Number Representation & Strings

A. What is the value of the `signed char` **`0x9E`** in decimal?

-128 + 16 + 8 + 4 + 2 = -98

B. What is the value of the `unsigned char` **`37`** in binary?

0b00100101

C. If **`a = 0x2C`**, complete the bitwise C statement so that **`b = 0x1F`**.

`b = a ^ 0x33`

For the following problems we are working with a floating point representation that follows the same conventions as IEEE 754 except using 7 bits split into the following fields:

`Sign (1) Exponent (3) Mantissa (3)`

D. What is the magnitude of the bias of this new representation?

$2^{3-1} - 1 = 3$

E. What is the decimal value encoded by **`0b1110101`** in this representation?

S = 1, E = 0b110 = 6, M = 0b101

Value = $(-1)^1 \times 1.101_2 \times 2^{6-3} = -1.101 \times 2^3 = -1101_2 = -13$

F. What value will be read after we try to store -18 in this representation? (Circle one)

-16   -NaN   -∞   -18

For the following problem, assume we are working with C strings encoded in ASCII. Consider the declaration:

`char str[] = “Hello!”;`

G. What will be stored in the array str? (Bytes given in hex)

48	65	6C	6C	6F	21	0

Pointers & Memory

For this problem we are using a 64-bit x86-64 machine (**little endian**). The current state of memory (values in hex) is shown below:

```
char* charP = 0xD;
short* shortP = 0x1E;
```

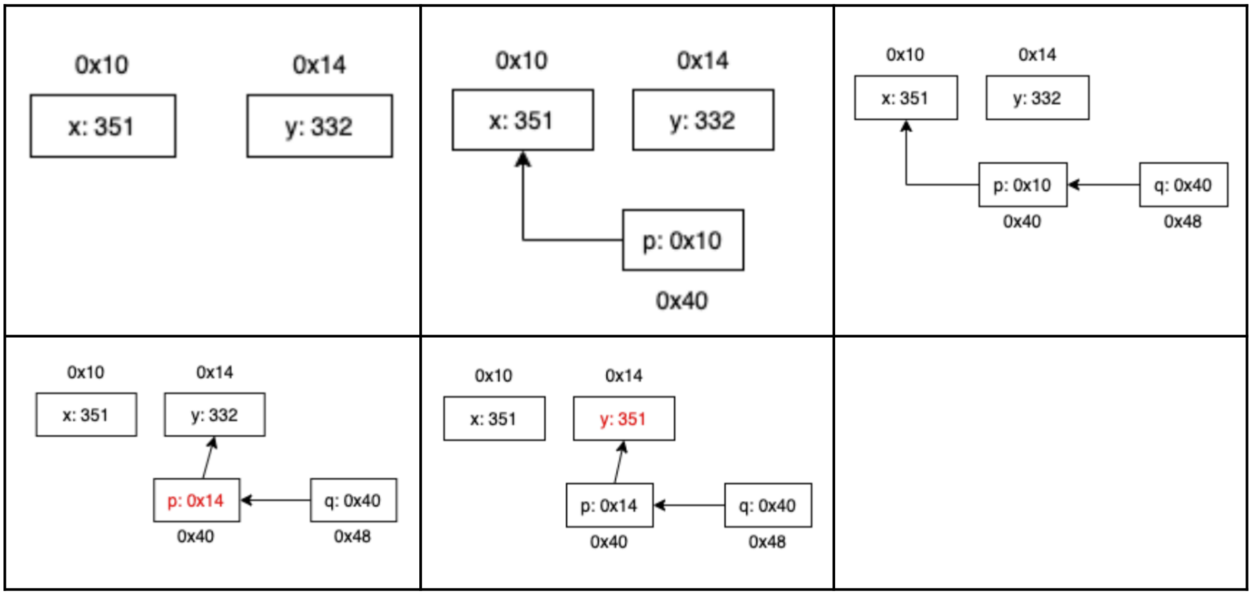
Word Addr	+0	+1	+2	+3	+4	+5	+6	+7
0x00	20	F6	EF	EA	A2	5E	9F	1A
0x08	A2	D0	4F	C4	A0	0C	F7	27
0x10	B8	BD	1A	CA	35	95	CB	80
0x18	84	3F	02	4F	8E	F3	F6	E5
0x20	CD	4A	F6	48	1A	6F	7E	63

A. Using the values shown above, ill in the C type and hex value for each of the following C expressions. Leading zeros are not required for the hex values.

C Expression	C Type	Hex Value
`*(charP + 6)`	char	0xCA
`(int**)shortP - 2`	int**	0xE

B. For the following snippet of C code, draw out a box-and-arrow diagram for the allocated memory.

```
int x = 351, y = 332;
int *p = &x;
int **q = &p;
*q = &y;
*(*q) = x;
```


0x10
0x14
x: 351
y: 332
0x10
0x14
x: 351
y: 332
p: 0x10
0x40
0x10
0x14
x: 351
y: 332
p: 0x10
q: 0x40
0x40
0x48
0x10
0x14
x: 351
y: 332
p: 0x14
q: 0x40
0x40
0x48
0x10
0x14
x: 351
y: 351
p: 0x14
q: 0x40
0x40
0x48

C & Assembly

Answer the questions below about the following x86-64 assembly function:

```
mystery:
          jmp     .L2                   # Line 1
.L4:      addq    $1, %rdi              # Line 2
          movb    %al, (%rsi)           # Line 3
          leaq    1(%rsi), %rsi         # Line 4
.L2:      movzbl  (%rdi), %eax          # Line 5
          testb   %al, %al              # Line 6
          je      .L3                   # Line 7
          cmpb    %dl, %al              # Line 8
          jne     .L4                   # Line 9
.L3:      movb    $0, (%rsi)            # Line 10
          retq                          # Line 11
```

A. What **variable type** would `%rdi` be in the corresponding C program?

`char*`, `unsigned char*` is also acceptable due to zero-extension.

