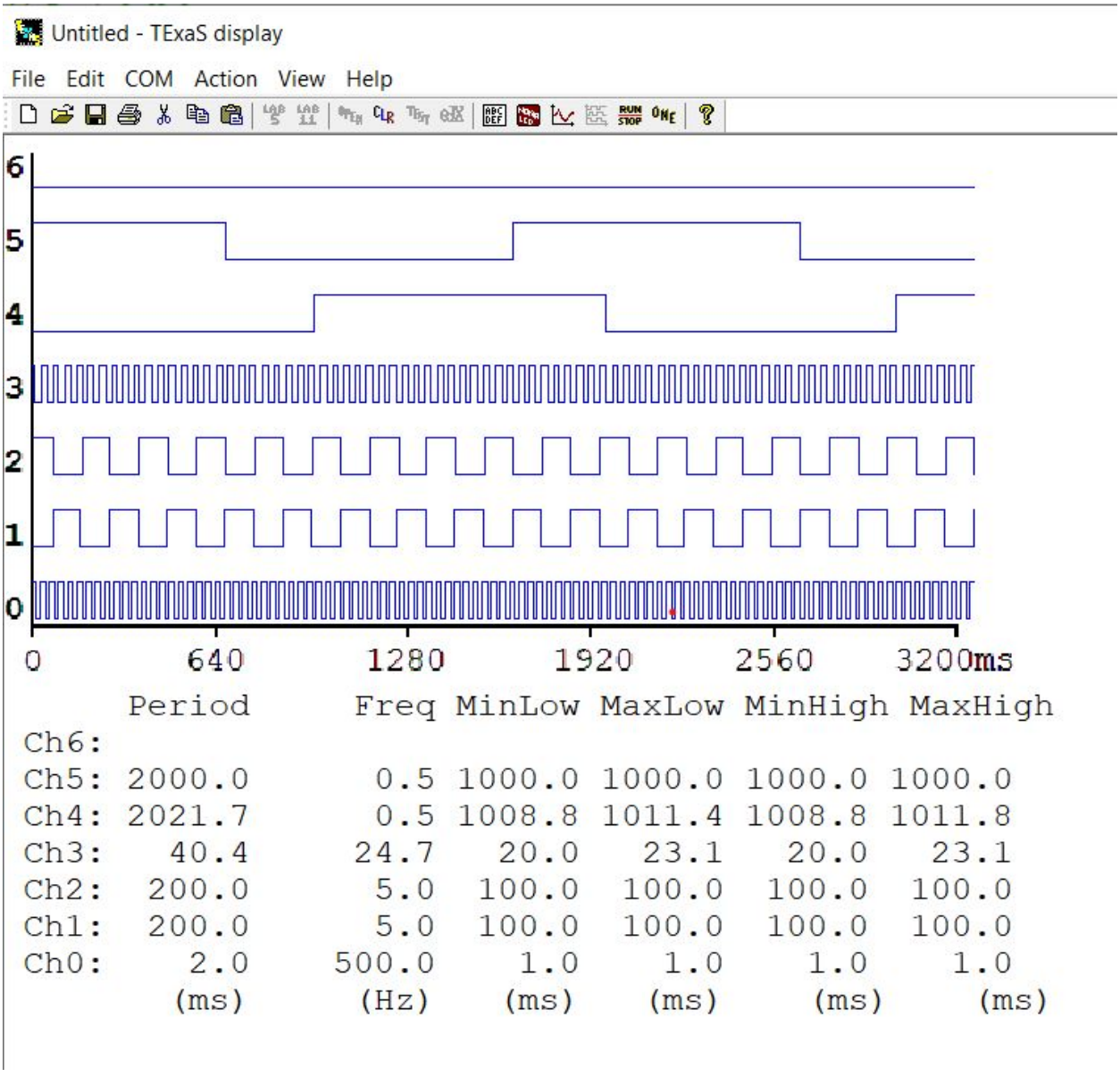
Riley Ruckman
TCES460, Wi21
Lab 13

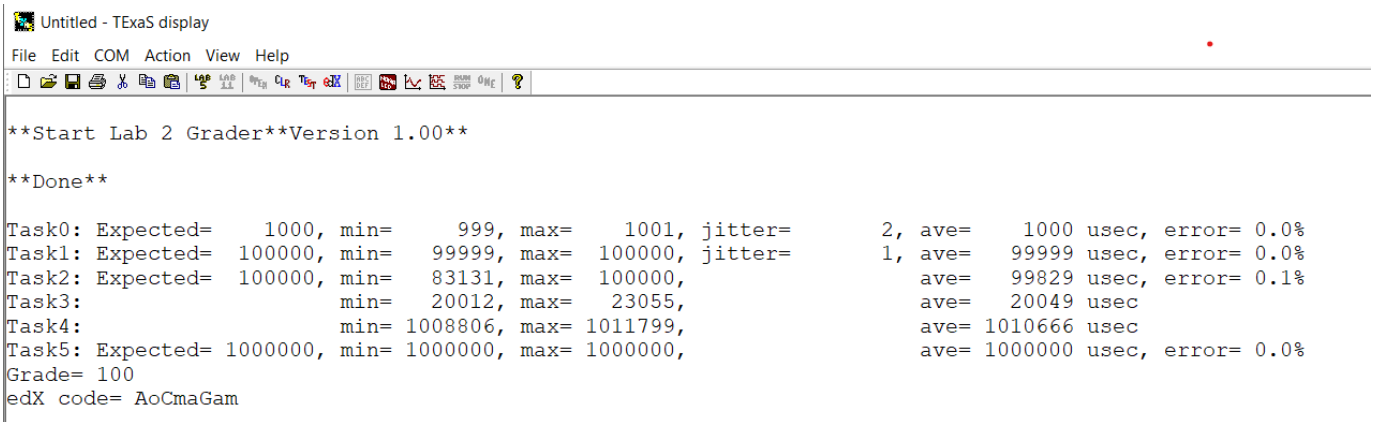
TExaS Display Screenshots:

LOGICANALYZER



GRADER

Lab 5:


Untitled - TExaS display
File Edit COM Action View Help
Start Lab 2 Grader Version 1.00**
Done
Task0: Expected= 1000, min= 999, max= 1001, jitter= 2, ave= 1000 usec, error= 0.0%
Task1: Expected= 100000, min= 99999, max= 100000, jitter= 1, ave= 99999 usec, error= 0.0%
Task2: Expected= 100000, min= 83131, max= 100000, ave= 99829 usec, error= 0.1%
Task3: min= 20012, max= 23055, ave= 20049 usec
Task4: min= 1008806, max= 1011799, ave= 1010666 usec
Task5: Expected= 1000000, min= 1000000, max= 1000000, ave= 1000000 usec, error= 0.0%
Grade= 100
edX code= AoCmaGam

Code:

os.c

```
// Riley Ruckman
// TCES460, Wi21
// Lab13 - os.c

// os.c
// Runs on LM4F120/TM4C123/MSP432
// Lab 2 starter file.
// Daniel Valvano
// February 20, 2016

#include <stdint.h>
#include "os.h"
#include "../inc/CortexM.h"
#include "../inc/BSP.h"

// function definitions in osasm.s
void StartOS(void);

tcbType tcbs[NUMTHREADS];
tcbType *RunPt;
int32_t Stacks[NUMTHREADS][STACKSIZE];

// ******** OS_Init ************
// Initialize operating system, disable interrupts
// Initialize OS controlled I/O: systick, bus clock as fast as possible
// Initialize OS global variables
// Inputs:  none
// Outputs: none
void OS_Init(void){
  DisableInterrupts();
  BSP_Clock_InitFastest();// set processor clock to fastest speed
  // initialize any global variables as needed
  //***YOU IMPLEMENT THIS FUNCTION*****

}

void SetInitialStack(int i){
  //***YOU IMPLEMENT THIS FUNCTION*****
          tcbs[i].sp = &Stacks[i][STACKSIZE-16]; // thread stack pointer
  Stacks[i][STACKSIZE-1] = 0x01000000;   // thumb bit
```

```
  Stacks[i][STACKSIZE-3] = 0x14141414;   // R14
  Stacks[i][STACKSIZE-4] = 0x12121212;   // R12
  Stacks[i][STACKSIZE-5] = 0x03030303;   // R3
  Stacks[i][STACKSIZE-6] = 0x02020202;   // R2
  Stacks[i][STACKSIZE-7] = 0x01010101;   // R1
  Stacks[i][STACKSIZE-8] = 0x00000000;   // R0
  Stacks[i][STACKSIZE-9] = 0x11111111;   // R11
  Stacks[i][STACKSIZE-10] = 0x10101010;  // R10
  Stacks[i][STACKSIZE-11] = 0x09090909;  // R9
  Stacks[i][STACKSIZE-12] = 0x08080808;  // R8
  Stacks[i][STACKSIZE-13] = 0x07070707;  // R7
  Stacks[i][STACKSIZE-14] = 0x06060606;  // R6
  Stacks[i][STACKSIZE-15] = 0x05050505;  // R5
  Stacks[i][STACKSIZE-16] = 0x04040404;  // R4
}

//******** OS_AddThreads ***************
// Add four main threads to the scheduler
// Inputs: function pointers to four void/void main threads
// Outputs: 1 if successful, 0 if this thread can not be added
// This function will only be called once, after OS_Init and before OS_Launch
int OS_AddThreads(void(*thread0)(void),
                  void(*thread1)(void),
                  void(*thread2)(void),
                  void(*thread3)(void)){ int32_t status;
          // initialize TCB circular list
          // initialize RunPt
          // initialize four stacks, including initial PC
  //***YOU IMPLEMENT THIS FUNCTION*****
          status = StartCritical();
  tcbs[0].next = &tcbs[1]; // 0 points to 1
  tcbs[1].next = &tcbs[2]; // 1 points to 2
  tcbs[2].next = &tcbs[3]; // 2 points to 3
