Final Exam

Date: May 16, 2022

UT EID: _Solution_

Printed Name: Sol
Last, First

Your signature is your promise that you have not cheated and will not cheat on this exam, nor will you help others to cheat on this exam:

Signature: ____

Instructions:

- Closed book and closed notes. No books, no papers, no data sheets (other than the last two pages of this Exam)
- No devices other than pencil, pen, eraser (no calculators, no electronic devices), please turn cell phones off.
- Please be sure that your answers to all questions (and all supporting work that is required) are contained in the space (boxes) provided. Do Not write answers on back of pages
- You have 180 minutes, so allocate your time accordingly.
- Unless otherwise stated, make all I/O accesses friendly.
- Please read the entire exam before starting.

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Total	100	

[15 points] Problem 1: Fundamentals. Answer the following short questions in the boxes provided.

1. (**5 pts**) Consider this piece of C code

```
const uint32_t *pt;
uint32_t Operate(uint32_t y){
  static uint32_t z=0;

  z++;

  return y+z;

}
```

A) Permanent in RAM
B) Permanent in nonvolatile ROM
C) Temporary in R0
D) On the stack
E) None of the above

Answer the following with one letter A – E (see above for meaning) assuming AAPCS.

a. (**2pts**) Where is the variable **pt** located? A)Permanent RAM
The data is in ROM, the pointer in RAM

b. (**1 pt**) Where is the parameter **y** located? C) R0
AAPCS

c. (**2 pts**) Where is the variable **z** located? A)Permanent RAM

This is a static variable

2. (**2 pts**) You performed `UART1_ICR_R=0x00000010;` in Lab 9. What does this do?

Acknowledged the interrupt or clears trigger flag, clears bit 4 in RIS register. Bit 4 was set when receiver fifo went from 7 to 8 elements

3. (**3 pts**) Assume memory contains byte values given below (left). Assume `R0 = 0x20000002`. What will be the value in `R1` if the instruction given on the right is executed? (Give your answer in hexadecimal.)

```
0x20000000 contains  0x44
0x20000001 contains  0x53
0x20000002 contains  0x62
0x20000003 contains  0x87
0x20000004 contains  0x98
0x20000005 contains  0xA2
```

```
LDRSH R1,[R0]
```

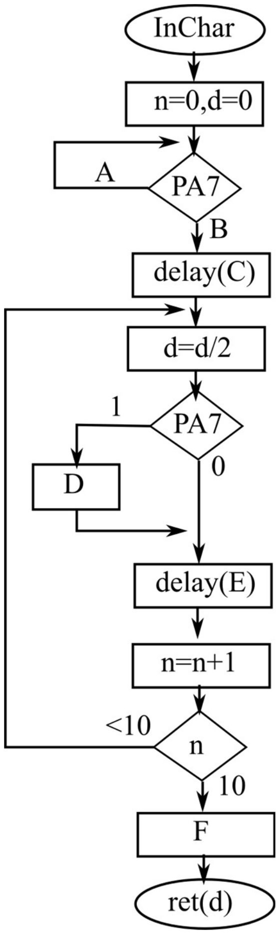
0xFFFF8762

R1:

We asked this question twice during quizzes. Little endian so gets 0x8762. Signed, so bit 15 is extended to bits 16-31

4. (**5 pts**) It is possible to communicate between two TM4Cs using the UART protocol without the UART hardware. It is done by following a strict protocol of writing bits to a GPIO pin with proper timing between bit writes if you are implementing the sender or bit reads if you are implementing the receiver. This is called bit-banging. The flowchart below is one possible algorithm to receive 8 bits of data, with some missing pieces that you have to choose from the options given. The C prototype for this function is **`uint8_t InChar(void);`**

The **`InChar()`** function uses the GPIO input pin, PA7. The protocol is 1 start bit, 8 data bits, and 1 stop bit (just like UART). You want to read the PA7 in the middle of the bit-time. The bit time is 10 ms. There is a function called **`delay(t)`** with input parameter **`t`** that waits exactly **`t`** ms. This **`InChar()`** function, when called, will wait for an incoming frame, accept the 10 bits, and return the 8-bit data value for the frame. Choose the best answers 1 2 3 or 4 for each box.



