CSE 333 Final Exam Sample Solution 6/12/13

Question 1. (18 points) A little C++ hacking. On the following page, implement function `intersect`. The input to the function is two lists of strings that are sorted in ascending order and do not contain duplicates. The function should replace the original contents of the output list with copies of all the strings that appear in both of the original lists, and the words should appear in the output list in the same sorted order they were found in the original lists.

For example, if we initially have

```
list<string> fruit = {"apple", "banana", "cherry", "lemon",
                      "mango", "orange", "watermelon"};
list<string> citrus = {"grapefruit","lemon","lime","orange"};
list<string> result = {"asparagus", "broccoli"};
```

then after the function call `intersect(fruit, citrus, &result)`, the list `result` should contain `{"lemon", "orange"}`.

For full credit, your function must scan the input lists only once, i.e., it should run in linear time proportional to the lengths of the input lists.

Hints and reference information:

- Remember that a STL `list` is a linked list underneath, so you must use iterators to scan it; you can't use `[]` subscripts to access individual list elements.
- If `lst` is a STL `list`, then `lst.begin()` and `lst.end()` return iterator values of type `list<…>::iterator` that might be useful.
- If `it` is an iterator, then `*it` can be used to reference the item it currently points to, and `++it` will advance `it` to the next item, if any.
- Some useful operations on sequential STL containers, including `list`:
  - `c.clear()` – remove all elements from c
  - `c.size()` – return number of elements in c
  - `c.empty()` – true if number of elements in c is 0, otherwise false
  - `c.push_back(x)` – copy x to end of c
  - `c.push_front(x)` – copy x to front of c

Note for the curious: this problem deliberately avoided using templates because they introduce some technical complications in variable declarations that seemed best omitted.

(write your answer on the next page – you may remove this page from the exam if you wish)

Question 1. (cont.) Complete the definition of function `intersect` below. Some useful `#include` directives as well as a `using` directive have been provided for convenience. You should add any additional libraries or code that you need (although the sample solution only needed the ones given here).

```
#include <string>
#include <iostream>
#include <list>

using namespace std;

// replace previous contents of ans with list of elements
// that appear in both lst1 and lst2.
// pre: lst1 and lst2 elements are sorted in ascending
//      order and the lists contain no duplicates.
void intersect(const list<string> &lst1,
               const list<string> &lst2,
               list<string> *ans)  {

  ans->clear();
  auto it1 = lst1.begin();  // or list<string>::iterator it1 = ...
  auto it2 = lst2.begin();
  while (it1 != lst1.end() && it2 != lst2.end()) {
    // both iterators point to valid list items.  If items
    // are equal, copy one to ans and advance both
    // iterators.  Otherwise skip past smallest item.
    if (*it1 == *it2) {
      ans->push_back(*it1);
      ++it1;
      ++it2;
    } else if (*it1 < *it2) {
      ++it1;
    } else { // *it1 > *it2
      ++ it2;
    }
  }
}
```

[Grading note: We forgot to restrict the problem to forbid the use of additional data besides simple scalar variables. So we did not deduct points from solutions that used additional containers provided the running time was still $O(n)$ – even though the problem can be solved without needing extra space proportional to the size of the data.]

Question 2. (12 points) A debugging exercise. Below, and continued on the next page is the valgrind output from a test run of the searchshell program from homework 2. Although the code seems to "work" in that it produces the right answer(s), the valgrind output suggests there are problems. What seems to be wrong and what is the evidence for your conclusions?

There are two problems:

1) The "invalid write" messages indicate that the program is writing 1 byte past the end of blocks of allocated memory. A common cause of this is failing to allocate an extra byte for the '\0' terminator at the end of a string, which was, in fact, one of the errors introduced into the program to produce this valgrind output. But the messages could have been caused by other off-by-one errors.

2) The error messages in the heap summary at the end indicate that blocks of memory allocated by `AllocateHashTable` using `malloc` were never freed.

