University of Washington – Computer Science & Engineering

Autumn 2016 Instructor: Justin Hsia 2016-11-02

CSE351 MIDTERM

Last Name:	**Perfect**
First Name:	**Perry**
Student ID Number:	1234567
Section you attend (circle):	Chris Yufang, John, Kevin, Sachin, Suraj Waylon, Thomas, Xi
Name of person to your Left | Right	Samantha Student | Larry Learner
All work is my own. I had no prior knowledge of the exam contents nor will I share the contents with others in CSE351 who haven't taken it yet. (please sign)	

Do not turn the page until 11:30.

Instructions

- This exam contains 10 pages, including this cover page. Show scratch work for partial credit, but put your final answers in the boxes and blanks provided.
- The last page is a reference sheet. Feel free to detach it from the rest of the exam.
- The exam is closed book (no laptops, tablets, wearable devices, or calculators). You are allowed one page (US letter, double-sided) of *handwritten* notes.
- Please silence and put away all cell phones and other mobile or noise-making devices. Remove all hats, headphones, and watches.
- You have 50 minutes to complete this exam.

Advice

- Read questions carefully before starting. Skip questions that are taking a long time.
- Read *all* questions first and start where you feel the most confident.
- Relax. You are here to learn.

Question	1	2	3	4	5	Total
Possible Points	12	12	8	11	12	**55**

Question 1: Number Representation [12 pts]

(A) What is the value of the `char` 0b 1101 1101 in decimal? [1 pt]

If x = 0xDD, –x = 0x23 = 2^5+3 = 35

Also accepted unsigned: 0xDD = (16+1)*13 = 221

-35 or 221

(B) What is the value of **`char`** `z = (0xB << 7)` in decimal? [1 pt]

0xB << 7 = 0b 1000 0000 = $\text{TMin}_{\text{char}}$ = -128

Also accepted unsigned: 0x80 = 128

-128 or 128

(C) Let `char x = 0xC0`. Give one value (in hex) for `char y` that results in *both* signed and unsigned overflow for `x+y`. [2 pt]

x<0, so need large enough (in magnitude) neg num for signed overflow. Unsigned overflow comes naturally along with this.

0x80 ≤ y ≤ 0xBF

For the rest of this problem we are working with a floating point representation that follows the same conventions as IEEE 754 except using 8 bits split into the following vector widths:

Sign (1)	Exponent (4)	Mantissa (3)

(D) What is the *magnitude* of the **bias** of this new representation? [2 pt]

Bias = $2^{4-1} - 1 = 7$

7

(E) Translate the floating point number 0b 1100 1110 into decimal. [3 pt]

-7

S = 1, E = 1001_2, M = 110_2. Notice that E indicates this is *not* a special case.

Exp = 9 – 7 = 2, Man = 1.110_2.

$(-1)^1 \times 1.110_2 \times 2^2 = -111_2 = -7$.

(F) What is the smallest positive integer that can't be represented in this floating point encoding scheme? <u>Hint</u>: For what integer will the "one's digit" get rounded off? [3 pt]

17

Look for number such that the 2^0=1 bit is just off the end of the mantissa.

So of the form $1.000\underline{1} \times 2^{\text{Exp}}$, with the underlined bit being 2^0.

Counting to the left, we find that Exp = 4, and $1.0001 \times 2^4 = 17$.

Question 2: Pointers & Memory [12 pts]

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

```
char* cp = 0x12
short* sp = 0x0C
unsigned* up = 0x2C
```

Word Addr	+0	+1	+2	+3	+4	+5	+6	+7
0x00	AC	AB	03	01	BA	5E	BA	11
0x08	5E	00	AB	0C	BE	A7	CE	FA
0x10	1D	B0	99	DE	AD	60	BB	40
0x18	14	CD	FA	1D	D0	41	ED	77
0x20	BA	B0	FF	20	80	AA	BE	EF

(A) What are the values (in hex) stored in each register shown after the following x86 instructions are executed? Remember to use the appropriate bit widths. [6 pt]

Instruction	Register	Value (hex)
	%rdi	0x0000 0000 0000 0004
	%rsi	0x0000 0000 0000 0000
`leaw (%rsi, %rdi), %ax`	%ax	**0x0004**
`movb 8(%rdi), %bl`	%bl	**0xBE**
`movswl (,%rdi,8), %ecx`	%rcx	**0x0000 0000 FFFF B0BA**

`movb` instruction pulls byte from memory at address 8+4 = 12 = 0x0C.

