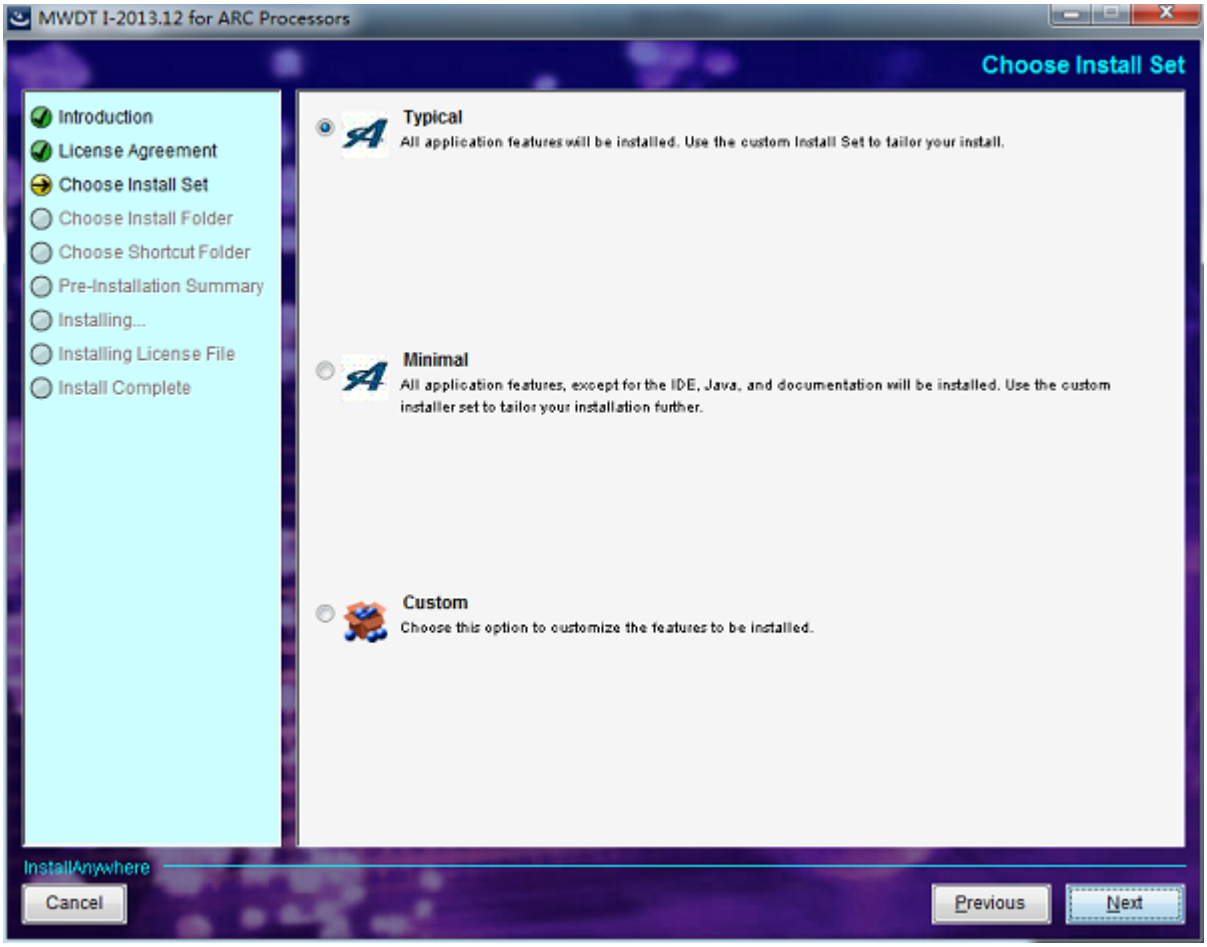
1. Double click the **mw_dekit_arc_i_2017_09_win_install.exe**, it will show



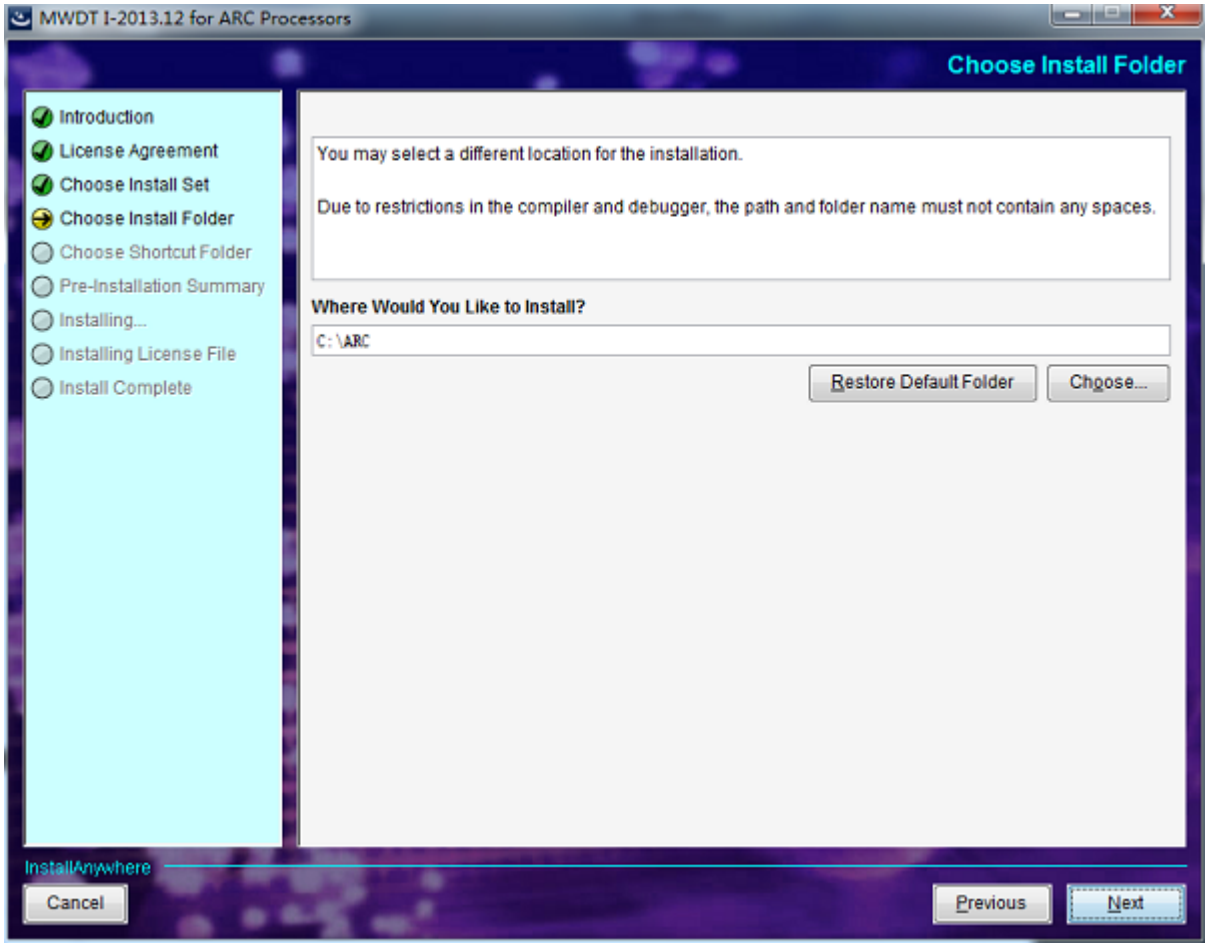
2. Click next, choose I accept, continue to click next



3. Choose Typical installation, then click next

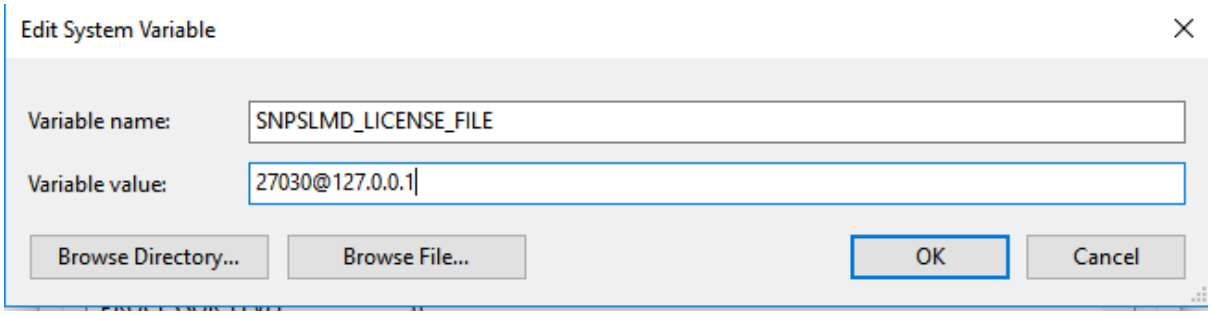


4. Set the install path (please use English letters only and no space), then click next until the installation is finished



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

- For Windows, go to Computer->property->Advanced->Environment Variables->System Variables->New to Set



- For Linux, please add SNPSLMD_LICENSE_FILE into your system variables

6. Test the MetaWare Development Toolkit and its license

Open cmd.exe in Windows and find the queens.c in the installation folder of MetaWare Development Toolkit, e.g., **C:\ARC\MetaWare\arc\demos\queen.c**. Type the following commands in cmd