In grading this problem we were most interested in whether you showed good understanding of what the valgrind output actually reported and could relate that to plausible things to look for in the code, not whether you precisely diagnosed the exact error. However it wasn't enough just to say, e.g., "there is a memory leak" or otherwise paraphrase the valgrind output – a more specific diagnosis was needed.

```
bash-4.2$ valgrind --leak-check=full ./searchshell test_tree/enron_email/
==10186== Memcheck, a memory error detector
==10186== Copyright (C) 2002-2012, and GNU GPL'd, by Julian Seward et al.
==10186== Using Valgrind-3.8.1 and LibVEX; rerun with -h for copyright info
==10186== Command: ./searchshell test_tree/enron_email/
==10186==
Indexing 'test_tree/enron_email/'
==10186== Invalid write of size 1
==10186==    at 0x4A09440: strncpy (mc_replace_strmem.c:476)
==10186==    by 0x401733: DTRegisterDocumentName (doctable.c:77)
==10186==    by 0x401495: HandleFile (filecrawler.c:181)
==10186==    by 0x4013D8: HandleDir (filecrawler.c:147)
==10186==    by 0x4011BA: CrawlFileTree (filecrawler.c:77)
==10186==    by 0x400C60: main (searchshell.c:46)
==10186==  Address 0x4c8d3ca is 0 bytes after a block of size 26 alloc'd
==10186==    at 0x4A0881C: malloc (vg_replace_malloc.c:270)
==10186==    by 0x401705: DTRegisterDocumentName (doctable.c:75)
==10186==    by 0x401495: HandleFile (filecrawler.c:181)
==10186==    by 0x4013D8: HandleDir (filecrawler.c:147)
==10186==    by 0x4011BA: CrawlFileTree (filecrawler.c:77)
==10186==    by 0x400C60: main (searchshell.c:46)
==10186==
```

(valgrind output continued on the next page)

Question 2. (cont.) Remainder of the valgrind output.

