University of Colorado **Boulder**

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Project 1 Module 5
ECEN 5803 MESA

Project 1 Module 5 Debug Monitor :

The Debug Monitor implementation project has successfully fulfilled a range of essential requirements. These requirements encompassed the activation of Timer0 for precise timing, the seamless integration of crucial mbed components, and the successful importation of key source code files, including shared.h, Monitor.cpp, UART_poll.cpp, and timer0.cpp. The Debug Monitor itself was effectively implemented, allowing for user interaction through commands like Normal, Debug, Version, Quite and new commands for register dump, memory dump, and stack memory dump. These additional commands significantly enhance the system's functionality and utility. Furthermore, the project underwent improvements, including enhancements to the visual appearance and the integration of flags for controlling LED blinking. Benchmarking was conducted successfully, and comprehensive documentation was generated using Doxygen.

Time 0 Implementation with Green & Red LED's :

We seamlessly integrated a precise system tick timer using the mbed ticker library, effectively running the timer0 function every 100 microseconds as specified in main.cpp. This ensured accurate timing for coordinating tasks within the embedded system, making it more reliable and functional. Additionally, we successfully added mbed components to control the green user on chip LED2 and thoroughly tested them, meeting project requirements and enhancing the system's capabilities.

We also incorporated code using flags in the timer0 function to make the Red GPIO LED blink at a 1-second period(500ms ON and 500ms OFF), fulfilling another project requirement. This addition improves the system's functionality by showcasing the effective use of flags to control hardware components.

Code for Green LED Implementation:

```
DigitalOut greenLED(LED2);
extern volatile uint16_t SwTimerIsrCounter;
Ticker tick;  // Creates a timer interrupt using mbed methods

void flip(void) {
    greenLED = !greenLED;  // Toggle the state of the green LED
}

if ((SwTimerIsrCounter & 0x1FFF) > 0x0FFF)
{
    // The bitwise AND operation masks (keeps) the 13 least significant bits
    // (LSBs) of SwTimerIsrCounter and sets all other bits to 0.
    // This effectively checks if the value of SwTimerIsrCounter is within the range of 0 to 0x1FFF.
    // If the result of this operation is greater than 0x0FFF, it means that
    // the value of SwTimerIsrCounter has reached or exceeded 0x0FFF within that range.
    flip();  // Toggle Green LED
}
```

Code for Read LED Implementation using flags:

```
DigitalOut redLED(PA_7);     // Red LED at Pin PA_7
int redLEDTickCounter = 0;   // Red LED Tick Counter

void toggleRedLED() {
    redLED = !redLED;  // Toggle the state of the red LED
}
```

```
// B. Heartbeat/ LED outputs
// Generate Outputs  ************************************

/****************       ECEN 5803 add code as indicated   **********************/
// Create a 0.5-second LED heartbeat here.
redLEDTickCounter++;
if ((redLEDTickCounter % 78) == 0) {
    toggleRedLED();
    redLEDTickCounter = 0;
}
```

Debug Monitor Serial Terminal Output:

Our current debug monitor features seven distinct commands: "Normal," "Quiet," "Debug," "Register Dump," "Stack Dump," "Memory Dump," and "Version." You can reference the screenshot of the entry point in the serial terminal, which is depicted in Figure(1) below.

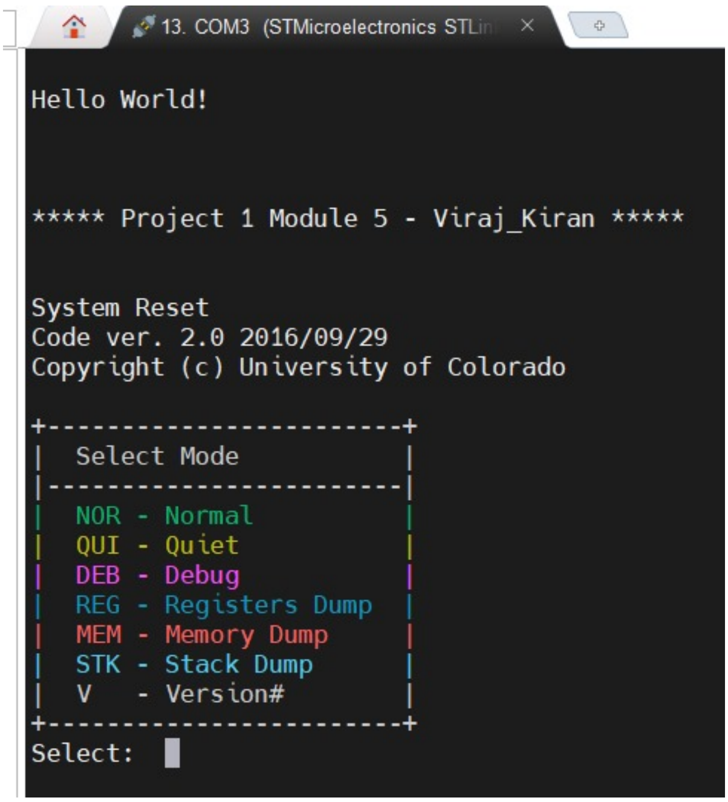


Figure 1 : Debug Monitor Commands

Version Information :

As depicted in the photograph titled "Figure 2 : Debug Monitor – Version Info, Normal & Quite Command", the debug monitor showcases its version as "2.0" with a date of "2016/09/29".

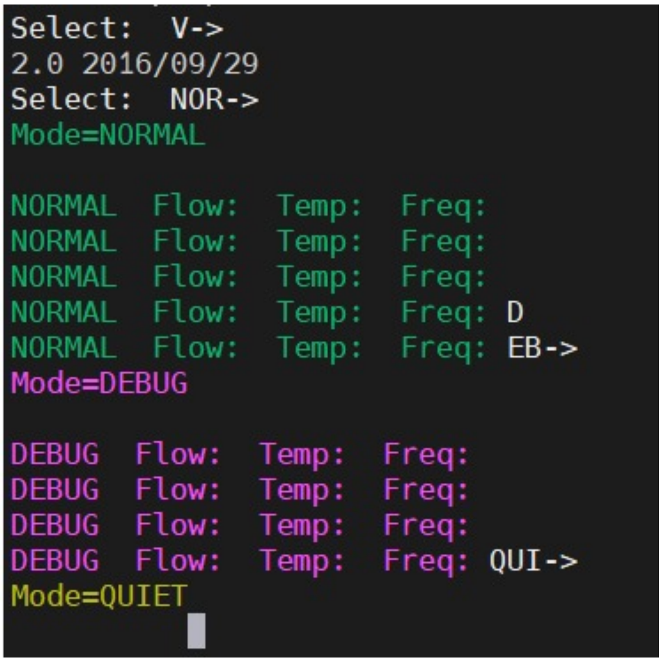


Figure 2 : Debug Monitor – Version Info, Normal & Quite Command

Normal Command :

The photograph titled "Figure 2 : Debug Monitor – Version Info, Normal & Quite Command" reveals the interface in 'Normal' mode. In this state, readings for 'Flow', 'Temp', and 'Freq' are prominently displayed. These parameters seem to be dynamically updated, providing real-time insights.

Note : The values at each command are refreshed every 1.6384 seconds.

Quiet Command Display :

As shown in the photograph titled "Figure 2 : Debug Monitor – Version Info, Normal & Quite Command", when the interface is in 'Quiet' mode, nothing will be printed or displayed. This behaviour suggests that in the 'Quiet' mode, the monitor silences its outputs, offering a minimalistic view as observed in the Figure (2).

