(15) Question 1. Select A, B, C, D, or E that best answers the question. Put answers in the boxes.

What type of computer is the ARM Cortex M?
A) Von Neumann
B) big endian
C) CISC
D) Harvard (separate bus for fetching op code from fetching data)
E) none of the above

Which of the following is a rule for proper use of the stack?
A) To push, first write at SP then decrement the SP by 4
B) To pop, we first read at SP then increment the SP by 4
C) It is ok to access memory locations above the SP (e.g., SP-8)
D) The software must execute something like LDR SP,=InitialSP to initialize the stack pointer
E) none of the above

Why does the Cortex M have multiple buses?
A) To reduce the number of mistakes software can make
B) To allow the microcontroller to access I/O ports
C) To reduce power saving energy
D) To speed up execution by allowing multiple actions to run in parallel
E) none of the above

What is a data flow graph?
A) A drawing with circles and rectangles. The circles are software modules and the rectangles are hardware. If module A invokes an operation in module B there is an arrow from A to B.
B) A drawing that describes the sequence of operations of software, defining what and when software actions will occur.
C) A drawing with circles and rectangles. The circles are software modules and the rectangles are hardware. If a module A passes data to module B, then an arrow is drawn from A to B.
D) To describe how data are stored in a computer, we draw a picture or graph of how the data are organized
E) none of the above

What is open collector logic?
A) It is logic used when the microcontroller creates an input port.
B) Logic that has two states, high and low.
C) Logic that has two states, high and off.
D) Logic that has three states, high, low, and off.
E) none of the above (open collector has two states low and off)
(15) **Question 2.** Interface the LED to PB0 such that if PB0 is low, the LED is on, and if PB0 is high the LED is off. The desired LED operating point is 1.0V at 4 mA. The $V_{OH}$ of the microcontroller is 3.1 V. The $V_{OL}$ of the microcontroller is 0.3 V. The $V_{OL}$ of the 7406 is 0.5 V. Your bag of parts includes the switch, the 7406, the LED, and resistors (you specify the values). Pick the fewest components to use. You will not need them all. You may also use 3.3V, 5V power and ground. Show the equations used to calculate the resistor value.

\[ R = \frac{3.3 - 1 - 0.3}{4} = \frac{2}{4} = 500 \Omega \]

![Circuit Diagram]

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(10) **Question 3.** Write an assembly subroutine, called `Mul7`, that multiplies by 7 using just shifts and adds (not the MUL instruction). The input is passed by value in Register R0, and the output is returned in Register R0. You may use Registers R1,R2,R3,R12 as scratch registers without saving and restoring them. Notice that if \( x \) is a variable, then \( 7x = 8x-x \), and also \( 7x = 4x+2x+x \).

```assembly
Mul7  RSB  R0, R0, R0, LSL #3  ;8*in-in
     BX   LR

Mul7  LSL  R1,R0,#3  ;8*in
     SUB  R0,R0,R1  ;in*7
     BX   LR

Mul7  MOV  R1,R0     ;in
     LSL  R0,#1     ;2*in
     ADD  R1,R1,R0  ;in*3
     LSL  R0,#1     ;4*in
     ADD  R0,R1,R0  ;in*7
     BX   LR
```

(15) **Question 4.** State the term that is best described by each definition.

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

```plaintext
volatile
```

**Part b)** The error that occurs after a division or a right shift such that some of the data in the least significant bits are lost.

```plaintext
dropout
```

**Part c)** Separation between what a function does and how it works.

```plaintext
abstraction, device driver, or modular
```

**Part d)** The name given to describe 1,024 bytes.

```plaintext
kibibyte
```

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

```plaintext
negative logic
```
Question 5. Assume that Port B is already initialized such that PB0 is an output and PB2 is an input. You do not have to write the initialization code. Write C function that toggles PB0 16 times. However, before each time your function outputs to PB0, it should read the PB2 input. If PB2 is low, your function stops toggling and waits until PB2 becomes high. After PB0 has been toggled 16 times, your function should return. You may define additional variables.

```c
void PortB_Toggle(void){
    long i;
    for(i=0; i<16; i++){
        while((GPIO_PORTB_DATA_R&0x04)==0){}; // wait for PB2 high
        GPIO_PORTB_DATA_R ^= 0x01; // toggle PB0
    }
}
```

```c
#define PB2 (*((volatile unsigned long *)0x40005010))
#define PB0 (*((volatile unsigned long *)0x40005004))
```

```c
void PortB_Toggle(void){
    long i;
    for(i=0; i<16; i++){
        while(PB2 == 0){}; // wait for PB2 high
        PB0 ^= 0x01; // toggle PB0
    }
}
```
(15) **Question 6.** Consider the following assembly language system. The subroutine `Circ` calculates the circumference of a circle. The input is passed in using R0 in cm, and the output is returned in R0, also in cm. $2\pi$ is approximated by $6283185/1000000$. The assembly listing is shown.

```
0x000005CC  Circ
0x000005CC  B502               PUSH  {r1,lr}
0x000005CE  49FA               LDR   R1,=6283185
0x000005D0  F000F801           BL    Multiply
0x000005D4  BD02               POP   {r1,pc}
0x000005D6  Multiply
0x000005D6  FB00F001           MUL   r0,r0,r1
0x000005DA  49F8               LDR   R1,=1000000
0x000005DC  FBB0F0F1           UDIV  R0,R0,R1 ;return R0*R1/1000000
0x000005E0  4770               BX    lr
0x000005E2  Start
0x000005E2  F04F007B           MOV   R0,#123 ;radius in cm
0x000005E6  F7FFFFF1           BL    Circ ;returns 772 cm in R0
0x000005EA  E7FE     Loop      B     Loop
```

**Part a)** In the first line of `Circ`, what does **0x000005CC** represent?  

**Part b)** In the first line of `Circ`, what does **B502** represent?  

**Part c)** What value is in the link register immediately after the **BL Multiply** instruction is executed?  

**Part d)** What addressing mode does the **LDR R1,=6283185** instruction use?  

**Part e)** Assume the stack is initially empty at the beginning of `Start`. In particular the SP has the value 0x20001000. Assume initial value of R1 is 0 at the beginning of Start. During the execution of the `Multiply` subroutine, draw a stack picture illustrating all values on the stack, and the exact location of the SP at this time.

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* actually the saved value of the return address will be 0x000005EB (so the T bit remains set)