University of Toronto
Faculty of Applied Science and Engineering

ECE 244F

PROGRAMMING FUNDAMENTALS

Fall 2018

Final Exam

Examiners: T.S. Abdelrahman and M. Mansour

Duration: 2.5 hours

This exam is OPEN Textbook and CLOSED notes. The use of computing and/or communicating devices is NOT permitted.

Do not remove any sheets from this exam book. Answer all questions in the space provided. No additional sheets are permitted.

Work independently. The value of each question is indicated. The total value of all questions is 100.

Write your name and student number in the space below. Do the same on the top of each sheet of this exam book.

Name: _____

Student Number: _____

Q1. _____/9	**Q10. _____/4**
Q2. _____/4	**Q11. _____/4**
Q3. _____/2	**Q12. _____/8**
Q4. _____/6	**Q13. _____/5**
Q5. _____/6	**Q14. _____/5**
Q6. _____/4	**Q15. _____/4**
Q7. _____/6	**Q16. _____/8**
Q8. _____/5	**Q17. _____/4**
Q9. _____/5	**Q18. _____/11**

Total

Question 1. (9 marks). *General.*

(a) (1 mark). **TRUE** or **FALSE**. Functions that are constant member functions may call the class mutator functions.

(b) (1 mark). **TRUE** or **FALSE**. If the member variables in a base class are marked as protected, a derived class can directly access those variables.

(c) (1 mark). **TRUE** or **FALSE**. Friend functions are members of the class.

(d) (1 mark). **TRUE** or **FALSE**. Destructors are not inherited into the derived class.

(e) (1 mark). **Circle one answer**. All the code between

```
#ifndef  MYCLASS_H
```

and

```
#endf
```

is _____ if `MYCLASS_H` is defined.

A. skipped
B. executed
C. compiled
D. debugged

(f) (1 mark). **Circle one answer**. Given a binary search tree, which traversal type would print the values in the nodes in sorted order?

A. Preorder
B. Postorder
C. Inorder
D. None of the above

(g) (1 mark). Circle one answer. Algorithm A has a time complexity of O(n). Algorithm B has a time complexity of O(log n).

1. Algorithm B is always more efficient then algorithm A.
2. Algorithm B is never more efficient than algorithm A.
3. Algorithm A can sometimes be faster than algorithm B.
4. None of the above.

(h) (1 mark). **Circle one or more answers**. Which of the following statements about binary trees is NOT true?

A. Every binary tree has at least one node.
B. Every non-empty tree has exactly one root node.
C. Every node has at most two children.
D. Every non-root node has exactly one parent.

(i) (1 mark). Circle one answer. When a class that has pointer to a dynamically allocated array as one of its members, the class should also include _____.

A. a copy constructor
B. a default constructor
C. a destructor
D. the assignment operator
E. all of the above.
F. none of the above

Question 2. (4 marks). *Pointers and Arrays.*

In the blank space for each part **(a)** – **(d)** below, provide the declaration and initialization of the variable **`i`** (for example: `int i = 10;`). Your initialization of `i` must make use of the variable `j`, and lead to the expected output when used in the statements that follow it.

(a) `int j = 10;`

```
// declare and initialize i:
```

```
cout << *i << endl;
j = 5;
cout << *i << endl;
```

Expected Output of (a)

```
10
5
```

(b) `int j = 10;`

```
// declare and initialize i:
```

```
cout << i << endl;
j = 5;
cout << i << endl;
```

Expected Output of (b)

```
10
10
```

(c) `int j = 10;`

```
// declare and initialize i:
```

```
cout << i[0] << endl;
j = 5;
cout << i[1] << endl;
```

Expected Output of (c)

```
10
10
```

(d)

```
int j = 10;

// declare and initialize i:
```

```
cout << *(i[0]) << endl;
j = 5;
cout << *(i[1]) << endl;
```

Expected Output of (d)

```
10
5
```

Question 3. (2 marks). *Amy's Dilemma.*

Amy (the same very good C++ programmer from the midterm test) designed and implemented a `Mystery` class so as objects of type `Mystery` can be created but not deleted by non-member functions. She did so by making the destructor of `Mystery` private, as shown below in `Mystery.h`.

```
#include "YetAnotherMystery.h"
class Mystery {

   private:

      YetAnotherMystery* mystery_variable;
      ~Mystery();

   public:

      Mystery();
      Mystery(const Mystery & other);
      Mystery & operator=(const Mystery & rhs);
      void operateOnMystery();
      void print () const;

};
```

Thus, if a function that is non-member of the `Mystery` class attempts to delete a `Mystery` object, a compile time error is generated.

Now Amy met Shannon. Like Amy, he is also a very good C++ programmer. Shannon wrote a non-member function that has the following prototype:

```
void mysterious ();
```

The function creates a `Mystery` object and would like to delete the object to avoid a memory leak. However, it cannot because the destructor of `Mystery` is private. Amy wants to allow only Shannon's non-member function to delete `Mystery` objects but still prevent all other non-member functions from doing the same. She wants to do so without making Shannon's function a member of her class.

Amy needs to add only one line to her `Mystery.h`. No other modifications to `Mystery.h` are allowed.

Write the line Amy should add.