Register Command Display :

The provided image "Figure 3 : Debug Monitor – Normal & Register Dump" starts by showing the system in "NORMAL" mode where values of 'Flow', 'Temp', and 'Freq' are given. It then transitions to the "Registers Dump" mode. Under "Registers Dump", the system is printing the values stored in various registers. Registers from R0 to R12 are listed, each displaying a unique hexadecimal value. Additionally, special registers such as SP (Stack Pointer), LR (Link Register), and PC (Program Counter) are also shown with their respective values.

```
Select:  NOR->
Mode=NORMAL

NORMAL  Flow:  Temp:  Freq:
NORMAL  Flow:  Temp:  Freq:
NORMAL  Flow:  Temp:  Freq: R
NORMAL  Flow:  Temp:  Freq: E
NORMAL  Flow:  Temp:  Freq: G->
Mode=Registers Dump

Printing Register Values
R0: 0x0000001A
R1: 0x0000000A
R2: 0x2000038C
R3: 0x0800150A
R4: 0x0800150A
R5: 0x08000BD5
R6: 0x00000064
R7: 0x0415DCE1
R8: 0x00000000
R9: 0x00000000
R10: 0x00000000
R11: 0x00000000
R12: 0x40004400
SP: 0x20017FF0
LR: 0x08001225
PC: 0x080001F8
```

Figure 3 : Debug Monitor –Normal & Register Dump

Memory Command Display :

In the "Memory Dump" mode, as shown in the "Figure 4: Debug Monitor – Memory & Stack Dump" image, the system is dumping memory contents from a specified location. In this case, it's dumping memory at location "0X20010000" and it provides 64 bytes of data. The memory dump not only provides the hexadecimal representation of the stored data but also attempts to provide a character representation, as seen on the right side of the hex values. This can be useful in understanding if any recognizable patterns or strings are present in the memory. Code also includes a functionality to take user input for start address and length for memory dump which is commented out for submission.

```
MEM->
Mode=Memory Dump

Dumping memory at Location 0X20010000 64 Bytes:
0x20010000: C0 DC 85 46 CD DA FB 71 CF B1 9A 1C 67 FE F6 15  ...F...q....g...
0x20010010: B7 10 D5 05 55 0C 6F C5 0D F6 3F BD 94 81 0A 55  ....U.o...?....U
0x20010020: 3F 88 2A 3D 99 8C DD 81 0A DD F5 71 55 80 A9 40  ?.*=.......qU..@
0x20010030: B2 FE D9 04 8F B3 45 60 74 BB EF 4D 91 B4 EE 45  ......E`t..M...E
STK->
Mode=Stack Dump

Print Stack
Current Stack Pointer SP: 0x20017FE8
Word 16: 0x20017FE8 : 0800150A
Word 15: 0x20017FE4 : 20017FE8
Word 14: 0x20017FE0 : 0000000F
Word 13: 0x20017FDC : 0800153C
Word 12: 0x20017FD8 : 200002D8
Word 11: 0x20017FD4 : 0800138F
Word 10: 0x20017FD0 : 00000064
Word 9: 0x20017FCC : 20017FE8
Word 8: 0x20017FC8 : 00000007
Word 7: 0x20017FC4 : 080034B1
Word 6: 0x20017FC0 : 00000000
Word 5: 0x20017FBC : 00000000
Word 4: 0x20017FB8 : 00000000
Word 3: 0x20017FB4 : 00000000
Word 2: 0x20017FB0 : 0439301F
Word 1: 0x20017FAC : 00000064
```

Figure 4 :s Debug Monitor – Memory & Stack Dump

Stack Pointer Command Display :

The "Stack Dump" mode offers insights into the current status of the system's stack. At the beginning of this mode, the "Current Stack Pointer SP" is shown with its value "0x20017FE8". Following this, the contents of the stack are printed, starting from the current stack pointer and then displaying word values in descending memory locations (which is typical of a descending stack). Each word is associated with its memory location, and the content at that location is displayed in a hexadecimal format. The stack content provides valuable information about the data stored in the stack and can be crucial for debugging purposes, especially to trace back the execution flow or to check for any stack corruption.

Documentation :

We have successfully auto-generated documentation for your codebase using Doxygen. The generated documentation is available in either an HTML directory or a PDF file. Refer the doxygen folder in submitted zip file.

Lab Questions :

Question 1: What is the count shown in timer0 if you let it run for 30 seconds? Explain why it is this?

The count shown by timer0, is 37856 as seen in figure(5) below. The variable timer0_count is constructed with 16 bits. Every 6.5 seconds, this 16-bit variable undergoes a reset due to the reloading of its count value. Within 30 seconds, this resetting occurs 4 times (6.5 multiplied by 4 equals 26 seconds). In the leftover 4 seconds, it increases to a count of 37856.

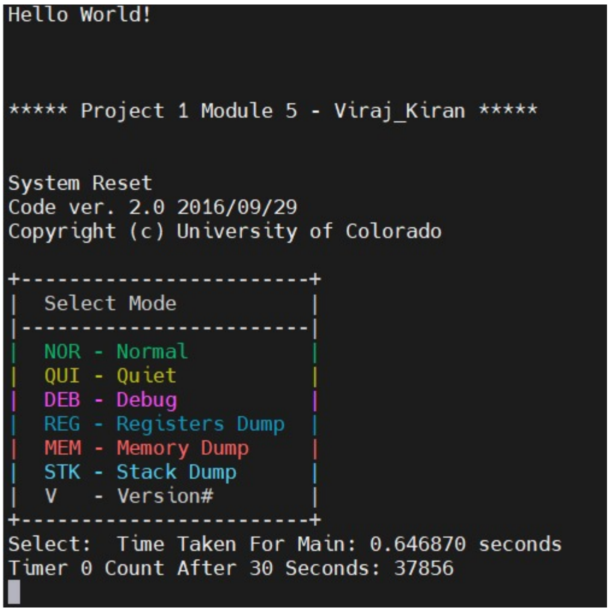


Figure 5 : Timer0 Count at 30 seconds

Question 2: How much time does the code spend in the main loop versus in Interrupt Service Routines?

Utilizing the Timer class from the mbed API, we initiated the timer using timer.start() at the beginning of both our main.cpp and ISR functions. By employing timer.reset(), timer.stop() at the conclusion of each function, we obtained specific timings for both the main function and the ISR, as illustrated in Figure(6) below.

Time take by Main() in seconds : **0.6468 sec**.

```
Hello World!


***** Project 1 Module 5 - Viraj_Kiran *****


System Reset
Code ver. 2.0 2016/09/29
Copyright (c) University of Colorado

+-----------------------+
|  Select Mode          |
|-----------------------|
|  NOR - Normal         |
|  QUI - Quiet          |
|  DEB - Debug          |
|  REG - Registers Dump |
|  MEM - Memory Dump    |
|  STK - Stack Dump     |
|  V   - Version#       |
+-----------------------+
Select:  Time Taken For Main: 0.646870 seconds
```

Figure 6 : Time taken by ISR

Time taken by ISR in seconds : **2 usec**.

```
Time Taken For ISR: 2.000000 micro seconds
Time Taken For ISR: 2.000000 micro seconds
Time Taken For ISR: 2.000000 micro seconds
Time Taken For ISR: 2.000000 micro seconds
Time Taken For ISR: 2.000000 micro seconds
Time Taken For ISR: 2.000000 micro seconds
Time Taken For ISR: 2.000000 micro seconds
Time Taken For ISR: 2.000000 micro seconds
```

Figure 7 : Time taken by ISR

Times calculated is before any command given to debug monitor. The reason being value could change for the different debug monitor commands, so we found the best way could be to test it before sending any command to debug monitor.

Question 3: Test each of the commands in the Debug Monitor and record the results. Explain anything you see that you did not expect. Are you able to display all the registers?

We thoroughly tested each of the commands in the Debug Monitor and documented the outcomes. The recorded results for each debug monitor command is already explained with screenshots in section Debug Monitor Serial Terminal [Click Here].

We also encountered a few unexpected new line (\n\r) occurrences during testing, notably when the version was displayed for the first time, as additional newline characters were randomly included. Another issue seen was the first character inputted to serial terminal is never echoed back.

Furthermore, we successfully displayed the values of all registers, including r0 to r13, as well as pc, sp, and lr as seen in figure(3).

Question 5: What is the new command you added to the debug menu, and what does it do? Capture a screenshot of the new monitor window.

Three new commands named “Register Dump”, “Memory Dump” and “Stack Dump” has been added in debug monitor code.

- Register Dump
    - The "Register Dump" command is designed to display the values and addresses of each register, spanning from r0 to r13. Additionally, it reveals the stack pointer, program counter, and link registers. A visual representation of this can be found in Figure (3).
- Memory Dump
    - The "Memory Dump" command serves as a HEX dump of the memory location. This command enables the dumping of memory at the address 0x20010000, complete with its corresponding ASCII representation. Various memory locations were tested, revealing that attempts to print memory locations such as the reserved memory space at 0x6000 0000 are not permitted. A visual representation of this can be found in Figure (4)

- Stack Dump
    - The "Stack Dump" command offers insights into the data present in the stack, presented in reverse chronological order, beginning from word 16 and proceeding to word 0. A visual representation of this can be found in Figure (4)

Question 6: Estimate the % of CPU cycles used for the main background process, assuming a 100 millisecond operating cycle.