`movswl` instruction pulls 2 bytes from memory starting at addresses 8*4 = 32 = 0x20.
Remember little-endian! Then sign extended to 32 bits, zero out top 32 bits.

(B) It's a memory scavenger hunt! Complete the C code below to fulfill the behaviors described in the comments using pointer arithmetic. [6 pt]

```
long v1 = (long) *(cp + __3__);   // set v1 = 0x60

unsigned* v2 = up + __5__;        // set v2 = 64

int v3  = *(int *)(sp + __1__);   // set v3 = 0xB01DFACE
```

v1: Byte 0x60 is at address 0x15. `0x15 - cp` = 3.

v2: No dereferencing, just pointer arithmetic (scaled by `sizeof(unsigned)=4`).
`up` = 0x2C = 44. To get to 64, need to add 20 (5 by pointer arithmetic).

v3: The correct bytes can be found (in little-endian order) in addresses 0x0E-0x11.
Want `(0x0E - sp)/sizeof(short)` = 1.

Question 3: Computer Architecture Design [8 pts]

Answer the following questions in the boxes provided with a **single sentence fragment**. Please try to write as legibly as possible.

(A) Why can't we upgrade to more registers like we can with memory? [2 pt]

Registers are part of the CPU (and the architecture) and are not modular like RAM.

(B) Why don't we see new assembly instruction sets as frequently as we see new programming languages? [2 pt]

Hard to implement/get adopted – need to build new hardware. (by comparison, a new programming language only needs a new compiler – software)

(C) Name one reason why a program written in a CISC language might run slower than the same program written in a RISC language and one reason why the reverse might be true: [4 pt]

CISC slower:	RISC slower:
Complicated instructions take longer to execute (fewer instructions, but each is slower).	Need more instructions to do complicated computations (faster instructions, but more numerous).

Question 4: C & Assembly [11 pts]

We are writing the function `toLower`, which takes a `char` pointer and converts a string of letters (assume only letters and spaces) to lowercase, leaving spaces as spaces. Example: If the pointer `p` points to “`TeST oNe`”, then after `toLower(p)`, `p` now points to “`test one`”.

ASCII	'A'	'Z'	Space
Binary	0b 0100 0001	0b 0101 1010	0b 0010 0000
Binary	0b 0110 0001	0b 0111 1010	0b 0010 0000
ASCII	'a'	'z'	Space

(A) Using the table of ASCII values (in binary) above, complete the function using a bitwise operator: [2 pt]

```
void toLower (char * p) {
    while(*p != 0) {

        *p = _*p | 0x20___________;

        p++;
    }
}
```

(B) Fill in the blanks in the x86-64 code below with the correct instructions and operands. *Remember to use the proper size suffixes and correctly-sized register names!* You may assume that Lines 4, 7, and 8 are correctly filled in. [9 pt]

```
   toLower(char*):
 1     movzbq  (%rdi), %rax       # get *p
 2     testb   %al,    %al        # conditional
 3     je      .Exit              # conditional jump
   .Loop:
 4     <<answer to part (A)>>     # to lowercase
 5     movb    %al,    (%rdi)     # update char in memory
 6     addq    $1,     %rdi       # increment p
 7     <<same as Line 1>>         # get new *p
 8     <<same as Line 2>>         # conditional
 9     jne     .Loop              # conditional jump
   .Exit:
10     ret                        # return
```

Grading Notes for Question 4:

Line 1: must be dereference, must be 64-bit register name, `p` is first argument (`%rdi`).

