Full Name: ________________________

Andrew ID: ________________________

Recitation Section: ________________________

CS 15-213, Spring 2001

Exam 1

February 27, 2001

Instructions:

• Make sure that your exam is not missing any sheets, then write your full name and Andrew ID on the front.

• Write your answers in the space provided below the problem. If you make a mess, clearly indicate your final answer.

• The exam has a maximum score of 70 points.

• This exam is OPEN BOOK. You may use any books or notes you like. You cannot, however, use any computers, calculators, palm pilots, .... Good luck!

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td>1:</td>
<td></td>
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<td>2:</td>
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<td>3:</td>
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<td>6:</td>
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<tr>
<td>TOTAL:</td>
<td></td>
</tr>
</tbody>
</table>
Problem 1. (12 points):

For each of the following statements circle whether it is always true (True), never true (False), or sometimes true (Some). Assume the integer representation and implementation used by the IA32 architecture. Use the following definitions:

short sy = Some_arbitrary_short();
int x = Some_arbitrary_int();
int y = sy;
unsigned ux = x;
unsigned uy = y;

Also note that INT_MAX is the maximum positive integer and INT_MIN is the most negative integer.

\[
\begin{align*}
\text{x & -1 == x} & \quad \text{True} & \quad \text{False} & \quad \text{Some} \\
\text{INT_MAX + INT_MIN == 0} & \quad \text{True} & \quad \text{False} & \quad \text{Some} \\
\text{x > 0 \Rightarrow x + INT_MAX < 0} & \quad \text{True} & \quad \text{False} & \quad \text{Some} \\
\text{x + -x == 0} & \quad \text{True} & \quad \text{False} & \quad \text{Some} \\
\text{(ux >> 1) == (x >> 1)} & \quad \text{True} & \quad \text{False} & \quad \text{Some} \\
\text{(ux > uy) \Rightarrow (x > y)} & \quad \text{True} & \quad \text{False} & \quad \text{Some} \\
\text{ux > INT_MIN} & \quad \text{True} & \quad \text{False} & \quad \text{Some} \\
\text{sy == y} & \quad \text{True} & \quad \text{False} & \quad \text{Some} \\
\text{((unsigned) sy) == uy} & \quad \text{True} & \quad \text{False} & \quad \text{Some} \\
\text{(~x + 1) == ~(x - 1)} & \quad \text{True} & \quad \text{False} & \quad \text{Some} \\
\text{x >> 4 == x / 16} & \quad \text{True} & \quad \text{False} & \quad \text{Some} \\
\text{ux & 255 == ux % 256} & \quad \text{True} & \quad \text{False} & \quad \text{Some}
\end{align*}
\]
Problem 2. (12 points):
Consider the following 6-bit floating point representation based on the IEEE floating point format:

- There is a sign bit in the most significant bit.
- The next 3 bits are the exponent. The exponent bias is 3.
- The last 2 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.

The rules are like those in the IEEE standard (normalized, denormalized, representation of 0, infinity, NAN, and round-to-even).

Please fill in the table below. You do not have to fill in boxes with "—" in them. If a number is NAN, you may disregard the \( M \), \( E \), and \( V \) fields below. However, fill the Description, Hex, and Binary fields with valid data.

Here are some guidelines for each field:

- **Description** - A verbal description if the number has a special meaning
- **Hex** - The Hexadecimal equivalent of the Binary field
- **Binary** - Binary representation of the number
- **M** - Significand (same as the \( M \) in the formula above)
- **E** - Biased Exponent (same as the \( E \) in \( 2^E \))
- **V** - Fractional Value represented

Please fill the \( M \), \( E \), and \( V \) fields below with rational numbers (fractions) rather than decimals

<table>
<thead>
<tr>
<th>Description</th>
<th>Binary</th>
<th>Hex</th>
<th>( M )</th>
<th>( E )</th>
<th>( V )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Largest <strong>Denormalized</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Largest <strong>Normalized</strong> (&lt; ( \infty ))</td>
<td>1 111 01</td>
<td>0x3D</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>—</td>
<td>—</td>
<td>0x12</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.0 + 0.375</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.0 * 3.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Problem 3. (12 points):

This problem tests your understanding of how while loops in C relate to IA32 assembly code. The following is the assembly code for function foo.

```assembly
foo:
pushl %ebp
movl %esp,%ebp
pushl %ebx
movl 8(%ebp),%edx
movl 12(%ebp),%ebx
xorl %ecx,%ecx
cmpl %ebx,%edx
jg .L19
.L20:
    movl %edx,%eax
    imull %edx,%eax
    addl %eax,%ecx
    incl %edx
cmpl %ebx,%edx
    jle .L20
.L19:
    movl %ecx,%eax
    popl %ebx
    movl %ebp,%esp
    popl %ebp
    ret
```

Fill in the blanks in the definition of foo. The only variables you need are x, y, and result.

```c
int foo (int x, int y) {
    int result;

    __________;
    while (________) {
        ____________;
    }
    __________;
    return result;
}
```
Problem 4. (12 points):

The following problem will test your understanding of stack frames. It is based on the following function:

```c
int power(int *val, int n)
{
    int result = 1;

    if (n > 0) result = *val * power(val, n-1);

    return result;
}
```