          tcbs[3].next = &tcbs[0]; // 3 points to 0

  SetInitialStack(0); Stacks[0][STACKSIZE-2] = (int32_t)(thread0); // PC
  SetInitialStack(1); Stacks[1][STACKSIZE-2] = (int32_t)(thread1); // PC
  SetInitialStack(2); Stacks[2][STACKSIZE-2] = (int32_t)(thread2); // PC
          SetInitialStack(3); Stacks[3][STACKSIZE-2] = (int32_t)(thread3); // PC
  RunPt = &tcbs[0];       // thread 0 will run first
  EndCritical(status);
  return 1;               // successful
}
```

```
//******** OS_AddThreads3 ***************
// add three foregound threads to the scheduler
// This is needed during debugging and not part of final solution
// Inputs: three pointers to a void/void foreground tasks
// Outputs: 1 if successful, 0 if this thread can not be added
int OS_AddThreads3(void(*task0)(void),
                   void(*task1)(void),
                   void(*task2)(void)){ int32_t status;
          // initialize TCB circular list (same as RTOS project)
          // initialize RunPt
          // initialize four stacks, including initial PC
  //***YOU IMPLEMENT THIS FUNCTION*****
          status = StartCritical();
  tcbs[0].next = &tcbs[1]; // 0 points to 1
  tcbs[1].next = &tcbs[2]; // 1 points to 2
  tcbs[2].next = &tcbs[0]; // 2 points to 0
  SetInitialStack(0); Stacks[0][STACKSIZE-2] = (int32_t)(task0); // PC
  SetInitialStack(1); Stacks[1][STACKSIZE-2] = (int32_t)(task1); // PC
  SetInitialStack(2); Stacks[2][STACKSIZE-2] = (int32_t)(task2); // PC
  RunPt = &tcbs[0];       // thread 0 will run first
  EndCritical(status);
  return 1;               // successful
}

//******** OS_AddPeriodicEventThreads ***************
// Add two background periodic event threads
// Typically this function receives the highest priority
// Inputs: pointers to a void/void event thread function2
//         periods given in units of OS_Launch (Lab 2 this will be msec)
// Outputs: 1 if successful, 0 if this thread cannot be added
// It is assumed that the event threads will run to completion and return
// It is assumed the time to run these event threads is short compared to 1 msec
// These threads cannot spin, block, loop, sleep, or kill
// These threads can call OS_Signal
void (*PeriodicEvent1)(void); // pointer to first periodic user function
uint32_t event1Period;                          // pointer to period of first periodic user
function
void (*PeriodicEvent2)(void); // pointer to second periodic user function
uint32_t event2Period;                          // pointer to period of second periodic user
function
int OS_AddPeriodicEventThreads(void(*thread1)(void), uint32_t period1,
  void(*thread2)(void), uint32_t period2){
  //***YOU IMPLEMENT THIS FUNCTION*****
          PeriodicEvent1 = thread1;
```

```
        event1Period = period1;
        PeriodicEvent2 = thread2;
        event2Period = period2;
  return 1;
}

//******** OS_Launch ***************
// Start the scheduler, enable interrupts
// Inputs: number of clock cycles for each time slice
// Outputs: none (does not return)
// Errors: theTimeSlice must be less than 16,777,216
void OS_Launch(uint32_t theTimeSlice){
  STCTRL = 0;               // disable SysTick during setup
  STCURRENT = 0;            // any write to current clears it
  SYSPRI3 =(SYSPRI3&0x00FFFFFF)|0xE0000000; // priority 7
