Name:______________________________________

CSE 303, Spring 2006, Final Examination
6 June 2006

Please do not turn the page until everyone is ready.

Rules:

- The exam is closed-book, closed-note, except for two 8.5x11in pieces of paper (both sides).
- **Please stop promptly at 4:20.**
- You can rip apart the pages, but please write your name on each page.
- There are **100 points** total, distributed **unevenly** among 11 questions (many of which have multiple parts).
- When writing code, style matters, but don't worry about indentation.

Question	Max	Grade
1	15	
2	12	
3	12	
4	10	
5	7	
6	7	
7	10	
8	10	
9	7	
10	4	
11	6	
Total	100	

Advice:

- Read questions carefully. Understand a question before you start writing.
- **Write down thoughts and intermediate steps so you can get partial credit.**
- The questions are not necessarily in order of difficulty. **Skip around.**
- If you have questions, ask.
- Relax. You are here to learn.

Name:____

1. (**15** points) Consider the following declarations in a C program:

```
typedef struct node {
  char *name;
} Node;


Node* create(char* message) {
  Node *new_element = (Node*)malloc(sizeof(Node));
  if ( !new_element ) {
      printf(‘‘Out of memory\n’’);
      return NULL;
  }
  new_element->name = message;
  return new_element;
}


void destroy(Node* garbage_element) {
    free(garbage_element->name);
    free(garbage_element);
}
```

   (a) (**4** points) Why will the following sequence of instructions cause a segmentation fault?

```
        char message[] = "Hello World";
        Node *element = create(message);
        if ( element ) {
            printf("Element is %s\n",element->name);
            destroy(element);
        }
```

Name:____

(b) (**4** points) What is the problem with the following sequence of instructions?

```
char message[] = "Hello World";
char *copy = (char*)malloc(strlen(message)+1);
strcpy(copy,message);

Node *element1 = create(copy);
Node *element2 = create(copy);
if ( element1 ) {
    destroy(element1);
}
if ( element2 ) {
    destroy(element2);
}
```

(c) (**7** points) Write a `create` function that avoids the problems above.

Name:____

Solution:

(a) The `create` function does not allocate new space on the heap for the string `name`. It makes `name` point directly to the string given as argument (which is not necessarily on the heap). The `destroy` function tries to free the memory corresponding to the string `name`. In the first example, this means that the `destroy` function tries to free a chunk of memory on the stack.

(b) After the two calls to `create`, `element1->name` and `element2->name` point to the same heap-allocated string. `destroy(element1)` frees that memory first, leaving `element2->name` dangling. `destroy(element2)` tries to free the same chunk of memory a second time.

(c) Because `destroy` will free `name`, `create` needs to allocate memory on the heap to hold the string:

```
Node* create(char* message) {

  Node *new_element = (Node*)malloc(sizeof(Node));
  if ( !new_element ) {
      printf(``Out of memory'');
      return NULL;
  }

  new_element->name = (char*)malloc(strlen(message)+1);
  if ( !new_element->name ) {
      printf(``Out of memory'');
      return NULL;
  }

  strcpy(new_element->name,message);
  return new_element;

}
```

Name:____

2. (**12** points) Consider a list of integers composed of self-referential structures of the form:

```
typedef struct node {
    int value;
    struct node *next;
} Node;
```

(a) (**7** points) Write a C function that meets the specifications below. You do not need to check the first precondition.

```
/**
 * Clears a list: removes all elements from the list and
 * frees the space that was allocated for each element
 *
 * Precondition 1: all elements in the list were allocated on the heap
 * Precondition 2: head is not NULL
 *
 * @param head, address of pointer to the first element in the list
 * @return nothing
 */
void clear(Node** head);
```

Solution:

```
void clear(Node** head) {

    // Checking the precondition
    assert(head);

    Node *current = *head;
    while (current) {

        Node *removed = current;
        current = current->next;
        free(removed);

    }

    *head = NULL;

}
```

