CSCI-1200 Data Structures
Test 2 — Practice Problem Solutions

1 Checking It Thrice [/ 22]

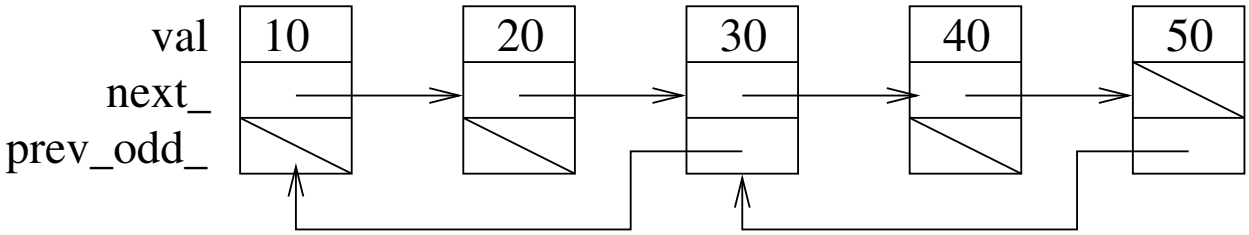
Each row in the table below contains two statements labeled `A` and `B`. Put a checkmark ☑ in up to three boxes per row. Each correct checkmark is worth +1, each blank checkbox is worth +0, and to discourage random guessing each incorrect checkmark is worth −2 points. Your score on this problem will not go below 0. Only two *A* statements are true because of their corresponding *B* statements.

A is		B is		A is true	Statemtents
True	False	True	False	**because** of B	
☑	☐	☑	☐	☐	**A**: STL vector erase() may invalidate an iterator. **B**: For programs that need to do a lot of erasing, you should use an STL list instead of an STL vector.
☑	☐	☐	☑	☐	**A**: A memory debugger like Valgrind or Dr. Memory can help find leaked memory. **B**: A memory debugger like Valgrind or Dr. Memory shows you the line on which you should have written delete/delete[] to fix the memory leak.
☐	☑	☑	☐	☐	**A**: Vec push_back() on average takes O(n) **B**: Vec push_back() sometimes has to allocate a new array that's 2*m_alloc
☑	☐	☑	☐	☑	**A**: If std::list<int>::iterator *itr* points to a valid location in list *l1*, writing `l1.erase(itr)++` may cause a memory error. **B**: Incrementing the end() iterator in any STL list has undefined behavior
☑	☐	☑	☐	☐	**A**: STL lists / dslist do not have operator[] defined **B**: Using operator[] on a pointer is the same as using pointer arithmetic and then dereferencing the result.
☐	☑	☑	☐	☐	**A**: Assuming std::vector<int>::iterator *itr* points to a valid location in vector *v1*, writing `v1.insert(itr,5); std::cout << *itr;` will always cause a memory error. **B**: std::vector<T>::insert() returns an iterator because insert() may invalidate the iterator passed in.
☑	☐	☐	☑	☐	**A**: If std::vector<int> *v1* is an empty vector, `v1.end()--` will result in undefined behavior. **B**: Decrementing the end() iterator in any STL vector has undefined behavior.
☐	☑	☑	☐	☐	**A**: If a recursive function does not use array indexes or pointers, and there's a segmentation fault in that function, it means you must have infinite recursion. **B**: Infinite recursion can result in a segmentation fault.
☑	☐	☐	☑	☐	**A**: Writing `int* x=5;` will result a compiler error. **B**: Memory addresses are not numbers, so you cannot store a number in a pointer.
☑	☐	☑	☐	☑	**A**: Writing `dslist<int> x; x.push_back(5); dslist<int> y = x;` will not result in calling `y.operator=(x)` even though there is an `=` sign in the last statement. **B**: `operator=` can only be called on objects that are already constructed.

2 Hop Lists [/ 37]

In this problem we will consider "hop lists", a made-up data structure based on "skip lists". A hop list is a linked list using the Node class listed below. For simplicity we will not make it templated and our Nodes will only contain integers. The *next_* pointer works the same way as in the singly and doubly-linked lists we have studied so far. However, the *prev_odd_* pointer is `NULL` for the 1^{st} element in the list, and for all other elements in an odd position (3^{rd} in the list, 5^{th} in the list, and so on), the *prev_odd_* pointer points two elements back. There is a diagram below to illustrate how this would look for a list with five nodes containing the values `10, 20, 30, 40, 50` in that order.

```
class Node{
public:
  Node(int v) : val(v), next_(NULL), prev_odd_(NULL) {}
  Node(int v, Node* next) : val(v), next_(next), prev_odd_(NULL) {}
  int val;
  Node* next_;
  Node* prev_odd_;
};
```