Answer:

Question 4. (6 marks). *Amy Goes to Hollywood.*

Amy (yes, the same one) went to Hollywood to write C++ code for a major movie studio. She wrote the following class definitions and implementations for `Movie` and `Chapter`. They respectively represent a movie and the chapters that make up the movie. She also wrote the functions `MovieDuration` and `main` to utilize these classes. The two classes, `MovieDuration` and `main` are all in one file and they compile with no errors.

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

class Chapter {
 private:
    string title;
    float duration;
 public:
    Chapter () {duration = 0.0;}
    Chapter (string t, float d) {title = t; duration = d;}
    string getTitle() const {return title;}
    float getDuration() const {return duration;}
};

class Movie {
 private:
    string title ;
    int numChapters;
    Chapter* chapters;
 public:
    Movie (string t, int num_c) {
        title = t ;
        numChapters = num_c ;
        chapters = new Chapter[numChapters] ;
    }

    ~Movie () {delete [] chapters;}

    int getNumChapters() const {return numChapters;}

    void addChapter (const Chapter& c, int i) {
         chapters[i] = *(new Chapter(c));
    }

    Chapter& getChapter (int i) const {return chapters[i];}
};


// Code continues on next page
```

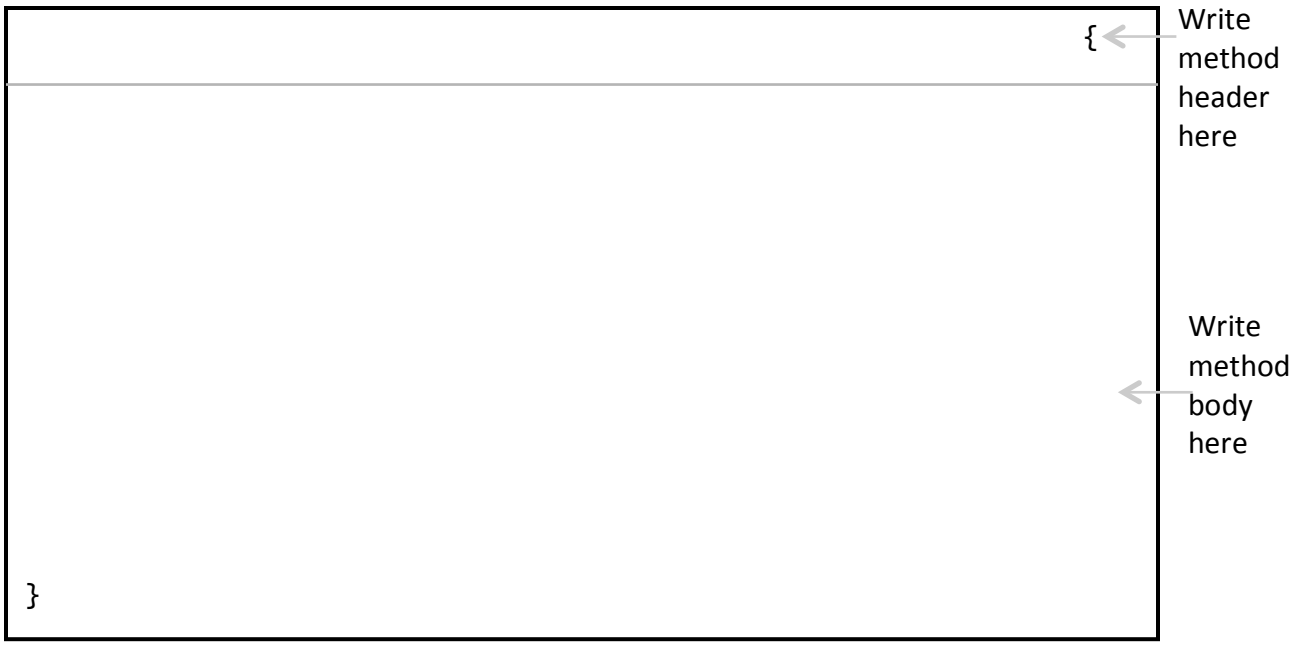
```
int MovieDuration (Movie m) {
    float m_duration = 0.0;
    for (int i=0; i < m.getNumChapters(); ++ i)
        m_duration = m_duration + m.getChapter(i).getDuration();
    return (m_duration);
}
int main() {
    string name = "The Adventures of an ECE244 Student";
    Movie ece244Movie(name, 13);

    // Code that creates the chapters and adds them to ece244Movie
    // Assume code will never add more chapters than numChapters

    cout << MovieDuration(ece244Movie) << endl;
    return 0;
}
```

However, it turns out that the code encounters a serious runtime problem when executed.

(a) (2 marks). Identify the problem using one short sentence. For example, if you think the problem is that the program divides by 0, then write: "the program divides by 0". Similarly, if you think it dereferences a null pointer, then write: "program dereferences a null pointer". Your answer should be this short and precise to receive marks.

Answer:

(b) (4 marks). The problem can be corrected by adding a single method in one of the classes. Write this method. Other than this method, you are not allowed to make any changes to the classes.



Question 5. (6 marks). *Amy in La La Land.*

Amy (the same very good C++ programmer) liked the movie La La Land so much that she wrote two classes, `LaLa` and `Land`, defined and implemented them correctly. She now wishes to use them together, along with integers, to support the operations shown in `main` below.