AB 1) A=0; B=1
2) A=1; B=0 wait for start bit
3) A none; B=0 or 1
4) other, specify the correct answer

□ 2

C 1) 0 ms
2) 5 ms to read in the middle
3) 10 ms
4) other, specify the correct answer

□ 2

D 1) d = d+1
2) d = d+0x80
3) d = d+0x200 enter on left because d is shifted to right
4) other, specify the correct answer

□ 3

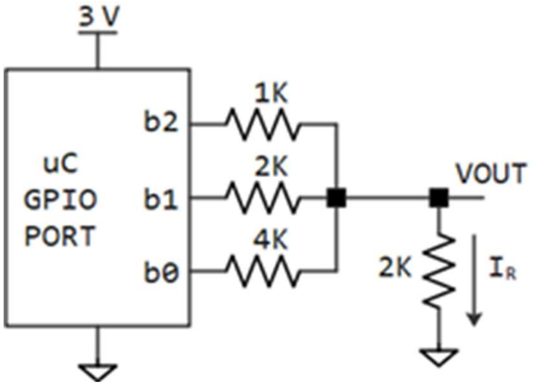
E 1) 0 ms
2) 5 ms
3) 10 ms this is the bit time
4) other, specify the correct answer

□ 3

F 1) d = d&0x01FE
2) d = d&0x00FF
3) d = (d/2)&0x00FF remove stop and start bits leave 8 data bits
4) other, specify the correct answer

□ 3

[10 points] Problem 2: DAC and circuits.
An engineering student who has taken EE 319K built the following DAC circuit. The analog **VOUT** is a linear function of the digital output of the microcontroller, but this DAC works differently than the DAC in Lab 6. Assume that a logic-low results in 0V, and a logic-high results in 3.0V for this microcontroller.



Answer the following

a. (**3 pts**) What is **VOUT** when the digital output is 0x1? Show your work.

2k||2k = 1k and 1k||1k = 0.5k Total resistance from b0 to GND is 4.5k
Voltage divider: Vout = 3.0V *0.5/4.5 = 3.0V/9 = 0.333V This is a 3-bit DAC with a resolution of 0.333V, so
Digital Analog Vout = n*0.333V

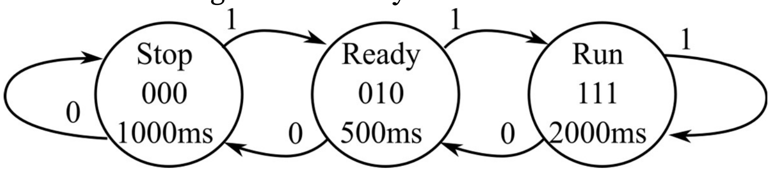
b. (**3 pts**) What is **VOUT** when the digital output is 0x7? Show your work.

2k||4k =2*4/(2+4) = (4/3)k (4/3)k||1k = (4/3)/(1+4/3) k = (4/7) k
Total resistance from b2,b1,b0=3.0 to GND is (2+(4/7))k = (18/7) k
Vout = 3V *2/(18/7) = 7/3 V = 2.333V, but it is easier to simply multiply by 0.333 by 7

c. (**4 pts**) For a particular digital output, the measured current through the $2K\Omega$ load resistor, $\mathbf{I_R}$, is between 0.6mA and 0.8mA. What was the digital output that resulted in this measurement? Show your work.

It is a DAC, let n be three bit digital value
VOUT = n*0.333V
0.6mA*2k = 1.2V, and 0.8mA*2k=1.6V, so answer is 0x04= 100
VOUT = 4*0.333V = 1.333V

[10 points] Problem 3: Finite State Machine. Consider the following FSM state transition graph (STG). The inputs and outputs in the STG are given in binary.



1. (**7 pts**) Complete the missing parts in the C implementation below. You do not implement the **doOutput** and **getInput** functions; these two functions are given.

```
enum StateNum {Stop, Ready, Run};
typedef enum StateNum SNum_t;

struct State {   // 1-bit input
  uint32_t Out;  // 3-bit output

  uint32_t Time; // 1ms units
 Snum_t        Next[  2  ];};
typedef const struct State State_t;

State_t FSM[3]={
{ 0x00 , 1000 ,{ Stop, Ready }},
{ 0x02 , 500 ,{ Stop Run }},
{ 0x07 , 2000 ,{ Ready,Run }}
};
```

```
int main(){
  SNum_t    CS = Stop;
  while(1){
   uint8_t in;
   doOutput(FSM[CS].Out);

   delay(FSM[CS].Time);
   in = getInput();

   CS = FSM[CS].Next[in]  ;

  }
}
```

2. (**3 pts**) Assuming the TM4C is running at 16 MHz, complete the following **delay** routine that was called to delay for **t** milliseconds. Assume SysTick is already initialized to run at 16 MHz without interrupts.