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

If you get the following message and no error, it means MetaWare Development Toolkit is successfully installed and license is ok.

```
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

2.2.3 Install embARC OSP

2.2.4 Install USB-JTAG Drivers

2.3 Final Check

Check the following items and set development environment.

- Make sure the paths of the above required tools for the MetaWare toolkit and ARC GNU toolchain are added to the system variable **PATH** in your environment variables.
- We recommend users to install ARC GNU IDE to default location. Otherwise you need to make additional changes as below.
  - If running and debugging embARC applications using **arc-elf32-gdb** and OpenOCD for ARC, make sure 1) the path of **OpenOCD** is added to the **PATH** in your environment variables, and 2) modify **OPENOCD_SCRIPT_ROOT variable** in *<embARC>/options/toolchain/toolchain_gnu.mk* according 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 purely makefile-based. *make/gmake* is provided in the MetaWare toolkit (gmake) and ARC GNU toolchain (make)

CHAPTER

THREE

LABS

3.1 Overview

3.2 Labs

3.2.1 Level 1 Labs

How to use ARC IDE

MetaWare ToolKit

Purpose

- Learn the MetaWare IDE integration interface
- Familiar with the use of the MetaWare IDE interface and command line
- Familiar with the features and usage of the MetaWare Debugger debugger

Equipment

PC, MetaWare Development Toolkit, nSIM simulator, core_test source file in embAR OSP

Content

Create a C project using the Metaware IDE graphical interface, import the code CoreTest.c, configure compilation options to compile, and generate executable files.

Start the debugger of MetaWare IDE 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, etc., combined with observing PC address, register status, global variable status and Profiling performance to analyze the debug target program.

Principles

Use the MetaWare IDE integrated development environment to create projects and load code. In the engineering unit, configure the compile option to compilation code, debug and analyze the compiled executable file.

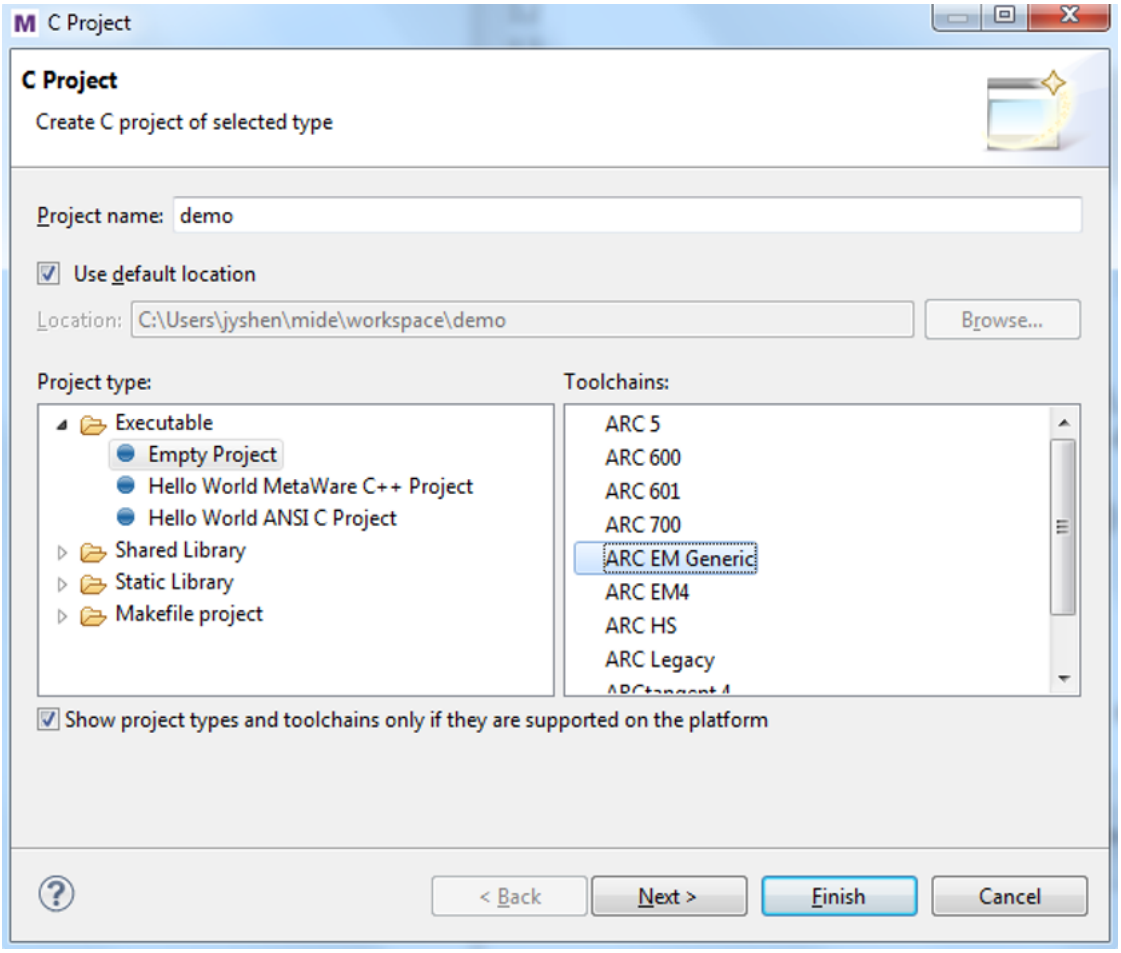
Routine code CoreTest.c:

```
//////////////////////////////////////////////////////////////////////////
// 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
//////////////////////////////////////////////////////////////////////////


#ifdef _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;
            }
        }

#ifdef _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 IDE, create an empty project called demo, and select the ARC EM series processor, as shown below(figure 1).

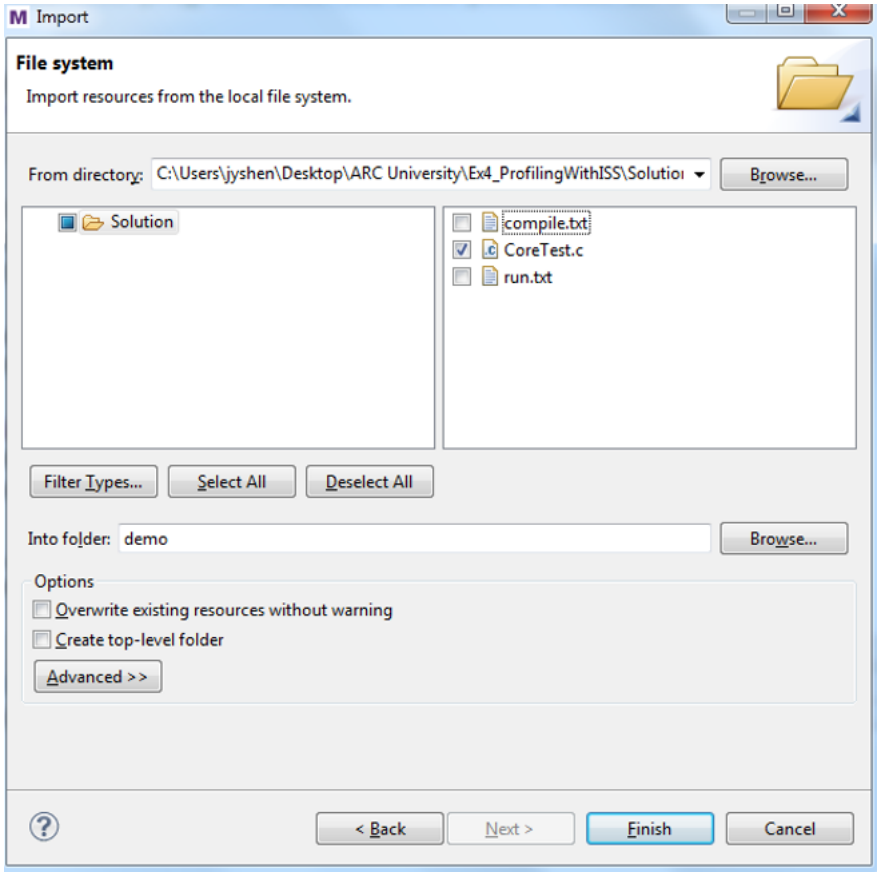


Import the code file CoreTest.c to the project demo.

In the Project Explorer on the left side of the MetaWare IDE main interface, click the icon 

and select Import from the pop-up menu.

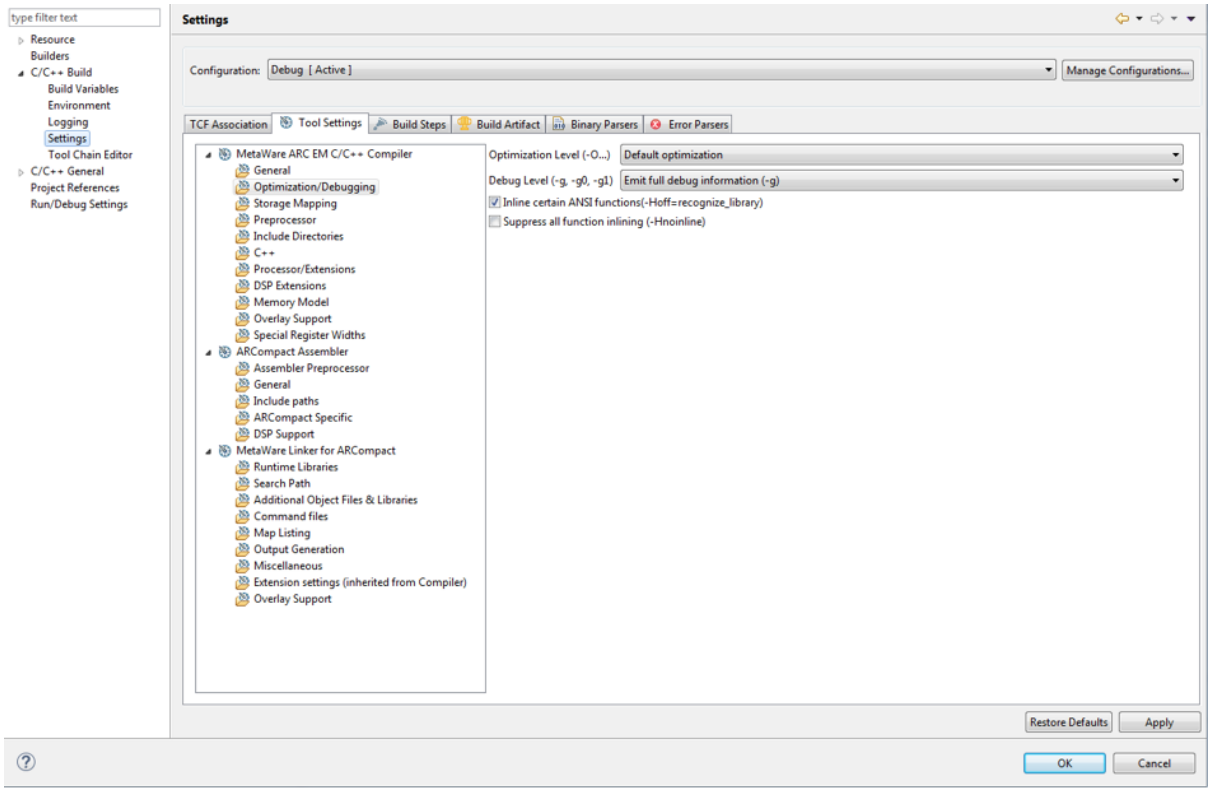
At this point, a dialog called Import appears, select the File System item in the General tab, and then click next. As shown in the figure below, add the file directory where the source code CoreTest.c is located. The dialog box will automatically display the name of the directory and the file name of the file contained in the directory. Select the file to be added, CoreTest.c, and click Finish to complete the entire import process(figure2).