```
int main() {
   LaLa a(1);
   Land b(2);
   int f = 3;

   a = a + b;  // a + b returns by value an object of type LaLa
   a = b + a;  // b + a returns by value an object of type Land

   a = a + f;  // a + f returns by value an object of type LaLa
   b = f + b;  // f + b returns by value an object of type Land

   return (0);
}
```

Amy **must** write a set of overloaded operators to make the above code work in `main`.

(a) (2 marks). How many of these operators **must** be non-member functions?

(b) (2 marks). How many of these operators **may** be member methods of class `LaLa`?

(c) (2 marks). How many of these operators **may** be member methods of class `Land`?

Hint: Amy says an overloaded `operator=` must be a class member.

Question 6. (4 marks). *Amy Runs for Office.*

There will be a Federal election in October of 2019. Amy (you guessed it, the same one) decided to run for local office. Vital to any election is vote counting. Thus, Amy would like you to design a **recursive** function called `count` to determine who got more votes without using "counters," i.e., variables that increment by a constant amount (e.g., `x = x + 1`).

Assume that votes are stored in a character array of length `n`. An '`I`' represents a vote for the incumbent, and a '`C`' represents a vote for the challenger (assume only one challenger). When processing the array, the function should return the difference in votes between the incumbent and the challenger (a positive number if the incumbent has more votes, and a negative number if the challenger has more votes).

For example, calling the `count` function on the following array:

vArray	I	I	C	C	C	I	C	C	C

returns a vote difference of –3.

Write your **recursive** implementation of the function `count` in the space below.

Hint: determine what the basis of recursion should be, then express the original problem in terms of one or more smaller (i.e., closer to the basis) problems.

```
int count ( char *voteArray, int lowIndex, int highIndex ) {

}

// Here is how the function is called for an n-element vArray
cout << count(vArray, 0, n-1);
```

Question 7. (6 marks). *Recursion.*

Consider the two classes `ListNode` and `LinkedList` used to implement a linked list. They are not unlike the ones described in class or those you implemented in the lab. Only the class members relevant to the question are shown.

```
class ListNode {
   private:
     int id;
     ListNode* next;
   public:
     ListNode* getNext() {return next;}

};
```

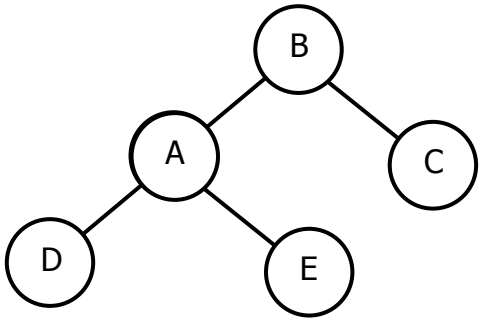
```
class LinkedList {
   private:
     ListNode* head;
   public:

     ListNode* getTail();

};
```

Write a ***recursive*** member function of `LinkedList` that returns a pointer to the last node in the list. If the list is empty it should return `NULL`. You may add new data members or methods to the classes.

```
ListNode* LinkedList::getTail()
```

Question 8. (5 marks). *Tree Traversals.*

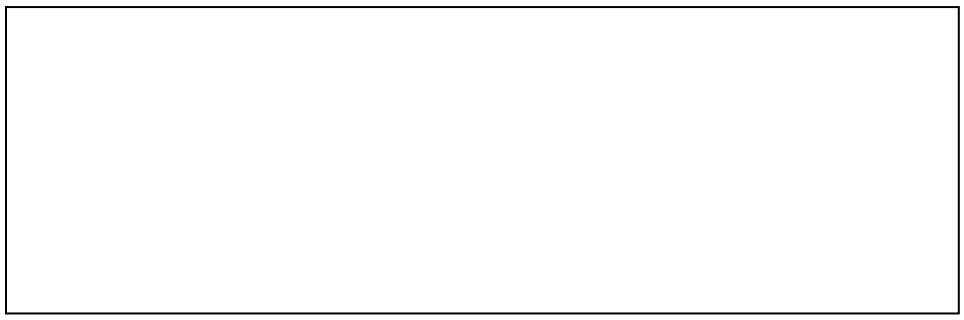
In the *reverse-postorder* traversal of a tree, the right subtree is first traversed (recursively in reverse-postorder), then the left subtree is traversed (also recursively in reverse-postorder), and finally the node is visited. That is, the order of the traversal is RLN. For example, the reverse-postorder traversal of the tree shown below is C E D A B.



Write a **recursive** function to perform the reverse-postorder traversal of a binary tree. Assume that visiting a node simply prints its data to `cout`. The body of the function should be very short (4-7 lines)! Longer code will be penalized.

You may assume the following declarations:

```
class treenode {
      public:
         int data;
         treenode* left;
         treenode* right;
};
treenode* root; // root of the tree

void reverse-postorder (treenode *myroot) {
```



```
}

// This is how reverse-postorder is called
reverse-postorder(root);
```

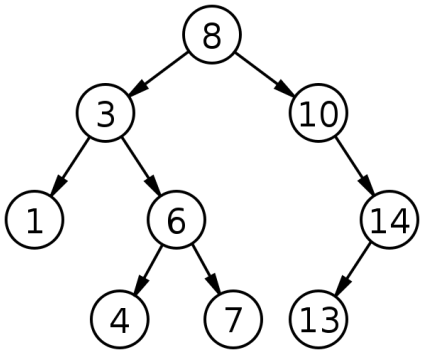
Question 9. (5 marks). *Binary Search Trees.*

Consider the following class declaration of a node in a binary search tree, called `BSTNode`.

