CS33: Intro Computer Organization
Fall 2019 Midterm

Name: [redacted]

UID:

IMPORTANT INSTRUCTIONS: You must write your name on both the FRONT AND BACK of the exam. You may do so now. Do not open the exam.

This is an open book, open notes exam, but you cannot share books/notes. Please follow the university guidelines in reporting academic misconduct.

Please wait until everyone has their exam to begin. We will let you know when to start.

Good luck!

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Question 1. C Puzzles (8pts)

You are running the following program on the cs33.seas.ucla.edu machine (ISA is x86-64).

```
// Create some random values
int x = random();
int y = random();
int z = random();
/* convert to other forms */
unsigned ux = (unsigned) x;
unsigned uy = (unsigned) y;
double dx = (double) x;
double dy = (double) y;
double dz = (double) z;
```

For each of the following C-puzzles, in the column marked answer, either mark true if the expression always holds (ie. always yields 1), or give a counterexample (eg. TMIN) which breaks the rule.

Expression	Answer ("True" or describe a counterexample)
(x<y) == (-x>-y)	(example) x=Tmin, y=0
ux-uy == -(y-x)	(a) true
(x >= 0) || (x < ux)	(b) $x = -1$
ux & (~(1 << 31)) < 0	(c) $ux = 1$
~x + ~y + 1 == ~(x+y)	(d) true
dx*dy == x*y	(e) $x = T_{max}$, $y = 2$
dx*y == x*dy	(f) true
dx+dy+dz == dz+dy+dx	(g) true
((x >> 31) << 31) <= x	(h) true

either all 1's or all 0's

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Question 2. Multiple Choice (10pts)

For the following multiple choice questions, select all that apply.

1. Which of the following registers are guaranteed to have the same value before and after a call instruction in x86-64?
   (a) rax
   (b) rbx
   (c) rdi
   (d) rbp
   (e) rsp

2. Which of the following instructions read memory?
   (a) movq %rbx, %rbp
   (b) cvtsi2ssl %rdi,%xmm0
   (c) leaq 4(%rax,%rbx,2), %rcx
   (d) cmov %rbx, %rcx
   (e) subq %rax, (%rbx)

3. Assuming our ISA is x86-64, which of the following operations could we identify as modifying the ***values on*** the program stack?
   (a) call <func>
   (b) addq $8, %rsp
   (c) movq %rax, (%rbp)
   (d) movq 20(%rsp), %rax
   (e) pushq %rbp
   (f) addq %rax, 8(%rsp)

4. What hexadecimal bit pattern would be found in memory in an x86-64 machine, for the number negative 33, when the corresponding datatype is an "int" in C?
   (a) `0x80 0x00 0x00 0x33`
   (b) `0x80 0x00 0x00 0x21`
   (c) `0x21 0x00 0x00 0x80`
   (d) `0x33 0x00 0x00 0x80`
   (e) `0xFF 0xFF 0xFF 0x21`
   (f) `0xDF 0xFF 0xFF 0xFF`
   (g) `0xFF 0x21`
   (h) `0xDF 0xFF`

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$-2^6 + 0\cdot2^5 + 1\cdot2^4 + 1\cdot2^3 + 1\cdot2^2 + 1\cdot2^1 + 1\cdot2^0$

11 01 → 13

F

reverse order

→

if anything is impossible, mark it as so

5. If a,b,c are n-bit signed integers, and c is the result of a+b, under what conditions can we be *guaranteed* that c is not the true result under full precision arithmetic?

(a) a >= 2^{n-2} && b >= 2^{n-2}

(b) a <= -2^{n-2} && b <= -2^{n-2}

(c) a - b > 0

(d) a + b > 0

(e) a > 0 && b > 0 && c < 0

(f) a < 0 && b < 0 && c > 0

$T_{max} = 2^{n-1} - 1$

need 2^{b+1} bits

where b is num of bits

each n-1 bits

→ would be n bits for true sum, but min/max 2^{n-1} bits

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Question 3. This Bytes (8pts)

For this question, either interpret the value as a bit pattern, or write down the corresponding value.

For floating point questions, use the following 8-bit floating point representation based on the IEEE floating point format:

- There is a sign bit in the most significant bit.
- The next 4 bits are the exponent. The exponent bias is: $2^{4-1}-1=7$ $Exp = E_{bits} - bias$
- The last 3 bits are the fraction.
- The representation encodes numbers of the form: $V = (-1)^s \times M \times 2^E$, where M is the significand and E is the biased exponent.

