Exam 1

Date: October 3, 2013

UT EID: ________________

Printed Name: **King** (Last,) **Solver** (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. *Anything outside the boxes will be ignored in grading*.
- You have 75 minutes, so allocate your time accordingly.
- For all questions, unless otherwise stated, find the most efficient (time, resources) solution.
- Unless otherwise stated, make all I/O accesses friendly.
- *Please read the entire exam before starting.*

Problem 1	10	
Problem 2	10	
Problem 3	10	
Problem 4	10	
Problem 5	10	
Problem 6	15	
Problem 7	25	
Problem 8	10	
Total	100	

(10) Question 1. State the term that is best described by each definition.

Part a) A software property such that when writing to an I/O register it only changes the bits needed to be changed and does not affect the other bits.

Friendly

Part b) Software is added to the system for the purpose of debugging, and this software has a small but inconsequential effect on the system.

Minimally intrusive

Part c) This C operator is used to perform a left shift.

<<

Part d) The name given to describe 1,024 (2^{10}) bytes.

Kibibyte

Part e) A type of logic where the voltage representing false is more than the voltage representing true.

Negative

Part f) A property of RAM such that data is lost if power is removed and then restored.

Volatile

Part g) This addressing mode is always used to access memory, shown here as the destination operand of this instruction: `STR R1,[R0]`?

Indexed

Part h) This declaration is used to create a variable in C that has a precision of 16 bits and cannot take negative values.

uint16_t
unsigned short

Part i) This C operator is used in if-then while-loop and do-while-loops for checking to see if two numbers are equal.

==

Part j) A drawing that describes the sequence of operations of software, defining what and when software actions will occur.

Flowchart

Question 2 (10 points) Consider the following 8-bit subtraction (assume registers are 8 bits wide)

```
Load      0x1F into R2
Load      0xC0 into R1
Subtract  R3 = R2-R1
```

a. What will be the 8-bit result in Register R3 (in hex)?

```
0x1F - 0xC0 = 0x5F
```

b. What is 8-bit result in Register R3 (as an unsigned decimal)?

```
5*16+15=95
```

c. What is 8-bit result in Register R3 (as a signed decimal)?

```
5*16+15=95
```

d. What will be the value of the carry (C) bit?

```
31 - 192 != 95
the unsigned answer is wrong, C=0
```

e. What will be the value of the overflow (V) bit?

```
31 - -64 == 95
the signed answer is correct, V=0
```

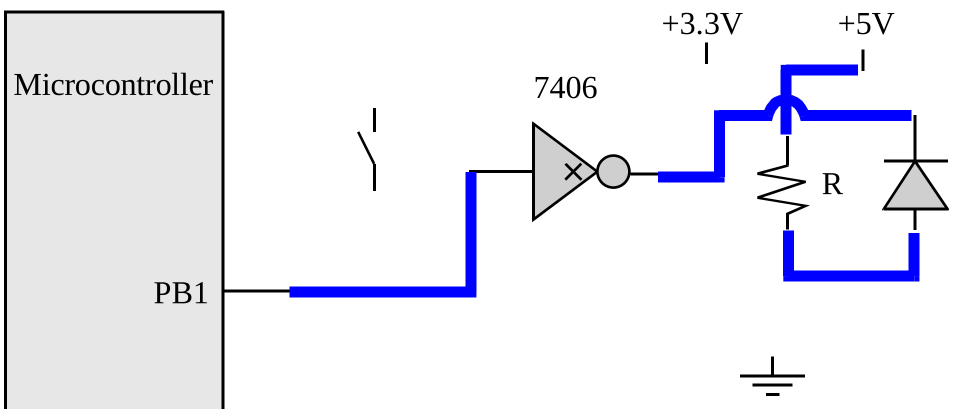
(10) Question 3. You will fill in the blanks of this C code that initializes Port B. Make pins PB7, PB4, PB1 outputs. Make the pin PB0 an input. To get full credit, this code must be friendly. Partial credit can be obtained by writing code that works, but is not friendly. Leave the box empty if it is not required to be executed at that spot in the initialization. You will use the following definitions:

```
#define GPIO_PORTB_DATA_R  (*((volatile unsigned long *)0x400053FC))
#define GPIO_PORTB_DIR_R   (*((volatile unsigned long *)0x40005400))
#define GPIO_PORTB_AFSEL_R (*((volatile unsigned long *)0x40005420))
#define GPIO_PORTB_DEN_R   (*((volatile unsigned long *)0x4000551C))
#define SYSCTL_RCGCGPIO_R  (*((volatile unsigned long *)0x400FE608))
```

```
GPIO_PORTB_DATA_R =    [ Skip, it will crash if you access the port before the clock ] ;

SYSCTL_RCGCGPIO_R |=   [ 0x02 ] ;

delay = SYSCTL_RCGCGPIO_R;     // allow time for clock to settle

GPIO_PORTB_DIR_R &=    [ ~0x01  0xFFFFFFFE  0xFE ] ;

GPIO_PORTB_DIR_R |=    [ 0x92 ] ;

GPIO_PORTB_AFSEL_R &=  [ ~0x93   0xFFFFFF6C  0x6C ] ;

GPIO_PORTB_DEN_R |=    [ 0x93 ] ;
```