```
class BSTNode {
   public:
     int val;
     BSTNode *left;
     BSTNode *right;
};
```

Given a binary search tree, write a non-member function called `printInRange` that prints all the keys in the binary search tree that fall within a given range *in sorted order.*

For example, given the following binary search tree



and the range 5 and 13, the function output is: 6 7 8 10 13.

Note that the range values are inclusive (i.e., a key is printed if it is equal to the given lower or upper bound). Write your answer below.

```
bool printInRange(BSTNode root, int lowerBound, int upperBound) {









}
```

Question 10. (4 marks). *Destructors.*

In lab assignment 5, you were asked to implement a binary search tree consisting of objects of type `TreeNode`. Assume the following simplified definition of `TreeNode`.

```
class TreeNode {
  public:
      int key;
      TreeNode *left;
      TreeNode *right;
};
```

Assume that your program creates a binary search tree with a pointer to its root node called `root`. Write the destructor of `TreeNode` so that the following statement deletes **all** the nodes in your tree (unlike your lab assignment).

```
    delete root;
```

Provide your answer below.

```
TreeNode::~TreeNode() {




}
```

Question 11. (4 marks). *Inheritance.*

Consider the following class definitions and implementations, as well as a `main` function that uses them. All the code appears in one file and it compiles with no errors.

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

class firstOne {
  private:
    int x;
    char* first;

  public:
     firstOne();
     firstOne(const char* s);
};

class secondOne : public firstOne {
   private:
     int y;
     char* second;

   public:
      secondOne(const char* s);
      secondOne(int v);
};

firstOne::firstOne() {
     x = 0;
     first = new char[1];
     first = '\0';
     cout << "Constructor 1 of firstOne done" << endl;
}

firstOne::firstOne(const char* s) {
     x = 0;
     int size = strlen(s);
     first = new char[size+1];
     strcpy(first,s);
     cout << "Constructor 2 of firstOne done" << endl;
}

secondOne::secondOne(const char* s) {
     y = 0;
     int size = strlen(s);
     second = new char[size+1];
     strcpy(second,s);
     cout << "Constructor 1 of secondOne done" << endl;
}

secondOne::secondOne(int v):firstOne("X") {
     y = v;
     second = new char[1];
     second = '\0';
     cout << "Constructor 2 of secondOne done" << endl;
}

// Code continues on next page
```

```
int main () {
     firstOne a;
     firstOne b("G");
     secondOne c("N");
     secondOne d(8);
}
```

Indicate what each statement in the above `main` function prints, using the table below. If no output is produced, write "NONE".

Statement	Output
`firstOne a;`	
`firstOne b("G");`	
`secondOne c("N");`	
`secondOne d(8);`	

Question 12. (8 marks). *Inheritance.*

Consider the following base and derived classes. They compile with no errors.

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

class Dessert {
   protected:
     int price=0;
   public:
     Dessert () {cout << "we have dessert\n";}
    ~Dessert () {cout << "no more dessert\n";}
     void print() {cout << "dessert unknown\n";}
     virtual int cost() = 0;
};

class Candy : public Dessert {
   protected:
      int weight_in_grams;
   public:
      Candy(int grams, int per_gram) {
           weight_in_grams = grams;
           price = per_gram;
           cout << "we have candy\n";
      }

     ~Candy() {cout << "no more candy\n";}

     void print() {
           cout << "Candy: " << weight_in_grams << " grams, at "
                << price << " cents per gram\n";
      }

      virtual int cost() {return weight_in_grams*price;}
};
class Cookies : public Dessert {
   protected:
      int num_dozens;
   public:
      Cookies(int dozens, int per_dozen) {
           num_dozens = dozens;
           price = per_dozen;
           cout << "we have cookies\n";
      }

     ~Cookies() {cout << "no more cookies\n";}

      void print() {
           cout << "Cookies: " << num_dozens << " dozens, at "
                << price << " cents per dozen\n";
      }

      virtual int cost () {return num_dozens*price;}
};
```

```
class IceCream : public Dessert {
   protected:
      string flavor = "Vanilla";
      int scoops;

   public:
      IceCream(string flv, int scps, int per_scoop) {
           flavor = flv;
           scoops = scps;
           price = per_scoop;
           cout << "we have " << flavor << " Ice Cream\n";
      }

     ~IceCream() {cout << "no more ice cream\n";}

      void print() {
           cout << "Ice Cream: " << scoops
                << " scoops, at " << price << " cents per scoop\n";
      }

      virtual int cost () {return scoops*price;}
};


class Sundae : public IceCream {
    protected:
       int topings_cost;

    public:
       Sundae(string flv, int scps, int per_scoop,
              int tps):IceCream(flv, scps, per_scoop) {
             topings_cost = tps;
             cout << "  with topings\n";
       }