Time taken by Main() = 0.6468 seconds
Time taken by ISR = 2 usec = 0.000002 seconds

Since the Timer ISR is set at 100 microseconds and gets called 1000 times in 100 milliseconds, the total time for ISR in 100 milliseconds = 0.000002 seconds * 1000 = 0.002 seconds

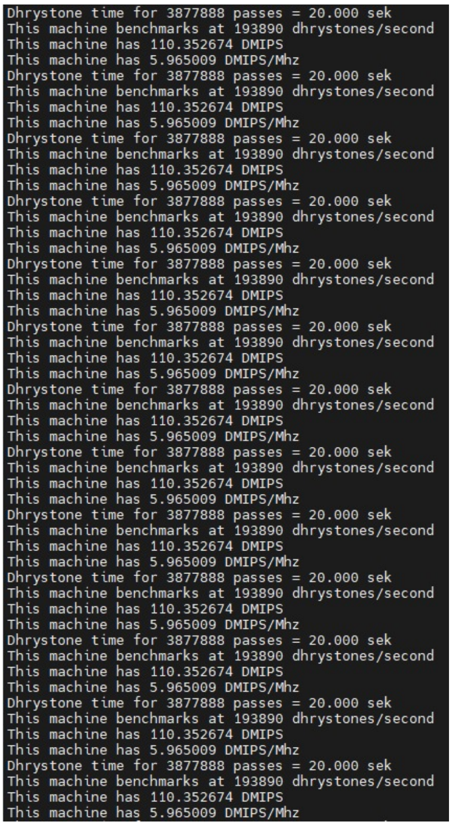
Total time for both Main() and ISR in 100 milliseconds = 0.6468 + 0.002 = 0.6488 seconds

Percentage of CPU cycles used for the main background process = (Time taken by Main() / Total time) * 100 = (0.6468/0.6488) * 100 = **99.69%**

We estimate that, during a 100 millisecond operating cycle, the main background process uses approximately 99.69% of the CPU cycles, calculated as (0.6468 seconds / 0.6488 seconds) * 100.

Question 7: What is your DMIPS estimate for the ST STM32F401RE MCU

Upon executing the Dhrystone benchmark and by referencing the Dhrystone documentation's methodology, as depicted in Figure 9, and using the provided formula. Each run yielded a DMIPS value of 110.352674 and DMIPS/MHz measure is seen as 5.9650 DMIPS/MHz . Consistent results were observed across all ten runs as displayed in Figure 8.



```
Dhrystone time for 3877888 passes = 20.000 sek
This machine benchmarks at 193890 dhrystones/second
This machine has 110.352674 DMIPS
This machine has 5.965009 DMIPS/Mhz
Dhrystone time for 3877888 passes = 20.000 sek
This machine benchmarks at 193890 dhrystones/second
This machine has 110.352674 DMIPS
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Dhrystone time for 3877888 passes = 20.000 sek
This machine benchmarks at 193890 dhrystones/second
This machine has 110.352674 DMIPS
This machine has 5.965009 DMIPS/Mhz
Dhrystone time for 3877888 passes = 20.000 sek
This machine benchmarks at 193890 dhrystones/second
This machine has 110.352674 DMIPS
This machine has 5.965009 DMIPS/Mhz
```
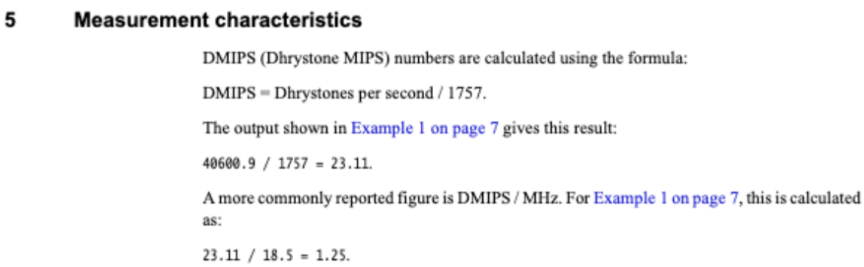

Figure 8 : Dhrystone Analysis



5 Measurement characteristics

DMIPS (Dhrystone MIPS) numbers are calculated using the formula:

DMIPS = Dhrystones per second / 1757.

The output shown in Example 1 on page 7 gives this result:

`40600.9 / 1757 = 23.11.`

A more commonly reported figure is DMIPS / MHz. For Example 1 on page 7, this is calculated as:

`23.11 / 18.5 = 1.25.`

Figure 9 : Dhrystone Documentation Of Measurement Characteristics

Code :

Main.cpp

```
/**----------------------------------------------------------------------------

   \file main.cpp

--                                                                           --
--              ECEN 5803 Mastering Embedded System Architecture             --
--                  Project 1 Module 4                                       --
--                Microcontroller Firmware                                   --
--                      main.cpp                                            --
--                                                                           --
-------------------------------------------------------------------------------
--
--  Designed for:  University of Colorado at Boulder
--
--
--  Designed by:  Tim Scherr
--  Revised by:  Student's name
--
-- Version: 3.0
-- Date of current revision:  2022-06-20
-- Target Microcontroller: ST STM32F401RE
-- Tools used:  ARM mbed compiler
--              ARM mbed SDK
--              ST Nucleo STM32F401RE Board
--
--
-- Functional Description:  Main code file generated by mbed, and then
--                           modified to implement a super loop bare metal OS.
--
--      Copyright (c) 2015, 2016, 2022 Tim Scherr  All rights reserved.
--
*/

#define MAIN
#include "shared.h"
#undef MAIN

#include "NHD_0216HZ.h"
#include "DS1631.h"
#include "pindef.h"

// Define green LED pin
DigitalOut greenLED(LED2);

// External ISR counter
extern volatile uint16_t SwTimerIsrCounter;

// Timer interrupt instance
Ticker tick;

 /****************      ECEN 5803 add code as indicated   ***************/
   // Add code to control LED LD2 here,
   // including a function to flip the LED state on and off

void flip(void) {
    greenLED = !greenLED;  // Toggle the state of the green LED
}


// Set up serial communication over USB
Serial pc(USBTX, USBRX);

// Create timer instance
Timer custom_timer2;


/*----------------------------------------------------------------------------
 MAIN function
 *----------------------------------------------------------------------------*/

int main()
```

```
{
       custom_timer2.start();
       pc.baud(9600);
/****************      ECEN 5803 add code as indicated   **********************/
              //  Add code to call timer0 function every 100 uS
         tick.attach_us(&timer0, 100);

 // Print the initial banner
    pc.printf("\r\nHello World!\n\n\r");
    uint32_t  count = 0;


// initialize serial buffer pointers
   rx_in_ptr =  rx_buf; /* pointer to the receive in data */
   rx_out_ptr = rx_buf; /* pointer to the receive out data*/
   tx_in_ptr =  tx_buf; /* pointer to the transmit in data*/
   tx_out_ptr = tx_buf; /* pointer to the transmit out */


/****************      ECEN 5803 add code as indicated   **********************/
    // uncomment this section after adding monitor code.
   /* send a starting message to the terminal  */
        pc.printf("\n\r\n\r***** Project 1 Module 5 - Viraj_Kiran *****\n\r\n\r");
   UART_direct_msg_put("\r\nSystem Reset\r\nCode ver. ");
   UART_direct_msg_put( CODE_VERSION );
   UART_direct_msg_put("\r\n");
   UART_direct_msg_put( COPYRIGHT );
   UART_direct_msg_put("\r\n");

   set_display_mode();

        custom_timer2.stop();
        //pc.printf("Time Taken For Main: %f seconds\n\r", custom_timer2.read());

    while(1)       /// Cyclical Executive Loop
    {

        count++;               // counts the number of times through the loop
//      __enable_interrupts();
//      __clear_watchdog_timer();

/****************      ECEN 5803 add code as indicated   **********************/
    // uncomment this section after adding monitor code.

        serial();            // Polls the serial port
        chk_UART_msg();     // checks for a serial port message received
        monitor();           // Sends serial port output messages depending
                         //     on commands received and display mode

        if ((SwTimerIsrCounter & 0x1FFF) > 0x0FFF)
/****************      ECEN 5803 add code as indicated   **********************/
         // The bitwise AND operation masks (keeps) the 13 least significant bits (LSBs)
                               // of SwTimerIsrCounter and sets all other bits to 0. This effectively
checks
                               // if the value of SwTimerIsrCounter is within the range of 0 to
0x1FFF.
                               // If the result of this operation is greater than 0x0FFF, it means
that the
                               // value of SwTimerIsrCounter has reached or exceeded 0x0FFF within
that range.
        {
            flip();  // Toggle Green LED
        }


               //Write your code here for any additional tasks



    }   /// End while(1) loop

}
```