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 IDE main interface.

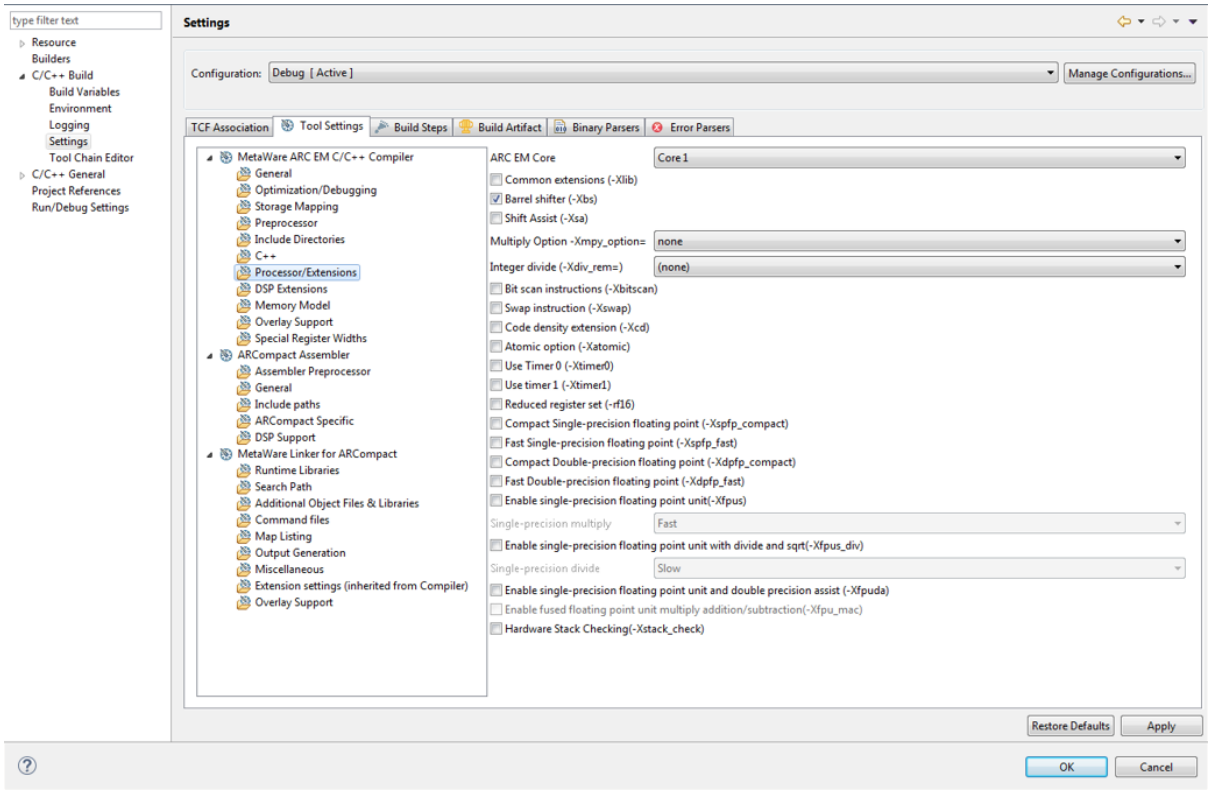
Set compilation options

Right click on the current project demo and select Properties in the popup tab. Click C/C++ Build, settings, Tool Settings to open the compile option settings page, as shown below(figure3).



In the current interface, 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

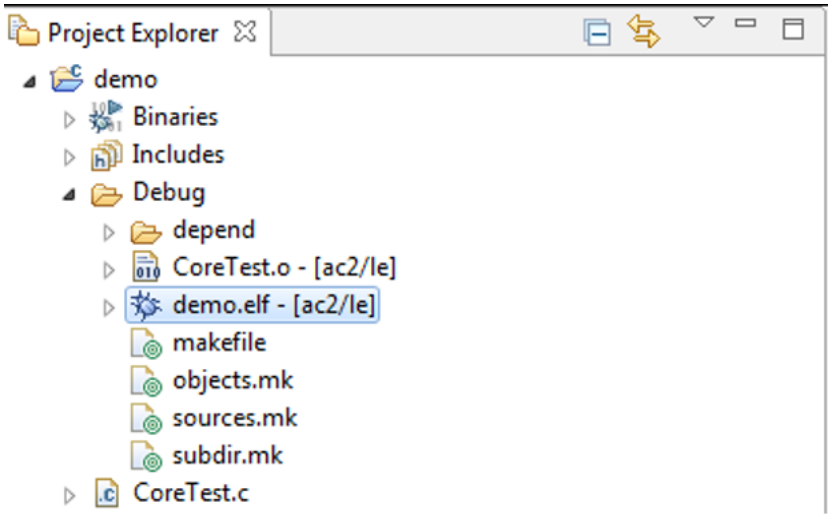
Select Processor/Extensions on the current interface to set the compile options corresponding to the target processor hardware properties, such as the version of the processor, whether to support extended instructions such as shift, multiplication, floating-point operations, etc., whether to include Timer0/1. As shown in the figure below, this setting indicates that the target processor supports normal extended instructions(figure4).



Finally select MetaWare ARC EM C/C++ and check the settings compile options in the All options column on the right. Then click OK to close the Properties dialog.

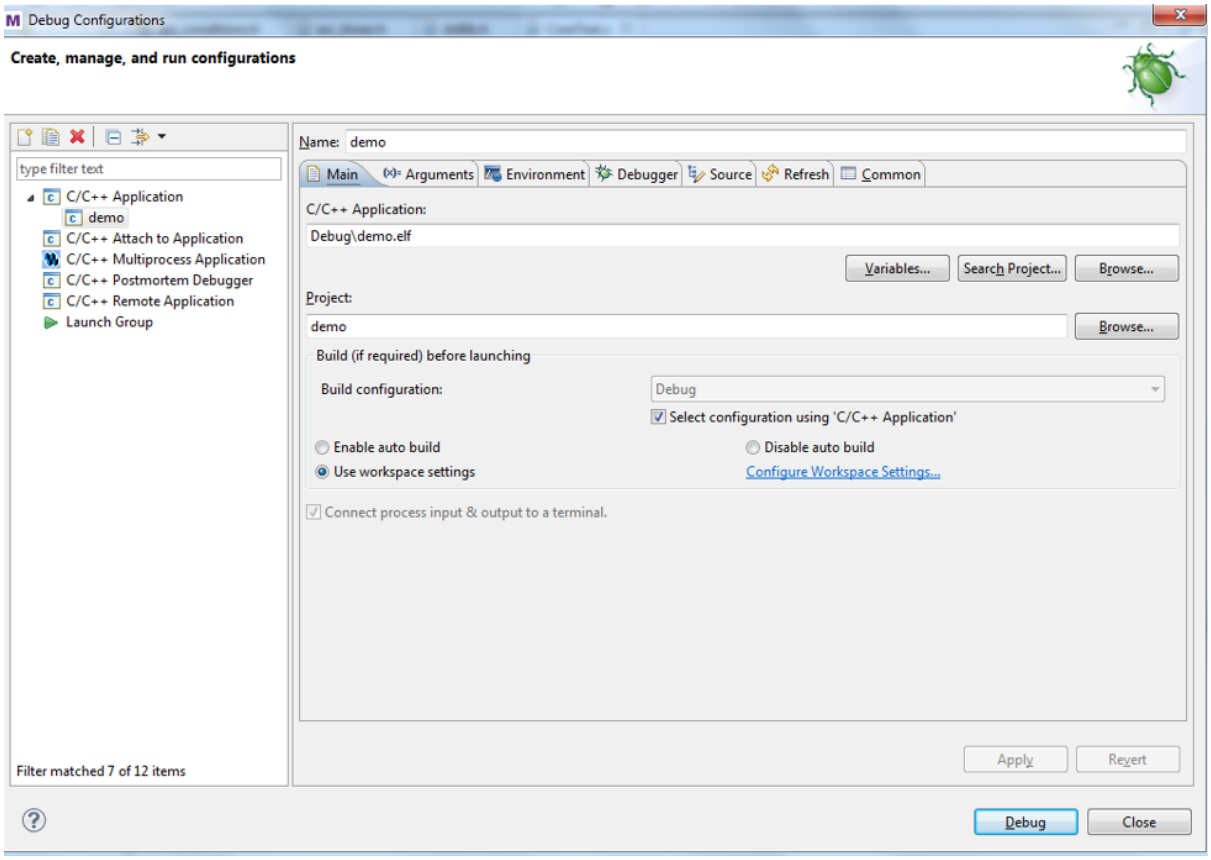
Compile project demo

Select Build Project from the Project drop-down menu in the MetaWare IDE main menu or click the icon . In the middle of the MetaWare IDE main interface, select the Console tab to view the logs during compilation. When the message 'Finished building target: demo.elf' appears, the compilation is successful, and the compiled executable file demo.elf can be seen in the Project Exporer on the left side of the MetaWare IDE main interface, as shown in the following figure(figure5).