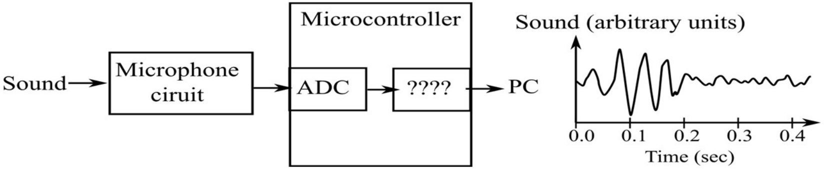
```
void delay(uint32_t t){
 for (uint32_t i=0; i < t; i++){

     NVIC_ST_RELOAD_R =  15900 to 16000  ; // 1ms is 16000

     NVIC_ST_CURRENT_R = 0;

     while ((NVIC_ST_CTL_R & 0x000010000 ) == 0){}// count flag
 }
}
```

[15 points] Problem 4: ADC, Interrupts, and Sampling

A microphone circuit has been hooked up to a stethoscope to form an electronic stethoscope that is used to measure fetal heart sounds.

- Fetal heart sounds have a frequency range of 50 to 200 Hz
- The analog microphone circuit behaves linearly and has a full-scale range of 20 Pascals (Pa). When the sound level is 0 Pa, the microphone circuit outputs 0V. When the sound level is 20 Pa, the circuit outputs 3.3V. When the sound level is 10 Pa, the circuit outputs 1.65V.

The output of the circuit is connected to the ADC on the microcontroller. One audible sound occurs with each heartbeat. The figure shows a typical sound:



The sound level will be stored in the computer as an 8-bit decimal fixed point number with resolution 0.1 Pa. The integer portion of the sound level should be stored in the following global

```
    uint8_t Isound; // 0.1 Pa
```

1. (**2 pts**) What is the minimum sampling rate that should be used to properly capture all signal content from a fetal heart?

   >400 Hz (strictly greater than) due to Nyquist

2. (**2 pts**) According to Valvano's postulate, what sampling rate should be used if you want to accurately recreate a graphical plot of the heart sounds being measured?

   >=2000 Hz (anything greater than or equal to 2000 Hz is acceptable)

3. (**3 pts**) What device would you use to communicate data to a PC, labeled as ???? in figure

   UART

4. (**10 pts**) Write the SysTick ISR in C that will perform the operations identified in comments below. The ADC has been initialized in 12-bit mode using sequencer 3, with software start. SysTick has been initialized to interrupt at the proper rate. The communication device you defined in question #3 has also been initialized. **Do not call any functions**, show all code needed. Comments to the right give you *what* needs to be done, you write the *code* to do it!!

`ADC0_PSSI_R = 0x0008;`	*// Start a conversion of the ADC*
`while((ADC0_RIS_R&0x08)==0){};`	*// Poll the ADC conversion status* *// and wait until ADC is complete* *// using busy-wait*

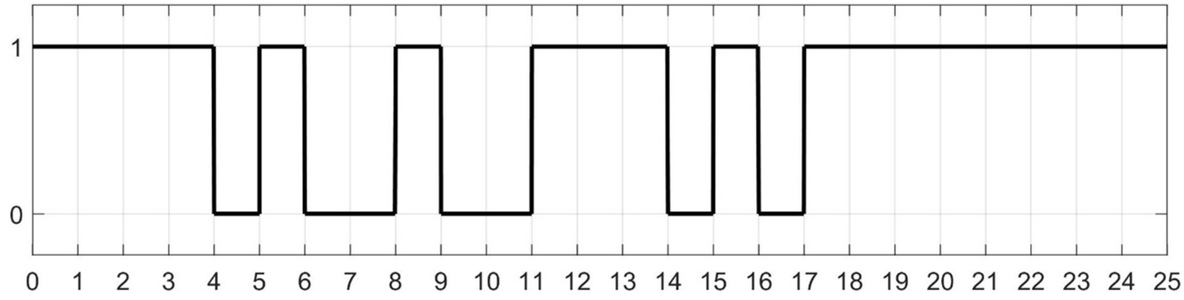
`uint32_t result = ADC0_SSFIFO3_R;`
`ADC0_ISC_R = 0x0008;`
	// Read the 12-bit ADC value from
	// the sequencer 3 FIFO and
	// acknowledge the ADC

`iSound = (result * 200) / 4096;`	*// Convert the ADC value to **iSound***

`while((UART0_FR_R&0x0020) != 0);`
`UART1_DR_R = iSound;`
	*// Send the **iSound** to the PC*
	// using busy-wait

[10 points] Problem 5: Communications/UART

An engineering student who has not taken EE 319K needs your help in identifying the data sent by a serial device. The student connected a logic analyzer to the UART output pin of the device and observed the following signal, which contains exactly **three frames**. Each frame has 1 start, **n** data bits, and 1 stop. There are no idle periods between the three frames. The time units on the graph are in ms.