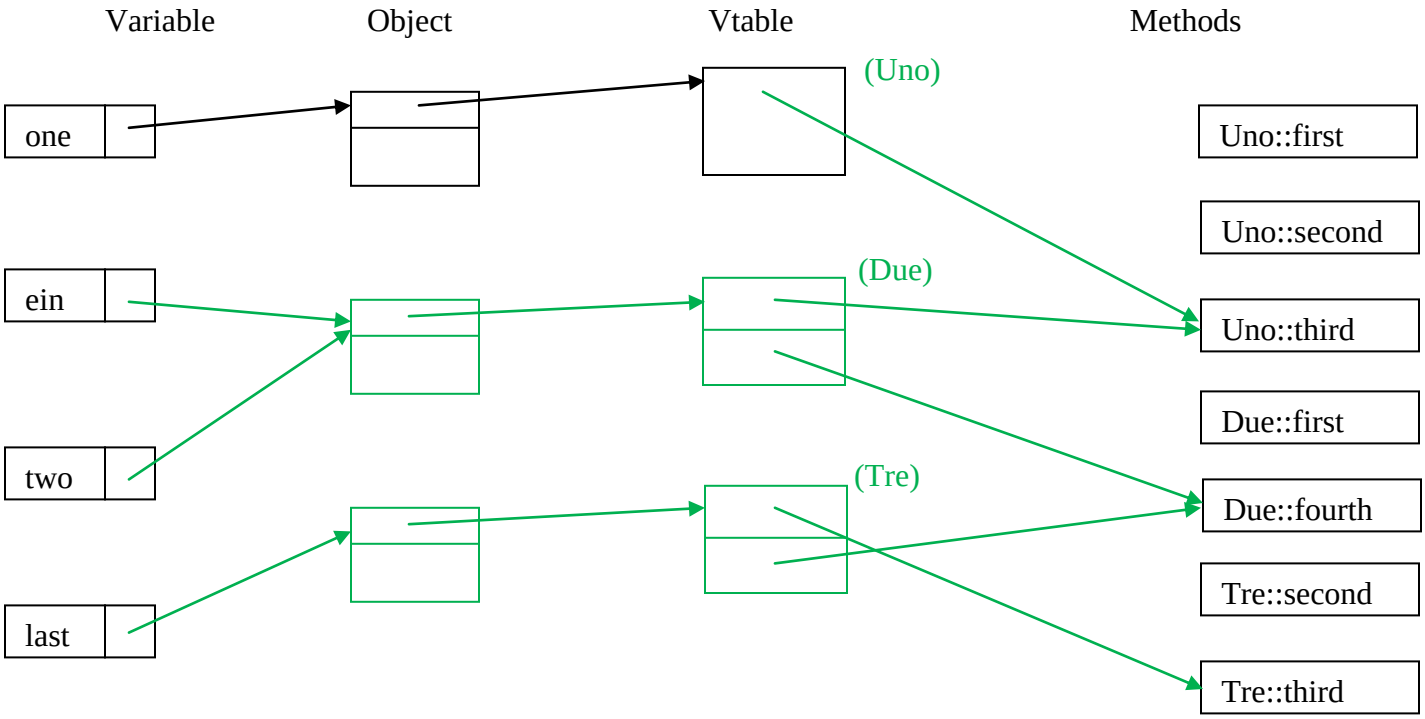
```
==10186== Invalid read of size 1
==10186==    at 0x4A09194: strlen (mc_replace_strmem.c:403)
==10186==    by 0x401851: DTRegisterDocumentName (doctable.c:106)
==10186==    by 0x401495: HandleFile (filecrawler.c:181)
==10186==    by 0x4013D8: HandleDir (filecrawler.c:147)
==10186==    by 0x4011BA: CrawlFileTree (filecrawler.c:77)
==10186==    by 0x400C60: main (searchshell.c:46)
==10186==  Address 0x4c8d3ca is 0 bytes after a block of size 26 alloc'd
==10186==    at 0x4A0881C: malloc (vg_replace_malloc.c:270)
==10186==    by 0x401705: DTRegisterDocumentName (doctable.c:75)
==10186==    by 0x401495: HandleFile (filecrawler.c:181)
==10186==    by 0x4013D8: HandleDir (filecrawler.c:147)
==10186==    by 0x4011BA: CrawlFileTree (filecrawler.c:77)
==10186==    by 0x400C60: main (searchshell.c:46)
==10186==
enter query:
xyzzy
enter query:
==10186==
==10186== HEAP SUMMARY:
==10186==     in use at exit: 178,112 bytes in 7,980 blocks
==10186==   total heap usage: 2,733,651 allocs, 2,725,671 frees, 57,300,024 bytes allocated
==10186==
==10186== 80,216 (24 direct, 80,192 indirect) bytes in 1 blocks are definitely lost in loss record
11 of 12
==10186==    at 0x4A0881C: malloc (vg_replace_malloc.c:270)
==10186==    by 0x4035FF: AllocateHashTable (HashTable.c:55)
==10186==    by 0x4015E0: AllocateDocTable (doctable.c:42)
==10186==    by 0x401130: CrawlFileTree (filecrawler.c:71)
==10186==    by 0x400C60: main (searchshell.c:46)
==10186==
==10186== 97,896 (24 direct, 97,872 indirect) bytes in 1 blocks are definitely lost in loss record
12 of 12
==10186==    at 0x4A0881C: malloc (vg_replace_malloc.c:270)
==10186==    by 0x4035FF: AllocateHashTable (HashTable.c:55)
==10186==    by 0x4015CF: AllocateDocTable (doctable.c:41)
==10186==    by 0x401130: CrawlFileTree (filecrawler.c:71)
==10186==    by 0x400C60: main (searchshell.c:46)
==10186==
==10186== LEAK SUMMARY:
==10186==    definitely lost: 48 bytes in 2 blocks
==10186==    indirectly lost: 178,064 bytes in 7,978 blocks
==10186==      possibly lost: 0 bytes in 0 blocks
==10186==    still reachable: 0 bytes in 0 blocks
==10186==         suppressed: 0 bytes in 0 blocks
==10186==
==10186== For counts of detected and suppressed errors, rerun with: -v
==10186== ERROR SUMMARY: 1978 errors from 4 contexts (suppressed: 2 from 2)
bash-4.2$
```

Question 3. (16 points) Virtual madness. Consider the following program, which compiles and executes without errors.

(See the rest of the question on the next page. You may remove this page for reference.)