Timer0.cpp

```
/**----------------------------------------------------------------------------
 *
 *            \file timer0.cpp
--                                                                         --
--              ECEN 5803 Mastering Embedded System Architecture           --
--                  Project 1 Module 4                                     --
--                Microcontroller Firmware                                 --
--                      Timer0.cpp                                         --
--                                                                         --
-----------------------------------------------------------------------------
--
--  Designed for:  University of Colorado at Boulder
--
--
--  Designed by:  Tim Scherr
--  Revised by:  Student's name
--
-- Version: 3.0
-- Date of current revision:  2022-06-20
-- Target Microcontroller: ST STM32F401RE
-- Tools used:  ARM mbed compiler
--              ARM mbed SDK
--              ST Nucleo STM32F401RE Board
--
--
   Functional Description:
   This file contains code for the only interrupt routine, based on the System
   Timer.
   The System Timer interrupt happens every
   100 us as determined by mbed Component Configuration.
   The System Timer interrupt acts as the real time scheduler for the firmware.
   Each time the interrupt occurs, different tasks are done based on critical
   timing requirement for each task.
   There are 256 timer states (an 8-bit counter that rolls over) so the
   period of the scheduler is 25.6 ms.  However, some tasks are executed every
   other time (the 200 us group) and some every 4th time (the 400 us group) and
   so on.  Some high priority tasks are executed every time.  The code for the
   tasks is divided up into the groups which define how often the task is
   executed.  The structure of the code is shown below:

   I.  Entry and timer state calculation
   II. 100 us group
      A.  Fast Software timers
      B.  Read Sensors
      C.  Update
   III. 200 us group
      A.
      B.
   IV.  400 us group
      A.  Medium Software timers
      B.
    V.   800 us group
      A.  Set 420 PWM Period
   VI   1.6 ms group
      A. Display timer and flag
      B. Heartbeat/ LED outputs
   VII  3.2 ms group
      A. Slow Software Timers
    VIII 6.4 ms group A
      A. Very Slow Software Timers
   IX.  Long time group
      A. Determine Mode
      B. Heartbeat/ LED outputs
   X.  Exit

--
--      Copyright (c) 2015, 2022 Tim Scherr  All rights reserved.
*/


#include "shared.h"
#include "mbed.h"
```

```
#define System Timer_INCREMENT_IN_US 1000

 typedef unsigned char uchar8_t;
 typedef unsigned char bit;
 typedef unsigned int uint32_t;
 typedef unsigned short uint16_t;

/*******************/
/*  Configurations */
/*******************/
#ifdef __cplusplus
extern "C" {
#endif
/**********************/
/*   Definitions     */
/**********************/

   volatile    uchar8_t swtimer0 = 0;
   volatile    uchar8_t swtimer1 = 0;
   volatile    uchar8_t swtimer2 = 0;
   volatile    uchar8_t swtimer3 = 0;
   volatile    uchar8_t swtimer4 = 0;
   volatile    uchar8_t swtimer5 = 0;
   volatile    uchar8_t swtimer6 = 0;
   volatile    uchar8_t swtimer7 = 0;

  volatile uint16_t SwTimerIsrCounter = 0U;
  uchar8_t  display_timer = 0;  // 1 second software timer for display
  uchar8_t  display_flag = 0;   // flag between timer interrupt and monitor.c, like
                        // a binary semaphore

   static   uint32_t System_Timer_count = 0; // 32 bits, counts for
                                                  // 119 hours at 100 us period
   static   uint16_t timer0_count = 0; // 16 bits, counts for
                                          // 6.5 seconds at 100 us period
   static   uchar8_t timer_state = 0;
   static   uchar8_t long_time_state = 0;
       //  variable which splits timer_states into groups
      //  tasks are run in their assigned group times
//    DigitalOut BugMe (PTB9);   // debugging information out on PTB9
#ifdef __cplusplus
}
#endif

DigitalOut redLED(PA_7);    // Red Led At Pin PA_7
int redLEDTickCounter = 0;  // Red Led Tick Counter
//bool redLEDFlag = false;    // Red Led Flag
extern Serial pc;

void toggleRedLED() {
    redLED = !redLED;  // Toggle the state of the red LED
}

Timer custom_timer;
int count30s = 0;    // 30 Seconds Tick Counter

/*********************************/
/*     Start of Code             */
/*********************************/
// I. Entry and Timer State Calculation
void timer0(void)
 {
        custom_timer.reset();
        custom_timer.start();
 //  BugMe = 1;  // debugging signal high during Timer0 interrupt on PTB9

/*************************************************/
//  Determine Timer0 state and task groups
/*************************************************/
   timer_state++;           // increment timer_state each time
   if (timer_state == 0)
   {
      long_time_state++;   // increment long time state every 25.6 ms

   }
```

```
/*****************************************************************/
/*      100 us Group                                             */
/*****************************************************************/
//  II.  100 us Group

//     A. Update Fast Software timers
   if (swtimer0 > 0)     // if not yet expired,
      (swtimer0)--;        // then decrement fast timer (1 ms to 256 ms)
   if (swtimer1 > 0)     // if not yet expired,
      (swtimer1)--;        // then decrement fast timer (1 ms to 256 ms)

//    B.   Update Sensors


/*****************************************************************/
/*      200 us Group                                             */
/*****************************************************************/

   if ((timer_state & 0x01) != 0)  // 2 ms group, odds only
   {
      ;
   } // end  2 ms group

/*****************************************************************/
/*      400 us Group                                             */
/*****************************************************************/
   else if ((timer_state & 0x02) != 0)
   {
//   IV.  400 us group
//           timer states 2,6,10,14,18,22,...254

//      A.  Medium Software timers
      if (swtimer2 > 0)  // if not yet expired, every other time
         (swtimer2)--;     // then decrement med timer  (4 ms to 1024 ms)
      if (swtimer3 > 0) // if not yet expired, every other time
         (swtimer3)--;        // then decrement med timer  (4 ms to 1024 ms)

//      B.
   } // end 4 ms group

/*****************************************************************/
/*      800 us Group                                             */
/*****************************************************************/
   else if ((timer_state & 0x04) != 0)
   {
//   V.   8 ms group
//           timer states 4, 12, 20, 28 ... 252   every 1/8

//     A.  Set
   }   // end 8 ms group

/*****************************************************************/
/*      1.6 ms Group                                             */
/*****************************************************************/
   else if ((timer_state & 0x08) != 0)
   {
// VI   1.6 ms group
//           timer states 8, 24, 40, 56, .... 248  every 1/16

   }   // end 1.6 ms group

/*****************************************************************/
/*      3.2 ms Group                                             */
/*****************************************************************/
   else if ((timer_state & 0x10) != 0)
   {
// VII  3.2 ms group
//          timer states 16, 48, 80, 112, 144, 176, 208, 240

//    A. Slow Software Timers
      if (swtimer4 > 0)  // if not yet expired, every 32nd time
         (swtimer4)--;        // then decrement slow timer (32 ms to 8 s)
      if (swtimer5 > 0) // if not yet expired, every 32nd time
         (swtimer5)--;        // then decrement slow timer (32 ms to 8 s)
```

```
//    B.  Update

   }   // end 3.2 ms group

/**********************************************************************/
/*      6.4 ms Group A                                                */
/**********************************************************************/
   else if ((timer_state & 0x20) != 0)
   {
// VIII 6.4 ms group A
//           timer states 32, 96, 160, 224

//    A. Very Slow Software Timers
      if (swtimer6 > 0)  // if not yet expired, every 64th
                                         // time
         (swtimer6)--;        // then decrement very slow timer (6.4 ms to 1.6s)

      if (swtimer7 > 0)  // if not yet expired, every 64th
                                         // time
         (swtimer7)--;        // then decrement very slow timer (64 ms to 1.6s)

//    B.  Update

   }   // end 6.4 ms group A

/**********************************************************************/
/*      6.4 ms Group B                                                */
/**********************************************************************/
   else
   {
// IX.  6.4 ms group B
//       timer states 0, 64, 128, 192

//    A.  Update

//    A. Display timer and flag
      display_timer--; // decrement display timer every 6.4 ms.  Total time is
                      // 256*6.4ms = 1.6384 seconds.
      if (display_timer == 1)
         display_flag = 1;     // every 1.6384 seconds, now OK to display


//    B. Heartbeat/ LED outputs
//   Generate Outputs  ************************************

/****************      ECEN 5803 add code as indicated   *********************/
    // Create an 0.5 second LED heartbeat here.
                      // Increment the counter for the red LED ticks
                      redLEDTickCounter++;

                      // Check if the counter has reached the value of 78
                      if ((redLEDTickCounter % 78) == 0) {
                                     // Toggle the state of the red LED
                                     toggleRedLED();

                                     // Reset the counter
                                     redLEDTickCounter = 0;
                      }

                      /* Code With Red LED Flag
                      if ( ((redLEDTickCounter % 78) == 0) && (redLEDFlag)) {
                              toggleRedLED();
                              redLEDTickCounter = 0;
                      }
                      else {
                              redLEDFlag = false;
                              redLEDTickCounter = 0;
                      }
                      */

   }   // end 6.4 ms group B

/**********************************************************************/
/*      Long Time Group                                               */
```

```
/*******************************************************************/
   if (((long_time_state & 0x01) != 0) && (timer_state == 0))
                            // every other long time, every 51.2 ms
   {
// X.   Long time group
//
//  clear_watchdog_timer();
     }
// Re-enable interrupts and return
   System_Timer_count++;
   timer0_count++;
   SwTimerIsrCounter++;
//   Bugme = 0;  // debugging signal high during Timer0 interrupt on PTB9
    // unmask Timer interrupt   (now done by mBed library)

    // enables timer interrupt again  (now done by mBed Library

        // Code To Print Timer 0 Count After 30 Seconds & To Print Time Taken In ISR
        //count30s++;
   /*
        if ((count30s % 300000) == 0) {
               pc.printf("Timer 0 Count After 30 Seconds: %d\n\r", timer0_count);
               count30s = 0;
        }
        */

        custom_timer.stop();
        //pc.printf("Time Taken For ISR: %f micro seconds\n\r", custom_timer.read()*1000000);

}
```