Help the student decode the data message by answering the following questions.

1. (**4 pts**) What is the bit-time?

0.5ms

2. (**1 pts**) What is **n** (5 bits, 6 bits, 7 bits, or 8 bits)? **3 bits was not a choice**

8 bits

3. (**5 pts**) Decode the message as three hex values in the order they were sent by the device:

Frame 1 = 10000110 = 0x86 (ok if 128+6=134) -1 if all three are reversed and correct

Frame 2 = 11111000 = 0xF8

Frame 3 = 11100110 = 0xE6

[15 points] Problem 6: Stack You are given the following C code:

```
typedef struct nums {
   uint32_t a;
   uint32_t b;
   uint32_t c;
   uint32_t sum;
} nums_t;
void sum_nums(nums_t *inp){
 (*inp).sum = (*inp).a + (*inp).b + (*inp).c;
}
```

```
static uint32_t result;
int main() { nums_t test;
   test.a = 0x50600000;
   test.b = 0x03040000;
   test.c = 0x00001020;
   test.sum = 0;
   sum_nums(&test);
   result = test.sum; // xxx
}
```

1. (**5 pts**) The `main` function has a local variable called `test`, which is of type `nums_t` and is allocated on the stack. Assuming the initial value of the `SP` at the beginning of main is `0x20000320`, show the contents of the stack at the line marked **xxx**. The struct is written to stack with its attribute `'a'` at the top of the stack. Leave blank any values that are unknown. **Mark the `SP` after `test` is placed on stack.** Following AAPCS guidelines.

Address	Value (displayed in hex as uint32)
0x2000030C	Must be blank
SP->0x20000310	0x50600000(must fill in)
0x20000314	0x03040000(must fill in)
0x20000318	0x00001020(must fill in)
0x2000031C	0x53641020 (must fill in)
0x20000320 (initial SP)	Must be blank
0x20000324	Must be blank

2. (**4 pts**) The function `sum_nums` is called by main passing the address of the local variable `test` to the function. In which register does the function receive this address, and what are the contents of this register?

Register: R0	Contents: 0x20000310

3. (**6 pts**) Convert the `sum_nums` function to assembly. It is partially done for you:

```
sum_nums     ;could just push R4, must match return
    push { R4,LR     }      ; you must use R4 in the next line
    LDR R4, [R0 ,  #0]      ; R4 = (*inp).a

    LDR R1,[R0,#4] ;R1 = (*inp).b
    LDR R2,[R0,#8] ;R1 = (*inp).c
    ADD R4,R4,R1
    ADD R4,R4,R2
    STR R4,[R0,#12] ;(*inp).sum = sum of three fields
    pop { R4,PC       } ; if didn't push LR, then must add BX LR
```