(10) Question 4. Interface the LED to PB1 such that if PB1 is high, the LED is on, and if PB1 is low the LED is off. The desired LED operating point is 3.0V at 20 mA. The V_{OH} of the microcontroller is 3.1 V. The V_{OL} of the microcontroller is 0.3 V. The maximum current that the microcontroller can source or sink is 8 mA. The V_{OL} of the 7406 is 0.5 V. The maximum current that the 7406 can sink is 40 mA. Your bag of parts includes the switch, the 7406, the LED, and a resistor (you specify the resistor value). Pick the fewest components to use. You will not need them all. You may also use 3.3V, 5V power, and/or ground. Show the equations used to calculate the resistor value.

Need 7406 because LED current above 8mA, need +5V because LED+V_{OL}>3.3,
R = (5-3-0.5)/20mA = 1.5V/20mA = 1.5V/0.02A = 1.5*50 ohm =75 ohm



(10) Question 5. Write an assembly subroutine, called **`Calc`**, that calculates *Output* = *Input*/4 -5. The *Input* and *Output* parameters are 8-bit signed numbers located in global RAM. You may use Registers R0-R3, or R12 as scratch registers without saving and restoring them. Full credit will be given to the fastest solution. Don't worry about the code to define *Input* and *Output*, just the subroutine.

```
; Calculate Output = Input/4 -5
; Input:  R0 (-128 to +127)
; Output: R0 (-37 to +26), can't underflow or overflow
Calc  LDR   R1,=Input
      LDRSB R0,[R1]
      ASR   R0,R0,#2   ; Input/4 (signed)
      SUB   R0,R0,#5   ; Input/4-5
      LDR   R2,=Output
      STRB  R0,[R2]
      BX    LR         ; return
```

(15) Question 6. Answer the following questions with reference to the C and assembly code below. You may assume that all linkages have been done to be able to call the assembly code from C.
Hint: Recall AAPCS

```
; C code calling assembly
int32_t Param1;
int32_t Param2;
int32_t Output;

int main() {
    Param1 = 2; Param2 = 8;
    Output = Sub(Param1,Param2);
}
```

```
; Assembly code
Bs   RN 0
Res  RN 1
Ex   RN 4
Prod RN 5
Sub  PUSH {R4,R5,LR}
     MOV  Ex,#0
     MOV  Prod,Bs
More CMP  Prod,Res
     BGT  Done
     MUL  Prod,Prod,Bs
     ADD  Ex,Ex,#1
     B    More
Done MOV  R0,Ex
     POP  {R4,R5,LR}
     BX   LR
```

(2) Part a) What is the numerical value in register R0 at the start of the assembly subroutine **Sub**?

R0 = 2

(2) Part b) What is the numerical value in register R1 at the start of the assembly subroutine **Sub**?

R1 = 8

(4) Part c) What is the numerical value of the C variable **Output** after the assignment statement,
Output = Sub(Param1, Param2); is executed?

output = 3

(2) Part d) Why did the subroutine **Sub**, save the registers R4 and R5 on the stack?