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

class Uno {
public:
  void first() {second();third(); cout << "Uno::first" << endl;}
  void second() { third(); cout << "Uno::second" << endl; }
  virtual void third() { cout<< "Uno::third" << endl; }
};

class Due : public Uno {
public:
  void first() { second(); cout << "Due::first" << endl; }
  virtual void fourth() {second();cout << "Due::fourth" << endl;}
};

class Tre : public Due {
public:
  void second() { first(); cout << "Tre::second" << endl; }
  virtual void third() { cout << "Tre::third" << endl; }
};


int main(void) {

  Uno * one = new Uno();
  one->first();

  cout << "-----" << endl;

  Uno * ein = new Due();
  ein->first();

  cout << "-----" << endl;

  Due * two = dynamic_cast<Due *>(ein);
  two->first();

  cout << "-----" << endl;

  Due * last = new Tre();
  last->fourth();

  /* draw diagram at this point*/
  return 0;
}
```

Question 3. (cont) (a) (8 points) Draw a diagram showing all of the variables, objects, vtables, and methods they point to when execution reaches the end of main, right before executing the return statement. Note that you can draw this diagram without tracing execution of the method calls. The diagram only depends on the variable declarations and object creation code (e.g., new). To save time, we've filled in part of the drawing, including the first variable (one), the object and vtable it refers to, and the method bodies for all three classes (but we haven't included any necessary vtable pointer(s) to methods).



(The vtables only contain entries for virtual functions. For non-virtual ones, the compiler determines what code to call at compile time and does not use runtime vtables to resolve function calls. Note that the pointer to the appropriate "third" method must be the first one in the vtables for subclasses of `Uno`; the order is fixed.)

(b) (8 points) What does this program print when it is executed?

Uno::third
Uno::second
Uno::third
Uno::first

Uno::third
Uno::second
Uno::third
Uno::first

Uno::third
Uno::second
Due::first

Tre::third
Uno::second
Due::fourth

Question 4. (6 points) When we were exploring architectures for concurrent servers, one of our example servers created a new process to handle each incoming request. The code used a "double-fork" trick to create a grandchild process to actually handle each request. A sketch of the code, with error handling omitted, looked something like this:

```
// Loop forever, accepting a connection from a client and processing
// queries arriving over it.
while (1) {
  int client_fd = client request;
  pid_t pid = fork();  // create child process

  if (pid > 0) {
    // I'm the parent
    int stat_loc;
    pid_t res = wait(&stat_loc);
    close(client_fd);
    break;  // handle next request

  } else if (pid == 0) {
    // I'm the child. Fork a grandchild and exit.
    pid = fork();
    if (pid > 0) {
      // I'm the child.  Exit!
      exit(EXIT_SUCCESS);
    } else if (pid == 0) {
      // I'm the grandchild.  Handle the client connection.
      HandleClient(...);
  }
}
```

So the question is, why bother with all of this complexity? Why create a grandchild process to handle the request – why not just have the child process handle it?

(Brief answers that explain key technical points succinctly make graders happy.)

The main reason is to avoid the zombie (process) apocalypse.

More technically: once a process terminates it remains in the system as a zombie until a parent process `wait()`s for it. If each child process directly handled client requests, the parent process would have to arrange to wait for those child processes, while still handling new incoming requests. That requires extra bookkeeping to keep track of which child processes are still running and to wait for them soon after they terminate.

Instead, each child forks a grandchild and immediately exits, and the parent process waits for that to happen, which will be very quick. When the grandchild later finishes handling the request and terminates it is adopted by the system `init` process, since its parent no longer exists. `init` immediately waits on any zombie processes that it acquires and that cleans up the grandchild process zombie.

Question 5. (7 points) Fun with concurrency!! Consider the following C program:

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

int x = 0;

void * thread_worker(void * ignore) {
  x = x + 1;
  printf("x=%d\n", x);
  return NULL;
}

int main() {
  pthread_t t1, t2;
  int ignore;
  ignore = pthread_create(&t1, NULL, &thread_worker, NULL);
  ignore = pthread_create(&t2, NULL, &thread_worker, NULL);
  pthread_join(t1, NULL);
  pthread_join(t2, NULL);

  printf("final x=%d\n", x);

  return 0;
}
```

For each of the following output sequences, circle "yes" if it could be produced by some possible execution of the above program and circle "no" if it could never happen under any circumstances. (Hint: at least one of these sequences is possible.)