[10 points] Problem 7: Stack in C

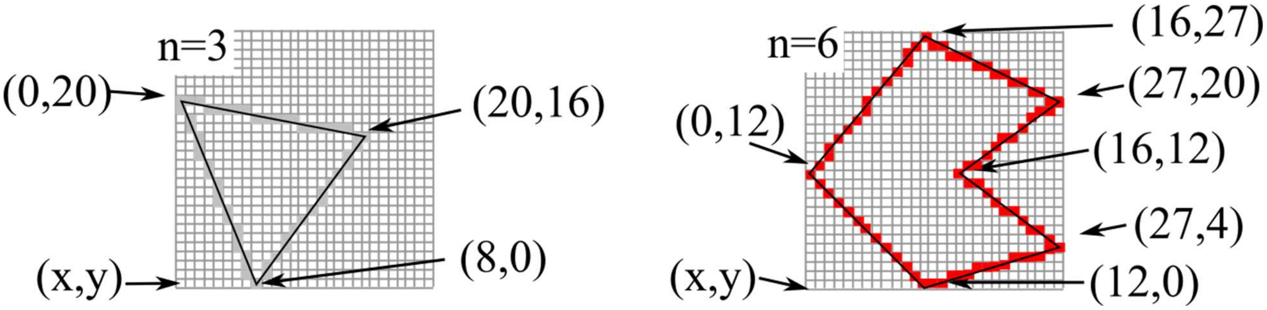
You will complete the implementation of a stack data structure where each element of the stack is a 16-bit unsigned integer. Hint: This works similar to assembly *push* and *pop* instructions with the `top` serving as the Stack Pointer. *Two good answers* blue *and* red. Notice the order of read/write and increment/decrement must be different between push and pop

```
// Variables and Constants
#define N 200   // Size of Stk
#define Fail  0
#define Success 1

uint16_t Stk[N]; // Stack Storage

// pointer to topmost element
uint16_t *top;

// Initialize the Stk to empty
// Input: None
// Make Stk empty
void Stk_Init(){
  // Initialize top

    top =  &Stk[N]                   ;

           &Stk[0]
}
```

```
// Push an item on the Stack
// Input: data has item to pushed
// Output: Success or Fail
int Stk_Push(uint16_t data){
  // check full
  if (   top == &Stk[0]                ) {
         top == &Stk[N]

     return Fail;
  }
  // Push data onto stack (2 lines)
   top--;
   *top = data;

   *top = data;
   top++;
  return Success;
}
// Pop an item from the Stack
// Input: dataptr pointer to empty place
//   into which data is to be popped
// Output: Success or Fail
int Stk_Pop(uint16_t *dataptr){
  // check Empty
  if (   top == &Stk[N]           ) {
         top == &Stk[0]
     return Fail;
  }
  // Pop from stack, write to *dataptr
  // with top value from stack (2 lines)
  *dataptr = *top;
   top--;

  top++;
  *dataptr = *top;

  return Success;
}
```

[15 points] Problem 8: **Programming, Data structures, and Design.**

The goal is to implement a sprite system that can represent closed polygons. Each polygon has an (x,y) position specifying the location of the lower left corner of the sprite within the LCD coordinate space. The vertices of the polygon are defined as a variable length array of points, relative to the (x,y) position. Polygons have 3 to 10 vertices, life, and color. The figure below shows examples of two polygons of 3 and 6 vertices. Note, the vertices are in the order they have to be connected to form the polygon, including connecting the last vertex to the first vertex.



The sprite data structure is fixed and should not be changed.

```
struct point{
  int32_t dx; // location relative to sprite position x
  int32_t dy; // location relative to sprite position y
};
typedef struct point point_t;

struct sprite{
  int32_t x,y;      // lower left corner of sprite
  uint32_t n;       // number of vertices in polygon
  uint16_t col;     // color for all lines
  point_t vert[10]; // 3 to 10 vertices, relative to (x,y)
  int life;         // 0 for dead, 1 for alive
};
typedef struct sprite sprite_t;


sprite_t Poly[100];
```

Write the draw function that draws all sprites that are alive. You are given a function that draws a line from (**x1,y1**) to (**x2,y2**) of color **c**:

```
    Line(int32_t x1, int32_t y1, int32_t x2, int32_t y2, uint16_t c);
```

Hint: A polygon with **n** vertices requires you to draw **n** lines total. You will need **all** attributes of a `sprite_t` struct to draw the polygon it represents.

```
// Draws all sprites that are alive in the Poly (global) array  Two good answers blue and red
void Draw(void){
int32_t i,j,x,y,m;
  for(i=0; i<100; i++){
    if(Poly[i].life){
      x = Poly[i].x;
      y = Poly[i].y;
      m = Poly[i].n;
      for(j=0; j < m-1; j++) {
        Line(x+Poly[i].vert[j].dx,
             y+Poly[i].vert[j].dy,
             x+Poly[i].vert[j+1].dx,
             y+Poly[i].vert[j+1].dy,
             Poly[i].col); // m-1 lines
      }
      Line(x+Poly[i].vert[m-1].dx,
           y+Poly[i].vert[m-1].dy,
           x+Poly[i].vert[0].dx,
           y+Poly[i].vert[0].dy,
           Poly[i].col); // last to first
    }
  }

int32_t i,j,x,y,m;
  for(i=0; i<100; i++){
    if(Poly[i].life){
      x = Poly[i].x;
      y = Poly[i].y;
      m = Poly[i].n;
      for(j=0; j < m; j++) {
        Line(x+Poly[i].vert[j].dx,
             y+Poly[i].vert[j].dy,
             x+Poly[i].vert[(j+1)%m].dx,
             y+Poly[i].vert[(j+1)%m].dy,
             Poly[i].col); // m lines
      }
    }
  }


}
```