CS 15-213, Spring 2004

Exam 1

February 26, 2004

Instructions:

- Make sure that your exam is not missing any sheets (there should be 15), then write your full name and Andrew login 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 80 points.
- The problems are of varying difficulty. The point value of each problem is indicated. Pile up the easy points quickly and then come back to the harder problems.
- This exam is OPEN BOOK. You may use any books or notes you like. No electronic devices are allowed. Good luck!

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>(9):</td>
</tr>
<tr>
<td>2</td>
<td>(14):</td>
</tr>
<tr>
<td>3</td>
<td>(12):</td>
</tr>
<tr>
<td>4</td>
<td>(8):</td>
</tr>
<tr>
<td>5</td>
<td>(12):</td>
</tr>
<tr>
<td>6</td>
<td>(12):</td>
</tr>
<tr>
<td>7</td>
<td>(6):</td>
</tr>
<tr>
<td>8</td>
<td>(7):</td>
</tr>
</tbody>
</table>

TOTAL (80):
Problem 1. (9 points):
Assume we are running code on a 10-bit machine using two’s complement arithmetic for signed integers. Short integers are encoded using 5 bits. Sign extension is performed whenever a short is casted to an int. For this problem, assume that all shift operations are arithmetic. Fill in the empty boxes in the table below.

```c
int i = -42;
unsigned ui = i;
short s = -7;
unsigned short us = s;
```

Note: You need not fill in entries marked with “–”. TMax denotes the largest positive two’s complement number and TMin denotes the minimum negative two’s complement number. Finally, you must use hexadecimal notation for your answers in the “Hex Representation” column, failure to do so will result in being marked incorrect on that portion of the question.

<table>
<thead>
<tr>
<th>Expression</th>
<th>Decimal Representation</th>
<th>Hex Representation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zero</td>
<td>0</td>
<td>000</td>
</tr>
<tr>
<td>–</td>
<td>-9</td>
<td>3f7</td>
</tr>
<tr>
<td>i</td>
<td>-42</td>
<td>3d6</td>
</tr>
<tr>
<td>i &gt;&gt; 5</td>
<td>-2</td>
<td>3fe</td>
</tr>
<tr>
<td>ui</td>
<td>982</td>
<td>3d6</td>
</tr>
<tr>
<td>(int) s</td>
<td>-7</td>
<td>3f9</td>
</tr>
<tr>
<td>(int)(s ^ -12)</td>
<td>13</td>
<td>00d</td>
</tr>
<tr>
<td>(int) us</td>
<td>25</td>
<td>019</td>
</tr>
<tr>
<td>TMax</td>
<td>511</td>
<td>1ff</td>
</tr>
<tr>
<td>Tmin</td>
<td>-512</td>
<td>200</td>
</tr>
</tbody>
</table>
Problem 2. (14 points):

Consider the following 11-bit floating point representation based on the IEEE floating point format:

- There is a sign bit in the most significant bit.
- The next \( k = 4 \) bits are the exponent. The exponent bias is 7.
- The last \( \tau = 6 \) bits are the significand.

Numeric values are encoded in this format as a value of the form \( V = (-1)^s \times M \times 2^E \), where \( s \) is the sign bit, \( E \) is exponent after biasing, and \( M \) is the significand.

Part I

How many FP numbers are in the following intervals \([a, b)\)?

For each interval \([a, b)\), count the number of \( x \) such that \( a \leq x < b \).

A. Interval \([1, 2)\) : \( 2^6 = 64 \)

B. Interval \([2, 2.5)\) : \( 2^4 = 16 \)

Part II

Answer the following problems using either decimal (e.g., 1.375) or fractional (e.g., 11/8) representations for numbers that are not integers.

A. For denormalized numbers:

(a) What is the smallest value \( E \) of the exponent after biasing? \( -6 \)

(b) What is the largest value \( M \) of the significand? \( 63/64 \)

B. For normalized numbers:

(a) What is the smallest value \( E \) of the exponent after biasing? \( -6 \)

(b) What is the largest value \( E \) of the exponent after biasing? \( 7 \)

(c) What is the smallest value \( M \) of the significand? \( 1 \)

(d) What is the largest value \( M \) of the significand? \( 127/64 \)
Part III

Fill in the blank entries in the following table giving the encodings for some interesting numbers.