Set debug options

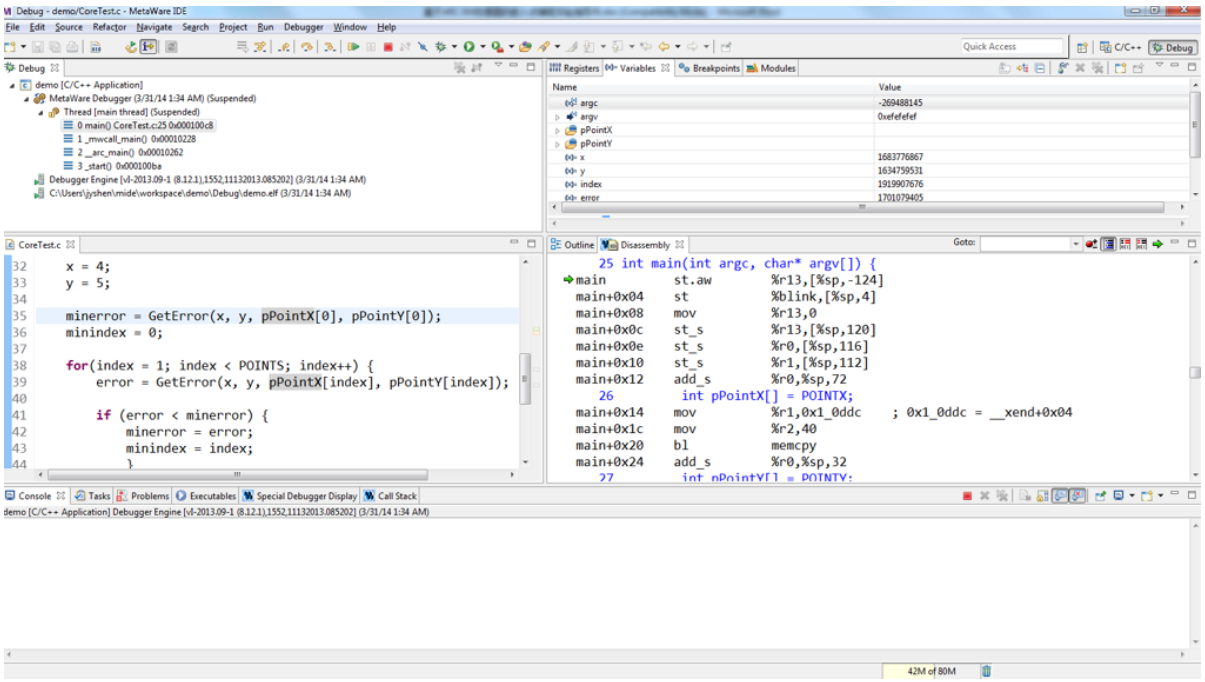
Select Debug Configurations from the Run drop-down menu in the MetaWare IDE main menu. Then double-click on C/C++ Application or right-click on New to get a dialog similar to the one below(figure6).



Click Debugger in the right tab, generally do not need to make any changes, finally check the contents of the bottom Debugger Options, click Debug to enter the debugging interface.

Debug executable file demo.elf

First, select the required debug window in the pull-down menu Debugger 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, etc., as shown in the following figure(figure7).

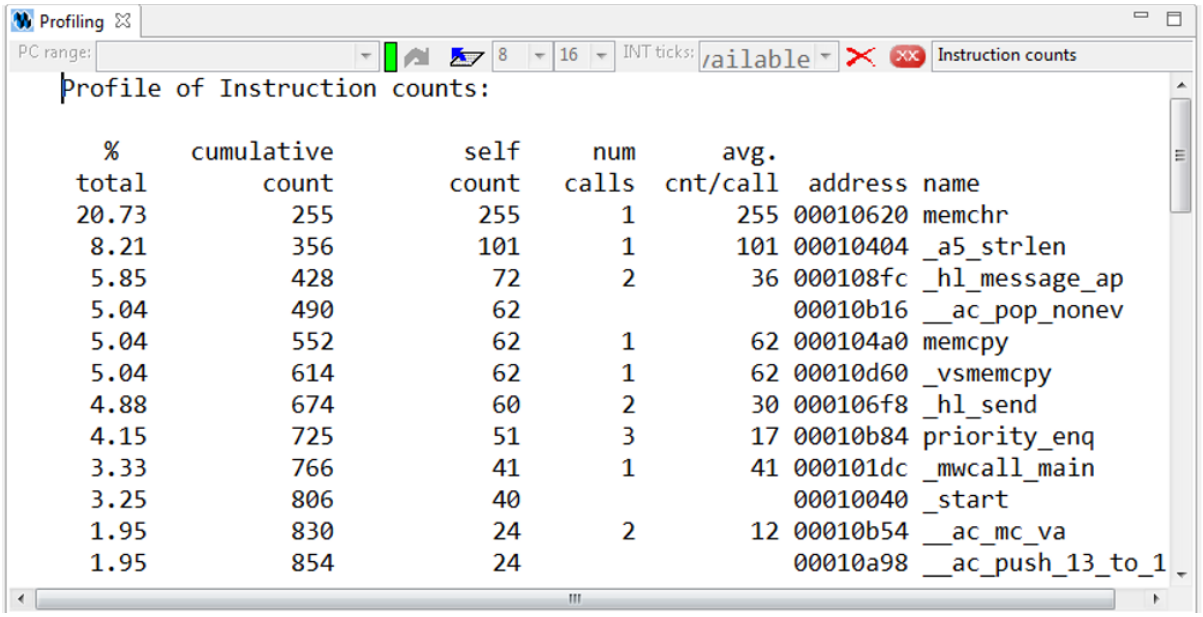


In the C code window, right-click the code line number on the left side of the window, select Toggle Breakpoint in the pop-up menu or double-click the line number to set a breakpoint on the current line. In the assembly code window, double-click a line of code to set a breakpoint on the current line.

Once the breakpoint is set, click the icon  to run the program. After that, the program will run directly to the nearest breakpoint. At this point, you can observe the current program execution and the relevant status information of the processor through the various windows called in the 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 the icon  . And if you want to return to the main MetaWare IDE page, click C/C++ in the upper right corner icon  .

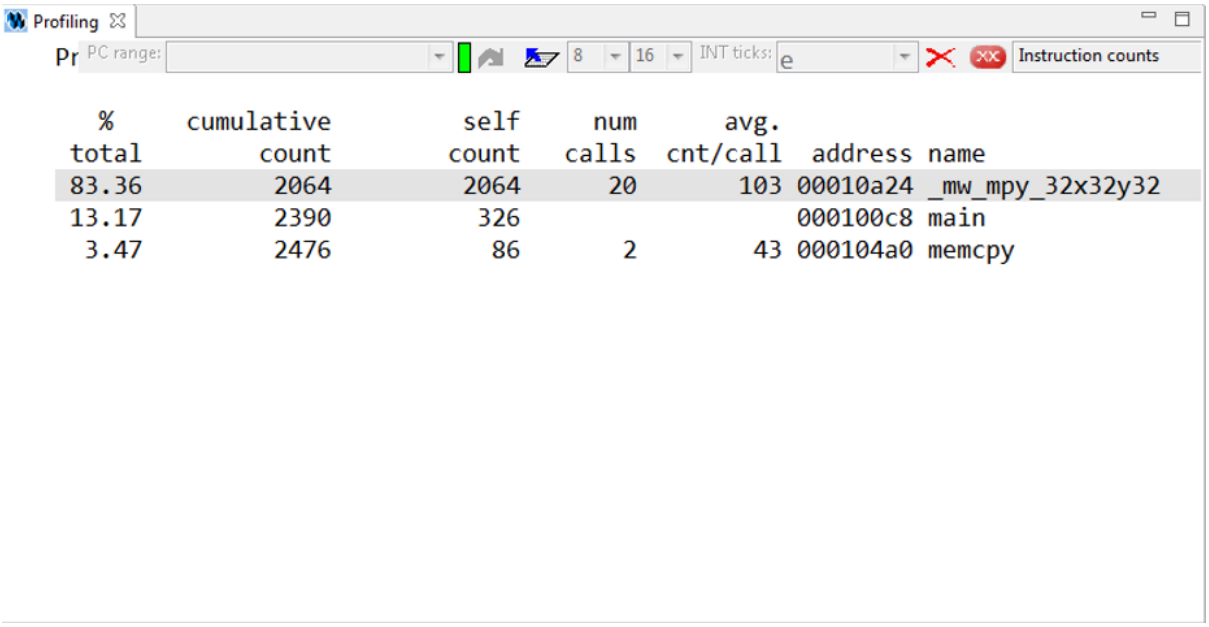
Code performance analysis using the debugger

Based on the previous project demo, open the Compile Options dialog in step 3 and set the Opimization Level to -O0 in the Optimization/Debugging column. Then click  to recompile the project, then click  to enter the debugging interface. Click Debugger in the main menu of the debugging interface, select Disassembly in the pop-up 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 the icon  in the window, as shown below(figure8).



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.

Let's take this project as an example to continue to introduce the use of the Profiling window. At this point, the program is paused at the entrance of the main() function and the Profiling window opens as shown above. The main() function is the main object of performance analysis optimization. At this time, the content displayed in the Profiling window is actually some function information initialized by the processor before the main() function is executed. Click the icon  in the Profiling window to clear the current information. If you click the icon  again, nothing will be displayed, And it indicat that the cleaning is successful. Then, set a breakpoint at the last statement of the main() function (either C statement or assembly statement), and click the icon  in the toolbar above the debug interface to let the program execute to the breakpoint. Next, click on the icon  in the Profiling window again, and only the information related to the main() function will be displayed, as shown below. Therefore, flexible setting of breakpoints, combined with the clear function, can perform performance analysis on the concerned blocks(figure9).



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 will spend 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 first 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.