      ~Sundae() {cout << "no more sundae\n";}

       void print() {
             IceCream::print();
             cout << "  topings cost is: " << topings_cost << endl;
       }

       virtual int cost () {return scoops*price + topings_cost;}
};
```

Consider each of the following `main` functions that use the above classes. You may assume that each `main` function includes the code of the classes above, including the `#include`'s and the `using namespace std;`.

For each `main` function, indicate if the function compiles with no errors or not (ignore warnings). If the function compiles with no errors, then indicate the output produced by the function?

(a)

```
int main() {
    Dessert a;
    Cookies b(2, 300);
    IceCream c("vanilla", 2, 350);
    return 0;
}
```

Does the program compile with no errors? Answer by Yes or No: [ ]

If it does compile with no errors, what is the output produced by the execution?

[ ]

(b)

```
int main() {
    Dessert* pc;
    IceCream* pi;
    pc = new Cookies(2, 250);
    pi = new IceCream("mint", 1, 250);
    delete pc;
    delete pi;
    return 0;
}
```

Does the program compile with no errors? Answer by Yes or No: [ ]

If it does compile with no errors, what is the output produced by the execution?

[ ]

(c)

```
int main() {

    Sundae* ps;
    IceCream* pi;
    pi = new IceCream("mint", 1, 250);
    ps = pi;
    delete ps;

   return 0;
}
```

Does the program compile with no errors? Answer by Yes or No:

If it does compile with no errors, what is the output produced by the execution?

(d)

```
int main() {
   Dessert* ps = new IceCream("vanilla", 2, 350);
   cout << ps->cost() << endl;
   return 0;
}
```

Does the program compile with no errors? Answer by Yes or No:

If it does compile with no errors, what is the output produced by the execution?

Question 13. (5 marks). *Amy's Lists. (Caution: Difficult).*

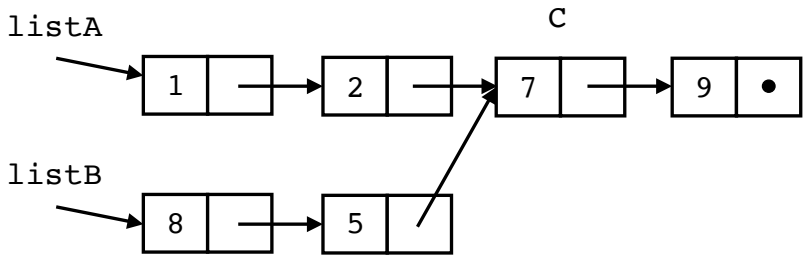
Amy (yup, the very good C++ programmer) wrote the class `ListNode` shown below. It represents a node in a linked list. It is similar to the one described in class and that you implemented in the labs.

```
class ListNode {
   public:
     int id;
     ListNode* next;
};
```

Consider two linked lists. The first is pointed to by `listA` and the second is pointed to by `listB`.

```
ListNode* listA;
ListNode* listB;
```

Normally the two lists contain separate nodes. However, it is possible due to some error for the two lists to share their nodes, as shown in the small example below.



Amy would like to write a function called `getCommon` that returns a pointer to the first node common to the two lists (node labeled `C` in the figure above). Otherwise, if there are no common nodes, the function returns NULL.

Amy decides to write this function with the help of a single additional <u>data member</u> in `ListNode`. This additional data member must be initialized by the constructor of `ListNode` and then used by the `getCommon` function. Amy would like to make this function run in O(n) as opposed to $O(n^2)$.

(a) (1 mark). Declare the additional member to be added to `ListNode` here:

Answer:

(b) (1 mark). Show how this member should be initialized in the constructor of `ListNode`:

Answer:

(c) (3 marks). Write the body of the `getCommon` function below.

```
ListNode* getCommon(ListNode* headA, ListNode* headB) {

}

// This is how getCommon is called
… = getCommon(listA, listB);
```

Question 14. (5 marks). *Binary Trees. (Caution: Difficult).*

Given a binary tree, you need to write a function to check if that tree is a *mirror* of itself. A tree is a mirror of itself if it is symmetric around its root.

For example the binary tree on the left below is a mirror. In contrast, the binary tree on the right below is not a mirror.

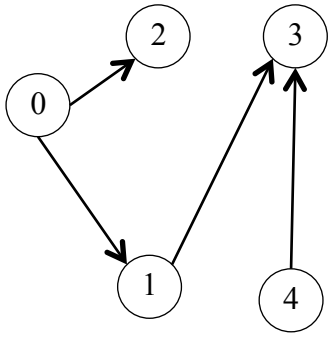
Given the class definition of a `TreeNode` shown below, write a *recursive* function `isSymmetric` that returns true if the tree is a mirror, otherwise, it returns false.

```
class TreeNode {
  public:
      int val;
      TreeNode *left;
      TreeNode *right;
};
TreeNode* root;

// This is how the function is called
isSymmetric(root->left, root->right);
```

```
bool isSymmetric(TreeNode *n1, TreeNode *n2) {
    if(n1 == NULL && n2 == NULL) return true; // If both nodes are null

        // Add your code here









}
```

Question 15. (4 marks). *Graphs.*

Consider the graph shown below.



(a) (2 marks). Give a *depth-first* traversal of the graph, starting at node 0. Assume that visiting a node means printing its number to the standard output.

Give the traversal here: | | | | | |

(b) (2 marks). Give a *breadth-first* traversal of the graph, starting at node 0. Assume that visiting a node means printing its number to the standard output.

Give the traversal here: | | | | | |

Question 16. (8 marks). *Complexity Analysis.*

Determine the ***worst-case*** time complexity (***expressed in big-O notation***) for each of the program segments below as a function of the size of the input `n`. Show the details of your analysis and clearly indicate your final result.

(a) (1 marks) The size of the input is `n`.