Line 2: any width specifier accepted as long as register names match
(`testq/%rax, testl/%eax, testw/%ax`).
Also accepted `compq $0, $rax` (same idea with width specifiers).

Line 5: points awarded as long as it matched the Line 1 blank.

Line 6: must be `q` width specifier because destination is `%rdi`.

Line 9: points awarded as long as it was the *opposite* of the Line 3 blank.

Line 10: `retq` also accepted.

Question 5: The Stack [12 pts]

The recursive factorial function `fact()` and its x86-64 disassembly is shown below:

```
int fact(int n) {
     if(n==0 || n==1)
          return 1;
     return n*fact(n-1);
```

```
000000000040052d <fact>:
  40052d:  83 ff 00          cmpl   $0, %edi
  400530:  74 05             je     400537 <fact+0xa>
  400532:  83 ff 01          cmpl   $1, %edi
  400535:  75 07             jne    40053e <fact+0x11>
  400537:  b8 01 00 00 00    movl   $1, %eax
  40053c:  eb 0d             jmp    40054b <fact+0x1e>
  40053e:  57                pushq  %rdi
  40053f:  83 ef 01          subl   $1, %edi
  400542:  e8 e6 ff ff ff    call   40052d <fact>
  400547:  5f                popq   %rdi
  400548:  0f af c7          imull  %edi, %eax
  40054b:  f3 c3             rep ret
```

(A) Circle one: [1 pt] `fact()` is saving `%rdi` to the Stack as a **Caller** // **Callee**

(B) How much space (in bytes) does this function take up in our final executable? [2 pt]

Count all bytes (middle columns) or subtract address of next instruction (0x40054d) from 0x40052d.

32 B

(C) **Stack overflow** is when the stack exceeds its limits (i.e. runs into the Heap). Provide an argument to `fact(n)` here that will cause stack overflow. [2 pt]

Any negative int

We did mention in the lecture slides that the Stack has 8 MiB limit in x86-64, so since 16B per stack frame, credit for anything between 2^{19} and TMax (2^{31}-1).

(D) If we use the `main` function shown below, answer the following for the execution of the entire program: [4 pt]

```
void main() {
      printf("result = %d\n",fact(3));
}
```

Total frames created: **5**	Maximum stack frame depth: **4**

main → fact(3) → fact(2) → fact(1)
→ printf

(E) In the situation described above where `main()` calls `fact(3)`, we find that the word `0x2` is stored on the Stack at address `0x7fffdc7ba888`. At what address on the Stack can we find the return address to `main`()? [3 pt]

`0x7fffdc7ba8a0`

Only `%rdi` (current `n`) and return address get pushed onto Stack during `fact()`.

Address	**Contents**
	<Rest of Stack>
`0x7fffdc7ba8a0`	Return addr to `main()`
`0x7fffdc7ba898`	Old `%rdi` (n=3)
`0x7fffdc7ba890`	Return addr to `fact()`
`0x7fffdc7ba888`	Old `%rdi` (n=2)
`0x7fffdc7ba880`	Return addr to `fact()`

CSE 351 Reference Sheet

Binary	Decimal	Hex
0000	0	0
0001	1	1
0010	2	2
0011	3	3
0100	4	4
0101	5	5
0110	6	6
0111	7	7
1000	8	8
1001	9	9
1010	10	A
1011	11	B
1100	12	C
1101	13	D
1110	14	E
1111	15	F

2^0	2^1	2^2	2^3	2^4	2^5	2^6	2^7	2^8	2^9	2^{10}
1	2	4	8	16	32	64	128	256	512	1024

IEEE 754 FLOATING-POINT STANDARD

Value: $\pm 1 \times \text{Mantissa} \times 2^{\text{Exponent}}$

Bit Fields: $(-1)^S \times 1.M \times 2^{(E+\text{bias})}$

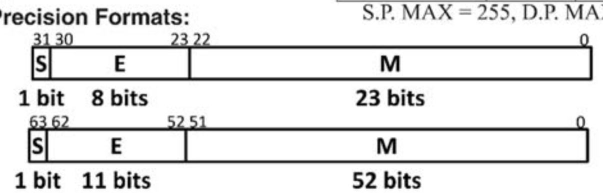
where Single Precision Bias = -127,
Double Precision Bias = -1023.