YES (NO) `x=0 x=1 final x=1`

(YES) NO `x=1 x=1 final x=1`

YES (NO) `x=1 x=2 final x=1`

YES (NO) `x=1 x=1 final x=2`

(YES) NO `x=1 x=2 final x=2`

(YES) NO `x=2 x=1 final x=2`

(YES) NO `x=2 x=2 final x=2`

Note that "x=x+1" involves a memory fetch, an addition, and a store; and printf either fetches the value again, or finds a copy in a temporary location like a register before printing. Execution can switch to another thread between any of these events.

Some short answer questions. Please help us give you the most points by being accurate, brief but complete, and to the point.

Question 6. (6 points) As part of opening a connection to a client, a TCP server must use both the `accept()` and `listen()` functions. What do these two functions do, and in what order should the server code execute them?

A server must do a `listen()` first to indicate that a particular socket is prepared to accept connections on a particular port.

Once the listening socket is ready, the server uses `accept()` on that socket to get a new file descriptor to use for reading and writing to each client.

Queston 7. (6 points) Most of our network programming used TCP sockets. Another protocol built on top of IP is UDP. What is the key difference between UDP and TCP, and what sort of applications is UDP suited for compared to TCP? (a specific example of two and why would be helpful)

TCP creates a reliable stream channel on top of the IP datagram layer.

UDP is a thin wrapper around IP that allows a client program to send and receive packet datagrams. There is no guarantee of reliable, in-order packet delivery as there is with TCP.

UDP is appropriate for applications like streaming audio and video where an occasional dropped packet is acceptable, and the overhead and latency of a reliable TCP stream is not appropriate. However, such applications are relatively rare.

Question 8. (6 points) Suppose we have two C++ classes related by inheritance:

```
class Base { … };
class Derived : public Base { … }
```

The subclass, `Derived`, can have additional methods and fields (instance variables) in addition to the ones it inherits from `Base`. In most of the code we've written using inheritance, we've used pointers and pointer assignments such as the following:

```
Derived * d = new Derived();
Base * b = d;
```

But what about object value assignment? Is the following code legal (i.e., will it compile)? What happens when it is executed, if it does compile?

```
Derived dobj = ... ;  // initialization omitted
Base bobj = dobj;
```

Yes it is legal, but only the bytes in the "`Base`" part of `dobj` are involved in setting the value of `bobj`, i.e., we use the slice of the `Derived` object containing only its `Base` part. That will cause problems later if we expect to be able to assign the value back to an object of type `Derived`, because the remaining parts of the original object are not present in the copy.

Question 9. (6 points) There are several kinds of *smart pointers* in the C++ library. One kind is weak pointers (`weak_ptr`). These are similar to `shared_ptr`, but not quite the same. Why do we have both kinds? What problem is solved by `weak_ptrs`?

A `shared_ptr` uses reference counting to keep track of how many smart pointers currently refer to an object. When a `shared_ptr` is deleted, it decrements the reference count and, if it becomes 0, deletes the object.

The trouble is if we have a linked structure containing a cycle. If we use only `shared_ptrs`, then every object in the cycle has another object pointing to it and cannot be deleted, even if the cycle is not reachable from anywhere else.

A `weak_ptr` does not contribute towards an object's reference count so it can be used as part of a cyclical data structure, while still allowing reference counts to eventually reach 0 once no outside references to the data exist.

Question 10. (6 points) The following function unlinks the first node from a single-linked list and returns the pointer to that node in addition to updating the head of the list:

```
struct node {
  int val;
  struct node * next;
};

// remove the first node from the list starting at head and
// return a pointer to the unlinked node.  Return NULL if
// the list is empty initially (head == NULL).
struct node * unlink(struct node ** head) {
  if (head == NULL)
    return NULL;
  struct node * tmp = *head;
  *head = (*head)->next;
  return tmp;
}
```

Are there any potential problems using this function to manage linked lists in a multi-threaded program? If so, what might go wrong? How could we fix it?

Yes. If another thread is also adding or deleting nodes at the same time, its operations could be interleaved with the statements in this function leading to all sorts of potential scrambled pointer problems.

One solution would be to associate an exclusive lock with the list data structure and require that any code that examines or alters the list structure must obtain the lock before starting and hold the lock until it is completely done. A lock operation should be inserted at the beginning of this function, with a corresponding unlock at the end, right before the `return` statement.