I. The input parameters are on the stack.
II. The output parameter is returned on the stack
III. Follows AAPCS convention
IV. In order to save the return address
V. None of the above.

(5) Part e) Which of the following statements describes what **Sub** does accurately?

I. Sub returns the product of the two inputs using successive addition
II. Sub returns the exponent of the first input raised to the second input
III. Sub returns the power to which the first input has to be raised to be equal to the second
IV. Sub returns the largest power to which the first input can be raised and still have it less than or equal to the second
V. Sub returns the smallest power to which the first input needs to be raised so that it is greater than or equal to the second

Answer is IV

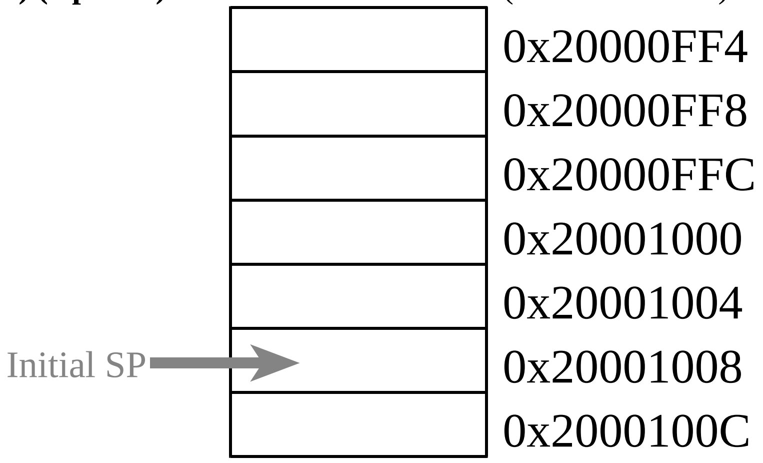
(20) Question 7. You are asked to develop the software for a control panel of a home automation system. ***You can write software in either assembly or C***. Make sure that all of your software is friendly and follows the AAPCS. You may assume the hardware is already connected, and Port B is already initialized so PB5 is an output and PB4–0 are inputs. Please use the port definition **`GPIO_PORTB_DATA_R`** to access Port B. You are not allowed to use bit-specific port addressing. The system has five door/window switches (sensors) connected to pins PB4, PB3, PB2, PB1, PB0. Door/window signals are high if OK, and low if there is danger. There is an LED connected to pin PB5, which signifies an alarm. The LED interface is negative logic. Write the main program of the control panel that continuously checks the sensors and turns the warning LED if, and only if, two or more door/window switches indicate there is danger.

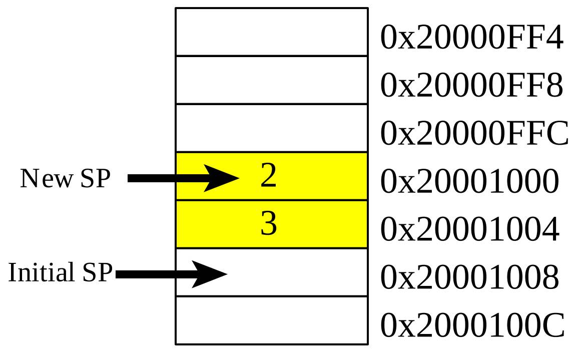
```
void main(void){ uint32_t count,mask;
  while(1){
    count = 0;
    for(mask = 0x01; mask < 0x20; mask=mask<<1){
      if((GPIO_PORTB_DATA_R&mask)==0){ // danger if low
        count++;
      }
    }
    if(count > 1){
      GPIO_PORTB_DATA_R &= ~0x20;  // negative logic LED on
    } else{
      GPIO_PORTB_DATA_R |= 0x20;   // negative logic LED off
    }
  }
}
void main(void){ uint32_t count;
  while(1){
    count = 0;
    if((GPIO_PORTB_DATA_R&0x01)==0) count++;  // PB0 not pressed
    if((GPIO_PORTB_DATA_R&0x02)==0) count++;  // PB1 not pressed
    if((GPIO_PORTB_DATA_R&0x04)==0) count++;  // PB2 not pressed
    if((GPIO_PORTB_DATA_R&0x08)==0) count++;  // PB3 not pressed
    if((GPIO_PORTB_DATA_R&0x10)==0) count++;  // PB4 not pressed
    if(count > 1){
      GPIO_PORTB_DATA_R &= ~0x20;  // negative logic LED on
    } else{
      GPIO_PORTB_DATA_R |= 0x20;   // negative logic LED off
    }
  }
}
```