Name:____

(b) (**5** points) Complete the implementation of the following C function

```
/**
 * Makes a copy of a list of integers
 *
 * Precondition: the src list is not empty
 *
 * @param src, pointer to the first element in the list to copy
 * @return a pointer to the first elment in the copy of the list
 */
Node* copy(Node* src) {

    // Checking precondition
    assert(src);

    // Step 1: make a copy of the first element in the list
    Node *dst = (Node*)malloc(sizeof(Node));
    if ( ! dst ) {
        printf("Out of memory");
        return NULL;
    }

    dst->value = src->value;
    dst->next = NULL;

    // Copy the other elements
    // ...
```

Name:____

Solution:

```
Node* copy(Node* src) {

    // Checking precondition
    assert(src);

    // Step 1: make a copy of the first element in the list
    Node *dst = (Node*)malloc(sizeof(Node));
    if ( ! dst ) {
        printf("Out of memory");
        return NULL;
    }

    dst->value = src->value;
    dst->next = NULL;

    // Copy the other elements
    Node *current_src = src->next; // Points to the element we are copying
    Node *current_dst = dst;       // Points to last element in the dst list

    // While there are still elements to copy
    while (current_src) {

        // Making a copy of the element
        Node *new_element = (Node*)malloc(sizeof(Node));
        if ( ! new_element ) {
            printf("Out of memory");
            return dst;
        }
        new_element->value = current_src->value;
        new_element->next = NULL;

        // Add new element to the dst list
        current_dst->next = new_element;

        // Advance to the next element in both lists
        current_src = current_src->next;
        current_dst = current_dst->next;

    }

    return dst;
}
```

Name:____

3. (**12** points) Suppose a program is composed of the following files: `A.h`, `A.cc`, `B.h`, `B.cc`, `X.h`, and `main.cc`. You are given the Makefile below:

```
CXX = g++
CXXFLAGS = -Wall -g
LDFLAGS =

PROGRAMS = main

OBJ  = A.o B.o main.o
HEADERS = A.h B.h X.h

all: $(PROGRAMS)

%.o: %.cc %.h X.h
        $(CXX) $(CXXFLAGS) -c $<

main.o: main.cc $(HEADERS)
        $(CXX) $(CXXFLAGS) -c $<

main:   $(OBJ)
        $(CXX) $(LDFLAGS) -o $@ $^

clean:
        rm -f *.o $(PROGRAMS)
```

Reminder:

- `$@` designates the current target
- `$^` designates all prerequisites
- `$<` designates the left-most prerequisite

Suppose we just executed `make`.

(a) (**7** points) Write the sequence of commands that will get executed if we delete `main.o` and type `make` again. List the commands in the exact order in which they will get executed.

Name:____

(b) (**5** points) Explain the difference between the sequence of commands that will get executed if we either modify `B.h` and type `make` or modify `X.h` and type `make`.

Solution:

(a) The first target in the Makefile is `all`. Starting from that target, `make` looks up all dependencies recursively and checks if they are up-to-date. If not, `make` rebuilds them. In this question, `all` depends on `main`, and `main` depends on `A.o`, `B.o`, and `main.o`. `A.o` and `B.o` are up-to-date, but `main.o` is missing. Hence make will execute:

```
g++ -Wall -g -c main.cc
g++  -o main A.o B.o main.o
```

(b) Because `A.o` depends on `X.h` but it does not depend on `B.h`, it will be rebuilt only if we modify `X.h` and not if we modify `B.h`. `main.o` and `B.o` depend on both `B.h` and `X.h`. These targets will be rebuilt in both cases. Hence, if we modify `X.h`, the following sequence of commands will be executed by make:

```
g++ -Wall -g -c A.cc
g++ -Wall -g -c B.cc
g++ -Wall -g -c main.cc
g++  -o main A.o B.o main.o
```

If we modify `B.h`, only the following commands will get executed:

```
g++ -Wall -g -c B.cc
g++ -Wall -g -c main.cc
g++  -o main A.o B.o main.o
```

Name:____

4. (**10** points) Alice, Bob, Chuck, and Donna are working on the project from the previous question.

   (a) (**3** points) They wish to manage the project with the version control system, CVS. Circle the files they should add to CVS:

```
 A.h     A.cc      A.o
 B.h     B.cc      B.o
 X.h   main.cc   main.o
main
```

   (b) (**5** points) Each team member checks-out a local copy of the project. They perform the following changes:

   - Alice moves part of the content from files `A.h` and `A.cc` into two new files `C.h` and `C.cc`. Alice modifies the `Makefile` and `main.cc` to reflect these changes.
   - Bob completes the implementation of `B.cc`.
   - Chuck and Donna do nothing.

