CSE 351 Spring 2017 – Final Exam (7 June 2017)

Please read through the entire examination first!
- You have 110 minutes for this exam. Don't spend too much time on any one problem!
- The last page is a reference sheet. Feel free to detach it from the rest of the exam.
- The exam is CLOSED book and CLOSED notes (no summary sheets, no calculators, no mobile phones).

There are 8 problems for a total of 65 points. The point value of each problem is indicated in the table below. Write your answer neatly in the spaces provided.

Please do not ask or provide anything to anyone else in the class during the exam. Make sure to ask clarification questions early so that both you and the others may benefit as much as possible from the answers.

POINTS WILL BE DEDUCTED if you are writing/erasing after the final bell has rung!

Good Luck!

Your Name:__Sample Solution________

UWNet ID:_____woof2017___________

Name of person to your left | Name of person to your right

_________________________ | ___________________________

Problem	**Topic**	**Max Score**
1	Caches	11
2	Processes	6
3	Virtual Memory	9
4	Memory Allocation	8
5	Java	9
6	Compilation	7
7	Representation	6
8	Assembly to C	9
TOTAL		**65**

1. Caches (11 points)

You are using a byte-addressed machine where physical addresses are 22-bits. You have a 4-way associative cache of total size 1 KiB with a cache block size of 32 bytes. It uses LRU replacement and write-back policies.

a) Give the number of bits needed for each of these:

Cache Block Offset: _____**5**______ Cache Tag: _____**14**________

b) How many sets will the cache have? ____**8**______

c) Assume that everything except the array **x** is stored in registers, and that the array **x** starts at address 0x0. Give the hit rate (as a fraction or a %) for the following code, assuming that the cache starts out empty. Also give the total number of hits.

```
#define LEAP 1
#define SIZE 256
int x[SIZE][8];
... // Assume x has been initialized to contain values.
... // Assume the cache starts empty at this point.
for (int i = 0; i < SIZE; i += LEAP) {
  x[i][0] += x[i][4];
}
```

Hit Rate: ___**2/3**_______ Total Number of **Hits**: ____**512**______

d) If we increase the cache block size to 64 bytes (and leave all other factors the same) what would the hit rate be?

Hit Rate: _____**5/6**_______ Total Number of **Hits**: _____**640**_______

e) For each of the changes proposed below, indicate how it would affect the **hit rate** of the code above in part c) *assuming that all other factors remained the same* as they were in the original cache:

Change associativity from 4-way to 2-way: increase / [✓ no change] / decrease

Change **LEAP** from 1 to 4: increase / [✓ no change] / decrease

Change cache size from 1 KiB to 2 KiB: increase / [✓ no change] / decrease

2. Processes (6 points)

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

int x = 0;

void say_hi(int *y) {
  if (fork() > 5000) {
    char *argv[2] = {"/bin/echo", "Hello"};
    int n = execv("/bin/echo", argv);
    printf("%d", *y);
  } else {
    printf("%d", x);
  }
}

int main(void) {
  int y = 5;
  if (fork() != 0) {
    y++;
    say_hi(&y);
  } else {
    x++;
  }
}
```

For the program above, list **all of the possible outputs**.

Hint: **`execv(path, arg)`** - replaces current process image with a new image.
`/bin/echo` simply prints the 2nd argument (in this case "Hello") to the screen.

Answer: **(3 possibilities)**

Hello0

0Hello

00

Note: You should check the return values of **`fork()`** and **`execv()`** for errors. **`execv()`** will not return UNLESS it has an error.

If **`execv()`** returns with an error, such as not being able to find the command echo, then two more possible outputs are possible: **`06`** and **`60`**.

We did not take off points missing these two outputs.

3. Virtual Memory (9 points)

Assume we have a virtual memory detailed as follows:

- 256 MiB Physical Address Space
- 4 GiB Virtual Address Space
- 1 KiB page size
- A TLB with 4 sets that is 8-way associative with LRU replacement

For the following questions it is fine to leave your answers as powers of 2.

a) How many bits will be used for:

Page offset? _____**10**______

Virtual Page Number (VPN)? ____**22**_____ Physical Page Number (PPN)? ___**18**______

TLB index? _______**2**_________ TLB tag? _______**20**__________

b) How many entries in this page table?

$$2^{22}$$

c) We run the following code with an empty TLB. Calculate the TLB miss rate for data (ignore instruction fetches). Assume `i` and `sum` are stored in registers and `cool` is page-aligned.