Note: The expand multiply instruction

How to use embARC OSP

Purpose

Equipment

Content

Principles

Steps

Exercises

ARC features: timer and auxiliary registers

Purpose

- To learn the timer resource of ARC EM processor
- To learn how to use the auxiliary registers to control the timer
- Read the count value of the timer, and implement a time clock by the timer

Equipment

PC, IoTDK, embARC OSP, example \Lab\timer in embARC OSP

Content

Read the auxiliary registers of ARC EM to get the version and other setting information of the timer resource. As all the EM processors have **Timer0**, we use the **Timer0** in this lab, and write the auxiliary registers to initialize, start and stop the timer. By reading the count value of the timer, we can calculate the execution time of a code block with the count value and the clock frequency.

Principles

Introduction of timer and auxiliary registers

The timers in ARC EM processor

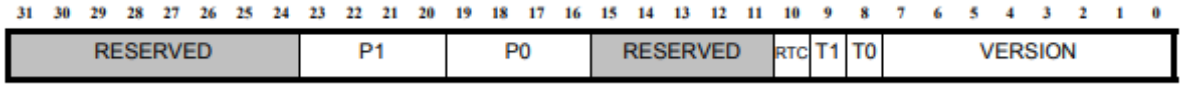
- Two 32-bits programmable timers **Timer0** and **Timer1**
- One 64-bits **RTC**(Real-Time Counter)

All the times are configurable, for example, there are four EM processor cores in **ARC EMSK1.1**, the configuration information are as follow.

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 storaged the timer resource information of an EM processor core, the register address of **TIMER_BUILD** is *0x75*.

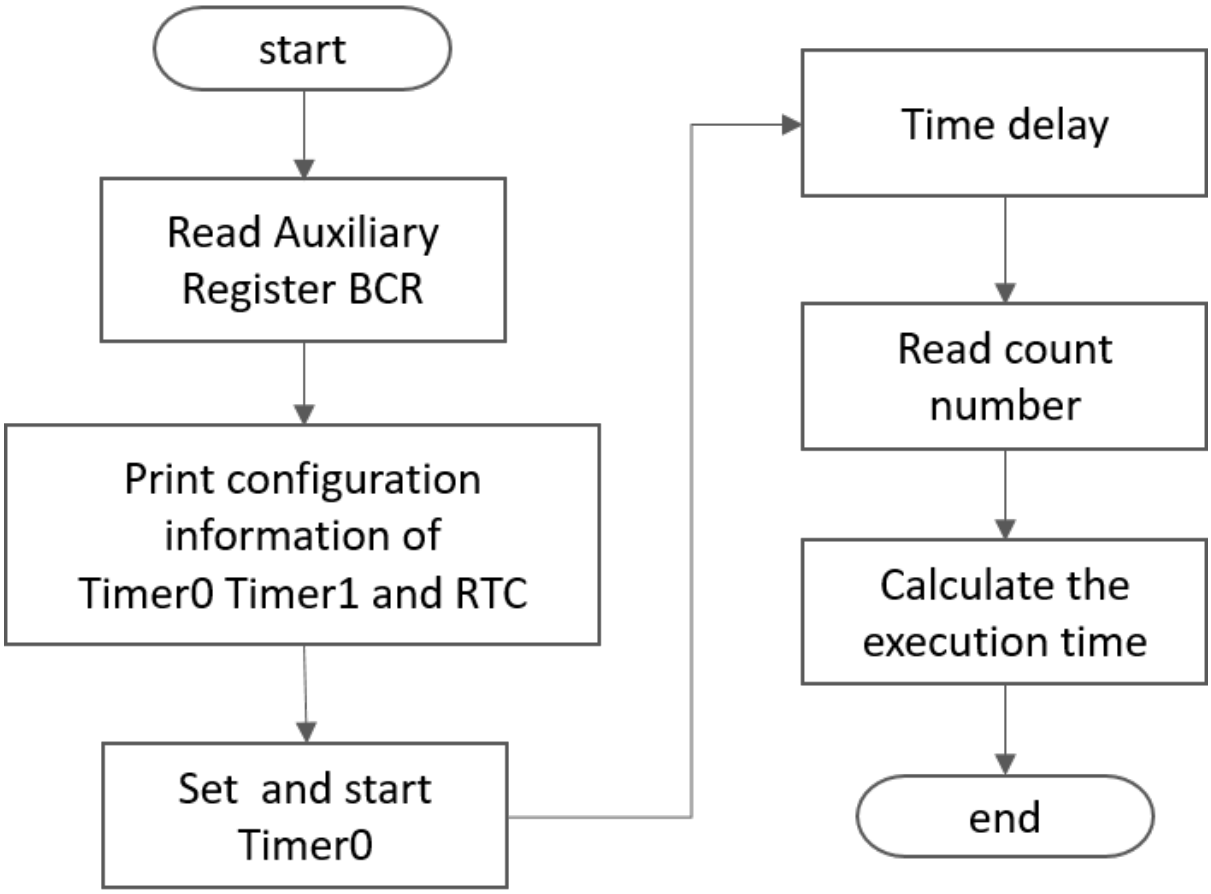
TIMER_BUILD



As we know the timer resources the EM processor configured, we can get the timer's configuration information and control the timers by writing and reading the auxiliary register of that timer. For example, there are 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 do the configuration.

First, configured by compile command, for example:

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

Second, configured by modifying the makefile. At here, the compile command will be very simple, for example:

```
make -j4 run
```

Open the folder *embarc_osp\example\Lab\timer*, and open the *makefile*, here is the default configuration.

```
# Application name
APPL ?= lab_3_Timer_Interrupts

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

##
# 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, we use the launch board *iotdk*

```
##
# 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

We can use the function `_arc_aux_read` 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**, 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

We can use the function `_arc_aux_write` to write the auxiliary register.

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

- **COUNT0**: write this register to set the initial value of the **Timer0**. It will increase 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, we should stop timer 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. And then set the timer work mode, enable interrupt or not and set the limit value. At last 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, we can read the count value of the timer,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
 */
```

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```
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` under the folder *example\Lab\timer*, input the compile command as follow:

```
make -j4 run
```

Note: If your toolchain is meteware, you should use `gmake`. If you don't use core configuration specified in makefile, you need to pass all the make options to trigger make command

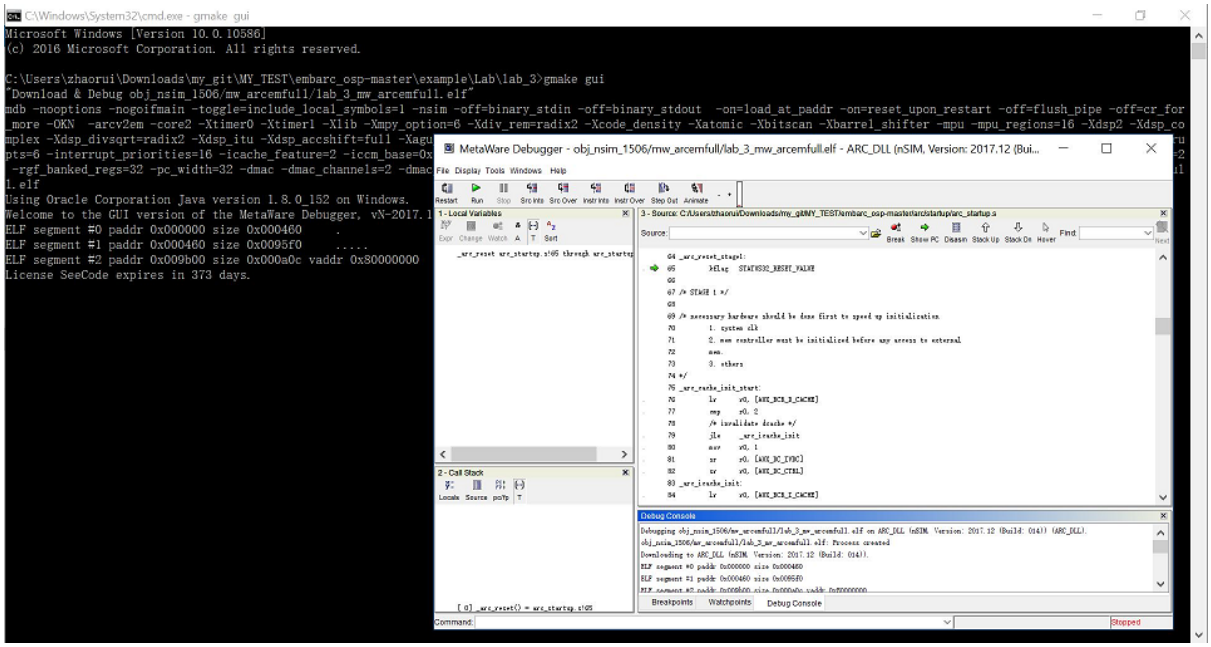
- Output

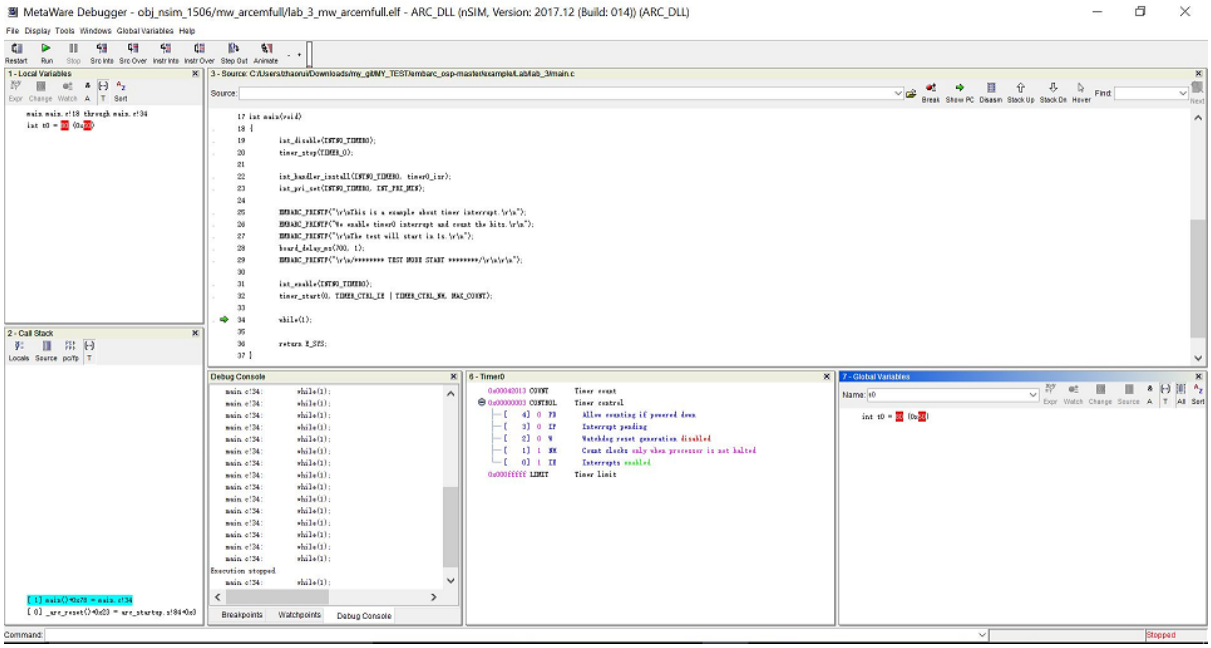
```
------------------------------------------------------------
      _____                                    _ _____
     |  _ \ ______       ______ _ __ ___  __| | __ ) _   _
     | |_) / _ \ \ /\ / / _ \ '__/ _ \/ _` |  _ \| | | | |
     |  __/ (_) \ V  V /  __/ | |  __/ (_| | |_) | |_| |
     |_|   \___/ \_/\_/ \___|_|  \___|\__,_|____/ \__, |
                                                   |___/
                          _        _    _____   _____
           ___ _ __ ___ | |__    / \  |  _ \ / ___|
          / _ \ '_ ` _ \| '_ \ / _ \ | |_) | |
         |  __/ | | | | | |_) / ___ \|  _ <| |___
          \___|_| |_| |_|_.__/_/   \_\_| \_\\____|
     ------------------------------------------------------------