In the following sections you will write two different versions of `AddPrevOddPointers`. Both versions take a Node pointer called *head* which points to the first Node in a hop list, and a Node pointer called *tail*. After the function is done, all of the *prev_odd_* pointers should be set correctly, and *tail* should point to the last element (furtherst from *head*) that is in an odd position. If there are not at least 3 Nodes in the list, then *tail* should be `NULL`. You can assume that all Nodes have their *next_* pointer correctly set before `AddPrevOddPointers` is called.

An example of calling the function might look like:

```
  //Start a new list
  Node* head = new Node(2561);
  /////Code to make the rest of the nodes/link forward omitted

  PrintListForward(head); //"Printing forward list..."
  Node* tail;
  AddPrevOddPointers(head,tail);
  PrintHopListBackwards(tail); //"Printing backwards..."
  std::cout << std::endl;
```

Here are two examples:

```
Printing forward list: 10 20 30 40 50 60 70 80 90 100 110
Value at tail: 110
Printing backwards every-other list: 110 90 70 50 30 10

Printing forward list: 31 32 33 34 35 36 37 38 39 301
Value at tail: 39
Printing backwards every-other list: 39 37 35 33 31
```

Note: A lot of students seemed to think this was a class. This was just a collection of `Node` objects that happened to point to each other. The names *head* and *tail* were there to give a hint about the purpose of the arguments and to make it easier to read code in the `AddPrevOddPointers` implementations. They are just a couple independent pointer variables and not part of a class like in `dslist`.

2.1 AddPrevOddPointers (Recursive Version) [/ 18]

Write a version of AddPrevOddPointers that uses recursion.

Solution:

```
void AddPrevOddPointers(Node* head, Node*& tail){
  //If empty list
  if(!head){
    tail = NULL;
    return;
  }

  //Assume we're on an odd node (1st, 3rd, etc.)
  //Figure out who's two nodes ahead:
  Node* tmp = head->next_;
  if(tmp){
    tmp = tmp->next_;
    if(tmp){
      //We have at least the next odd, assign it to head (the current odd)
      tmp->prev_odd_ = head;
      //Update tail
      tail = tmp;
      //Continue from the next odd point
      AddPrevOddPointers(tmp, tail);
    }
    else if(!head->prev_odd_){ //Size 2 list
      tail = NULL;
    }
  }
  else if(!head->prev_odd_){ //Size 1 list
    tail = NULL;
  }
}
```

2.2 AddPrevOddPointers (Iterative Version) [/ 15]

Write a version of AddPrevOddPointers that does not use any recursion.

Solution:

```
void AddPrevOddPointers(Node* head, Node*& tail){
  //If we don't have >=3 nodes, return NULL
  if(!head || !head->next_ || !head->next_->next_){
    tail = NULL;
    return;
  }

  Node* tmp = head->next_->next_; //Set a pointer 2 nodes ahead of head
  while(tmp->next_ && tmp->next_->next_){
    tmp->prev_odd_ = head; //Connect tmp back to head

    //If we can't advance 2 nodes further, stop
    if(!tmp->next_ || !tmp->next_->next_){
      break;
    }

    //Move head and tmp pointers 2 positions forward
    head = tmp;
    tmp = tmp->next_->next_;
  }

  tmp->prev_odd_ = head; //Connect the last node

  tail= tmp;
}
```

2.3 `AddPrevOddPointers` Complexity [/ 4]

If the hop list has n elements, what is the running time order notation of the iterative version of `AddPrevOddPointers`? What about for the recursive version?

Solution: O(n). Both versions have to visit all n nodes, and perform a constant number of operations per node.