Line 5: we read a byte out of memory by dereferencing the value in `%rdi`

B. What **variable typ**e would the third argument be in the corresponding C program?

`char`

Line 8: `%dl` (lowest byte of `%rdx`) is compared to the byte read out of memory.

C. This function uses a `while` loop. Fill in the two conditionals below, using register names as variable names (no declarations necessary).

```
              al
           al != 0
            *rdi           al != dl
    while( *rdi != 0 && *rdi != dl)
```

Conditional 1 is from Lines 6-7, which exit loop if `%al = 0`
Conditional 2 is from Lines 8-9, which loop back if `%al - %dl != 0`

D. Taking the variable types into account, describe at a high level what the *purpose* of Line 10 is (not just what it does mechanically).

Adds a null terminator (char with value 0) to the end of `*rsi` (the destination string).

E. Describe at a high level what you think this function *accomplishes* (not line-by-line).

It copies all of the characters from a source string (in `%rdi`) to a destination string (In `%rsi`) until it sees a specified character (in `%dl`) or the end of the source string. The destination string is then null-terminated.

Procedures & The Stack

The recursive function `count_nz` counts the number of *non-zero* elements in an `int` array. Example: if `int a[] = {-1,0,1,255}`, then `count_nz(a,4)` returns 3. The function and its x86-64 *disassembly* are shown below:

```
int count_nz(int* ar, int num) {
      if (num > 0)
          return !!(*ar) + count_nz(ar + 1,num - 1);
      return 0;
}
```

```
0000000000400536 <count_nz>:
 400536: 85 f6              testl %esi,%esi
 400538: 7e 1b              jle 400555 <count_nz+0x1f>
 40053a: 53                 pushq %rbx
 40053b: 8b 1f              movl (%rdi),%ebx
 40053d: 83 ee 01           subl $0x1,%esi
 400540: 48 83 c7 04        addq $0x4,%rdi
 400544: e8 ed ff ff ff     callq 400536 <count_nz>
 400549: 85 db              testl %ebx,%ebx
 40054b: 0f 95 c2           setne %dl
 40054e: 0f b6 d2           movzbl %dl,%edx
 400551: 01 d0              addl %edx,%eax
 400553: eb 06              jmp 40055b <count_nz+0x25>
 400555: b8 00 00 00 00     movl $0x0,%eax
 40055a: c3                 retq
 40055b: 5b                 popq %rbx
 40055c: c3                 retq
```

A. How much space (in bytes) does this function take up in our final executable?

39 B. Count all bytes (middle columns) or subtract the address of next instruction (`0x40055d`) from `0x400536`.

B. The compiler automatically creates labels it needs in assembly code. How many labels are used in `count_nz` (including the procedure itself)?

3. The addresses `0x400536, 0x400555 (BaseCase:),0x40055b (Exit:)`

C. In terms of the *C function*, what value is being saved on the stack?

`*ar`. `movl` instruction at `0x40053b` puts `*ar` into `%rbx`, which is pushed onto the stack by the pushq instruction at `0x40053a`.

D. What is the return address to `count_nz` that gets stored on the stack (in hex)?

`0x400549`. The address of the instruction *after* `call`.

E. Assume `main` calls `count_nz(a,5)` with an appropriately-sized array and then prints the result using `printf`. Starting with (including) `main`, answer the following *in the number of stack frames*.

Total created: 8	Max depth: 7

main→count_nz(a,5)→(a+1,4)→(a+2,3)→(a+3,2)→(a+4,1)→(a+5,0)→printf

F. Assume `main` calls `count_nz(a,6)` with **`int`** `a[] = {3,5,1,4,1,0}`. We find that the return address to `main` is stored on the stack at address `0x7fffeca3f748`. What data will be stored on the stack at address **`0x7fffeca3f720`**?

0x7fffeca3f748	<ret addr to main>
0x7fffeca3f740	<original rbx>
0x7fffeca3f738	0x400549 <ret addr>
0x7fffeca3f730	0x3 <*a>
0x7fffeca3f728	0x400549 <ret addr>
0x7fffeca3f720	**0x5 <*(a+1)>**

G. A similar function `count_z` that counts the number of *zero* elements in an array is made by making a single change to `count_nz`. What is the address of the changed assembly instruction?

`0x40054b`. Changing the `setne` to a `sete` changes the double bang in the C code to a single bang and counts the zero elements instead.

Design Questions

A. What values can `S` take in an `x86-64` memory operand? *Briefly* describe why these choices are useful/important.

Values: 1, 2, 4, 8	
Importance: These values represent the different scaling factors used in pointer arithmetic based on the data type sizes.	

B. Until very recently (Java 8/9), Java did not support *unsigned* integer data types. Name one advantage and one disadvantage to this decision to omit `unsigned`.

Advantage: Some possible answers:

- Less confusing/more consistent arithmetic interpretations for the programmer
- Fewer cases of implicit casting
- Fewer data types to worry about

Disadvantage: Some possible answers:

- Need to use larger data widths for numbers in the range (TMax, UMax] for a given width
- More difficult to do unsigned comparisons
- More difficult to do zero-extension

C. **Condition codes** are part of the *processor/CPU state*. Would our instruction set architecture (ISA) still work if we got rid of the condition codes? *Briefly* explain.

Circle one: Yes **No**

Explanation: Our jump and set instructions, which rely on the values of the condition codes, would no longer work. Without jump instructions, we couldn't implement most of our program's control flow.