Monitor.cpp

```
/**----------------------------------------------------------------------------
            \file Monitor.cpp
--                                                                          --
--              ECEN 5003 Mastering Embedded System Architecture            --
--                  Project 1 Module 4                                      --
--                Microcontroller Firmware                                  --
--                      Monitor.cpp                                           --
--                                                                          --
-------------------------------------------------------------------------------
--
--  Designed for:  University of Colorado at Boulder
--
--
--  Designed by:  Tim Scherr
--  Revised by:  Student's name
--
-- Version: 2.0
-- Date of current revision:  2022-06-20
-- Target Microcontroller: ST STM32F401RE
-- Tools used:  ARM mbed compiler
--              ARM mbed SDK
--              ST Nucleo STM32F401RE Board
--
--
   Functional Description: See below
--
--      Copyright (c) 2015, 2022 Tim Scherr All rights reserved.
--
*/

#include <stdio.h>
#include "shared.h"
#include "memory.h"

//extern bool redLEDFlag;


/*******************************************************************************
* Set Display Mode Function
* Function determines the correct display mode.  The 3 display modes operate as
```

```
*   follows:
*
*  NORMAL MODE       Outputs only mode and state information changes
*                     and calculated outputs
*
*  QUIET MODE        No Outputs
*
*  DEBUG MODE        Outputs mode and state information, error counts,
*                    register displays, sensor states, and calculated output
*                  (currently not all features are operation, could be enhanced)
*
* There is deliberate delay in switching between modes to allow the RS-232 cable
* to be plugged into the header without causing problems.
*******************************************************************************/


//*****************************************************************************/
/// \fn void set_display_mode(void)
///
/// \brief Displays a selection menu over UART.
///
/// This function sends a series of messages over UART to display a menu
/// allowing the user to choose between different modes. Each mode is
/// highlighted with a different color.
//*****************************************************************************/

void set_display_mode(void)
{
    UART_direct_msg_put("\033[37m\r\n+------------------------+\033[0m");
    UART_direct_msg_put("\r\n\033[37m|  Select Mode           |\033[0m");
    UART_direct_msg_put("\033[37m\r\n|------------------------|\033[0m");
    UART_direct_msg_put("\r\n\033[32m|  NOR - Normal          |\033[0m");
    UART_direct_msg_put("\r\n\033[33m|  QUI - Quiet           |\033[0m");
    UART_direct_msg_put("\r\n\033[35m|  DEB - Debug           |\033[0m");
    //UART_direct_msg_put("\r\n\033[31m|  RED - Red Led(1s)      |\033[0m");
    UART_direct_msg_put("\r\n\033[34m|  REG - Registers Dump  |\033[0m");
    UART_direct_msg_put("\r\n\033[31m|  MEM - Memory Dump     |\033[0m");
    UART_direct_msg_put("\r\n\033[36m|  STK - Stack Dump      |\033[0m");
    UART_direct_msg_put("\r\n\033[97m|  V   - Version#        |\033[0m");
    UART_direct_msg_put("\033[37m\r\n+------------------------+\033[0m");
    UART_direct_msg_put("\033[0m\r\nSelect:  ");
}




//*****************************************************************************/
/// \fn void chk_UART_msg(void)
///
///  \brief - fills a message buffer until return is encountered, then calls
///          message processing
//*****************************************************************************/
/***************      ECEN 5803 add code as indicated   *********************/
  // Improve behavior of this function
void chk_UART_msg(void)
{
   uchar8_t j;
   while( UART_input() )      // becomes true only when a byte has been received
   {                                    // skip if no characters pending
      j = UART_get();                 // get next character

      if( j == '\r' )           // on a enter (return) key press
      {                // complete message (all messages end in carriage return)
                               //UART_msg_put("");
         UART_direct_msg_put("->");
         UART_msg_process();
      }
      else
      {
         if ((j != 0x02) )          // if not ^B
         {                                // if not command, then
            UART_put(j);                // echo the character
         }
         else
         {
```

```
          ;
        }
        if( j == '\b' )
        {                             // backspace editor
           if( msg_buf_idx != 0)
           {                       // if not 1st character then destructive
              UART_msg_put(" \b");// backspace
              msg_buf_idx--;
           }
        }
        else if( msg_buf_idx >= MSG_BUF_SIZE )
        {                                // check message length too large
           UART_msg_put("\r\nToo Long!");
           msg_buf_idx = 0;
        }
        else if ((display_mode == QUIET) && (msg_buf[0] != 0x02) &&
                 (msg_buf[0] != 'D') && (msg_buf[0] != 'N') &&
                 (msg_buf[0] != 'V') && (msg_buf[0] != 'R') &&
                                                               (msg_buf[0] != 'M') && (msg_buf[0]
!= 'S') &&
                 (msg_buf_idx != 0))
        {                          // if first character is bad in Quiet mode
           msg_buf_idx = 0;        // then start over
        }
        else {                        // not complete message, store character

           msg_buf[msg_buf_idx] = j;
           msg_buf_idx++;
           if (msg_buf_idx > 3)
           {
              UART_msg_process();
           }
        }
     }
  }
}


//*****************************************************************************/
///  \fn void UART_msg_process(void)
///UART Input Message Processing
//*****************************************************************************/
void UART_msg_process(void)
{
   uchar8_t chr,err=0;
//   unsigned char  data;

   // Check if the first character of the message buffer is an uppercase letter
   if( (chr = msg_buf[0]) <= 0x60 )
   {      // Upper Case
      switch( chr )
      {
         // DEBUG Mode
         case 'D':
            if((msg_buf[1] == 'E') && (msg_buf[2] == 'B') && (msg_buf_idx == 3))
            {
               display_mode = DEBUG;
               UART_direct_msg_put("\r\n\033[35mMode=DEBUG\033[0m\n");
               display_timer = 0;
            }
            else
               err = 1;
            break;

         // NORMAL Mode
         case 'N':
            if((msg_buf[1] == 'O') && (msg_buf[2] == 'R') && (msg_buf_idx == 3))
            {
               display_mode = NORMAL;
               UART_direct_msg_put("\r\n\033[32mMode=NORMAL\033[0m\n");
               //display_timer = 0;
            }
            else
               err = 1;
            break;
```

```
         // QUIET Mode
         case 'Q':
            if((msg_buf[1] == 'U') && (msg_buf[2] == 'I') && (msg_buf_idx == 3))
            {
               display_mode = QUIET;
               UART_direct_msg_put("\r\n\033[33mMode=QUIET\033[0m\n");
               display_timer = 0;
            }
            else
               err = 1;
            break;

         // VERSION Info
         case 'V':
            display_mode = VERSION;
            UART_direct_msg_put("\033[97m\r\n");
            UART_direct_msg_put(CODE_VERSION);
                                  UART_direct_msg_put("\033[0m\r\nSelect:  ");
            display_timer = 0;
            break;
/****************      ECEN 5803 add code as indicated   **********************/
//  Add other message types here
                               /* For Red Led Flag Mode
                               case 'R':
                                       if((msg_buf[1] == 'E') && (msg_buf[2] == 'D') && (msg_buf_idx
== 3))
            {
               display_mode = RED;
               UART_msg_put("\r\n\033[31mMode=RED LED(1s)\033[0m\n");
               display_timer = 0;
            }
            else
               err = 1;
                                             break;
                               */
         // Register Dump
                               case 'R':