```
for (int i=0; i < n; ++i) {
    for (int j=0; j < 100000000 ; ++j) {
         // Some code with O(1)
    }
}
```

T(n) = 

(b) (2 marks) The size of the input is `n`.

```
for (int i=0; i < n; ++i) {
    for (int j=0; j < 3*n ; ++j) {
         // Some code with O(1)
    }
}
```

T(n) = 

(c) (2 marks). The size of the input is `n`. Assume `n` is a power of two.

```
for (int i=1; i <= n; i=i*2) {
    for (int k=0; k < n ; ++k) {
         // Some code with O(1)
    }
}
```

T(n) = 

(d) (3 marks). Assume for simplicity that `n` is a power of two.

```
int recursive(int n) {
   int x;
   int y;

   if (n <= 1) return 0;
   else {
       for (int i=0; i < n ; ++i) // Some code with O(1)
       recursive (n/2);
       recursive (n/2);
       return (1);
   }
}
```

Write the recurrence equation for `T(n)`.

Solve the recurrence equation (by expansion) to obtain an expression of `T(n)` in terms of `n`.

Express `T(n)` using the ***big-O notation***.

`T(n) =` [ ]

Question 17. (4 marks). *Memory Management.*

Consider the code below in a file called `main.cpp`. The line numbers shown are not part of the code and are there to facilitate your answer. The writer of this code suspects that it contains errors in how it uses memory, and runs `valgrind` on it. The output produced by `valgrind` is shown after the code and indicates several problems.

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

03      class Mystery {
04      private:
05         int *v;
06         int size;
07      public:
08         Mystery(int _size);
09         ~Mystery();
10         int& operator[] (int index);
11         int getsize () const;
12         void print () const;
13      };

14      Mystery::Mystery (int _size) {
15         size = _size;
16         v = new int[size];
17      }

18      Mystery::~Mystery () {
19         delete v;
20      }

21      int& Mystery::operator[] (int index) {
22         return (v[index]);
23      }

24      void Mystery::print () const {
25         for (int i = 0; i <= getsize(); i++)
26             cout << v[i] << " ";
27         cout << endl;
28      }

29      int Mystery::getsize () const {
30         return size;
31      }

32      int main () {
33         Mystery a(5);
34         for (int i=0; i < 5; i++) a[i] = i;
35         a.print();
36         return 0;
37      }
```

The `valgrind` output is as follows:

```
==10620== Memcheck, a memory error detector
==10620== Copyright (C) 2002-2015, and GNU GPL'd, by Julian Seward et al.
==10620== Using Valgrind-3.11.0 and LibVEX; rerun with -h for copyright info
==10620== Command: main.exe
==10620==
==10620== Invalid read of size 4
==10620==    at 0x400A57: Mystery::print() const (in /u/user/amy/ece244/main.exe)
==10620==    by 0x400AEC: main (in /u/user/amy/ece244/main.exe)
==10620==  Address 0x4c45054 is 0 bytes after a block of size 20 alloc'd
==10620==    at 0x4A078F0: operator new[](unsigned long) (vg_replace_malloc.c:421)
==10620==    by 0x4009CB: Mystery::Mystery(int) (in /u/user/amy/ece244/main.exe)
==10620==    by 0x400AB4: main (in /u/user/amy/ece244/main.exe)
==10620==
0 1 2 3 4 0
==10620== Mismatched free() / delete / delete []
==10620==    at 0x4A06738: operator delete(void*) (vg_replace_malloc.c:574)
==10620==    by 0x4009F4: Mystery::~Mystery() (in /u/user/amy/ece244/main.exe)
==10620==    by 0x400AFD: main (in /u/user/amy/ece244/main.exe)
==10620==  Address 0x4c45040 is 0 bytes inside a block of size 20 alloc'd
==10620==    at 0x4A078F0: operator new[](unsigned long) (vg_replace_malloc.c:421)
==10620==    by 0x4009CB: Mystery::Mystery(int) (in /u/user/amy/ece244/main.exe)
==10620==    by 0x400AB4: main (in /u/user/amy/ece244/main.exe)
==10620==
==10620==
==10620== HEAP SUMMARY:
==10620==     in use at exit: 0 bytes in 0 blocks
==10620==   total heap usage: 1 allocs, 1 frees, 20 bytes allocated
==10620==
==10620== All heap blocks were freed -- no leaks are possible
==10620==
==10620== For counts of detected and suppressed errors, rerun with: -v
==10620== ERROR SUMMARY: 2 errors from 2 contexts (suppressed: 4 from 4)
```

In the table on the following page, indicate the changes required to the code to fix the bugs. A change must be one of: Remove, Replace with or Insert Before. **No changes should be made to the main() function; all fixes must be made with changes to the other functions.** Please list your fixes in increasing line order. You may or may not need all the rows in the table.