     embARC Build Time: Aug 22 2018, 15:32:54
     Compiler Version: Metaware, 4.2.1 Compatible Clang 4.0.1 (branches/release_40)
     Does this timer0 exist?  YES
     timer0's operating mode:0x00000003
     timer0's limit value :0x00023280
     timer0's current cnt_number:0x0000c236

     Does this timer1 exist?  YES
     timer1's operating mode:0x00000000
     timer1's limit value :0x00000000
     timer1's current cnt_number:0x00000000

     Does this RTC_timer exist?   NO

     The start_cnt number is:2
     /******** TEST MODE START ********/

     This is TEST CODE.

     This is TEST CODE.

     This is TEST CODE.

     /******** TEST MODE END ********/
     The end_cnt number is:16785931
     The board cpu clock is:144000000

     Total time of TEST CODE BLOCK operation:116
```

- Debug

Open `cmd` under the folder *example\Lab\timer*, input the command as follow:

```
make gui
```





The debug view will pop up automatically, we can watch the variables and registers.

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

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3.2.2 Level 2 Labs

A WiFi temperature monitor

Purpose

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Principles

Steps

- Learn how to register tasks in FreeRTOS
- Get familiar with inter-task communication of FreeRTOS

Equipment

PC, IoTDK, embARC OSP, example \Lab\FreeRTOS in embARC OSP

Content

This lab utilizes FreeRTOS v9.0.0, and will create 3 tasks based on embARC_osp. You should apply inter-task communicate methods such as semaphore and message queue in order to get running LEDs result. We should go though basic functions of FreeRTOS first.

Principles

Background

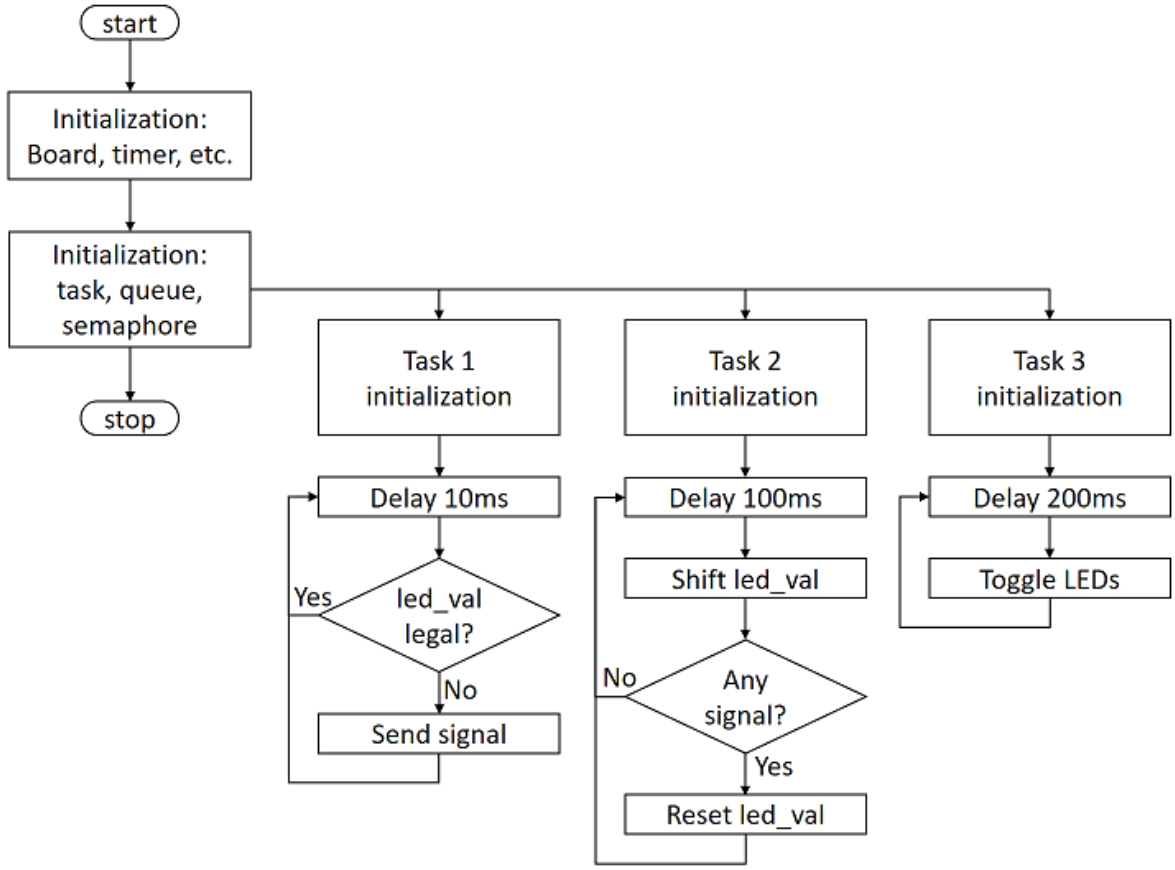
A Real Time Operating System (RTOS) is an operating system intended to serve real-time applications that process data in limited time as it comes in. Being within time bound and highly reliable are two important characters of RTOS.

As resources becoming abundant for morden micro processors, the cost to run RTOS is become increasingly neglectable. RTOS also provides event-driven mode for better utilizaion of CPU with efficiency. Among RTOSs for micro processors, FreeRTOS stands out as a free for use, opensourced RTOS with complete documents. These are the reasons of why we choose to learn FreeRTOS in this lab.

Design

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

The flow chat of the program is shown below:



Realization

The code of system is shown below, including various Initialization and task time delay.

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

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 dtq1_id;

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

int main(void)
{
```

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```
        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
        dtq1_id = xQueueCreate(8, sizeof(uint32_t));

        xTaskResumeAll();
        vTaskSuspend(NULL);

        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###
        }
}
```

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```
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 incompleted code

the code is at 'embarc_osp\example\Lab\lab_9', use an uart terminal console and run the code, you will see a message from program like the one shown below:

```
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 implys that three tasks are working correctly.

Implement task 3

It is required for task 3 to retrive new value from the queue and assign the value to led_val. The LED controls are already implemented in previous labs, so the only new function to learn is xQueueReceive(). This is a FreeRTOS

API to pop and read an item from queue. Please take reference from FreeRTOS documents 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. Please take reference from FreeRTOS documents 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(). Please take reference from FreeRTOS documents 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 can't 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 noddle, each fork is placed between two adjacent philosophers It's hard to eat noddle with one fork, so all philosophers need two forks in order to eat.