  STRELOAD = theTimeSlice - 1; // reload value
  STCTRL = 0x00000007;      // enable, core clock and interrupt arm
  StartOS();                // start on the first task
}

uint32_t Counter = 0;
// runs every ms
void Scheduler(void){ // every time slice
  // run any periodic event threads if needed
  // implement round robin scheduler, update RunPt
  //***YOU IMPLEMENT THIS FUNCTION*****
        Counter = (Counter + 1) % (event1Period*event2Period);
        if (Counter%event1Period == 0)
                (*PeriodicEvent1)();

        if (Counter%event2Period == 1)
                (*PeriodicEvent2)();
        RunPt = RunPt->next;// Round Robin scheduler
}

// ******** OS_InitSemaphore ************
// Initialize counting semaphore
// Inputs:  pointer to a semaphore
//          initial value of semaphore
// Outputs: none
void OS_InitSemaphore(int32_t *semaPt, int32_t value){
  //***YOU IMPLEMENT THIS FUNCTION*****
        *semaPt = value;
}
```

```
// ******** OS_Wait ************
// Decrement semaphore
// Lab2 spinlock (does not suspend while spinning)
// Lab3 block if less than zero
// Inputs:  pointer to a counting semaphore
// Outputs: none
void OS_Wait(int32_t *semaPt){
        DisableInterrupts();
        while((*semaPt) == 0) {
                EnableInterrupts();
                DisableInterrupts();
        }
        (*semaPt) = (*semaPt) - 1;
        EnableInterrupts();
}

// ******** OS_Signal ************
// Increment semaphore
// Lab2 spinlock
// Lab3 wakeup blocked thread if appropriate
// Inputs:  pointer to a counting semaphore
// Outputs: none
void OS_Signal(int32_t *semaPt){
//***YOU IMPLEMENT THIS FUNCTION*****
        DisableInterrupts();
        (*semaPt) = (*semaPt) + 1;
        EnableInterrupts();
}

// ******** OS_MailBox_Init ************
// Initialize communication channel
// Producer is an event thread, consumer is a main thread
// Inputs:  none
// Outputs: none
int32_t Mail;                           // Shared data
int32_t Send;           // semaphore for sent data
int32_t Ack;            // semaphore for data received acknowledgement
void OS_MailBox_Init(void){
  // include data field and semaphore
  //***YOU IMPLEMENT THIS FUNCTION*****
        Mail = 0;
        Send = 0;
        Ack = 0;
```

```
}

// ******** OS_MailBox_Send ************
// Enter data into the MailBox, do not spin/block if full
// Use semaphore to synchronize with OS_MailBox_Recv
// Inputs:  data to be sent
// Outputs: none
// Errors: data lost if MailBox already has data
uint32_t Lost = 0;
void OS_MailBox_Send(uint32_t data){
  //***YOU IMPLEMENT THIS FUNCTION*****
        Mail = data;
        if(Send) {
                Lost++;
        } else {
                OS_Signal(&Send);
        }
}

// ******** OS_MailBox_Recv ************
// retreive mail from the MailBox
// Use semaphore to synchronize with OS_MailBox_Send
// Lab 2 spin on semaphore if mailbox empty
// Lab 3 block on semaphore if mailbox empty
// Inputs:  none
// Outputs: data retreived
// Errors:  none
uint32_t OS_MailBox_Recv(void){
  //***YOU IMPLEMENT THIS FUNCTION*****
        OS_Wait(&Send);
  return Mail;
}
```

os.h

```
// os.h
// Runs on LM4F120/TM4C123/MSP432
// A very simple real time operating system with minimal features.