Question 11. (6 points) Orders of magnitude. Circle the time that is the closest to the typical time needed for the following operations. (msec = milliseconds, µsec = microseconds, nsec = nanoseconds)

(a) Time for a modern laptop processor to add two numbers

100 msec 10 msec 1 msec 100 µsec 10 µsec 1 µsec 100 nsec 10 nsec (1 nsec)

(b) Time to access main (not cache) memory on a modern laptop **

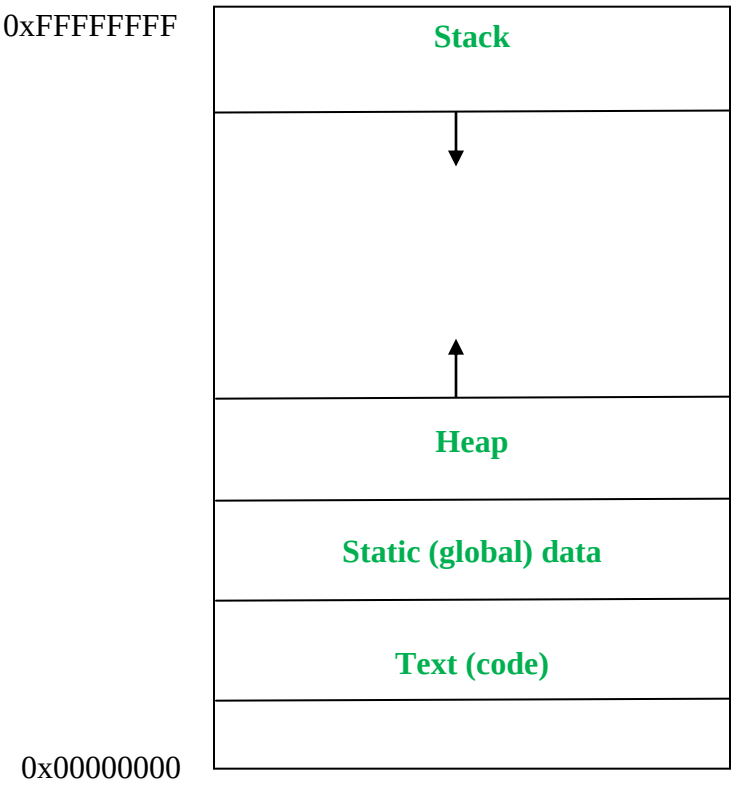
100 msec 10 msec 1 msec 100 µsec 10 µsec 1 µsec (100 nsec) (10 nsec) 1 nsec

(c) Time to read or write one record off of a rotating hard disk drive

100 msec (10 msec) 1 msec 100 µsec 10 µsec 1 µsec 100 nsec 10 nsec 1 nsec

****We awarded credit for either 10nsec or 100nsec for memory speed. Memory is getting faster and access times are in the 30-40 nsec. range these days.**

Question 12. (4 points) Had to ask this one. Below is the standard diagram of the memory address space for a process. Label the boxes.



Question 13. (1 point – circle the letter of your choice)

The ***BEST*** thing about C++ is:

(a) simple stream I/O (`cout`/`cin` instead of `printf`/`scanf`)

(b) type-safe `new` and `delete` operators

(c) it still requires manual memory management and it's possible to have dangling pointers, memory leaks, and all the other goodies – none of that wimpy garbage collection stuff.

(d) references as well as pointers

(e) smart pointers – not just the old, dumb ones

(f) a much bigger library (STL, collections, iterators, etc.)

(g) classes and objects

(h) dynamic *and* static method dispatch

(i) destructors

(j) multiple inheritance

(k) operator overloading

(l) the many meanings of `const`

(m) the many meanings of `static`

(n) templates

(o) function overloading

(p) namespaces

(q) You forgot the best one!! It's really _____ !!!

(r) It's all great!!!!!!!!!!!

(s) C++ is the most loathsome programming language ever invented. There's nothing good about it except that maybe by knowing it I'll be able to get a job at Google. Even then I hope never to see it again.

(t) I don't care – just give me my free point

(u) I do care, but don't have time to think about it – just give me my free point

All answers received a point.