(10) Question 8. Show the contents of the stack after the two marked points in the execution of the following code. Assume R0=0, R1=1, R2=2, R3=3, R4=4, R5=5, and R6=6. The initial stack pointer is 0x20001008.

```
    PUSH {R2,R3}
    ADD  R4,R1,R0 ; <---- A
    POP  {R5,R6}
    ADD  R5,R5,R4
    ADD  R6,R6,R5
    PUSH {R0,R4-R6};
                    <---- B
```

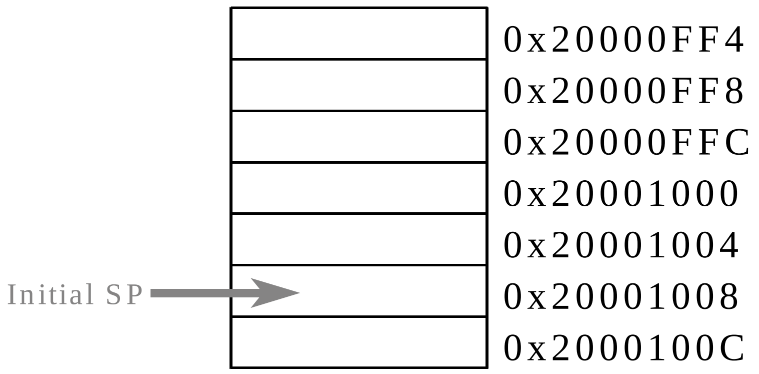
a) (4 points) The contents of the stack (SP and contents) after execution point A:

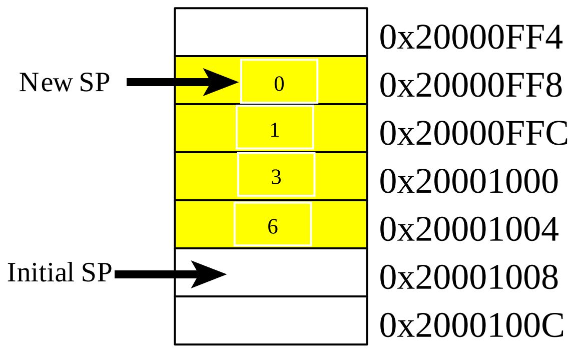




b) (6 points) The contents of the stack (SP and contents) after execution point B:

```
    ADD  R4,R1,R0 ; R4=1
    POP  {R5,R6}  ; R5=2, R6=3
    ADD  R5,R5,R4 ; R5=1+2=3
    ADD  R6,R6,R5 ; R6=3+3=6
    PUSH {R0,R4-R6}; push 0,1,3 and 6
                    <---- B
```