A compiler on an IA-32 Linux machine produces the following object code for this function, which we have disassembled (using objdump) back into assembly code:

```
080483b4 <power>:
    080483b4:   55  push   %ebp
    080483b5:   89 e5  mov    %esp,%ebp
    080483b7:   83 ec 14  sub    $0x14,%esp
    080483ba:   53  push   %ebx
    080483bb:   8b 5d 08  mov    0x8(%ebp),%ebx
    080483bc:   8b 55 0c  mov    0xc(%ebp),%edx
    080483c1:   b8 01 00 00 00  mov    $0x1,%eax
    080483c6:   85 d2  test   %edx,%eax
    080483c8:   7e 10  jle    80483da <power+0x26>
    080483ca:   83 c4 f8  add    $0xffffffff,%esp
    080483cd:   8d 42 ff  lea    0xffffffff(%edx),%eax
    080483d0:   50  push   %eax
    080483d1:   53  push   %ebx
    080483d2:   e8 dd ff ff ff  call   80483b4 <power>
    080483d7:   0f af 03  imul   (%ebx),%eax
    080483da:   8b 5d e8  mov    0xfffff(%ebp),%ebx
    080483dd:   89 ec  mov    %ebp,%esp
    080483df:   5d  pop    %ebp
    080483e0:   c3  ret
    080483e1:   8d 76 00  lea    0x0(%esi),%esi
```

A. On the next page, you have the diagram of the stack immediately after some function makes a call to `power()`. The value of register `%esp` is `0xbfffff6d8`. The instruction to be executed next is denoted with an arrow (`→`) in the assembly code above. For each of the numeric values shown in the table, give a short description of the value. If the value has a corresponding variable in the original C source code, use the name of this variable as its description.

B. Assume that `power()` runs until it reaches the position denoted with an arrow (`→`) again. In the table on the next stage, fill in the updated stack. Use a numeric value (if possible, else write `n/a`) and provide a short description of the value. Cross out any stack space not used.

C. Which instruction (give its address) computes the value `n-1`?
<table>
<thead>
<tr>
<th>Address</th>
<th>Numeric Value</th>
<th>Comments/Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0xbfff6e4</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>0xbfff6e0</td>
<td>0xbfff704</td>
<td></td>
</tr>
<tr>
<td>0xbfff6dc</td>
<td>0x080483ff</td>
<td></td>
</tr>
<tr>
<td>0xbfff6d8</td>
<td>0xbfff708</td>
<td></td>
</tr>
<tr>
<td>0xbfff6d4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0xbfff6d0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0xbfff6cc</td>
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<td></td>
</tr>
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<td>0xbfff6c8</td>
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<td>0xbfff6c0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0xbfff6bc</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0xbfff6b8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0xbfff6b4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0xbfff6b0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0xbfff6ac</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0xbfff6a8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0xbfff6a4</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Problem 5. (12 points):

For the following problem assume the IA-32 Windows alignment convention—i.e., values of type `double` must be 8-byte aligned (vs. the Linux convention where they are only 4-byte aligned). Consider the following definition:

```c
typedef struct {
    short s;
    int i;
    double *d;
    union1 un;
    int j;
} struct1;

struct1 A[3][2];
```

The following template is provided as an aid to help you solve this problem. You do not have to use it and **anything written in this template will not be graded**.

```
<table>
<thead>
<tr>
<th>Byte Offset</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
</tr>
</tbody>
</table>
```

What is the byte offset relative to the start of `A` for each of the following locations (assuming IA-32 conventions):

1. &A[0][0]
2. &A[0][0].s
3. &A[0][0].i
4. &A[0][0].d
5. &A[0][0].un.s
6. &A[0][0].un.d
7. &A[1][0]
8. &A[0][1]
9. &A[0][0] + 1
10. &A[0][0].s + 1
11. &A[0][0].un.i + 1
Problem 6. (10 points):
The following C file, p.c, contains a simple function called process as shown below.

    extern int status;
    void toggle(void);

    void process(int n)
    {
        if (((n < 0) && (status == 1)) || ((n > 0) && (status == -1))) toggle();
    }

The function references an external global variable called status and a function called toggle. Both status and toggle are defined in the file toggle.c, which is shown below.

    int status = 1;
    int changes = 0;

    void toggle(void)
    {
        status = -status;
        changes++;
    }

A relocatable object file p.o has been created and then disassembled using the commands

    gcc -O2 -c -o p.o p.c
    objdump -d p.o > p.bdis

The disassembled file p.bdis is shown on the next page. The relocation directives in the relocatable object file p.o are NOT displayed in p.bdis, because objdump was invoked without the -r flag. Not shown is the relocatable object file toggle.o, which was created as follows:

    gcc -O2 -c -o toggle.o toggle.c

Your task is to circle all of the bytes in the disassembled object file p.bdis that the linker ld will modify when it creates an executable object file that includes the relocatable object files p.o and toggle.o.
process.o: file format elf32-i386

Disassembly of section .text:

00000000 <process>:
  0:  55           push   %ebp
  1:  89 e5        mov     %esp,%ebp
  3:  83 ec 08     sub     $0x8,%esp
  6:  8b 45 08     mov     0x8(%ebp),%eax
  9:  85 c0        test    %eax,%eax
 b:  7d 09        jge     16 <process+0x16>
 d:  83 3d 00 00 00 00 01 cmpl   $0x1,0x0
14:  74 0d        je      23 <process+0x23>
16:  85 c0        test    %eax,%eax
18:  7e 0e        jle     28 <process+0x28>
1a:  83 3d 00 00 00 00 ff cmpl   $0xffffffff,0x0
21:  75 05        jne     28 <process+0x28>
23: e8 fc ff ff ff call    24 <process+0x24>
28:  89 ec        mov     %ebp,%esp
2a:  5d           pop     %ebp
2b:  c3           ret