```
#define LEAP 8
int cool[512];
... // Some code that assigns values into the array cool
... // Now flush the TLB. Start counting TLB miss rate from here.
int sum;
for (int i = 0; i < 512; i += LEAP) {
  sum += cool[i];
}
```

TLB Miss Rate: (fine to leave you answer as a fraction) ____ $\frac{1}{32}$ __________

4. Memory Allocation (8 points)

a) In Garbage Collection, describe what it means (in 1-2 sentences) for a block to be "reachable". Be specific.

A block is reachable if a process has a path from any root (register, stack location, global variable) to that block. Non-reachable blocks are garbage .

b) TRUE / **FALSE**: In a C program, freeing the same address multiple times will be detected by the memory allocator and ignored.

c) The following two C functions have errors:

```
int* foo() {
   int val;
   return &val;
}
```

What is the error? ____ **Returning a pointer/address to memory on the stack**

Why is this bad? _____ **Stack memory is "deallocated" after the function returns and the value at the address may be overridden by another function call** _

```
void bar() {
   int *x = (int *) malloc( 10 * sizeof(int) );
   return;
}
```

What is the error? ____ **Memory Leak**___________________________________

Why is this bad? ____ **If bar is called enough times in the lifespan of a program, you may run out of heap memory.**

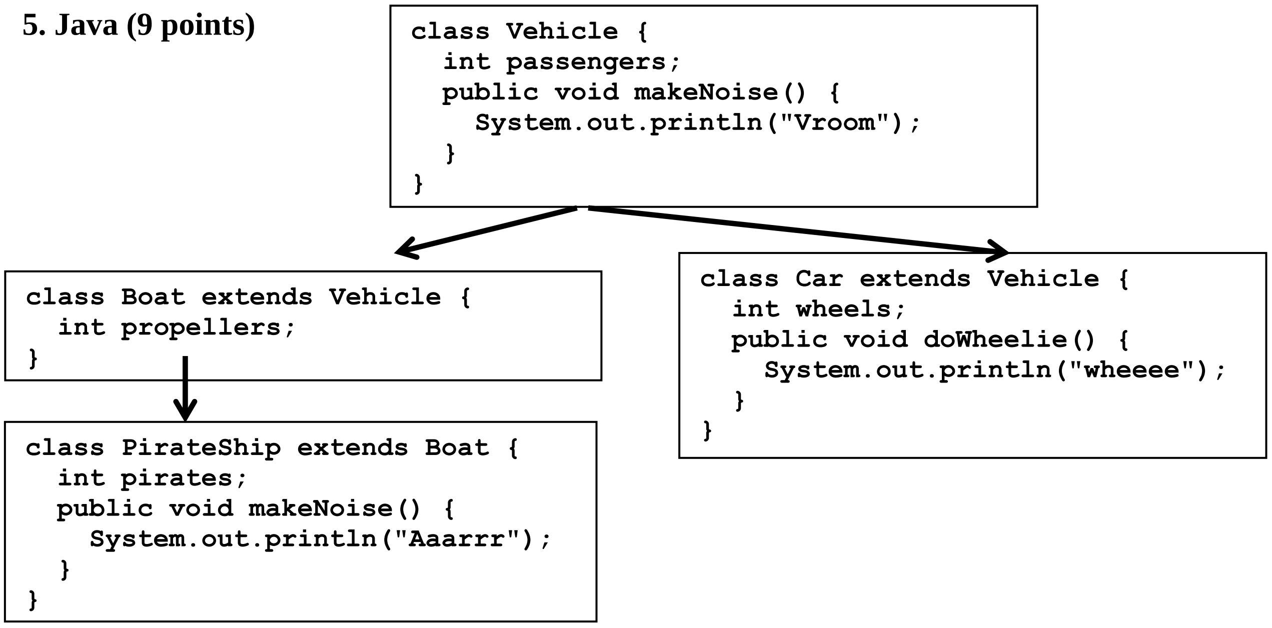
For **bar**, which of the following is most true (circle **ONLY** one):

i. This error will always be detected by the compiler.

ii. If this code runs, the error will always (eventually) cause the program to stop running unexpectedly.

[✓ **iii. If this code runs, the error could potentially go undetected**.]

5. Java (9 points)



```
class Vehicle {
  int passengers;
  public void makeNoise() {
    System.out.println("Vroom");
  }
}
```

```
class Boat extends Vehicle {
  int propellers;
}
```

```
class Car extends Vehicle {
  int wheels;
  public void doWheelie() {
    System.out.println("wheeee");
  }
}
```

```
class PirateShip extends Boat {
  int pirates;
  public void makeNoise() {
    System.out.println("Aaarrr");
  }
}
```

Given the class hierarchy above and the following additional code:

```
class FinalExam {
 public static void main(String[] args) {
   Boat       b1  = new Boat();
   PirateShip ps1 = new Boat();
   Boat       b2  = new PirateShip();
   Vehicle    v   = new PirateShip();
   PirateShip ps2 = (PirateShip) b1;
   PirateShip ps3 = (PirateShip) v;
 }
}
```

Compiler Error?	Runtime Error?	No Error
		×
×		
		×
		×
	×	
		×

a) Mark the appropriate column(s) of the table above to indicate if the line will cause a compiler and/or runtime error or no error.

b) Given our discussion in class, circle whether you would expect the following to be True or False:

i. [✓ TRUE] / FALSE: A **`Car`** object will be the same size as a **`Boat`** object.

ii. TRUE / [✓ FALSE]: A **`PirateShip`** object will be the same size as a **`Boat`** object.

iii. TRUE / [✓ FALSE]: The vtable for a **`Car`** will be the same size as the vtable for a **`Boat`**.

iv. TRUE / [✓ FALSE]: The vtable for a **`PirateShip`** will be the same size as the vtable for a **`Car`**.

v. TRUE / [✓ FALSE]: The code for **`doWheelie`** will be on the heap.

c) Given: **`Vehicle v2 = new PirateShip();`**

`v2.makeNoise();` will print ___________ Aaarrr _______________

6. Compiling and Running Programs (7 points)

a) Assume you were given a file `fact.c` identical to the one used in Homework 3, containing two functions `factorial` and `main`. Fill in the missing parts of the table below:

Tool Name (gcc command)	Type of file Produced (Give a description, not just file name or extension)	Can you run this file directly (yes/no)?	Can you easily edit this file in a text editor (yes/no)?
Linker (`gcc fact.o`)	**Executable (`a.out`)**	**Yes**	**No**
Compiler (`gcc -S fact.c`)	**Assembly (`fact.s`)**	**No**	**Yes**
Assembler (`gcc -c fact.s`)	**Object file (`fact.o`)**	**No**	**No**

b) In C, who determines whether an array is allocated on the stack or the heap?

[✓ **Programmer**] Compiler Language (Java) Runtime Operating System

c) In C, who determines whether local variables are allocated on the stack or stored in registers?

Programmer [✓ **Compiler**] Language (C) Runtime Operating System

d) Who/what assigns process IDs to individual processes?

Programmer Compiler Language (C, Java) Runtime [✓ **Operating System**]

e) Who/what finds data in the L1 cache and brings it into a register?

[✓ **Hardware**] Compiler Language (C, Java) Runtime Operating System

7. Representation (6 points)

a) Given the following declaration:

```
int x = …; // x < 0
```

For each of the following, indicate if it is TRUE for all possible values of **`x < 0`**. **<u>If not, select FALSE and give a BRIEF one sentence justification for your answer</u>**– BE SPECIFIC. You do not need to give a justification for true answers.

`i)  x == (int)(float) x` TRUE [✓ **FALSE**]

`The float type only has 23 bits for precision vs. 32 bits in int, so when converting from int to float we may lose precision.`

`ii) x == (int)(double) x` [✓ **TRUE**] FALSE

b) On a 64-bit word machine, you are given the following array declaration in C: `int a[6][3]`. If `a` starts at address 0, what will the expression `&(a[2][5])` evaluate to? (If "unknown" or "cannot be guaranteed", state that. Otherwise give your answer in **<u>decimal</u>**.)

2 * 3 * 4 + 5 * 4 = 24 + 20 = 44 (0x2c in hex)

c) Given the following struct in x86-64:

```
struct student {
    char name[10];
    int id;
    char color[7];
    double weight;
};
```

What is the total size of this struct in bytes? **32**

As a programmer, could you have declared this struct differently so that it uses less memory? If no, <u>explain why not</u>. If yes, <u>show how you would declare it</u> and <u>give the new total size</u> in bytes.

NO - there is no way to reorder the fields that will not still have 3 wasted bytes of padding somewhere.

8. Assembly to C (9 points)
Fill in the rest of the C code for the assembly code given below:

```
sunny(int*, int):
        cmpl    $1, %esi
        jne     .L2
        movl    (%rdi), %eax
        ret
.L2:
        cmpl    $4, %esi
        jg      .L4
        leal    -1(,%rsi,4), %esi
        addq    $4, %rdi
        call    sunny(int*, int)
        ret
.L4:
        testq   %rdi, %rdi
        jne     .L5
        leal    0(,%rsi,8), %eax
        subl    %esi, %eax
        ret
.L5:
        movl    (%rdi), %eax
        shll    $4, %eax
        ret
```

```
int sunny (int* n, int k) {

  if (____k == 1__________) {

    ____ return *n; __________________________

  } else if (__ k <= 4______) { // or k < 5

    _____ return sunny(n++, 4 * k - 1);______

  } else if (___ n == 0_____) {

    ______ return 7 * k;_________________

  } else {

    _______ return (*n) << 4;___________ // or (*n) * 16
  }
}
```