                                       if((msg_buf[1] == 'E') && (msg_buf[2] == 'G') && (msg_buf_idx
== 3))
            {
               display_mode = REGISTERS;
               UART_msg_put("\r\n\033[34mMode=Registers Dump\033[0m\n");
               display_timer = 0;
            }
            else
               err = 1;
                                             break;

         // Memory Dump
                                      case 'M':
                                       if((msg_buf[1] == 'E') && (msg_buf[2] == 'M') && (msg_buf_idx
== 3))
            {
               display_mode = MEMORY;
               UART_msg_put("\r\n\033[31mMode=Memory Dump\033[0m\n");
               display_timer = 0;
            }
            else
               err = 1;
                                             break;

                                      // Stack Dump
                                      case 'S':
                                       if((msg_buf[1] == 'T') && (msg_buf[2] == 'K') && (msg_buf_idx
== 3))
            {
               display_mode = STACK;
               UART_msg_put("\r\n\033[36mMode=Stack Dump\033[0m\n");
               display_timer = 0;
            }
            else
               err = 1;
                                             break;
```

```
         // DEFAULT
         default:
            err = 1;
      }
   }
   // Display error messages based on the error code
   else
   {                    // Lower Case
      switch( chr )
      {
        default:
         err = 1;
      }
   }

   if( err == 1 )
   {
      UART_direct_msg_put("\n\rEntry Error!");
   }
   else if( err == 2 )
   {
      UART_direct_msg_put("\n\rNot in DEBUG Mode!");
   }
   else
   {
    msg_buf_idx = 0;          // put index to start of buffer for next message
      ;
   }
   msg_buf_idx = 0;          // put index to start of buffer for next message


}


//*******************************************************************************
///   \fn   is_hex
/// Function takes
///  @param a single ASCII character and returns
///  @return 1 if hex digit, 0 otherwise.
///
//*******************************************************************************
uchar8_t is_hex(uchar8_t c)
{
   if( (((c |= 0x20) >= '0') && (c <= '9')) || ((c >= 'a') && (c <= 'f'))  )
      return 1;
   return 0;
}

/*******************************************************************************
*   \fn  DEBUG and DIAGNOSTIC Mode UART Operation
*******************************************************************************/
void monitor(void)
{

/**********************************/
/*     Spew outputs               */
/**********************************/

   switch(display_mode)
   {
      case(QUIET):
         {
                                            //redLEDFlag = false;
             UART_msg_put("\r\n ");
             display_flag = 0;
         }
         break;
      case(VERSION):
         {
                                      //redLEDFlag = false;
             display_flag = 0;
         }
         break;
      case(NORMAL):
         {
```

```
                                //redLEDFlag = false;
            if (display_flag == 1)
            {
               UART_msg_put("\r\n\033[32mNORMAL ");
               UART_msg_put(" Flow: ");
               // ECEN 5803 add code as indicated
               //  add flow data output here, use UART_hex_put or similar for
               // numbers
               UART_msg_put(" Temp: ");
               //  add flow data output here, use UART_hex_put or similar for
               // numbers
               UART_msg_put(" Freq: \033[0m");
               //  add flow data output here, use UART_hex_put or similar for
               // numbers
               display_flag = 0;
                                   //wait_ms(500);
            }
         }
         break;
      case(DEBUG):
         {
                                //redLEDFlag = false;
            if (display_flag == 1)
            {
               UART_msg_put("\r\n\033[35mDEBUG ");
               UART_msg_put(" Flow: ");
               // ECEN 5803 add code as indicated
               //  add flow data output here, use UART_hex_put or similar for
               // numbers
               UART_msg_put(" Temp: ");
               //  add flow data output here, use UART_hex_put or similar for
               // numbers
               UART_msg_put(" Freq: \033[0m");
               //  add flow data output here, use UART_hex_put or similar for
               // numbers


/****************      ECEN 5803 add code as indicated   *********************/
               //  Create a display of  error counts, sensor states, and
               //  ARM Registers R0-R15
                                          //print_registers();

               //  Create a command to read a section of Memory and display it
               //dump_memory();

               //  Create a command to read 16 words from the current stack
               // and display it in reverse chronological order.
                                          //display_last_16_stack_words();


               // clear flag to ISR
               display_flag = 0;
                                          //wait_ms(500);
             }
         }
         break;
                   /* Red Led Flag Mode
                   case(RED):
                   {
                        redLEDFlag = true;
                        if (display_flag == 1) {
                             UART_msg_put("\r\n\033[31mRed LED(1s)\033[0m ");
                             display_flag = 0;
                        }
                   }
                   break;
                   */
                   // Check if the current mode is REGISTERS
                   case(REGISTERS):
                   {
                         // The following line is commented out, but if active, it would turn
off a red LED flag
                         //redLEDFlag = false;

                         // Check if the display_flag is set
```

```
                if (display_flag == 1) {
                        // Send a new line and set the text color to blue
                        UART_direct_msg_put("\n\r\033[34m");

                        // Print the register values
                        print_registers();

                        // Reset the text color to default and send a new line
                        UART_direct_msg_put("\033[0m\n\r");

                        // Reset the display_flag
                        display_flag = 0;
                }
            }
            break;  // End of REGISTERS case

            // Check if the current mode is MEMORY
            case(MEMORY):
            {
                // The following line is commented out, but if active, it would turn
off a red LED flag
                //redLEDFlag = false;

                // Check if the display_flag is set
                if (display_flag == 1) {
                        // Send a new line and set the text color to red
                        UART_direct_msg_put("\n\r\033[31m");

                        // Dump the memory values
                        dump_memory();

                        // Reset the text color to default and send a new line
                        UART_direct_msg_put("\033[0m\n\r");

                        // Reset the display_flag
                        display_flag = 0;
                }
            }
            break;  // End of MEMORY case

            // Check if the current mode is STACK
            case(STACK):
            {
                // The following line is commented out, but if active, it would turn
off a red LED flag
                //redLEDFlag = false;

                // Check if the display_flag is set
                if (display_flag == 1) {
                        // Send a new line and set the text color to cyan
                        UART_direct_msg_put("\n\r\033[36m");

                        // Display the last 16 words of the stack
                        display_last_16_stack_words();

                        // Reset the text color to default and send a new line
                        UART_direct_msg_put("\033[0m\n\r");

                        // Reset the display_flag
                        display_flag = 0;
                }
            }
            break;  // End of STACK case


      default:
      {
         UART_msg_put("Mode Error");
      }
   }
}
```