Bit Pattern	Value Description
(a) 10000000	Negative of smallest possible signed integer (ie. -TMin)
(b) 01000000	Largest signed integer that is a power-of-2
(c) 11111111	TMin + Tmax
(d) 0 11100 0000	Floating Point value: 32
00100001	(e) 33 (interpret as "char"-sized integer)
11011110	(f) -34 (interpret as "char"-sized integer)
00111000	(g) 1 (interpret as "8-bit float")
10111111	(h) -1.875 (interpret as "8-bit float")

$-1.111_2 = -(1 + \frac{1}{2} + \frac{1}{4} + \frac{1}{8})$

32: ↓ $1 \cdot 2^5 + 0 \ldots 0$ M: $1\,000000$

$5 = E - bias$

$\Rightarrow E = 12 \rightarrow 1 \cdot 2^3 + 1 \cdot 2^2 + 0 \cdot 2^1 + 0 \cdot 2^0$

Question 4. Be the compiler! (6 pts)

Suppose we have the following C code:

```
if(a>b) { a+=b;}
```

Also assume that a and b are "int", **a** is in %eax, **b** is in %ebx. You can use other registers as temporaries.

(a) Write an x86-64 assembly snippet that is equivalent to this statement in C, while making sure to use a jump (aka branch) instruction. Please use a label (.eg L1) as the target of the jump. **(4 pts)**

```
cmp  %ebx, %eax   if a≤b: ret.
jle  L1
add  %ebx, %eax
L1:
```

(b) Write an x86-64 assembly snippet that is equivalent to this statement in C, while making sure ***NOT*** to use a jump (aka branch) instruction. **(2 pts)**

```
mov   %ebx, %edi
add   %eax, %edi
cmp   %ebx, %eax
cmovg %edi, %eax
```

Question 5: Interpreting Assembly (6 pts)

For each of the functions in x86-64 assembly below, convert them into a plausible version of the C code.

Assembly of function	Write a plausible C-code for the function

`movq %rdi,%rax`
`salq $4, %rax`
`addq %rdi,%rax`
`addq %rax,%rax`
`ret`
	`int fun( int x ) {`
	`int t = x<<4;`
	`t+=x;`
	`t+=t;`
	`return t;`
	`}`

`movl (%rdi),%edx`
`addl %edx,(%rsi)`
`movl %edx,%eax`
`ret`
	`int fun( int* x, int* y ) {`
	`int t= *x;`
	`*y +=t;`
	`return t;`
	`}`

Question 6: (6 pts)

The C code and assembly is given below for a function, but without values of M and N.

```
#define M __
#define N __

int array1[M][N];
int array2[N][M];
int copy(int i, int j) {
  array1[i][j] = array2[j][i];
}
```

```
movslq %edi,%rdi
movslq %esi,%rax
lea    (%rax,%rax,4),%rdx
add    %rdi,%rdx
mov    array2(,%rdx,4),%edx
lea    0x0(,%rdi,8),%rsi
sub    %rdi,%rsi
add    %rax,%rsi
mov    %edx,array1(,%rsi,4)
retq
```

What are the values of M and N?

M = 5 ✓

N = 7 ✓

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Question 7. ISA Design (4 pts)

In one or two sentences only, why have 32-bit ISAs become less popular for personal computers (laptops/desktops/cell-phones) over the last two decades?

So vague though!

That way they can run stuff made with 64-bits, and there are more addresses that they can use for memory.

:)

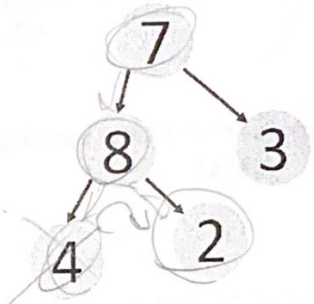
Question 8: Stack Structures (12pts)

Considered an *unordered* tree represented with this struct. The function "smallest" will retrieve the smallest element from the tree.

```
struct node {
  int value;
  struct node* left, *right;
} node;

int smallest(node * n) {
  int temp, ret = n->value;
  if(n->left) {
      temp=smallest(n->left);
      if(temp<ret) ret = temp;
  }
  if(n->right) {
      temp=smallest(n->right);
      if(temp<ret) ret = temp;
  }
  return ret;
}
```