   List the CVS operations (add, commit, or update) that each team member must perform in order for everyone to end-up with the most recent version of the project. List the commands, and the users who need to execute them, in an order that achieves the desired result. Pick any of the possible orders.

   (c) (**2** points) Donna and Chuck now make different changes to the same lines inside file `main.cc`. Donna commits her changes first. What happens when Chuck tries to update `main.cc` before committing his own changes. Circle the appropriate answer:

   i. CVS merges the changes made by Donna and Chuck. Because the changes affect the same lines, Donna's changes automatically overwrite Chuck's changes.

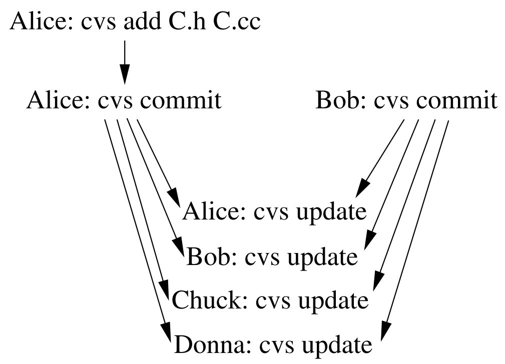
   ii. CVS merges the changes made by Donna and Chuck. Because the changes affect the same lines, Chuck's changes automatically overwrite Donna's changes.

   iii. CVS tries to merge the changes made by Donna and Chuck. Because the changes affect the same lines, CVS labels the changes as conflicting. Chuck must resolve the conflicts manually.

Solution:

(a) None of the automatically generated files should be added to CVS. Only the source files, `A.h, A.cc, B.h, B.cc, X.h, main.cc`, should be added. The `Makefile`, which was missing from the list by accident, did not count for any points.

(b) The following figure shows the operations that each team member needs to perform. Arrows show dependencies between operations: if operation A must occur before operation B, we show an arrow from A to B. An exception is that whoever commits last can update before the commit.



(c) CVS tries to merge the changes made by Donna and Chuck. Because the changes affect the same lines, CVS labels the changes as conflicting. Chuck must resolve the conflicts manually.

Name:____

5. (**7** points) Given the following specification for function `count_occurrences`, and the two sample test-cases, write 5 additional test-cases for this function:

```
/**
 * Computes the number of occurrences of a word in a file.
 * Precondition: file_name cannot be null
 * Precondition: word cannot be null
 * If the file does not exist, returns zero
 * If the word is the empty string, returns zero
 * @param file_name, the name of the file to search
 * @param word, the word to search for in the file
 * @return the number of occurrences of word in the file file_name.
 * Computes occurrences only up to 100. If a word occurs
 * more than 100 times, the function returns 100.
 */
int count_occurrences(char* file_name, char* word);
```

(a) A set of inputs where `word` is NULL. [Correction: this is actually a bad test case. Even though it is good programming practice to test all preconditions explicitly (for example by using the `assert` macro), the specifications do not say what happens when preconditions are violated. Therefore, black-box tests should NOT include test cases where inputs violate preconditions].

(b) A set of inputs where `word` occurs in the file `file_name` exactly once.

Solution:
The idea is to test the function on sets of inputs that exercise different conditions in the specification, such as the various error conditions, the case when the word is not in the file, the case when it occurs exactly 100 times, more than 100 times, and less than 100 times. Different solutions are possible. Full-credit was given for any set of 5 test-cases that exercised different conditions. Below are some possible test-cases:

(a) A set of inputs where `file_name` is NULL. [Correction: this is actually a bad test case for the same reason as above].

(b) A set of inputs where `file_name` is the name of a file that does not exist.

(c) A set of inputs where `word` is the empty string.

(d) A set of inputs where `word` does not occur in the file `file_name`.

(e) A set of inputs where `word` occurs in the file `file_name` 99 times.

(f) A set of inputs where `word` occurs in the file `file_name` 100 times.

(g) A set of inputs where `word` occurs in the file `file_name` 101 times.