3 Shape Overlays [/ 14]

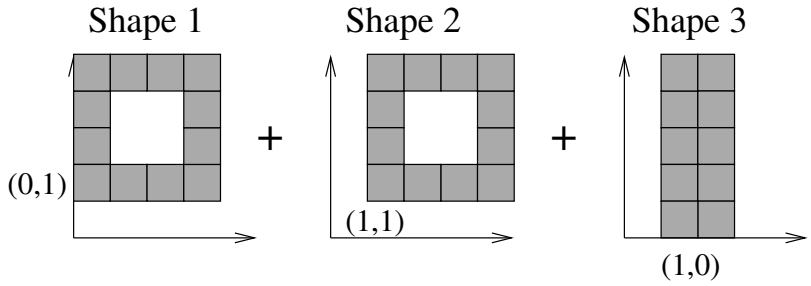
Given a series of `Shape` objects in a `vector<Shape>` *shapes*, the code below should allocate and fill a 2D dynamic array of integers, *overlay* that represents an overlay of all the shapes. If all of the shapes were to be put on top of each other, an overlay would show for every position (x,y) how many shapes had a pixel on at that position. You can assume that *shapes* is not empty and each shape is at least 1x1 in size. The coordinates use the Cartesian coordinate system, where (0,0) is the origin, $x = 1$ is to the right of the origin, and $y = 1$ is above the origin. You can also assume non-negative x,y coordinates for everything and that the overlay starts with the bottom left corner at (0,0). The example shapes and overlay output have (0,0) in the bottom left corner for easy visualization.

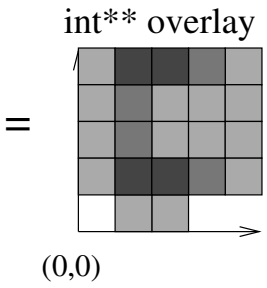
```
Shape 1 (outline rectangle)
Printing 4 x 4 overlay:
XXXX
X..X
X..X
XXXX

Lower left is at (0, 1)
```

```
Shape 2 (outline rectangle)
Printing 4 x 4 overlay:
 XXXX
 X..X
 X..X
 XXXX

Lower left is at (1, 1)
```

```
Shape 3 (filled in rectangle)
Printing 5 x 2 overlay:
 XX
 XX
 XX
 XX
 XX
Lower left is at (1, 0)
```

```
Printing 5 x 5 overlay:
13321
12111
12111
13321
01100
```






```
class Point{
public:
  Point(int x=0, int y=0) : m_x(x), m_y(y) {}
  int m_x, m_y;
};

class Shape{
public:
  bool pixelOn(int x, int y) const;
  void getDimensions(int& width, int& height, Point& corner) const;
...
};
```

```
void MakeOverlay(int**& overlay, int& height, const std::vector<Shape>& shapes){
  int shape_height, shape_width, width;
  height = width = 0; //Start by assuming a 0x0 overlay
  Point shape_corner; //Holds the lower left corner of the shape

  //Cycle through each shape and find the further-upper-right point
  for(unsigned int i=0; i<shapes.size(); i++){
    shapes[i].getDimensions(shape_width, shape_height, shape_corner);
    height = std::max(height, shape_corner.m_y + shape_height);
    width = std::max(width, shape_corner.m_x + shape_width);
  }

  //STUDENT PORTION #1: ALLOCATE OVERLAY, first box on next page goes here

  //STUDENT PORTION #2: FILL IN OVERLAY, second box on next page goes here

  PrintOverlay(overlay, width, height); //DO NOT WRITE THIS FUNCTION
}
```

3.1 #1: Allocate Overlay [/ 8]

Write the code that should go under the "STUDENT PORTION #1" comment in `MakeOverlay`.

Solution:

```
overlay = new int*[height];
for(unsigned int y=0; y<height; y++){
  overlay[y] = new int[width];
  for(unsigned int x=0; x<width; x++){
    overlay[y][x] = 0;
  }
}
```

3.2 #2: Fill In Overlay [/ 6]

Write the code that should go under the "STUDENT PORTION #2" comment in `MakeOverlay`.

Solution:

```
for(unsigned int i=0; i<shapes.size(); i++){
  shapes[i].getDimensions(shape_width, shape_height, shape_corner);
  for(int y=0; y<shape_height; y++){
    int true_y = shape_corner.m_y + y;
    for(int x=0; x<shape_width; x++){
      int true_x = shape_corner.m_x + x;
      bool pixel_on = shapes[i].pixelOn(true_x, true_y);
      if(pixel_on){
        overlay[true_y][true_x] += 1;
      }
    }
  }
}
```

4 Pivoting Lists [/ 24]

Write a void function `MovePivots` that takes an STL `list<string>` *a* and a constant STL `list<string>` *pivots*. The function should rearrange *a* so that all instances of strings that are in both *a* and *pivots* are at the front of *a*. The order of other elements in *a* should not be changed, and the elements that were moved to the front should be in the order they were found in originally in *a*. The elements in *a* are not guaranteed to be unique. Do not create any new lists/vectors/arrays. Do not use anything from <algorithm>. Your function does not need to print anything.