// Daniel Valvano
// February 20, 2016

/* This example accompanies the book

   "Embedded Systems: Real-Time Operating Systems for ARM Cortex-M Microcontrollers",
   ISBN: 978-1466468863, , Jonathan Valvano, copyright (c) 2016
   Programs 4.4 through 4.12, section 4.2

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 OR CONSEQUENTIAL DAMAGES, FOR ANY REASON WHATSOEVER.
 For more information about my classes, my research, and my books, see
 http://users.ece.utexas.edu/~valvano/
 */


#ifndef __OS_H
#define __OS_H  1
// grader needs access to TCBs and stacks
#define NUMTHREADS  4        // maximum number of threads
#define STACKSIZE   100      // number of 32-bit words in stack per thread
struct tcb{
  int32_t *sp;       // pointer to stack (valid for threads not running
  struct tcb *next;  // linked-list pointer
};
typedef struct tcb tcbType;

// ******** OS_Init ************
// Initialize operating system, disable interrupts
// Initialize OS controlled I/O: systick, bus clock as fast as possible
```

```
// Initialize OS global variables
// Inputs:  none
// Outputs: none
void OS_Init(void);



//******** OS_AddThreads ***************
// Add four main threads to the scheduler
// Inputs: function pointers to four void/void main threads
// Outputs: 1 if successful, 0 if this thread can not be added
// This function will only be called once, after OS_Init and before OS_Launch
int OS_AddThreads(void(*thread0)(void),
                  void(*thread1)(void),
                  void(*thread2)(void),
                  void(*thread3)(void));

//******** OS_AddThreads3 ***************
// add three foregound threads to the scheduler
// This is needed during debugging and not part of final solution
// Inputs: three pointers to a void/void foreground tasks
// Outputs: 1 if successful, 0 if this thread can not be added
int OS_AddThreads3(void(*task0)(void),
                   void(*task1)(void),
                   void(*task2)(void));

//******** OS_AddPeriodicEventThreads ***************
// Add two background periodic event threads
// Typically this function receives the highest priority
// Inputs: pointers to a void/void event thread function2
//         periods given in units of OS_Launch (Lab 2 this will be msec)
// Outputs: 1 if successful, 0 if this thread cannot be added
// It is assumed that the event threads will run to completion and return
// It is assumed the time to run these event threads is short compared to 1 msec
// These threads cannot spin, block, loop, sleep, or kill
// These threads can call OS_Signal
int OS_AddPeriodicEventThreads(void(*thread1)(void), uint32_t period1,
  void(*thread2)(void), uint32_t period2);

//******** OS_Launch ***************
// Start the scheduler, enable interrupts
// Inputs: number of clock cycles for each time slice
// Outputs: none (does not return)
// Errors: theTimeSlice must be less than 16,777,216
```

```
void OS_Launch(uint32_t theTimeSlice);


// ******** OS_InitSemaphore ************
// Initialize counting semaphore
// Inputs:  pointer to a semaphore
//          initial value of semaphore
// Outputs: none
void OS_InitSemaphore(int32_t *semaPt, int32_t value);

// ******** OS_Wait ************
// Decrement semaphore
// Lab2 spinlock (does not suspend while spinning)
// Lab3 block if less than zero
// Inputs:  pointer to a counting semaphore
// Outputs: none
void OS_Wait(int32_t *semaPt);

// ******** OS_Signal ************
// Increment semaphore
// Lab2 spinlock
// Lab3 wakeup blocked thread if appropriate
// Inputs:  pointer to a counting semaphore
// Outputs: none
void OS_Signal(int32_t *semaPt);

// ******** OS_MailBox_Init ************
// Initialize communication channel
// Producer is an event thread, consumer is a main thread
// Inputs:  none
// Outputs: none
void OS_MailBox_Init(void);

// ******** OS_MailBox_Send ************
// Enter data into the MailBox, do not spin/block if full
// Use semaphore to synchronize with OS_MailBox_Recv
// Inputs:  data to be sent
// Outputs: none
// Errors: data lost if MailBox already has data
void OS_MailBox_Send(uint32_t data);

// ******** OS_MailBox_Recv ************
// retreive mail from the MailBox
// Use semaphore to synchronize with OS_MailBox_Send
```

```
// Lab 2 spin on semaphore if mailbox empty
// Lab 3 block on semaphore if mailbox empty
// Inputs:  none
// Outputs: data retreived
// Errors:  none
uint32_t OS_MailBox_Recv(void);

#endif
```

osasm.s

```
; Riley Ruckman
; TCES460, Wi21