Please 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 onboard resources

Equipment

Reguired Hardware

- [DesignWare ARC EM Starter Kit(EMSK)]

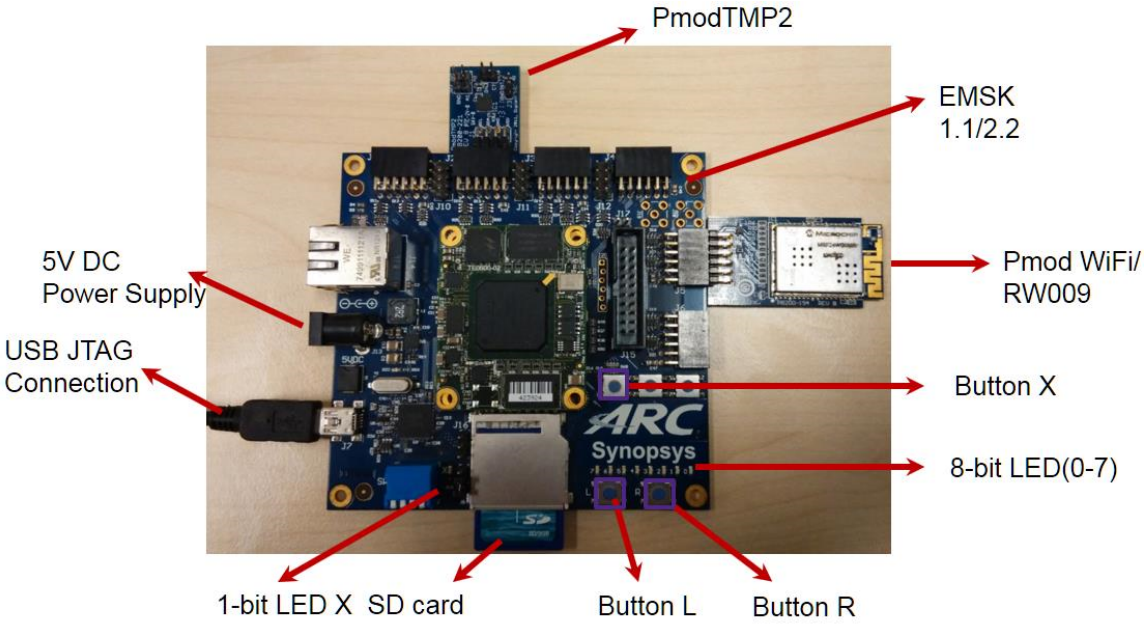
- [Digilent PMOD WiFi(MRF24WG0MA)]
- [Digilent PMOD TMP2]
- SD Card
- WiFi Hotspot(SSID:**embARC**, Password:**qazwsxedc**, WPA/WPA2 encypted)

Required Software

- Metaware or ARC GNU Toolset
- Serial port terminal, such as putty, tera-term or minicom

Hardware Connection(EMSK Board)

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

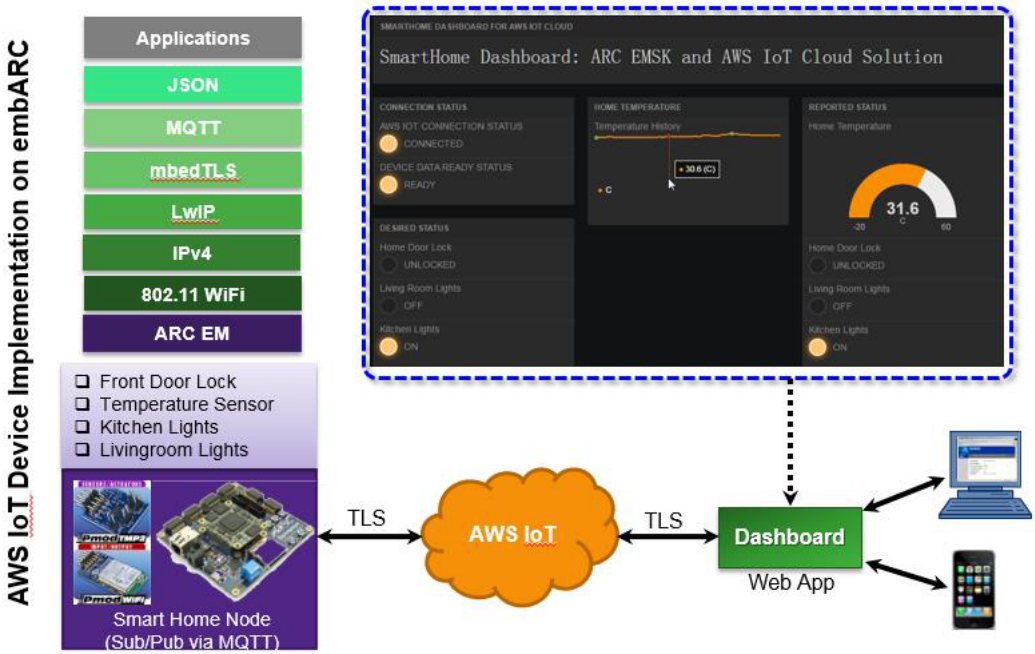


- Required hardware: EMSK 1.1/2.2, PmodTMP2, PmodWiFi, SDCard
- USB UART can be connected to PC for interoperation using NT-Shell.
  - Configure your hardware with proper core configuration.
  - The hardware resources are allocated as following table.

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 article provides instructions on how to establish connection between the EMSK and Amazon Web Services Internet of Things (AWS IoT) cloud in a simulated smart home application. AWS IoT is a managed cloud platform that lets connected devices securely interact with cloud applications and other devices. It supports Message Queue 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

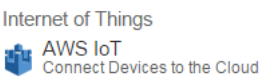
This application demonstrates the smart home solution based on EMSK by establishing the connection between EMSK Board and AWS IoT Cloud. The AWS IoT Device C SDK for the embedded platform has been optimized and transplanted for embARC.

In the application, the EMSK Board peripheral modules and onboard resources are used to simulate the objects which is controlled and monitored in smart home, the AWS IoT Cloud is used as the Cloud host and control platform which communicate with the EMSK Board through the MQTT protocol, and a special HTML5 Web APP is designed, which provide a dash board to monitor and control smart home nodes.

Steps

Creating and setting smart home node

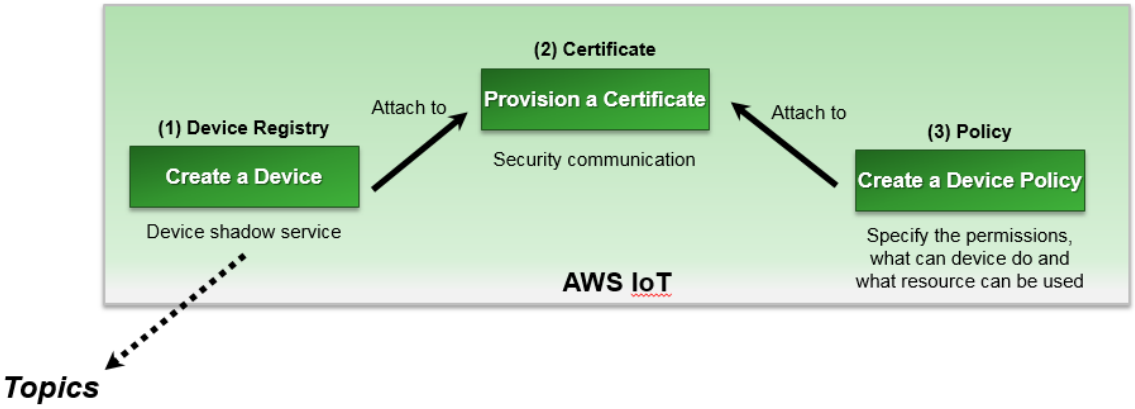
1. Create an AWS account in [here]. Amazon offers various account levels, including a free tier for AWS IoT.
2. Log into AWS console and choose AWS IoT.

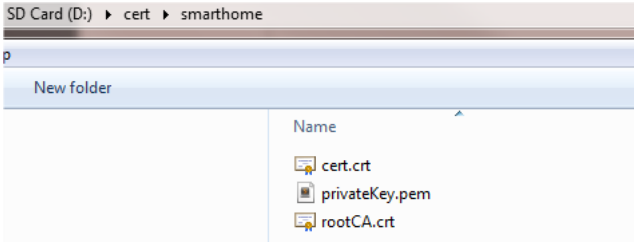
3. Choose an appropriate IoT server in the top right corner of the AWS IoT console page.

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.

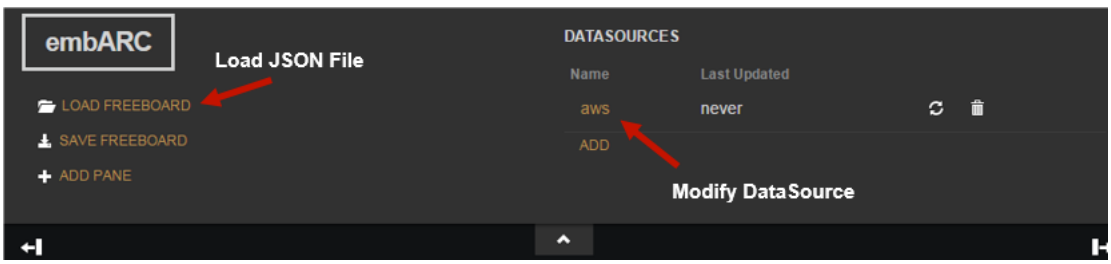
Note: for more details [Using a Smart Home Iot Application with EMSK]



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\smarthome*. Insert the SD card to your PC, and copy the certificate folder cert to the SD Card root.