Name:____

6. (**7** points) For each statement below, indicate if it is true or false.

   (a) The goal of specifications is to describe the details of how a software system is implemented.
   true false

   (b) The goal of testing is to guarantee that there are no bugs in a software system.
   true false

   (c) A function should always explicitly check that all preconditions hold.
   true false

   (d) If a program allocates only a small number of objects on the heap, it is safe to assume that all allocations always succeed. There is not need to check if `malloc` or `new` return NULL.
   true false

   (e) When performing black-box testing, the test-cases are designed in terms of the specifications.
   true false

   (f) When performing white-box testing, the test-cases are designed in terms of the implementation.
   true false

   (g) Code readability is not important as long as the code is fast.
   true false

Solution:

(a) false

(b) false

(c) true [Clarification: it is good programming practice to always check all preconditions explicitly. However, sometimes it is not possible to test a precondition and sometimes it is possible but it would be very expensive. Therefore, there are cases when preconditions are not checked.]

(d) false

(e) true

(f) true

(g) false

Name:____

7. (**10** points) In a C program called `main`, an integer, `x`, is transformed by a series of four functions: `f1`, `f2`, `f3`, and `f4` as shown below:

```
// x is the program input
int x2 = f1(x);
// ... some code that does not use x2
int x3 = f2(x2);
// ... some code that does not use x3
int x4 = f3(x3);
// ... some code that does not use x4
int x5 = f4(x4);
// ... some code that does not use x5
```

   (a) (**5** points) As you test the program, you notice that for some inputs, the output `x5`, is not what you expect. Explain how you would use a debugger, such as `gdb`, to determine which one of the four functions performs the wrong computation.

Name:____

(b) (**5** points) As you continue testing the program, you notice that for some inputs, the program takes a very long time to execute. What type of tool can you use to determine where the problem is? Name the type of tool and two types of information that this tool can provide about a program.

Solution:

(a) We need to compile the program with the debugging information (option `-g`), and execute the program with the debugger (`gdb main`). Before starting the program, we can place a breakpoint at the end of each one of the four functions. We can do this by specifying the appropriate line numbers. We can then run the program on one of the inputs that produces the wrong result. Every time the execution stops at a breakpoint, we should print and examine the current value of the computation, and compare it to the value that we expect. If the values do not match, we have found the erroneous function.

A second approach is to put breakpoints on the lines where the functions are invoked. Every time the execution stops at a breakpoint, we can print the value of the input argument to the function. We can then step to the next instruction, stop and examine the value of the result from the previous invocation. We can then continue to the next breakpoint. Eventually, we will find the function for which the output does not correspond to what we expected.

(b) A profiler such as `gprof` can help us find where a program spends most of its time. The profiler instruments a program and collects statistics including the fraction of time that the program spent in each function and the number of times that each function was invoked. It can also measure the fraction of time spent on each line of code.

Name:____

8. (**10** points) Indicate the output of the following C++ program using the provided blanks. **Be careful!** Carefully examine all function signatures.

```
// --------------------------------------------------
// Content of Simple.h
// --------------------------------------------------
#ifndef SIMPLE_H
#define SIMPLE_H

#include <iostream>
#include <string>
#include <sstream>

using namespace std;

#define DEFAULT 100

class Simple {

public:
    Simple(int value = DEFAULT);
    ~Simple();
    int  getValue();
    void setValue(int new_value);
    string toString();

private:
    int _id;
    int _value;
    static int s_counter;
};

#endif

// --------------------------------------------------
// Content of Simple.cc
// --------------------------------------------------
#include "Simple.h"

int Simple::s_counter = 1;

Simple::Simple(int value)
    : _id(s_counter),
      _value(value) {
    s_counter++;
}

Simple::~Simple() {
}
```