; Lab13 - os.c

;/*****************************************************************************/
; OSasm.s: low-level OS commands, written in assembly                       */
; Runs on LM4F120/TM4C123/MSP432
; Lab 2 starter file
; February 10, 2016
;


      AREA |.text|, CODE, READONLY, ALIGN=2
      THUMB
      REQUIRE8
      PRESERVE8

      EXTERN  RunPt          ; currently running thread
      EXPORT  StartOS
      EXPORT  SysTick_Handler
      IMPORT  Scheduler


SysTick_Handler               ; 1) Saves R0-R3,R12,LR,PC,PSR
   CPSID   I                  ; 2) Prevent interrupt during switch
   PUSH    {R4-R11}           ; 3) Save remaining regs r4-11
   LDR     R0, =RunPt         ; 4) R0=pointer to RunPt, old thread
   LDR     R1, [R0]           ;    R1 = RunPt
   STR     SP, [R1]           ; 5) Save SP into TCB
;   LDR     R1, [R1,#4]       ; 6) R1 = RunPt->next
;   STR     R1, [R0]          ;    RunPt = R1
   PUSH    {R0,LR}
   BL      Scheduler
   POP     {R0,LR}
   LDR     R1, [R0]           ; 6) R1 = RunPt, new thread
   LDR     SP, [R1]           ; 7) new thread SP; SP = RunPt->sp;
   POP     {R4-R11}           ; 8) restore regs r4-11
   CPSIE   I                  ; 9) tasks run with interrupts enabled
   BX      LR                 ; 10) restore R0-R3,R12,LR,PC,PSR

StartOS
   LDR     R0, =RunPt         ; currently running thread
```

```
LDR     R2, [R0]          ; R2 = value of RunPt
LDR     SP, [R2]          ; new thread SP; SP = RunPt->stackPointer;
POP     {R4-R11}          ; restore regs r4-11
POP     {R0-R3}           ; restore regs r0-3
POP     {R12}
ADD     SP,SP,#4          ; discard LR from initial stack
POP     {LR}              ; start location
ADD     SP,SP,#4          ; discard PSR
CPSIE   I                 ; Enable interrupts at processor level
BX      LR                ; start first thread

ALIGN
END
```

Code Screenshots:

os.c

```
// Riley Ruckman
// TCES460, Wi21
// Lab13 - os.c

// os.c
// Runs on LM4F120/TM4C123/MSP432
// Lab 2 starter file.
// Daniel Valvano
// February 20, 2016

#include <stdint.h>
#include "os.h"
#include "../inc/CortexM.h"
#include "../inc/BSP.h"

// function definitions in osasm.s
void StartOS(void);

tcbType tcbs[NUMTHREADS];
tcbType *RunPt;
int32_t Stacks[NUMTHREADS][STACKSIZE];

// ******** OS_Init ************
// Initialize operating system, disable interrupts
// Initialize OS controlled I/O: systick, bus clock as fast as possible
// Initialize OS global variables
// Inputs:  none
// Outputs: none
void OS_Init(void){
  DisableInterrupts();
  BSP_Clock_InitFastest();// set processor clock to fastest speed
  // initialize any global variables as needed
  //***YOU IMPLEMENT THIS FUNCTION*****

}

void SetInitialStack(int i){
  //***YOU IMPLEMENT THIS FUNCTION*****
  tcbs[i].sp = &Stacks[i][STACKSIZE-16]; // thread stack pointer
  Stacks[i][STACKSIZE-1] = 0x01000000;   // thumb bit
  Stacks[i][STACKSIZE-3] = 0x14141414;   // R14
  Stacks[i][STACKSIZE-4] = 0x12121212;   // R12
  Stacks[i][STACKSIZE-5] = 0x03030303;   // R3
  Stacks[i][STACKSIZE-6] = 0x02020202;   // R2
  Stacks[i][STACKSIZE-7] = 0x01010101;   // R1
  Stacks[i][STACKSIZE-8] = 0x00000000;   // R0
  Stacks[i][STACKSIZE-9] = 0x11111111;   // R11
  Stacks[i][STACKSIZE-10] = 0x10101010;  // R10
  Stacks[i][STACKSIZE-11] = 0x09090909;  // R9
  Stacks[i][STACKSIZE-12] = 0x08080808;  // R8
  Stacks[i][STACKSIZE-13] = 0x07070707;  // R7
  Stacks[i][STACKSIZE-14] = 0x06060606;  // R6
  Stacks[i][STACKSIZE-15] = 0x05050505;  // R5
```

```
54    Stacks[i][STACKSIZE-16] = 0x04040404;  // R4
55  }
56
57  //******** OS_AddThreads ***************
58  // Add four main threads to the scheduler
59  // Inputs: function pointers to four void/void main threads
60  // Outputs: 1 if successful, 0 if this thread can not be added
61  // This function will only be called once, after OS_Init and before OS_Launch
62  int OS_AddThreads(void(*thread0)(void),
63                    void(*thread1)(void),
64                    void(*thread2)(void),
65                    void(*thread3)(void)){ int32_t status;
66    // initialize TCB circular list
67    // initialize RunPt
68    // initialize four stacks, including initial PC
69    //***YOU IMPLEMENT THIS FUNCTION*****
70    status = StartCritical();
71    tcbs[0].next = &tcbs[1]; // 0 points to 1
72    tcbs[1].next = &tcbs[2]; // 1 points to 2
73    tcbs[2].next = &tcbs[3]; // 2 points to 3
74    tcbs[3].next = &tcbs[0]; // 3 points to 0