UART_Poll.cpp

```
/**----------------------------------------------------------------------------
      \file UART_poll.cpp

--                                                                           --
--              ECEN 5803 Mastering Embedded System Architecture             --
--                  Project 1 Module 4                                       --
--                Microcontroller Firmware                                   --
--                      UART_poll.c                                          --
--                                                                           --
-------------------------------------------------------------------------------
--
--  Designed for:  University of Colorado at Boulder
--
--
--  Designed by:  Tim Scherr
--  Revised by:  Student's name
--
-- Version: 3.0
-- Date of current revision:  2022-06-20
-- Target Microcontroller: ST STM32F401RE
-- Tools used:  ARM mbed compiler
--              ARM mbed SDK
--              ST Nucleo STM32F401RE Board
--
--
--  Functional Description:  This file contains routines that support messages
--    to and from the UART port.  Included are:
--       Serial() - a routine to send/receive bytes on the UART port to
--                      the transmit/receive buffers
--       UART_put()  - a routine that puts a character in the transmit buffer
--       UART_get()  - a routine that gets the next character from the receive
--                      buffer
--       UART_msg_put() - a routine that puts a string in the transmit buffer
--       UART_direct_msg_put() - routine that sends a string out the UART port
--       UART_input() - determines if a character has been received
--       UART_hex_put() - a routine that puts a hex byte in the transmit buffer
--
--      Copyright (c) 2015, 2022 Tim Scherr  All rights reserved.
--
*/



/*******************/
/*  Configurations */
/*******************/
/*

*/

#include <stdio.h>
#include "shared.h"
//#include "MKL25Z4.h"

// NOTE:  UART0 is also called UARTLP in mbed
// Using USART2 for virtual serial port in STM32F401RE
#define OERR (USART2->SR & USART_SR_ORE)    // Overrun Error bit
#define CREN (USART2->CR1 & USART_CR1_RE)    // continuous receive enable bit
#define RCREG USART2->DR                        // Receive Data Register
#define FERR (USART2->SR & USART_SR_FE)    // Framing Error bit
#define RCIF (USART2->SR & USART_SR_RXNE) // Receive Interrupt Flag (full)
#define TXIF (USART2->SR & USART_SR_TXE) // Transmit Interrupt Flag (empty)
#define TXREG USART2->DR                        // Transmit Data Register
#define TRMT (USART2->SR & USART_SR_TC)    // Transmit Shift Register Empty

/***********************************
 *       Start of code             *
 ***********************************/

 uchar8_t error_count = 0;

///  \fn void serial(void)
```

```
/// function polls the serial port for Rx or Tx data
void serial(void)        // The serial function polls the serial port for
                         // received data or data to transmit
{
                          // deals with error handling first
   if ( OERR )            // if an overrun error, clear it and continue.
   {
      error_count++;
                             // resets and sets continous receive enable bit
      USART2->CR1 = USART2->CR1 & (!USART_CR1_RE);
      USART2->CR1 = USART2->CR1 | USART_CR1_RE;
   }

   if ( FERR){        // if a framing error, read bad byte, clear it and continue.
      error_count++;
      RCREG;          // This will also clear RCIF if only one byte has been
                      // received since the last int, which is our assumption.

                      // resets and sets continous receive enable bit
      USART2->CR1 = USART2->CR1 & (!USART_CR1_RE);
      USART2->CR1 = USART2->CR1 | USART_CR1_RE;
   }
   else               // else if no frame error,
   {
      if ( RCIF )    // Check if we have received a byte
      {              // Read byte to enable reception of more bytes
                     // For PIC, RCIF automatically cleared when RCREG is read
                     // Also true of Freescale KL25Z and STM32F401RE
         *rx_in_ptr++ = RCREG;         /* get received character */
         if( rx_in_ptr >= RX_BUF_SIZE + rx_buf )
         {
            rx_in_ptr = rx_buf;    /* if at end of buffer, circles rx_in_ptr
                                      to top of buffer */
         }

      }
   }

   if (TXIF)           //  Check if transmit buffer empty
   {
      if ((tx_in_ptr != tx_out_ptr) && (display_mode != QUIET))
      {
         TXREG = *tx_out_ptr++;     /* send next char */
         if( tx_out_ptr >= TX_BUF_SIZE + tx_buf )
            tx_out_ptr = tx_buf;           /* 0 <= tx_out_idx < TX_BUF_SIZE */
         tx_in_progress = YES;          /* flag needed to start up after idle */
      }
      else
      {
         tx_in_progress = NO;             /* no more to send */
      }
  }
//  serial_count++;          // increment serial counter, for debugging only
  serial_flag = 1;         // and set flag
}

/*******************************************************************************
* The function UART_direct_msg_put puts a null terminated string directly
* (no ram buffer) to the UART in ASCII format.
*******************************************************************************/
void UART_direct_msg_put(const char *str)
{
   while( *str != '\0' )
   {
      TXREG = *str++;
      while( TXIF == 0 || TRMT == 0 )  // waits here for UART transmit buffer
                                       // to be empty
      {
    //   __clear_watchdog_timer();
      }
   }
}

/*******************************************************************************
* The function UART_put puts a byte, to the transmit buffer at the location
```

```
* pointed to by tx_in_idx.  The pointer is incremented circularly as described
* previously.  If the transmit buffer should wrap around (should be designed
* not to happen), data will be lost.  The serial interrupt must be temporarily
* disabled since it reads tx_in_idx and this routine updates tx_in_idx which is
* a 16 bit value.
*******************************************************************************/
void UART_put(uchar8_t c)
{
   *tx_in_ptr++ = c;                    /* save character to transmit buffer */
   if( tx_in_ptr >= TX_BUF_SIZE + tx_buf)
      tx_in_ptr = tx_buf;                     /* 0 <= tx_in_idx < TX_BUF_SIZE */
}

/*******************************************************************************
* The function UART_get gets the next byte if one is available from the receive
* buffer at the location pointed to by rx_out_idx.  The pointer is circularly
* incremented and the byte is returned in R7. Should no byte be available the
* function will wait until one is available. There is no need to disable the
* serial interrupt which modifies rx_in_idx since the function is looking for a
* compare only between rx_in_idx & rx_out_idx.
*******************************************************************************/
uchar8_t UART_get(void)
{
   uchar8_t c;
   while( rx_in_ptr == rx_out_ptr );      /* wait for a received character,
                                                      indicated */
                                          // when pointers are different
                                          // this could be an infinite loop, but
                                          // is not because of UART_input check
   c = *rx_out_ptr++;
   if( rx_out_ptr >= RX_BUF_SIZE + rx_buf )  // if at end of buffer
   {
      rx_out_ptr = rx_buf;                /* 0 <= rx_out_idx < RX_BUF_SIZE */
                                        // return byte from beginning of buffer
   }                                    // next time.
   return(c);
}

/*******************************************************************************
* The function UART_input returns a 1 if 1 or more receive byte(s) is(are)
* available and a 0 if the receive buffer rx_buf is empty.  There is no need to
* disable the serial interrupt which modifies rx_in_idx since function is
* looking for a compare only between rx_in_idx & rx_out_idx.
*******************************************************************************/
uchar8_t UART_input(void)
{
   if( rx_in_ptr == rx_out_ptr )
      return(0);                          /* no characters in receive buffer */
   else
      return(1);                        /* 1 or more receive characters ready */
}

/*******************************************************************************
* The function UART_msg_put puts a null terminated string through the transmit
* buffer to the UART port in ASCII format.
*******************************************************************************/
void UART_msg_put(const char *str)
{
   while( *str != '\0' )
   {
      *tx_in_ptr++ = *str++;        /* save character to transmit buffer */
      if( tx_in_ptr >= TX_BUF_SIZE + tx_buf)
         tx_in_ptr = tx_buf;                  /* 0 <= tx_in_idx < TX_BUF_SIZE */
   }
}


/*******************************************************************************
* The function UART_low_nibble_put puts the low nibble of a byte in hex through
* the transmit buffer to the UART port.
*******************************************************************************/
//void UART_low_nibble_put(uchar8_t c)
//{
//   UART_put( hex_to_asc( c & 0x0f ));
//}
```

```
/******************************************************************************
* The function UART_high_nibble_put puts the high nibble of a byte in h
* UART port.
******************************************************************************/
//void UART_high_nibble_put(unsigned char c)
//{
//   UART_put( hex_to_asc( (c>>4) & 0x0f ));
//}

/******************************************************************************
* HEX_TO_ASC Function
* Function takes a single hex character (0 thru Fh) and converts to ASCII.
*****************************************************************************/
uchar8_t hex_to_asc(uchar8_t c)
{
   if( c <= 9 )
      return( c + 0x30 );
   return( ((c & 0x0f) + 0x37 ));        /* add 37h */
}

/******************************************************************************
* ASC_TO_HEX Function
* Function takes a single ASCII character and converts to hex.
******************************************************************************/
uchar8_t asc_to_hex(uchar8_t c)
{
   if( c <= '9' )
      return( c - 0x30 );
   return( (c & 0xdf) - 0x37 );    /* clear bit 5 (lower case) & subtract 37h */
}


/******************************************************************************
* The function UART_hex_put puts 1 byte in hex through the transmit buffer to
* the UART port.
******************************************************************************/
void UART_hex_put(unsigned char c)
{
   UART_put( hex_to_asc( (c>>4) & 0x0f ));  // could eliminate & as >> of uchar8_t
                                             // by definition clears upper bits.
   UART_put( hex_to_asc( c & 0x0f ));
}

/******************************************************************************
* The function UART_direct_hex_put puts 1 byte in hex directly (no ram buffer)
* to the UART.
******************************************************************************/
void UART_direct_hex_put(unsigned char c)
{
   TXREG = hex_to_asc( (c>>4) & 0x0f );
   while( TXIF == 0 )
   {
    //  __clear_watchdog_timer();
   }
   TXREG = hex_to_asc( c & 0x0f );
   while( TXIF == 0 )
   {
    //  __clear_watchdog_timer();
   }
}
```