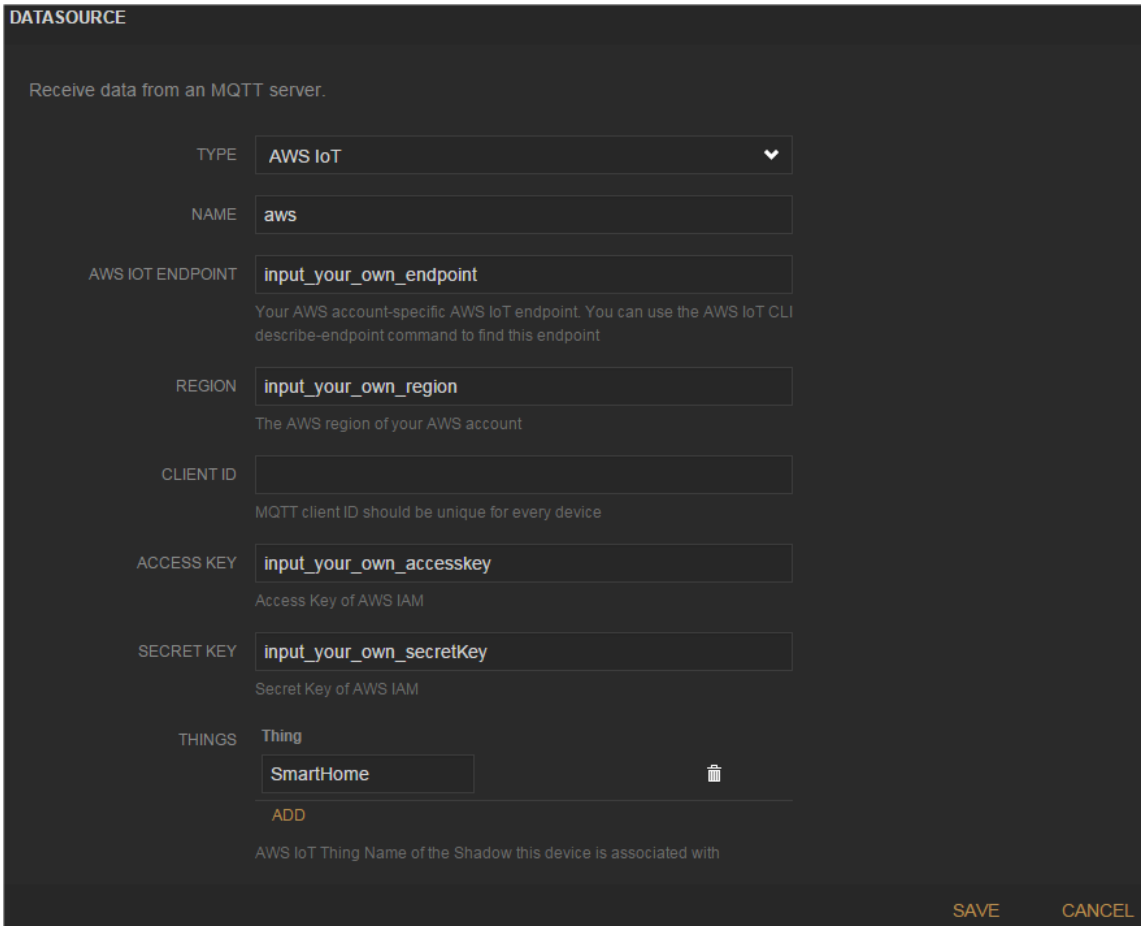
6. Open the [Web App] in a web browser and load the configuration file dashboard-smarthomesinglething.json obtained from *embARC\example\freertos\iot\aws\smarthome_demo*. The dashboard can be loaded automatically



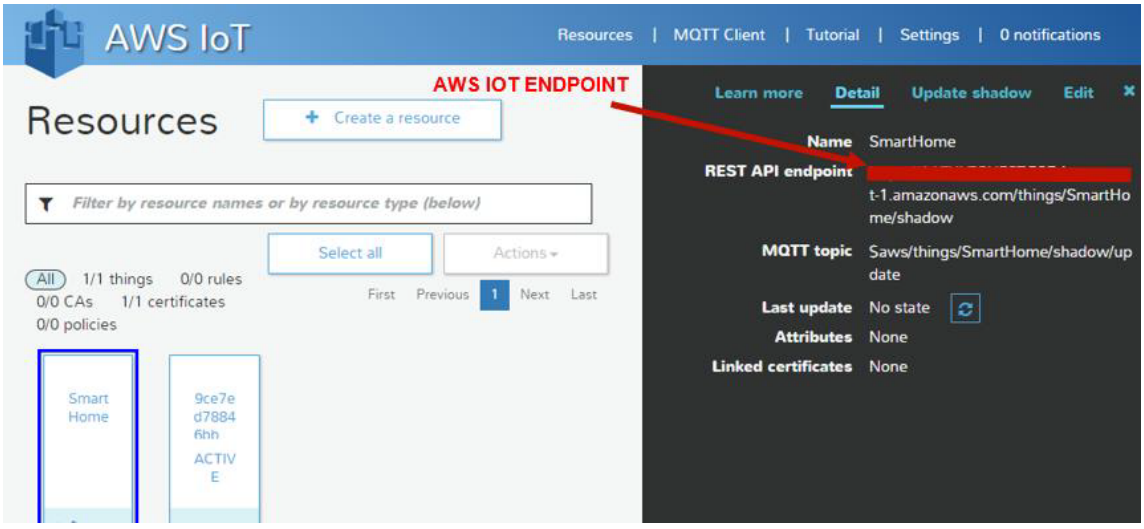
7. Click "ADD" to go to DATASOURCE page and fill up the forms.

a) TYPE: Choose AWS IoT.

b) NAME: Name is aws.



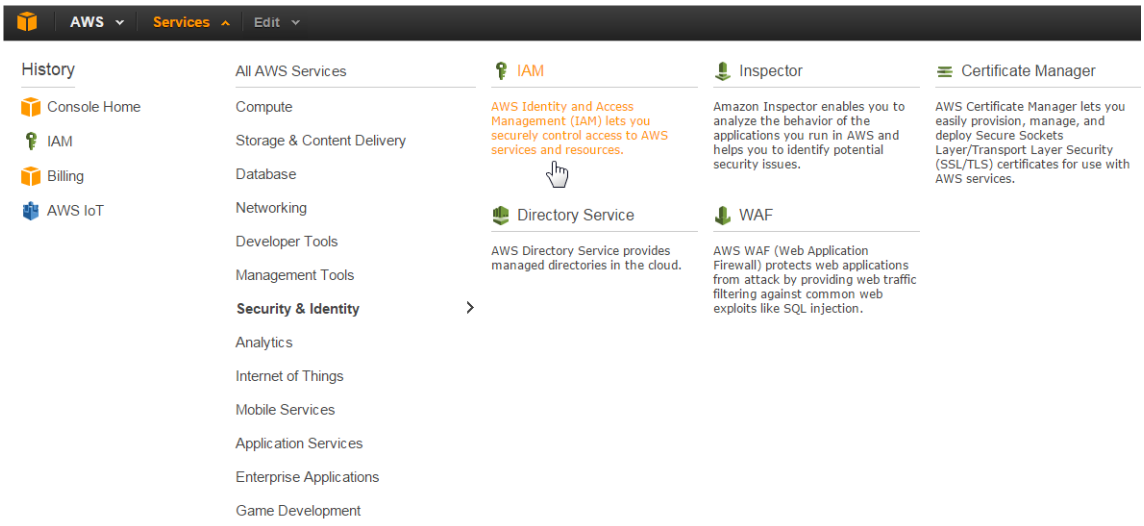
c) AWS IOT ENDPOINT: Go to AWS IoT console and click your smart home node "SmartHome". Copy the content XXXXXXXXXXXXXX.iot.us-east-1.amazonaws.com in REST API endpoint to AWS IOT ENDPOINT.



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.

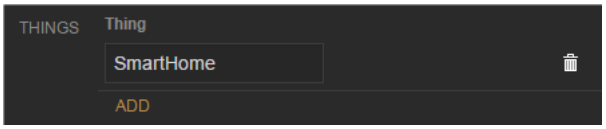
f) ACCESS KEY and SECRET KEY: Go to AWS Services page and click “IAM”.



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.

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              "XXXXXXXXXXXXX.iot.us-east-1.amazonaws.com" ///< Cus
#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 ev
#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, input the compile command as follow:

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

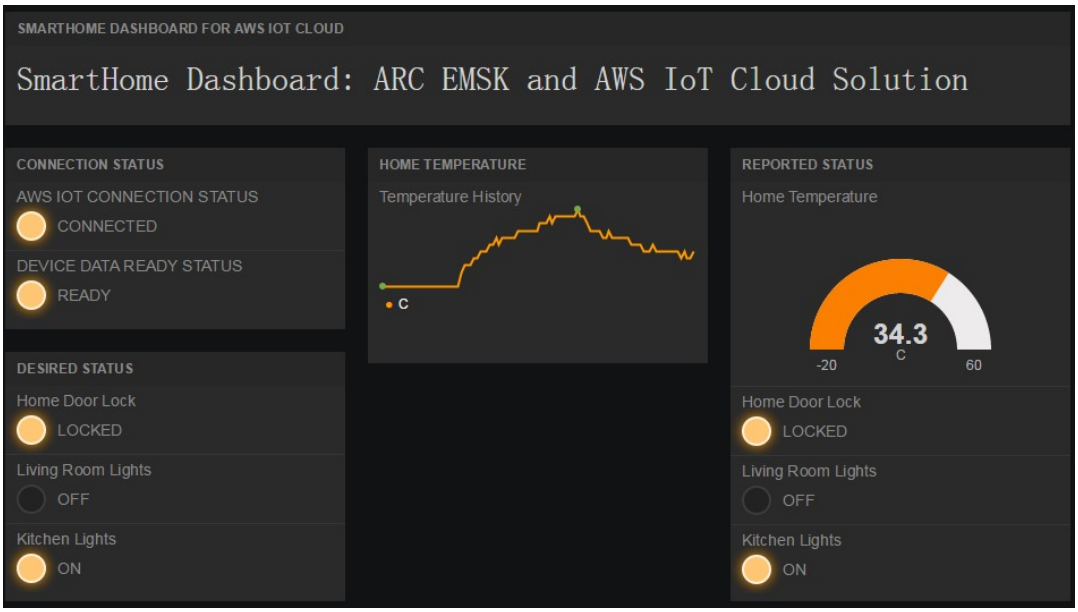
4. FreeRTOS-based runtime environment can be loaded automatically. Wait for WiFi initialization and connection establishment(30 seconds or less) until the "WiFi connected" message is shown in the terminal emulator. "Network is ok" will be shown after the certificate files cert.crt, privateKey.pem and 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":29.600000,"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":29.600000,"DoorLocked":true,"
KitchenLights":true,"LivingRoomLights":false}}, "clientToken":"csdk-SH-1"}
********************************************************************************
*********

Update Accepted !!
Update Shadow: {"state":{"reported":{"temperature":29.600000,"DoorLocked":true,"
KitchenLights":true,"LivingRoomLights":false}}, "clientToken":"csdk-SH-2"}
********************************************************************************
*********
```

4. Interact using EMSK and Dashboard. You can press the button L/R/X to see the led changes on board and also on dashboard web app. You can also click the lights of DESIRED STATUS pane on the dashboard app, and see the led changes 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 do the Multi Node AWS IoT Smarthome Demo.

Note: Related demo codes you can find [here]

CHAPTER

FOUR

APPENDIX

CHAPTER

FIVE

INDICES AND TABLES

- genindex
- search