75    SetInitialStack(0); Stacks[0][STACKSIZE-2] = (int32_t)(thread0); // PC
76    SetInitialStack(1); Stacks[1][STACKSIZE-2] = (int32_t)(thread1); // PC
77    SetInitialStack(2); Stacks[2][STACKSIZE-2] = (int32_t)(thread2); // PC
78    SetInitialStack(3); Stacks[3][STACKSIZE-2] = (int32_t)(thread3); // PC
79    RunPt = &tcbs[0];       // thread 0 will run first
80    EndCritical(status);
81    return 1;               // successful
82  }
83
84  //******** OS_AddThreads3 ***************
85  // add three foregound threads to the scheduler
86  // This is needed during debugging and not part of final solution
87  // Inputs: three pointers to a void/void foreground tasks
88  // Outputs: 1 if successful, 0 if this thread can not be added
89  int OS_AddThreads3(void(*task0)(void),
90                     void(*task1)(void),
91                     void(*task2)(void)){ int32_t status;
92    // initialize TCB circular list (same as RTOS project)
93    // initialize RunPt
94    // initialize four stacks, including initial PC
95    //***YOU IMPLEMENT THIS FUNCTION*****
96    status = StartCritical();
97    tcbs[0].next = &tcbs[1]; // 0 points to 1
98    tcbs[1].next = &tcbs[2]; // 1 points to 2
99    tcbs[2].next = &tcbs[0]; // 2 points to 0
100   SetInitialStack(0); Stacks[0][STACKSIZE-2] = (int32_t)(task0); // PC
101   SetInitialStack(1); Stacks[1][STACKSIZE-2] = (int32_t)(task1); // PC
102   SetInitialStack(2); Stacks[2][STACKSIZE-2] = (int32_t)(task2); // PC
103   RunPt = &tcbs[0];       // thread 0 will run first
104   EndCritical(status);
```

```
105   return 1;               // successful
106 }
107
108 //******** OS_AddPeriodicEventThreads ***************
109 // Add two background periodic event threads
110 // Typically this function receives the highest priority
111 // Inputs: pointers to a void/void event thread function2
112 //         periods given in units of OS_Launch (Lab 2 this will be msec)
113 // Outputs: 1 if successful, 0 if this thread cannot be added
114 // It is assumed that the event threads will run to completion and return
115 // It is assumed the time to run these event threads is short compared to 1 msec
116 // These threads cannot spin, block, loop, sleep, or kill
117 // These threads can call OS_Signal
118 void (*PeriodicEvent1)(void);   // pointer to first periodic user function
119 uint32_t event1Period;         // pointer to period of first periodic user function
120 void (*PeriodicEvent2)(void);   // pointer to second periodic user function
121 uint32_t event2Period;         // pointer to period of second periodic user function
122 int OS_AddPeriodicEventThreads(void(*thread1)(void), uint32_t period1,
123   void(*thread2)(void), uint32_t period2){
124   //***YOU IMPLEMENT THIS FUNCTION*****
125   PeriodicEvent1 = thread1;
126   event1Period = period1;
127   PeriodicEvent2 = thread2;
128   event2Period = period2;
129   return 1;
130 }
131
132 //******** OS_Launch ***************
133 // Start the scheduler, enable interrupts
134 // Inputs: number of clock cycles for each time slice
135 // Outputs: none (does not return)
136 // Errors: theTimeSlice must be less than 16,777,216
137 void OS_Launch(uint32_t theTimeSlice){
138   STCTRL = 0;                  // disable SysTick during setup
139   STCURRENT = 0;               // any write to current clears it
140   SYSPRI3 =(SYSPRI3&0x00FFFFFF)|0xE0000000; // priority 7
141   STRELOAD = theTimeSlice - 1; // reload value
142   STCTRL = 0x00000007;         // enable, core clock and interrupt arm
143   StartOS();                   // start on the first task
144 }
145
146 uint32_t Counter = 0;
147 // runs every ms
148 void Scheduler(void){ // every time slice
149   // run any periodic event threads if needed
150   // implement round robin scheduler, update RunPt
151   //***YOU IMPLEMENT THIS FUNCTION*****
152   Counter = (Counter + 1) % (event1Period*event2Period);
153   if (Counter%event1Period == 0)
154     (*PeriodicEvent1)();
155
```

```
156     if (Counter%event2Period == 1)
157       (*PeriodicEvent2)();
158     RunPt = RunPt->next;  // Round Robin scheduler
159   }
160
161   // ******** OS_InitSemaphore ************
162   // Initialize counting semaphore
163   // Inputs:  pointer to a semaphore
164   //          initial value of semaphore
165   // Outputs: none
166   void OS_InitSemaphore(int32_t *semaPt, int32_t value){
167     //***YOU IMPLEMENT THIS FUNCTION*****
168     *semaPt = value;
169   }
170
171   // ******** OS_Wait ************
172   // Decrement semaphore