Memory access instructions

```
   LDR    Rd, [Rn]        ; load 32-bit number at [Rn] to Rd
   LDR    Rd, [Rn,#off]   ; load 32-bit number at [Rn+off] to Rd
   LDR    Rd, =value      ; set Rd equal to any 32-bit value (PC rel)
   LDRH   Rd, [Rn]        ; load unsigned 16-bit at [Rn] to Rd
   LDRH   Rd, [Rn,#off]   ; load unsigned 16-bit at [Rn+off] to Rd
   LDRSH  Rd, [Rn]        ; load signed 16-bit at [Rn] to Rd
   LDRSH  Rd, [Rn,#off]   ; load signed 16-bit at [Rn+off] to Rd
   LDRB   Rd, [Rn]        ; load unsigned 8-bit at [Rn] to Rd
   LDRB   Rd, [Rn,#off]   ; load unsigned 8-bit at [Rn+off] to Rd
   LDRSB  Rd, [Rn]        ; load signed 8-bit at [Rn] to Rd
   LDRSB  Rd, [Rn,#off]   ; load signed 8-bit at [Rn+off] to Rd
   STR    Rt, [Rn]        ; store 32-bit Rt to [Rn]
   STR    Rt, [Rn,#off]   ; store 32-bit Rt to [Rn+off]
   STRH   Rt, [Rn]        ; store least sig. 16-bit Rt to [Rn]
   STRH   Rt, [Rn,#off]   ; store least sig. 16-bit Rt to [Rn+off]
   STRB   Rt, [Rn]        ; store least sig. 8-bit Rt to [Rn]
   STRB   Rt, [Rn,#off]   ; store least sig. 8-bit Rt to [Rn+off]
   PUSH   {Rt}            ; push 32-bit Rt onto stack
   POP    {Rd}            ; pop 32-bit number from stack into Rd
   ADR    Rd, label       ; set Rd equal to the address at label
   MOV{S} Rd, <op2>       ; set Rd equal to op2
   MOV    Rd, #im16       ; set Rd equal to im16, im16 is 0 to 65535
   MVN{S} Rd, <op2>       ; set Rd equal to -op2
```

Branch instructions

```
   B    label   ; branch to label    Always
   BEQ  label   ; branch if Z == 1   Equal
   BNE  label   ; branch if Z == 0   Not equal
   BCS  label   ; branch if C == 1   Higher or same, unsigned ≥
   BHS  label   ; branch if C == 1   Higher or same, unsigned ≥
   BCC  label   ; branch if C == 0   Lower, unsigned <
   BLO  label   ; branch if C == 0   Lower, unsigned <
   BMI  label   ; branch if N == 1   Negative
   BPL  label   ; branch if N == 0   Positive or zero
   BVS  label   ; branch if V == 1   Overflow
   BVC  label   ; branch if V == 0   No overflow
   BHI  label   ; branch if C==1 and Z==0  Higher, unsigned >
   BLS  label   ; branch if C==0 or  Z==1  Lower or same, unsigned ≤
   BGE  label   ; branch if N == V   Greater than or equal, signed ≥
   BLT  label   ; branch if N != V   Less than, signed <
   BGT  label   ; branch if Z==0 and N==V  Greater than, signed >
   BLE  label   ; branch if Z==1 and N!=V  Less than or equal, signed ≤
   BX   Rm      ; branch indirect to location specified by Rm
   BL   label   ; branch to subroutine at label
   BLX  Rm      ; branch to subroutine indirect specified by Rm
```

Interrupt instructions

```
   CPSIE  I                ; enable interrupts  (I=0)
   CPSID  I                ; disable interrupts (I=1)
```

Logical instructions

```
   AND{S} {Rd,} Rn, <op2> ; Rd=Rn&op2    (op2 is 32 bits)
   ORR{S} {Rd,} Rn, <op2> ; Rd=Rn|op2    (op2 is 32 bits)
   EOR{S} {Rd,} Rn, <op2> ; Rd=Rn^op2    (op2 is 32 bits)
   BIC{S} {Rd,} Rn, <op2> ; Rd=Rn&(~op2) (op2 is 32 bits)
   ORN{S} {Rd,} Rn, <op2> ; Rd=Rn|(~op2) (op2 is 32 bits)
   LSR{S} Rd, Rm, Rs       ; logical shift right Rd=Rm>>Rs  (unsigned)
   LSR{S} Rd, Rm, #n       ; logical shift right Rd=Rm>>n   (unsigned)
   ASR{S} Rd, Rm, Rs       ; arithmetic shift right Rd=Rm>>Rs (signed)
   ASR{S} Rd, Rm, #n       ; arithmetic shift right Rd=Rm>>n  (signed)
   LSL{S} Rd, Rm, Rs       ; shift left Rd=Rm<<Rs (signed, unsigned)
   LSL{S} Rd, Rm, #n       ; shift left Rd=Rm<<n  (signed, unsigned)
```