Here are some examples of before and after the function, with five strings in *pivots*: `ant bear cat dog eel`

```
Before List (size 3): bob ant cod
After List (size 3): ant bob cod
Before List (size 3): eel ant cat
After List (size 3): eel ant cat
Before List (size 9): bob blob cod eel cod ant eel eel ant
After List (size 9): eel ant eel eel ant bob blob cod cod
```

4.1 `MovePivots` Implementation [/ 20]

Solution:

```
void MovePivots(std::list<std::string>& a, const std::list<std::string>& pivots){
  std::list<std::string>::iterator first_pivot_it = a.begin(); //Place AFTER where to insert next pivot

  for(std::list<std::string>::iterator l_it = a.begin(); l_it!=a.end(); l_it++){
    for(std::list<std::string>::const_iterator v_it = pivots.begin(); v_it != pivots.end(); v_it++){
      if(*v_it == *l_it){
        if(l_it == first_pivot_it){ //Don't move a correctly placed element
          first_pivot_it++; //Do update the pivot point though!
          break;
        }
        first_pivot_it = a.insert(first_pivot_it,*l_it);
        first_pivot_it++;
        l_it = a.erase(l_it);

        //We know we cannot be the head, because we just inserted something BEFORE our current position, so
        //just decrement l_it to compensate for loop incrementing l_it.
        //If we could not guarantee this we might risk doing head--
        //if(first_pivot_it != a.begin())
          l_it--;

        //Stop the search for potential efficiency. Not required for solution
        break;
      }
    }
  }
}
```

4.2 `MovePivots` Complexity [/ 4]

If there are p strings in *pivots*, and w strings in a, what is the running time order notation for `MovePivots`? Explain your analysis.

Solution: O(pw), because each search through pivots takes O(p) and we may have to search the entire pivot list O(w) times.

Note: We didn't give a variable for the length of the longest word in *pivots* or a, so there wasn't a variable to discuss string comparisons. If we were being tricky we could have introduced variables for this, in which case every comparison would take O(longest string length shared between *pivots* and a) for a total runtime of O(p*w*(longest shared string length)).

5 Time Complexity [/ 20]

For each of the functions, write the time complexity assuming there are n elements stored in the container. If there is a difference between C++98 and C++11, you should assume C++11. For the singly-linked list, assume that we only have the *head_* pointer and no other member variables. For the singly-linked list, assume that *erase()* is given a pointer to the node we want to erase **and** a pointer to the node before the one we want to erase.

	`STL vector or Vec<T>`	`Singly-linked List`	`STL list or dslist<T>`
size()	**O(1)**	**O(n)**	**O(1)**
push_back()	**O(1)**	**O(n)**	**O(1)**
erase()	**O(n)**	**O(1)**	**O(1)**
insert()	**O(n)**	**O(1)**	**O(1)**
pop_back()	**O(1)**	**O(n)**	**O(1)**

Write 2-3 complete sentences about one of the above methods which is more efficient for STL `list`s than for STL `vector`s and why this is the case.

Lists do not have to have a contiguous space in memory, and use links to chain individual nodes together. Because of this, inserting or erasing in an STL list (which is doubly-linked) is O(1) since only a few links need to be changed (4 for insert, 2 for erase). If we're removing or adding frequently, the O(1) list operations for insert/erase are a huge savings compared to STL vector's O(n) cost.

push_back might be a tempting answer, but over the course of n pushback operations, the overhead averages out so that we end up with an amortized worst case of O(1) for vectors.

6 Pokémon Battles [/ 16]

Players, known as trainers, collect teams of Pokémon. Trainers then have battles against each other where they use one Pokémon at a time from their team to try and defeat their opponent's team. Each face-off between two Pokémon is considered a "fight". A series of fights between two trainers is called a "battle". When a Pokémon loses a fight, it cannot be used again in the same battle. A battle is not over until one of the trainers has no more usable Pokémon, at which point their opponent wins.

Each monster is represented by an instance of the class `Pokemon`. You do not need to know the details of the class. To determine which Pokémon will win in a fight, the following function is used - it returns a negative number if *p1* wins, and a positive number if *p2* wins. There are no ties.

```
int pokemonFight(const Pokemon & p1, const Pokemon & p2);
```

In this problem you will be completing an implementation for the recursive function *TrainerOneWins()*. The function takes in two Node pointers which represent two lists of Pokémon, *trainer1* represents the Pokémon belonging to Trainer 1, and *trainer2* represents the Pokémon belonging to Trainer 2. The function returns `true` if Trainer 1 wins, and `false` if Trainer 2 wins. A trainer wins if they still have usable Pokémon but their opponent does not. If a trainer's Pokémon loses, the trainer will use the next Pokémon in their list.