173   // Lab2 spinlock (does not suspend while spinning)
174   // Lab3 block if less than zero
175   // Inputs:  pointer to a counting semaphore
176   // Outputs: none
177   void OS_Wait(int32_t *semaPt){
178     DisableInterrupts();
179     while((*semaPt) == 0) {
180       EnableInterrupts();
181       DisableInterrupts();
182     }
183     (*semaPt) = (*semaPt) - 1;
184     EnableInterrupts();
185   }
186
187   // ******** OS_Signal ************
188   // Increment semaphore
189   // Lab2 spinlock
190   // Lab3 wakeup blocked thread if appropriate
191   // Inputs:  pointer to a counting semaphore
192   // Outputs: none
193   void OS_Signal(int32_t *semaPt){
194   //***YOU IMPLEMENT THIS FUNCTION*****
195     DisableInterrupts();
196     (*semaPt) = (*semaPt) + 1;
197     EnableInterrupts();
198   }
199
200   // ******** OS_MailBox_Init ************
201   // Initialize communication channel
202   // Producer is an event thread, consumer is a main thread
203   // Inputs:  none
204   // Outputs: none
205   int32_t Mail;       // Shared data
206   int32_t Send;   // semaphore for sent data
```

```
207  int32_t Ack;    // semaphore for data received acknowledgement
208  void OS_MailBox_Init(void){
209    // include data field and semaphore
210    //***YOU IMPLEMENT THIS FUNCTION*****
211    Mail = 0;
212    Send = 0;
213    Ack = 0;
214  }
215
216  // ******** OS_MailBox_Send ************
217  // Enter data into the MailBox, do not spin/block if full
218  // Use semaphore to synchronize with OS_MailBox_Recv
219  // Inputs:  data to be sent
220  // Outputs: none
221  // Errors: data lost if MailBox already has data
222  uint32_t Lost = 0;
223  void OS_MailBox_Send(uint32_t data){
224    //***YOU IMPLEMENT THIS FUNCTION*****
225    Mail = data;
226    if(Send) {
227      Lost++;
228    } else {
229      OS_Signal(&Send);
230    }
231  }
232
233  // ******** OS_MailBox_Recv ************
234  // retreive mail from the MailBox
235  // Use semaphore to synchronize with OS_MailBox_Send
236  // Lab 2 spin on semaphore if mailbox empty
237  // Lab 3 block on semaphore if mailbox empty
238  // Inputs:  none
239  // Outputs: data retreived
240  // Errors:  none
241  uint32_t OS_MailBox_Recv(void){
242    //***YOU IMPLEMENT THIS FUNCTION*****
243    OS_Wait(&Send);
244    return Mail;
245  }
246
```

os.h

```
// os.h
// Runs on LM4F120/TM4C123/MSP432
// A very simple real time operating system with minimal features.
// Daniel Valvano
// February 20, 2016

/* This example accompanies the book

   "Embedded Systems: Real-Time Operating Systems for ARM Cortex-M Microcontrollers",
   ISBN: 978-1466468863, , Jonathan Valvano, copyright (c) 2016
   Programs 4.4 through 4.12, section 4.2

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 For more information about my classes, my research, and my books, see
 http://users.ece.utexas.edu/~valvano/
 */


#ifndef __OS_H
#define __OS_H  1
// grader needs access to TCBs and stacks
#define NUMTHREADS  4        // maximum number of threads
#define STACKSIZE   100      // number of 32-bit words in stack per thread
struct tcb{
  int32_t *sp;       // pointer to stack (valid for threads not running
  struct tcb *next;  // linked-list pointer
};
typedef struct tcb tcbType;

// ******** OS_Init ************
// Initialize operating system, disable interrupts
// Initialize OS controlled I/O: systick, bus clock as fast as possible
// Initialize OS global variables
// Inputs:  none
// Outputs: none
void OS_Init(void);



//******** OS_AddThreads ***************
// Add four main threads to the scheduler
// Inputs: function pointers to four void/void main threads
// Outputs: 1 if successful, 0 if this thread can not be added
// This function will only be called once, after OS_Init and before OS_Launch
int OS_AddThreads(void(*thread0)(void),
                  void(*thread1)(void),
```

```
                  void(*thread2)(void),
                  void(*thread3)(void));

//******** OS_AddThreads3 ***************
// add three foregound threads to the scheduler
// This is needed during debugging and not part of final solution
// Inputs: three pointers to a void/void foreground tasks
// Outputs: 1 if successful, 0 if this thread can not be added
int OS_AddThreads3(void(*task0)(void),
                   void(*task1)(void),
                   void(*task2)(void));

//******** OS_AddPeriodicEventThreads ***************
// Add two background periodic event threads