Assume this is the input data-structure stored using node structs:



if unknown pointer val. put it.

```
smallest:
0x4004ed <+0>:  push   %rbp
0x4004ee <+1>:  push   %rbx
0x4004ef <+2>:  sub    $0x8,%rsp
0x4004f3 <+6>:  mov    %rdi,%rbx
0x4004f6 <+9>:  mov    (%rdi),%ebx
0x4004f8 <+11>: mov    0x8(%rdi),%rdi
0x4004fc <+15>: test   %rdi,%rdi
0x4004ff <+18>: je     0x40050b <smallest+30>
0x400501 <+20>: callq  0x4004ed <smallest>
0x400506 <+25>: cmp    %eax,%ebx
0x400508 <+27>: cmovg  %eax,%ebx
0x40050b <+30>: mov    0x10(%rbp),%rdi
0x40050f <+34>: test   %rdi,%rdi
0x400512 <+37>: je     0x40051e <smallest+49>
0x400514 <+39>: callq  0x4004ed <smallest>
0x400519 <+44>: cmp    %eax,%ebx
0x40051b <+46>: cmovg  %eax,%ebx
0x40051e <+49>: mov    %ebx,%eax
0x400520 <+51>: add    $0x8,%rsp
0x400524 <+55>: pop    %rbx
0x400525 <+56>: pop    %rbp
0x400526 <+57>: retq
```

(note, cmov is conditional move)

Caller Return Address
old rbp
old rbx
<Stack Space>
0x400506
pointer to node 7
7
<stack space>
rsp → 0x400519

(assume 8 bytes wide!!)

(a) Draw what is on the stack, provided in the space above, when smallest(2) is entered (ie. when it is called, and just before the instruction at 0x4004ed is executed) . Assume the root of the pictured tree is the input.
Note: If you don't know what a register value is, just mark it as "old rbp" etc. If you know what a register value is, write the corresponding value. **(6pts)**

(b) What is the size of the node struct? **(2pts)**

24 bytes.

(c) Is there any padding in the struct "node" due to alignment rules? **(1pts)**

Yes. 4 bytes between the int and first double.

(d) Can you rearrange the elements of "node" to reduce its size? **(1pts)**

No, since although you could move the 4 bytes of padding to the end, you would still need them to make the overall size align with 8.

(e) Which of the following are possible starting addresses for a node: **(2pts)**

(i) `0x7ffe4d3be87c`
(ii) `0x7ffe4d3be874`
(iii) `0x000444444440`
(iv) `0xfffff1234568`

→ needs to be multiple of 8: 1000 / 8 or 0000 / 0 last bit

Question 9 (Bonus): Your points overfloweth! (5pts)

Consider the following code (a variation on a hopefully-familiar example).

```
#include <stdio.h>
#include <stdlib.h>

typedef struct {
  int a[2];
  double d;
} struct_t;

double fun(int i, int j) {
  volatile struct_t s;
  s.d = 12345.0;
  s.a[i] = j;
  return s.d;
}
```

4 bytes | 4 bytes | 8 bytes

What input arguments to function "fun" would return the value 33.0? i=3

12345: $1\cdot2^{13} + 1\cdot2^{12} + 0 \ldots 0 + 1\cdot2^{5} + 1\cdot2^{4} + 1\cdot2^{3} + 0 + 0 + 1\cdot2^{0}$

$1.100\ldots00111001 \times 2^{13}$

can alter 4 bytes

double: 1 bit, 11-bits, 52-bits (2 bytes + 4 bits)

33 mantissa: $1.00001000\ldots0 \times 2^{5}$

need to alter exponent.

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Question 10 (bonus): (5pts)

The following is a student's submission from a previous year's question on the datalab.

```
int function(int x) {
    int m1 = 0x11 | (0x11 << 8);
    int mask = m1 | (m1 << 16);
    int s = x & mask;
    s += x>>1 & mask;
    s += x>>2 & mask;
    s += x>>3 & mask;
    s = s + (s >> 16);
    mask = 0xF | (0xF << 8);
    s = (s & mask) + ((s >> 4) & mask);
    return (s + (s>>8)) & 0x3F;
}
```

m1 = 0001 0001 0001 0001

mask = 0001 ... 0001

What does this function do?

it returns the number of 1's in x's binary representation

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