Arithmetic instructions

```
   ADD{S} {Rd,} Rn, <op2> ; Rd = Rn + op2
   ADD{S} {Rd,} Rn, #im12 ; Rd = Rn + im12, im12 is 0 to 4095
   SUB{S} {Rd,} Rn, <op2> ; Rd = Rn - op2
   SUB{S} {Rd,} Rn, #im12 ; Rd = Rn - im12, im12 is 0 to 4095
   RSB{S} {Rd,} Rn, <op2> ; Rd = op2 - Rn
   RSB{S} {Rd,} Rn, #im12 ; Rd = im12 – Rn
   CMP    Rn, <op2>       ; Rn – op2      sets the NZVC bits
   CMN    Rn, <op2>       ; Rn - (-op2)   sets the NZVC bits
   MUL{S} {Rd,} Rn, Rm    ; Rd = Rn * Rm       signed or unsigned
   MLA    Rd, Rn, Rm, Ra  ; Rd = Ra + Rn*Rm    signed or unsigned
   MLS    Rd, Rn, Rm, Ra  ; Rd = Ra - Rn*Rm    signed or unsigned
   UDIV   {Rd,} Rn, Rm    ; Rd = Rn/Rm         unsigned
   SDIV   {Rd,} Rn, Rm    ; Rd = Rn/Rm         signed
```

Notes `Ra Rd Rm Rn Rt represent 32-bit registers`

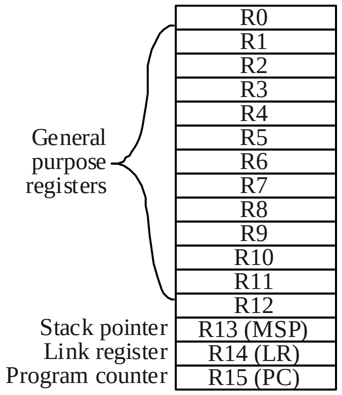
`value`	`any 32-bit value: signed, unsigned, or address`
`{S}`	`if S is present, instruction will set condition codes`
`#im12`	`any value from 0 to 4095`
`#im16`	`any value from 0 to 65535`
`{Rd,}`	`if Rd is present Rd is destination, otherwise Rn`
`#n`	`any value from 0 to 31`
`#off`	`any value from -255 to 4095`
`label`	`any address within the ROM of the microcontroller`
`op2`	`the value generated by <op2>`

Examples of flexible operand **`<op2>`** creating the 32-bit number. E.g., **`Rd = Rn+op2`**

```
   ADD Rd, Rn, Rm         ; op2 = Rm
   ADD Rd, Rn, Rm, LSL #n ; op2 = Rm<<n  Rm is signed, unsigned
   ADD Rd, Rn, Rm, LSR #n ; op2 = Rm>>n  Rm is unsigned
   ADD Rd, Rn, Rm, ASR #n ; op2 = Rm>>n  Rm is signed
   ADD Rd, Rn, #constant  ; op2 = constant
```

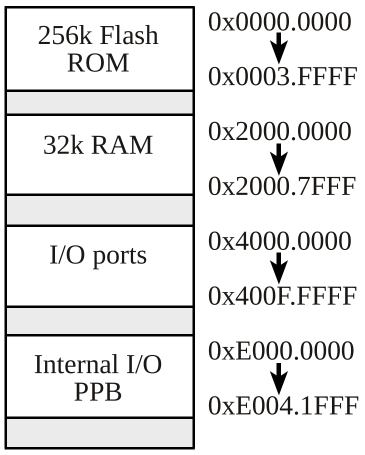
, where **`X`** and **`Y`** are hexadecimal digits:

- produced by shifting an 8-bit unsigned value left by any number of bits
- in the form **`0x00XY00XY`**
- in the form **`0xXY00XY00`**
- in the form **`0xXYXYXYXY`**



Condition code bits

N negative
Z zero
V signed overflow
C carry or
   unsigned overflow


256k Flash ROM
0x0000.0000
0x0003.FFFF
32k RAM
0x2000.0000
0x2000.7FFF
I/O ports
0x4000.0000
0x400F.FFFF
Internal I/O PPB
0xE000.0000
0xE004.1FFF