// Typically this function receives the highest priority
// Inputs: pointers to a void/void event thread function2
//         periods given in units of OS_Launch (Lab 2 this will be msec)
// Outputs: 1 if successful, 0 if this thread cannot be added
// It is assumed that the event threads will run to completion and return
// It is assumed the time to run these event threads is short compared to 1 msec
// These threads cannot spin, block, loop, sleep, or kill
// These threads can call OS_Signal
int OS_AddPeriodicEventThreads(void(*thread1)(void), uint32_t period1,
  void(*thread2)(void), uint32_t period2);

//******** OS_Launch ***************
// Start the scheduler, enable interrupts
// Inputs: number of clock cycles for each time slice
// Outputs: none (does not return)
// Errors: theTimeSlice must be less than 16,777,216
void OS_Launch(uint32_t theTimeSlice);


// ******** OS_InitSemaphore ************
// Initialize counting semaphore
// Inputs:  pointer to a semaphore
//          initial value of semaphore
// Outputs: none
void OS_InitSemaphore(int32_t *semaPt, int32_t value);

// ******** OS_Wait ************
// Decrement semaphore
// Lab2 spinlock (does not suspend while spinning)
// Lab3 block if less than zero
// Inputs:  pointer to a counting semaphore
// Outputs: none
void OS_Wait(int32_t *semaPt);

// ******** OS_Signal ************
// Increment semaphore
// Lab2 spinlock
```

```
105 // Lab3 wakeup blocked thread if appropriate
106 // Inputs:  pointer to a counting semaphore
107 // Outputs: none
108 void OS_Signal(int32_t *semaPt);
109
110 // ******** OS_MailBox_Init ************
111 // Initialize communication channel
112 // Producer is an event thread, consumer is a main thread
113 // Inputs:  none
114 // Outputs: none
115 void OS_MailBox_Init(void);
116
117 // ******** OS_MailBox_Send ************
118 // Enter data into the MailBox, do not spin/block if full
119 // Use semaphore to synchronize with OS_MailBox_Recv
120 // Inputs:  data to be sent
121 // Outputs: none
122 // Errors: data lost if MailBox already has data
123 void OS_MailBox_Send(uint32_t data);
124
125 // ******** OS_MailBox_Recv ************
126 // retreive mail from the MailBox
127 // Use semaphore to synchronize with OS_MailBox_Send
128 // Lab 2 spin on semaphore if mailbox empty
129 // Lab 3 block on semaphore if mailbox empty
130 // Inputs:  none
131 // Outputs: data retreived
132 // Errors:  none
133 uint32_t OS_MailBox_Recv(void);
134
135 #endif
136
```

osasm.s

```
; Riley Ruckman
; TCES460, Wi21
; Lab13 - os.c

;/*****************************************************************************/
; OSasm.s: low-level OS commands, written in assembly                       */
; Runs on LM4F120/TM4C123/MSP432
; Lab 2 starter file
; February 10, 2016
;


        AREA |.text|, CODE, READONLY, ALIGN=2
        THUMB
        REQUIRE8
        PRESERVE8

        EXTERN  RunPt            ; currently running thread
        EXPORT  StartOS
        EXPORT  SysTick_Handler
        IMPORT  Scheduler


SysTick_Handler                ; 1) Saves R0-R3,R12,LR,PC,PSR
    CPSID   I                  ; 2) Prevent interrupt during switch
    PUSH    {R4-R11}           ; 3) Save remaining regs r4-11
    LDR     R0, =RunPt         ; 4) R0=pointer to RunPt, old thread
    LDR     R1, [R0]           ;    R1 = RunPt
    STR     SP, [R1]           ; 5) Save SP into TCB
;    LDR     R1, [R1,#4]       ; 6) R1 = RunPt->next
;    STR     R1, [R0]          ;    RunPt = R1
    PUSH    {R0,LR}
    BL      Scheduler
    POP     {R0,LR}
    LDR     R1, [R0]           ; 6) R1 = RunPt, new thread
    LDR     SP, [R1]           ; 7) new thread SP; SP = RunPt->sp;
    POP     {R4-R11}           ; 8) restore regs r4-11
    CPSIE   I                  ; 9) tasks run with interrupts enabled
    BX      LR                 ; 10) restore R0-R3,R12,LR,PC,PSR

StartOS
    LDR     R0, =RunPt         ; currently running thread
    LDR     R2, [R0]           ; R2 = value of RunPt
    LDR     SP, [R2]           ; new thread SP; SP = RunPt->stackPointer;
    POP     {R4-R11}           ; restore regs r4-11
    POP     {R0-R3}            ; restore regs r0-3
    POP     {R12}
    ADD     SP,SP,#4           ; discard LR from initial stack
    POP     {LR}               ; start location
    ADD     SP,SP,#4           ; discard PSR
    CPSIE   I                  ; Enable interrupts at processor level
    BX      LR                 ; start first thread

```

```
54      ALIGN
55      END
56
```