Line Number	Remove / Replace with / Insert Before (choose one)	Code to Insert or Replace with

Question 18. (11 marks). *Iterators. (Caution: Difficult).*

In C++, an *iterator* is a class whose objects facilitate traversals of collections (i.e., data structures). Consider the following definition of a class for a linked list, similar to the one you used in your lab assignment 4 to maintain your list of asteroids, simplified for the purposes of the question.

```
class ListNode {
    public:
        int value;
        ListNode* next;
       // Other members that are not relevant to the question
};

class List {
     public:
         ListNode* head;    // Head of the list
         ListNode* begin(); // returns a pointer to the first term
                            // on the list, NULL if list is empty
         ListNode* end();   // returns a pointer to the node
                            // past the end of the list;
                            // assume NULL
         // Other member that are not relevant to the question
};
List mylist;
```

In the main function, we wish to write the following code:

```
for (ListIterator it = mylist.begin(); it != mylist.end(); it++) {
      cout << *it << endl;
}
```

This allows the main function to traverse the list with no knowledge of how the list is implemented.

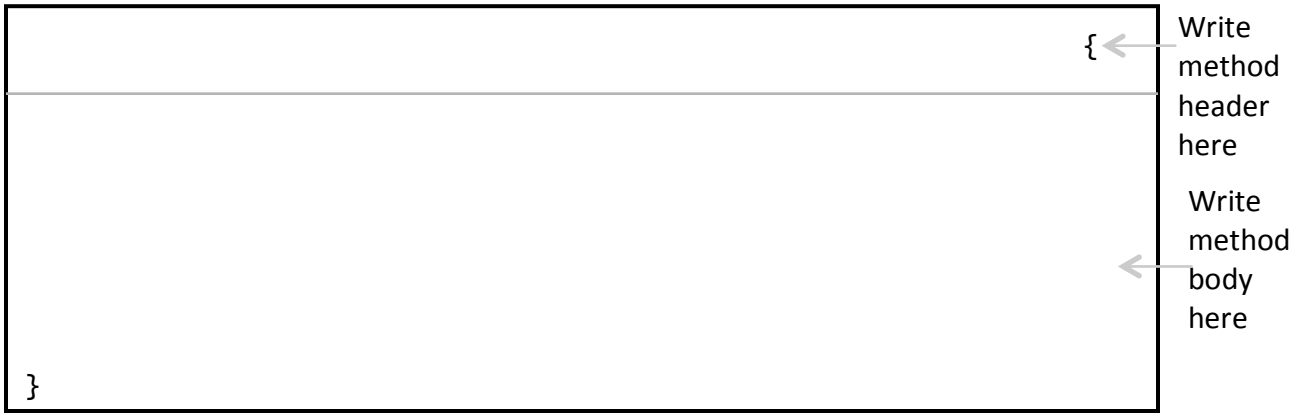
However, in order for the above code to work, a class called `ListIterator` is defined.

```
class ListIterator {
    public:
    // One data member is defined here

    // One constructor is defined here

    // Some methods are defined here
};
```

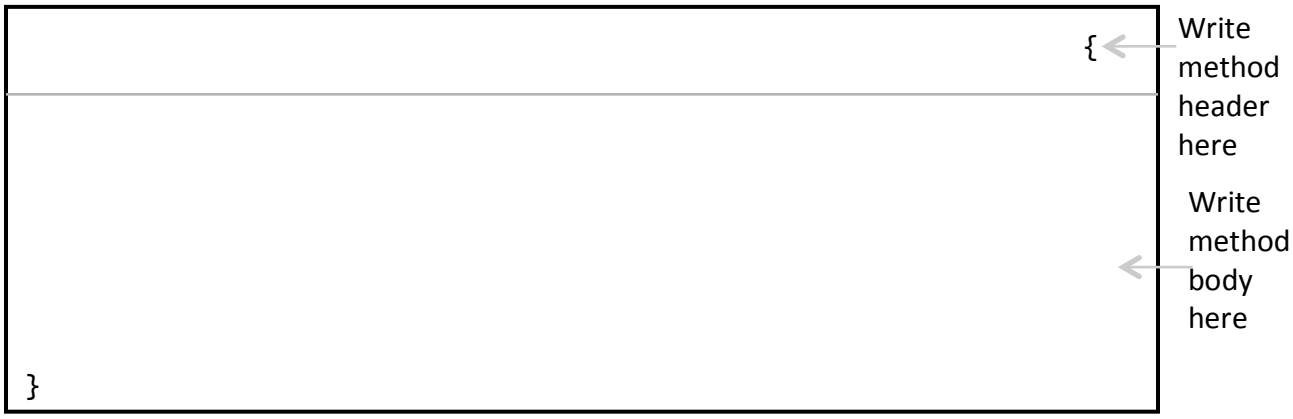
(a) (1 marks). The `ListIterator` class must define one data member. Show the declaration of this data member here.