<table>
<thead>
<tr>
<th>Description</th>
<th>$E$</th>
<th>$M$</th>
<th>$V$</th>
<th>Binary Encoding</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zero</td>
<td>-6</td>
<td>0</td>
<td>0</td>
<td>0 0000 000000</td>
</tr>
<tr>
<td>Smallest Positive (nonzero)</td>
<td>-6</td>
<td>1/64</td>
<td>1/4096</td>
<td>0 0000 000001</td>
</tr>
<tr>
<td>Largest denormalized</td>
<td>-6</td>
<td>63/64</td>
<td>63/4096</td>
<td>0 0000 111111</td>
</tr>
<tr>
<td>Smallest positive normalized</td>
<td>-6</td>
<td>1</td>
<td>1/64</td>
<td>0 0001 000000</td>
</tr>
<tr>
<td>Positive Infinity</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>0 1111 000000</td>
</tr>
<tr>
<td>Negative Infinity</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>1 1111 000000</td>
</tr>
</tbody>
</table>
Problem 3. (12 points):

Consider the following assembly code:

```
8048333 <func>:
  55  push %ebp
  89 e5  mov %esp,%ebp
  83 ec 0c  sub $0xc,%esp
  c7 45 fc 00 00 00 00  movl $0x0,0xffffffff(%ebp)
  8b 45 08  mov 0x8(%ebp),%eax
  0f af 45 0c  imul 0xc(%ebp),%eax
  39 45 fc  cmp %eax,0xffffffff(%ebp)
  72 02  jb 804834e <func+0x1b>
  eb 2f  jmp 804837d <func+0x4a>
  8b 45 08  mov 0x8(%ebp),%eax
  0f af 55 0c  imul 0xc(%ebp),%edx
  8d 45 fc  lea 0xffffffff(%ebp),%eax
  01 10  add %edx,(%eax)
  8b 45 08  mov 0x8(%ebp),%eax
  48  dec %eax
  89 44 24 04  mov %eax,0x4(%esp,1)
  8b 45 0c  mov 0xc(%ebp),%eax
  03 45 08  add 0x8(%ebp),%eax
  d1 e8  shr $0x1,%eax
  89 04 24  mov %eax,(%esp,1)
  e8 bf ff ff ff  call 8048333 <func>
  89 c2  mov %eax,%edx
  8d 45 fc  lea 0xffffffff(%ebp),%eax
  29 10  sub %edx,(%eax)
  eb c3  jmp 8048340 <func+0xd>
  8b 45 fc  mov 0xffffffff(%ebp),%eax
  c9  leave
  c3  ret
```
The assembly on the previous page corresponds to the C code below. Fill in the blanks in the C code to match the operations done in the assembly.

```c
unsigned int func(unsigned int a, unsigned int b)
{
    unsigned int result = 0;
    while (result < a*b) {
        result += a*b;
        result -= func((a+b)/2, a-1);
    }
    return result;
}
```
Problem 4. (8 points):
Consider the following C declarations:

```c
struct a_struct {
    char a;
    struct a_struct *b;
};

struct b_struct {
    char c;
    int i;
    double * d;
    short e[3];
    struct a_struct m;
};
```

A. Using the templates below (allowing a maximum of 32 bytes), indicate the allocation of data for `struct b_struct`. Mark off and label the areas for each individual element (arrays may be labeled as a single element). **Cross hatch the parts that are allocated, but not used, and be sure to clearly indicate the end of the structure. Assume the Linux alignment rules discussed in class.**

```
<table>
<thead>
<tr>
<th>0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15</th>
</tr>
</thead>
<tbody>
<tr>
<td>c X X X</td>
</tr>
<tr>
<td>+---------------------------------------</td>
</tr>
<tr>
<td>e e X X</td>
</tr>
<tr>
<td>+---------------------------------------</td>
</tr>
</tbody>
</table>
```
B. How would you define the `struct b2_struct` structure to minimize the number of bytes allocated for the structure using the same fields as the `struct b_struct` structure?

```c
struct b2_struct {
    char c;
    short e[3];
    int i;
    double * d;
    struct a_struct m;
}
```

(Most solutions with e and c adjacent work.)