In this problem, the Node class is defined as follows:

```
template <class T> class Node {
public:
  T data;
  Node* next;
};
```

As an example consider the following case. You do not need to know anything about specific Pokémon to solve this problem.

Node<Pokemon> list1* has Bulbasuar, Ivysaur, Geodude

Node<Pokemon> list2* has Squirtle, Charmander

Running the following code:

```
if(TrainerOneWins(list1,list2)){
  std::cout << "Trainer 1 wins." << std::endl;
}
else{
  std::cout << "Trainer 2 wins." << std::endl;
}
```

A possible run using might look something like this. The output is handled in *pokemonFight()*, you should not write any output statements:

```
Bulbasuar wins against Squirtle
Charmander wins against Bulbasaur
Charmander wins against Ivysaur
Geodude wins against Charmander
Trainer 1 wins.
```

6.1 `TrainerOneWins` Implementation [/12]

```
bool TrainerOneWins(Node<Pokemon> * trainer1, Node<Pokemon> * trainer2)
{
  if(trainer1 == NULL || trainer2 == NULL)
  {
    return trainer1!=NULL;
  }

  int fight_result = pokemonFight(trainer1->data, trainer2->data);

  if(fight_result < 0){
    return TrainerOneWins(trainer1, trainer2->next);
  }
  else{
    return TrainerOneWins(trainer1->next, trainer2);
  }
}
```

6.2 `TrainerOneWins` Complexity [/4]

If *pokemonFight()* is O(1), and there are m pokemon in Trainer 1's list and n pokemon in Trainer 2's list, what is the time complexity for *TrainerOneWins()*?

Solution: O(m+n). The length of both lists is important, we could have a 500 vs. 1 battle or a 1 vs. 500 battle or a 500 vs 500 Pokémon battle.

O(max(m,n)) might be tempting, but it's a much "looser" bound in asymmetric cases.

7 Print-and-Modify Functions [/ 20]

In this problem you must infer the behavior of two functions from the code sample and output provided below. You should not hard-code any values. *Hint: Write out the relationship between the numbers before and after AddByPositionAndPrint().*

Running this code:

```
int main(){
  std::list<int> counts = std::list<int>(3,0);
  AddOneAndPrint(counts);
  AddOneAndPrint(counts);
  counts.push_back(9);
  counts.push_front(11);
  AddOneAndPrint(counts);
  std::list<int> add_amounts;
  add_amounts.push_back(4); add_amounts.push_back(1); add_amounts.push_back(-3);
  add_amounts.push_back(0); add_amounts.push_back(4);
  AddByPositionAndPrint(counts,add_amounts);
  AddOneAndPrint(add_amounts);
  return 0;
}
```

Produces this output, with one line coming from each non-STL function call:

```
Elements after updates: 1 1 1
Elements after updates: 2 2 2
Elements after updates: 12 3 3 3 10
Elements after updates: 16 4 0 3 14
Elements after updates: 5 2 -2 1 5
```

7.1 AddByPositionAndPrint [/ 14]

```
void AddByPositionAndPrint(std::list<int>& counts, const std::list<int>& adds){
  std::cout << "Elements after updates:";
  std::list<int>::iterator it = counts.begin();
  std::list<int>::const_iterator it2 = adds.begin();
  for(; it!=counts.end(); it++, it2++){
    *it += *it2;
    std::cout << " " << *it;
  }
  std::cout << std::endl;
}
```

7.2 AddOneAndPrint [/ 6]

```
void AddOneAndPrint(std::list<int>& counts){
  AddByPositionAndPrint(counts,std::list<int>(counts.size(),1));
}
```

8 Mystery List Function [/ 20]

This problem focuses on a couple similar functions that are used to manipulate a collection of doubly linked nodes:

```
template <class T>
class Node{
public:
  Node(const T& v) : value(v), next(NULL), prev(NULL) {}
  T value;
  Node<T> *next, *prev;
};
```

We also define a function for printing nodes:

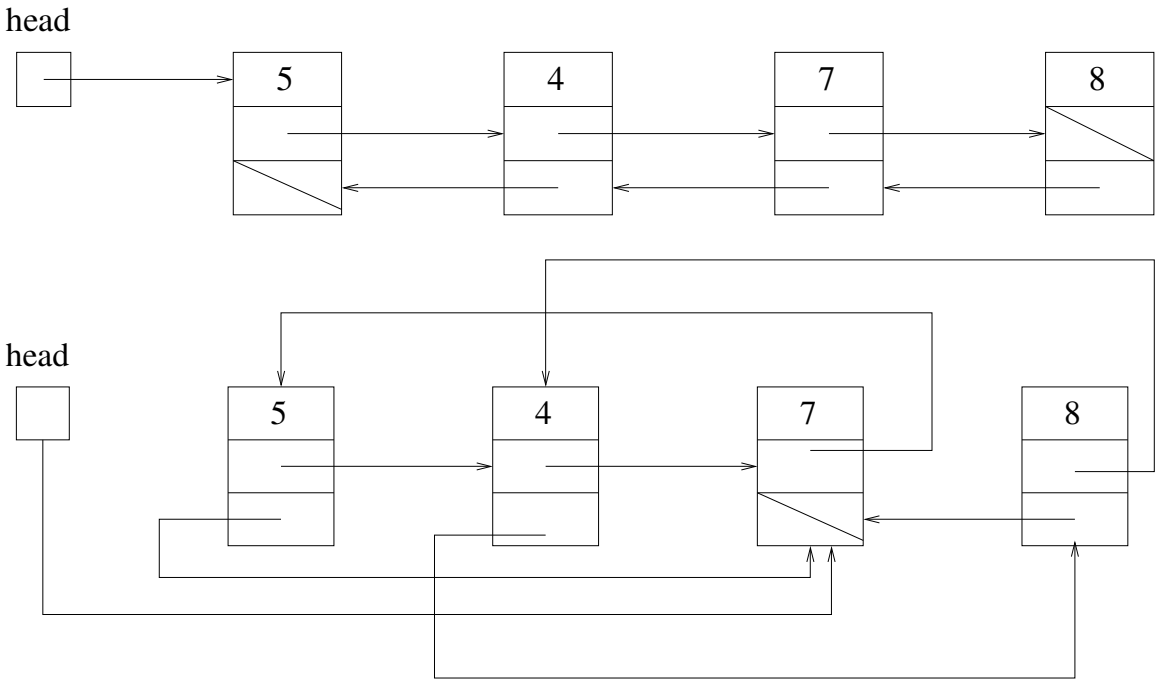
```
template <class T>
void PrintList(Node<T>* head){
  std::cout << "List:";
  while(head){
    std::cout << " " << head->value;
    head = head->next;
  }
  std::cout << std::endl;
}
```

Here is the mystery function you will be working with:

```
 1 void MysteryA(Node<int>*& ptr1, Node<int>* ptr2){
 2   while(ptr2 && (ptr2->value % 2 == 0 || ptr2->value % 7))
 3     ptr2 = ptr2->next;
 4   if(ptr2 && ptr2 != ptr1){
 5     Node<int>* ptr3 = ptr2->next;
 6     Node<int>* ptr4 = ptr2->prev;
 7     ptr2->next = ptr1;
 8     ptr1->prev = ptr2;
 9     ptr1 = ptr2;
10     if(ptr3)
11       ptr3->next = ptr4;
12     if(ptr4)
13       ptr4->prev = ptr3;
14     ptr1->prev = NULL;
15   }
16 }
```

8.1 Visualizing *MysteryA* [/ 14]

In the box below, a list is shown. Below it is a copy of the nodes with none of the pointers added. Update the bottom list to illustrate how the list has changed after a call to *MysteryA(head,head)*.



The function is supposed to find the first odd multiple of 7 by using *ptr2* and if it's not already at the head, the function should make *ptr2* the new head by moving it to the front and updating links accordingly. It also has to update the pointer passed in. Assume that *ptr1* is a list head and that *ptr2* belongs to the same list as *ptr1*.

8.2 Fixing MysteryA [/ 6]

Consider the original list given in 4.1 and the following code fragment:

```
PrintList(head);
MysteryA(head,head);
PrintList(head);
```

Explain what will happen when this code runs. If there are bugs, explain which lines of code need to be changed and what the corrected lines of code should be. Use the line numbers provided in the left margin of the code.