IEEE 754 Symbols

Exponent	Fraction	Object
0	0	± 0
0	≠0	± Denorm
1 to MAX - 1	anything	± Fl. Pt. Num.
MAX	0	±∞
MAX	≠0	NaN

S.P. MAX = 255, D.P. MAX = 2047

IEEE Single Precision and Double Precision Formats:



Assembly Instructions

mov a, b	Copy from a to b.
movs a, b	Copy from a to b with sign extension.
movz a, b	Copy from a to b with zero extension.
lea a, b	Compute address and store in b. *Note:* the scaling parameter of memory operands can only be 1, 2, 4, or 8.
push src	Push src onto the stack and decrement stack pointer.
pop dst	Pop from the stack into dst and increment stack pointer.
call <func>	Push return address onto stack and jump to a procedure.
ret	Pop return address and jump there.
add a, b	Add from a to b and store in b (and sets flags).
imul a, b	Multiply a and b and store in b (and sets flags).
and a, b	Bitwise AND of a and b, store in b (and sets flags).
sar a, b	Shift value of b *right* (*arithmetic*) by a bits, store in b (and sets flags).
shr a, b	Shift value of b *right* (*logical*) by a bits, store in b (and sets flags).
shl a, b	Shift value of b *left* by a bits, store in b (and sets flags).
cmp a, b	Compare b with a (compute b-a and set condition codes based on result).
test a, b	Bitwise AND of a and b and set condition codes based on result.
jmp <label>	Unconditional jump to address.
j* <label>	Conditional jump based on condition codes (*more on next page*).
set* a	Set byte based on condition codes.

Conditionals

Instruction		cmp b, a	test a, b
je	"Equal"	a == b	a & b == 0
jne	"Not equal"	a != b	a & b != 0
js	"Sign" (negative)		a & b < 0
jns	(non-negative)		a & b >= 0
jg	"Greater"	a > b	a & b > 0
jge	"Greater or equal"	a >= b	a & b >= 0
jl	"Less"	a < b	a & b < 0
jle	"Less or equal"	a <= b	a & b <= 0
ja	"Above" (unsigned >)	a > b	
jb	"Below" (unsigned >)	a < b	

Sizes

C type	x86-64 suffix	Size (bytes)
char	b	1
short	w	2
int	l	4
long	q	8

Registers

Name	Convention	Name of "virtual" register		
		Lowest 4 bytes	Lowest 2 bytes	Lowest byte
%rax	Return value – Caller saved	%eax	%ax	%al
%rbx	Callee saved	%ebx	%bx	%bl
%rcx	Argument #4 – Caller saved	%ecx	%cx	%cl
%rdx	Argument #3 – Caller saved	%edx	%dx	%dl
%rsi	Argument #2 – Caller saved	%esi	%si	%sil
%rdi	Argument #1 – Caller saved	%edi	%di	%dil
%rsp	Stack Pointer	%esp	%sp	%spl
%rbp	Callee saved	%ebp	%bp	%bpl
%r8	Argument #5 – Caller saved	%r8d	%r8w	%r8b
%r9	Argument #6 – Caller saved	%r9d	%r9w	%r9b
%r10	Caller saved	%r10d	%r10w	%r10b
%r11	Caller saved	%r11d	%r11w	%r11b
%r12	Callee saved	%r12d	%r12w	%r12b
%r13	Callee saved	%r13d	%r13w	%r13b
%r14	Callee saved	%r14d	%r14w	%r14b
%r15	Callee saved	%r15d	%r15w	%r15b