C. What is the value of `sizeof(struct b2_struct)`? 24
Problem 5. (12 points):
Consider the following C code:

```c
struct triple {
    int x;
    char c;
    int y;
};

int mystery1(int x);
int mystery2(int x);
int mystery3(struct triple* t);

int main()
{
    struct triple t = {35, 'q', 10};

    int result1 = mystery1(42);
    int result2 = mystery2(19);
    int result3 = mystery3(&t);

    printf("result1 = %d\n", result1);
    printf("result2 = %d\n", result2);
    printf("result3 = %d\n", result3);

    return 0;
}
```

Using the assembly code for mystery1, mystery2, and mystery3 on the next page, fill in the proper values in this program’s output:

result1 = \underline{3} \\
result2 = \underline{19} \\
result3 = \underline{350}
80483d0 <mystery1>:
80483d0:  55            push %ebp
80483d1:  89 e5         mov %esp,%ebp
80483d3:  53            push %ebx
80483d4:  8b 45 08     mov 0x8(%ebp),%eax
80483d7:  89 c3         mov %eax,%ebx
80483d9:  83 e3 01     and $0x1,%eax
80483dc:  89 c3         mov %eax,%ebx
80483de:  74 0b         je 80483eb <mystery1+0x1b>
80483e0:  c1 f8 01     sar $0x1,%eax
80483e3:  50            push %eax
80483e4:  e8 e7 ff ff ff call 80483d0 <mystery1>
80483e9:  01 c3        add %eax,%ebx
80483eb:  89 d8         mov %ebx,%eax
80483ed:  8b 5d fc     mov 0xfffffffff(%ebp),%ebx
80483ef:  c9            leave
80483f1:  c3            ret

80483f4 <mystery2>:
80483f4:  55            push %ebp
80483f5:  89 e5         mov %esp,%ebp
80483f7:  8b 55 08     mov 0x8(%ebp),%edx
80483fa:  31 c0         xor %eax,%eax
80483fc:  85 d2         test %edx,%edx
80483fe:  7e 06        jle 8048406 <mystery2+0x12>
8048400:  40            inc %eax
8048401:  4a            dec %edx
8048402:  85 d2         test %edx,%edx
8048404:  7f fa        jg 8048400 <mystery2+0xc>
8048406:  c9            leave
8048407:  c3            ret

8048408 <mystery3>:
8048408:  55            push %ebp
8048409:  89 e5         mov %esp,%ebp
804840b:  8b 45 08     mov 0x8(%ebp),%eax
804840e:  8b 10         mov (%eax),%edx
8048410:  0f af 50 08   imul 0x8(%eax),%edx
8048414:  89 d0         mov %edx,%eax
8048416:  c9            leave
8048417:  c3            ret
Problem 6. (12 points):

This problem tests your understanding of byte ordering and the stack discipline. The following program reads a string from standard input and prints an integer in its hexadecimal format based on the input it was given.

```c
#include <stdio.h>

int get_key () {
    int key;
    scanf (%s, &key);
    return key;
}

int main () {
    printf ("0x%8x\n", get_key());
    return 0;
}
```

Here is the corresponding machine code on a Linux/x86 machine:

```
08048414 <get_key>:
  08048414: 55 push %ebp
  08048415: 89 e5 mov %esp,%ebp
  08048417: 83 ec 18 sub $0x18,%esp
  0804841a: 83 c4 f8 add $0xffffffff8,%esp
  0804841d: 8d 45 fc lea 0xfffffffc(%ebp),%eax
  08048420: 50 push %eax  address arg for scanf
  08048421: 68 b8 84 04 08 push $0x80484b8  format string for scanf
  08048426: e8 d2 ff ff ff call 804830c <_init+0x50>  call scanf
  0804842b: 8b 45 fc mov 0xfffffffffc(%ebp),%eax
  08048430: 5d pop %ebp
  08048431: c3 ret

08048434 <main>:
  08048434: 55 push %ebp
  08048435: 89 e5 mov %esp,%ebp
  08048437: 83 ec 08 sub $0x8,%esp
  0804843a: 83 c4 f8 add $0xffffffff8,%esp
  0804843d: e8 d2 ff ff ff call 8048414 <get_key>
  08048442: 50 push %eax  integer arg of printf
  08048443: 68 bb 84 04 08 push $0x80484bb  format string for printf
  08048448: e8 ef fe ff ff call 804833c <_init+0x80>  call printf
  0804844d: 31 c0 xor %eax,%eax
  0804844f: 89 ec mov %ebp,%esp
  08048451: 5d pop %ebp
  08048452: c3 ret
```

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Here are a few notes to help you with the problem:

- `scanf ("\%s", i)` reads a string from the standard input stream and stores it at address `i` (including the terminating `\0` character. It does **not** check the size of the destination buffer.