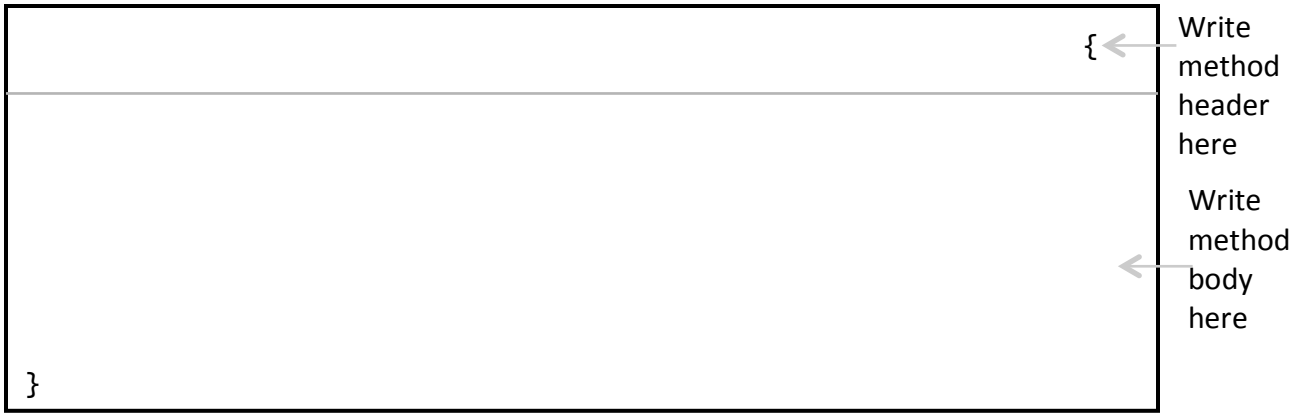
Answer:

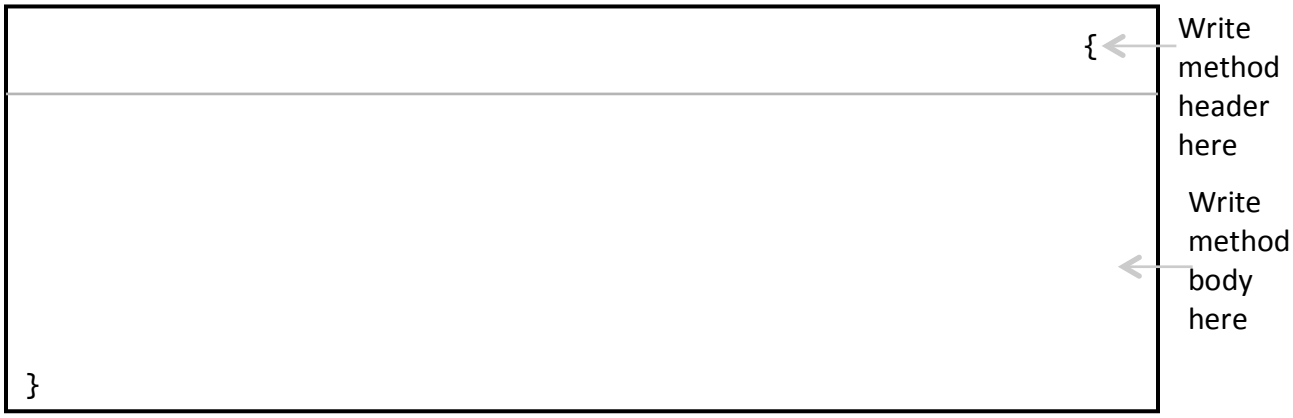
(b) (2 marks). The `ListIterator` class must define one constructor. Show the implementation of this constructor below. Make sure to include both the header and the body of the constructor.

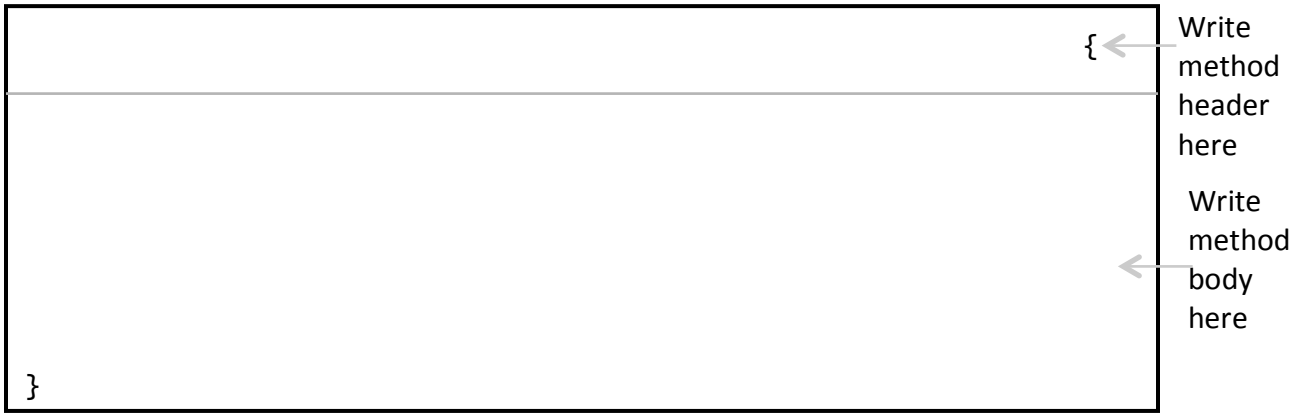


(c) (8 marks). The `ListIterator` class must define four overloaded operators. Show the implementation of these overloaded operators below. For each, make sure to include both the header and the body of the operator. Assume them all to be members of the class `ListIterator`.




{
Write method header here
Write method body here
}


{
Write method header here
Write method body here
}


{
Write method header here
Write method body here
}

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