Memory.cpp

```
//****************************************************************************/
///
/// \file memory.cpp
///
/// \brief Functions to interact with memory, registers, and the UART interface.
///
/// \author Kiran Jojare, Viraj Patel
///
//****************************************************************************/

#include "memory.h"
```

```
#include "mbed.h"
#include "stdio.h"

extern Serial pc;

//*****************************************************************************/
/// \fn void read_serial_input(char *buffer, int length)
///
/// \brief Reads input from the serial interface.
///
/// This function captures characters from the UART until a newline or a carriage
/// return character is detected. Additionally, it handles backspaces by erasing
/// the previously entered character.
//*****************************************************************************/
void read_serial_input(char *buffer, int length) {
    int count = 0;
    while (count < length - 1) {
        while (!pc.readable());
        char c = pc.getc();

        if (c == '\r' || c == '\n') {
            break;
        } else if (c == 0x08 || c == 0x7F) { // Backspace detected
            if (count > 0) {
                count--;
                pc.putc(0x08); // Move cursor one position back
                pc.putc(' ');  // Replace last character with space
                pc.putc(0x08); // Move cursor one position back again
            }
        } else {
            pc.putc(c); // Echo back to terminal for other characters
            buffer[count++] = c;
        }
    }
    buffer[count] = '\0';
}

/*
void read_serial_input(char *buffer, int length) {
    int count = 0;
    while (count < length - 1) {
        while (!pc.readable());
        char c = pc.getc();
        pc.putc(c); // Echo back to terminal
        if (c == '\r' || c == '\n') {
            break;
        }
        buffer[count++] = c;
    }
    buffer[count] = '\0';
}
*/

//*****************************************************************************/
/// \brief Fetch value of R1 register.
__asm uint32_t get_r0() {
    MOV R0, R0
    BX LR
}
//*****************************************************************************/
/// \brief Fetch value of R2 register.
__asm uint32_t get_r1() {
    MOV R0, R1
    BX LR
}
//*****************************************************************************/
/// \brief Fetch value of R3 register.
__asm uint32_t get_r2() {
    MOV R0, R2
    BX LR
}
//*****************************************************************************/
/// \brief Fetch value of R4 register.
__asm uint32_t get_r3() {
    MOV R0, R3
```

```
    BX LR
}
//*****************************************************************************/
/// \brief Fetch value of R5 register.
__asm uint32_t get_r4() {
    MOV R0, R4
    BX LR
}
//*****************************************************************************/
/// \brief Fetch value of R6 register.
__asm uint32_t get_r5() {
    MOV R0, R5
    BX LR
}
//*****************************************************************************/
/// \brief Fetch value of R7 register.
__asm uint32_t get_r6() {
    MOV R0, R6
    BX LR
}
//*****************************************************************************/
/// \brief Fetch value of R8 register.
__asm uint32_t get_r7() {
    MOV R0, R7
    BX LR
}
//*****************************************************************************/
/// \brief Fetch value of R9 register.
__asm uint32_t get_r8() {
    MOV R0, R8
    BX LR
}
//*****************************************************************************/
/// \brief Fetch value of R10 register.
__asm uint32_t get_r9() {
    MOV R0, R9
    BX LR
}
//*****************************************************************************/
/// \brief Fetch value of R11 register.
__asm uint32_t get_r10() {
    MOV R0, R10
    BX LR
}
//*****************************************************************************/
/// \brief Fetch value of R12 register.
__asm uint32_t get_r11() {
    MOV R0, R11
    BX LR
}
//*****************************************************************************/
/// \brief Fetch value of R13 register.
__asm uint32_t get_r12() {
    MOV R0, R12
    BX LR
}

//*****************************************************************************/
/// \brief Fetch value of Stack Pointer register.
__asm uint32_t get_sp() {
    MOV R0, SP
    BX LR
}

//*****************************************************************************/
/// \brief Fetch value of Link Register.
__asm uint32_t get_lr() {
    MOV R0, LR
    BX LR
}

//*****************************************************************************/
/// \brief Fetch value of Program Counter register.
__asm uint32_t get_pc() {
    MOV R0, PC
```

```
    BX LR
}
//******************************************************************************/
/// \fn void print_registers(void)
///
/// \brief Prints the values of the registers.
///
/// This function sends the current values of the processor's registers over UART.
//******************************************************************************/
void print_registers() {
               pc.printf("Printing Register Values\n\r");
    pc.printf("R0: 0x%08lX\r\n", get_r0());
    pc.printf("R1: 0x%08lX\r\n", get_r1());
    pc.printf("R2: 0x%08lX\r\n", get_r2());
    pc.printf("R3: 0x%08lX\r\n", get_r3());
    pc.printf("R4: 0x%08lX\r\n", get_r4());
    pc.printf("R5: 0x%08lX\r\n", get_r5());
    pc.printf("R6: 0x%08lX\r\n", get_r6());
    pc.printf("R7: 0x%08lX\r\n", get_r7());
    pc.printf("R8: 0x%08lX\r\n", get_r8());
    pc.printf("R9: 0x%08lX\r\n", get_r9());
    pc.printf("R10: 0x%08lX\r\n", get_r10());
    pc.printf("R11: 0x%08lX\r\n", get_r11());
    pc.printf("R12: 0x%08lX\r\n", get_r12());
    pc.printf("SP: 0x%08lX\r\n", get_sp());
    pc.printf("LR: 0x%08lX\r\n", get_lr());
    pc.printf("PC: 0x%08lX\r\n", get_pc());
}

//******************************************************************************/
/// \fn void dump_memory(void)
///
/// \brief Dumps memory content from a given address for a given length.
///
/// This function sends the content of the memory from a specified address
/// and for a given length over UART.
//******************************************************************************/
void dump_memory(void) {
               /* Custom Input Code
               char input_buffer[32];
    uint32_t memory_location;
    uint32_t length;
               pc.printf("SP: 0x%08lX\r\n", get_sp());
    pc.printf("Enter memory location in hex format (e.g., 0x20010000): ");
    read_serial_input(input_buffer, sizeof(input_buffer));
    sscanf(input_buffer, "%lx", &memory_location);

    pc.printf("\r\nEnter length: ");
    read_serial_input(input_buffer, sizeof(input_buffer));
    sscanf(input_buffer, "%lu", &length);

    pc.printf("\r\nYou entered location: 0x%08lX and length: %lu\r\n", memory_location, length);
         */
               uint32_t memory_location = 0x20010000;
    uint32_t length = 64;
    pc.printf("Dumping memory at Location 0X%08X %d Bytes:\r\n", memory_location, length);

               uint32_t start_address = memory_location ;
    const uint32_t bytes_per_line = 16;
    uint8_t *ptr = (uint8_t *)start_address;

    for (uint32_t i = 0; i < length; i += bytes_per_line) {
        // Print the memory address
        pc.printf("0x%08lX: ", (uint32_t)(ptr + i));

        // Print the hex values
        for (uint32_t j = 0; j < bytes_per_line; j++) {
            if (i + j < length) {
                pc.printf("%02X ", ptr[i + j]);
            } else {
                pc.printf("   "); // for alignment when length is not a multiple of bytes_per_line
            }
        }

        pc.printf(" ");
```

```
        // Print the ASCII values
        for (uint32_t j = 0; j < bytes_per_line; j++) {
            if (i + j < length) {
                char c = ptr[i + j];
                if (c < 32 || c > 126) { // non-printable chars
                    c = '.';
                }
                pc.printf("%c", c);
            }
        }

        pc.printf("\r\n");
    }
}
//*****************************************************************************/
/// \fn void display_last_16_stack_words(void)
///
/// \brief Displays the last 16 words in the stack.
///
/// This function sends the last 16 words of the current stack over UART.
//*****************************************************************************/
void display_last_16_stack_words() {
    uint32_t *stack_ptr = (uint32_t *)get_sp();
               pc.printf("Print Stack \n\r");
               pc.printf("Current Stack Pointer SP: 0x%08lX\r\n", stack_ptr);
    for (int i = 0; i < 16; i++) {
                      pc.printf("Word %d: 0x%08X : %08X\r\n", 16 - i, stack_ptr - i,*(stack_ptr-i));
    }
}
```