Name:____________________________________

```
int Simple::getValue() {
    return _value;
}

void Simple::setValue(int new_value) {
    _value = new_value;
}

string Simple::toString() {
    stringstream s;
    s << "(" << _id << "," << _value << ")";
    return s.str();
}

// ------------------------------------------------
// Content of main.cc
// ------------------------------------------------
#include "Simple.h"

void increase_value(Simple object) {
    int new_value = 2*object.getValue();
    object.setValue(new_value);
}

void decrease_value(Simple& object) {
    int new_value = object.getValue()/2;
    object.setValue(new_value);
}

int main() {

    Simple object1(20);

    Simple object2;

    cout << object1.toString() << endl;  // Output: __________

    cout << object2.toString() << endl;  // Output: __________

    increase_value(object1);

    decrease_value(object2);

    cout << object1.toString() << endl;  // Output: __________

    cout << object2.toString() << endl;  // Output: __________

    return 0;
}
```

Solution:

```
int main() {

    Simple object1(20);
    Simple object2;

    cout << object1.toString() << endl;  // Output: (1,20)
    cout << object2.toString() << endl;  // Output: (2,100)

    increase_value(object1);
    decrease_value(object2);

    cout << object1.toString() << endl;  // Output: (1,20)
    cout << object2.toString() << endl;  // Output: (2,50)

    return 0;
}
```

Name:____

9. (**7** points) Indicate the output of the following C++ program using the provided blanks.

```
#include <iostream>
using namespace std;

class Parent {

public:
    void print1() {
        cout << "Parent ";
    }
    virtual void print2() {
        cout << "Parent ";
    }
    void print3() {
        cout << "Parent ";
        print2();          // Note that this->print2(); would produce the same result
    }
};

class Child: public Parent {

public:
    void print1() {
        cout << "Child ";
    }
    virtual void print2() {
        cout << "Child ";
    }
    void print3() {
        cout << "Child ";
        print2();          // Note that this->print2(); would produce the same result
    }
};

int main() {

    Parent *p = new Child();

    p->print1();   // Output: __________________

    p->print2();   // Output: __________________

    p->print3();   // Output: __________________

    return 0;
}
```

Solution:

```
int main() {

    Parent *p = new Child();

    p->print1();   // Output: Parent

    p->print2();   // Output: Child

    p->print3();   // Output: Parent Child

    return 0;
}
```

Name:____

10. (**4** points) A program is composed of two threads and a shared variable `x`. Each thread performs the sequence of actions shown below.

```
// Thread 1
int t1 = x;
t1 = t1 + 1;
x = t1;

// Thread 2
int t2 = x;
t2 = t2 - 1;
x = t2;
```

A thread cannot be interrupted during the execution of an instruction (in the middle of a line). A thread can be interrupted between any two instructions (between lines).

Assume the original value of `x` is 0. If the two threads execute concurrently, what are the possible final values for `x`?

Solution:
Without locks, the instructions for the two threads can get interleaved in any order. The possible final values for x are: 0, -1, and 1.

Name:____

11. (**6** points) A program is composed of three threads and shared objects `X`, `Y`, and `Z`.

Which one of the following locking strategies can cause a deadlock? Show the sequence of operations that lead to the deadlock and explain why the other strategy will never cause a deadlock.

```
//   Strategy 1              //   Strategy 2

// Thread 1                  // Thread 1
Acquire lock for X           Acquire lock for X
Acquire lock for Y           Acquire lock for Y
Modify X and Y               Modify X and Y
Release lock on Y            Release lock on Y
Release lock on X            Release lock on X

// Thread 2                  // Thread 2
Acquire lock for Z           Acquire lock for X
Acquire lock for X           Acquire lock for Z
Modify Z and X               Modify Z and X
Release lock on X            Release lock on Z
Release lock on Z            Release lock on X

// Thread 3                  // Thread 3
Acquire lock for Y           Acquire lock for Y
Acquire lock for Z           Acquire lock for Z
Modify Y and Z               Modify Y and Z
Release lock on Z            Release lock on Z
Release lock on Y            Release lock on Y
```

Solution:
Strategy 1 can lead to a deadlock. If each thread acquires its first lock and gets preempted, then thread 1 will block waiting for thread 3, thread 3 will block waiting for thread 2, and thread 2 will block waiting for thread 1. You only need to show one counterexample here that leads to a deadlock.

Strategy 2 will never cause a deadlock because all threads acquire locks in the same order: X, Y, then Z. At any time, there must be at least one thread which can run to completion, because locks cannot form a cycle. Once this thread completes, we apply this argument again for the remaining threads. This shows how deadlock cannot happen in any case.