There will be an infinite loop because the node with 8 points back to 4, and 4's next still points to 7 which is now the head. The roles of *ptr3* and *ptr4* are switched. We should do L11 ptr3->prev = ptr4 and L13 ptr4->next = ptr3. Alternately we could do L5 Node<int>* ptr3 = ptr2->prev; and L6 Node<int>* ptr4 = ptr2->next;

9 Acrostic Printing [/ 21]

An "acrostic" is a word that is found by a column reading top-to-bottom when looking at several words stacked on top of each other. For example, if our input is a vector of 4 strings:

```
Had
a
Nice
Day
```

then we could look at the first letter in each word to see that they spell a new word: "HaND". Similarly, we could look at the second letter in each word and see they spell: "aia". Your task is to write a function, *acrostics()*, which takes a vector of strings (each string contains exactly one word) and returns an array of C-style strings where each string is one column of the acrostic. For the input shown above, the return array should contain the following strings:

```
HaND
aia
dcy
e
```

You can ignore the null-terminating character, '\0' for simplicity. We have given you a partial implementation, you will need to fill in the rest of it. You should not use any arrays besides *ret*, and you should not call the `delete` keyword. You cannot declare any new vectors/lists in your code. Finally, keep in mind that you should be memory efficient and not allocate more space than you need in the return array.

```
char** acrostics(const std::vector<std::string>& v){
  unsigned int max_return_length = 0;

  for(unsigned int i=0; i<v.size(); i++){
    max_return_length = std::max(max_return_length, (unsigned int)v[i].size());
  }

  std::vector<int> characters_per_string(max_return_length,0);
  for(unsigned int i=0; i<v.size(); i++){
    for(unsigned int j=0; j<v[i].size(); j++){
      characters_per_string[j]++;
    }
  }

  char** ret = new char*[max_return_length];
  for(unsigned int i=0; i<max_return_length; i++){
    //ret[i] = new char[characters_per_string[i]]; //If we don't use \0, need one less character
    ret[i] = new char[characters_per_string[i]+1]; //Not needed for exam, but need a null terminator
    unsigned int v_it, ret_it;
    for(v_it=0,ret_it=0 ; v_it<v.size(); v_it++){
      if(i< v[v_it].size()){
        ret[i][ret_it] = v[v_it][i];
        ret_it++;
      }
    }
    ret[i][characters_per_string[i]]='\0'; //Not needed for exam, but need a null terminator
  }
  return ret;
}
```

If there are m input strings, the length of the longest input string is n, and there are c characters in all input strings combined, what is the time complexity and the space (memory) complexity of *acrostic*?

Time: O(mn) because the loop we have to implement tries every column O(n) and has to check if that position is valid in every word O(m). While O(c) is tempting, we still check the vector even if we don't copy the character.

Space:

O(c) - we copy every character exactly once. The *characters_per_string* vector is O(n), and n ≤ c, so we can reduce O(c+n) to O(c).

10 Iterating Over a List and Inserting New Points [/21]

In this question you are asked to write two functions that use iterators to traverse and manipulate STL lists.

Don't worry about `#include` or `#define` statements. You may assume `using namespace std`.

10.1 `Lists` Finding Zeros [/6]

First, write a function that will be passed a **const** reference to an STL list of ints and returns a new list of ints containing the positions of zeros in the input list. The function should iterate through the list using a list iterator. It should not use *find()* or similar STL functions.

For example, if the original list contained 1 0 11 16 0 0 50 75 85 90 0, the returned list should contain 1 4 5 10.

Solution:

```
// they can also pass the new list in as a reference
std::list<int> find_zeros(const std::list<int>& lst) {
  std::list<int> zeros;
  if (lst.size() == 0)
     return zeros;

  std::list<int>::const_iterator it1 = lst.begin();

  unsigned int pos = 0;
  while (it1 != lst.end()) {
    if (*it1 == 0)
      zeros.push_back(pos);
    pos++;
    it1++;
  }

  return zeros;
}
```

10.2 `Lists` Replacing Zeros[/15]

Now, write a second function. This **void** function will be passed a reference to an STL list of ints. In this function each zero in the list should be replaced with the sum of the adjacent numbers. A zero in the first or last position of the list should not be replaced. For example, if the list originally contained 1 0 11 16 0 0 50 75 85 90 0, the returned list will contain 1 12 11 16 16 66 50 75 85 90 0. Iterate through the list from left to right and replace the elements sequentially. Notice how consecutive zeros are handled. The first zero is replaced and the replacement value becomes the adjacent value for the next zero. That is, a list containing x 0 0 0 y will become x x x x+y y, where x and y are integers.