- `printf ("0x%8x\n", j)` prints 8 digits of the integer `i` in hexadecimal format as `0xxxxx`

- Recall that Linux/x86 machines are Little Endian.

- You will need to know the hex values for the following characters:

<table>
<thead>
<tr>
<th>Character</th>
<th>Hex Value</th>
<th>Character</th>
<th>Hex Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>'E'</td>
<td>0x45</td>
<td>'s'</td>
<td>0x73</td>
</tr>
<tr>
<td>'v'</td>
<td>0x76</td>
<td>'h'</td>
<td>0x68</td>
</tr>
<tr>
<td>'i'</td>
<td>0x69</td>
<td>'!'</td>
<td>0x21</td>
</tr>
<tr>
<td>'l'</td>
<td>0x6c</td>
<td>'\0'</td>
<td>0x00</td>
</tr>
</tbody>
</table>

A. Suppose we run this program on a Linux/x86 machine with the input string “Evil!”.  

Here is a template for the stack, showing the location of `key`. Indicate with a labelled arrow where `%ebp` points to, and fill in the stack with the values that were just read in **after** the call to `scanf` (**addresses increase from left to right**).

```
|<------ key ------>
+----+----+----+----+----+----+----+----+----+----+----+----+----+
| | | | | 45 | 76 | 69 | 6c | 21 | 00 | | | |
+----+----+----+----+----+----+----+----+----+----+----+----+----+
^ %ebp
```

What is the 4-byte integer (in hex) printed by `printf` inside `main`?

0x 6c697645
B. Suppose we instead gave it the input string “Evillish!”.

For the remaining problems, each answer should be an unsigned 4-byte integer expressed as 8 hexadecimal digits.

(a) What is the value of (key)[1] just after scanf returns to get_key?

(key)[1] = 0x6873696c

(b) What is the value of %ebp immediately before the execution of the ret instruction of get_key?

%ebp = 0x6873696c

You can use the following template of the stack as scratch space. This will not be considered for credit.

```
+----+----+----+----+----+----+----+----+----+----+----+----+----+
| | | | | | | | | | | | | |
+----+----+----+----+----+----+----+----+----+----+----+----+----+
```

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Problem 7. (6 points):

Consider the following code for a matrix multiplication function:

```c
for (i=0; i<n; i++) {
    for (j=0; j<n; j++) {
        sum = 0.0;
        for (k=0; k<m; k++)
            sum += a[i][k] * b[k][j];
        c[i][j] = sum;
    }
}
```

with matrices $a[n][m], b[m][n]$ and $c[n,n]$.

1. Assume that $m$ is twice as large as $n$. Is the above loop optimally arranged for preserving locality? If not, state the optimal nesting of these loops.

   No,
   Nest them as

   ```c
   for ( ... i ... )
       for ( ... k ... )
           for ( ... j ... )
   ```

   see class13, slides 30-40

2. Assume that $n$ is twice as large as $m$. Is the above loop optimally arranged for preserving locality? If not, state the optimal nesting of these loops.

   No,
   Nest them as

   ```c
   for ( ... i ... )
       for ( ... k ... )
           for ( ... j ... )
   ```

   see class13, slides 30-40
Problem 8. (7 points):
Answer true or false for each of the statements below. For full credit your answer must be correct and you must write the entire word (either true or false in the answer space.

1. If it takes less time to do either a cache access or a main memory access than to perform a branch, then loop unrolling always improves performance. false

2. On the Fish machines the most effective way to time a short routine is to use the cycle counter. true

3. Loop invariant code motion can be applied to expressions involving the loop induction variable false

4a. typedef int (*a)(int *);
typedef a b[10];
typedef b* (*c)();
c d;
int *(*(*) (int *)) [10] (*e)();
d and e have the same type.
either

4b. e and c have the same type. false

5. In C, the variable f is declared as: int f[12][17]. The address for f[3][8] can sometimes be greater than the address for f[8][3]. false

6. The largest possible finite denormalized IEEE floating number is greater than the smallest possible positive normalized IEEE floating number: false