The zeros are to be replaced in the original list. Do not make a copy of the list. Iterate through the list and replace the elements. Do not use *std::replace* or *std::find*.

Solution:

```
void replace_zeros(std::list<int>& lst) {
  if (lst.size() == 0)
    return;

  std::list<int>::iterator it1 = lst.begin();
  it1++;

  while (it1 != lst.end())  {
    std::list<int>::iterator it_prev = it1;
    it_prev--;
    std::list<int>::iterator it_next = it1;
    it_next++;
    if (*it1 == 0 && it_next != lst.end()) {
      it1 = lst.erase(it1);
```

```
      it1 = lst.insert(it1, *it_prev + *it_next);
    }
    it1++;
  }
}
```

11 Recursive Lists [/25]

In this question, don't worry about `#include` or `#define` statements. You may assume `using namespace std`.

11.1 `Recursive Lists` Delete a List[/6]

A templated class for Nodes is defined as:

```
template <class T>
class Node {
public:
  T value;
  Node<T>* next;
};
```

First, write a templated **recursive** function to delete a list of $Node < T >$s.

Solution:

```
template <class T>
void delete_list(Node<T>* node_ptr) {
  if (node_ptr == NULL)
    return;
  delete_list(node_ptr->next);
  delete node_ptr;
}

/* an alternate method
template <class T>
void delete_list(Node<T>* node_ptr) {
  if (node_ptr == NULL)
    return;
  Node<T>* tmp = node_ptr;
  node_ptr = node_ptr->next;
  delete tmp;
  delete_list(node_ptr);
}
*/
```

11.2 `Recursive Lists` Recursive Merge [/19]

Merging two or more sorted lists is a common operation. It is a basic part of the merge sort which we recently covered in lecture. The idea behind merging two lists is to travel through the two sorted input lists and produce a third *sorted* list containing all of the elements of the two original lists.

For example, if the first list contains *apple cow rhino tree* and the second list contains *cat dog mongoose zebra*, the merged list should contain *apple cat cow dog mongoose rhino tree zebra*.

Write a templated **recursive** function that takes two pointers to sorted singly linked lists of *Nodes*, defined on the previous page, and a reference to a pointer to a singly linked list of *Nodes*. On return from the function, the third list should contain the merged sorted list. Your merged list must copy the data in the sorted lists.

The function must be *recursive*. Do not sort the list. Merge the lists, don't sort. These are not STL lists, use the pointers to iterate through the lists. You may include any helper functions that you find necessary. Do not edit the Node class. You don't have to write a main() function.

Solution:

```
template <class T>
void merge(const Node<T>* list1,
     const Node<T>* list2,
```

```
   Node<T>*& merged_list) {
if (list1 == NULL && list2 == NULL)
  return;

if (list1 == NULL) {
  Node<T>* tmp = new Node<T>;
  tmp->value = list2->value;
  tmp->next = NULL;
  merged_list = tmp;
  merge(list1, list2->next, merged_list->next);
  return;
}

if (list2 == NULL) {
  Node<T>* tmp = new Node<T>;
  tmp->value = list1->value;
  tmp->next = NULL;
  merged_list = tmp;
  merge(list1->next, list2, merged_list->next);
  return;
}

// It's OK to use a loop to run out the lists, but list1, list2
// pointers can't be const then
//
// if (list1 == NULL) {
//   Node<T>* tmp = list2;
//   Node<T>* tmp2 = merged_list;
//   while (tmp != NULL) {
//     Node<T>* new_node = new Node<T>;
//     new_node->value = tmp->value;
//     new_node->next = NULL;
//     tmp2->next = new_node;
//     tmp2 = tmp2->next;
//     tmp = tmp->next;
//   }
//   return;
// }

// if (list2 == NULL) {
//   Node<T>* tmp = list1;
//   Node<T>* tmp2 = merged_list;
//   while (tmp != NULL) {
//     Node<T>* new_node = new Node<T>;
//     new_node->value = tmp->value;
//     new_node->next = NULL;
//     if (tmp2 == NULL)
//       merged_list = new_node;
//     else
//       tmp2->next = new_node;
//     tmp2 = new_node;
//     tmp = tmp->next;
//   }
//   return;
// }

if (list1->value <= list2->value) {
  Node<T>* tmp = new Node<T>;
  tmp->value = list1->value;
  tmp->next = NULL;
  merged_list = tmp;
  merge(list1->next, list2, merged_list->next);
} else {
  Node<T>* tmp = new Node<T>;
  tmp->value = list2->value;
```

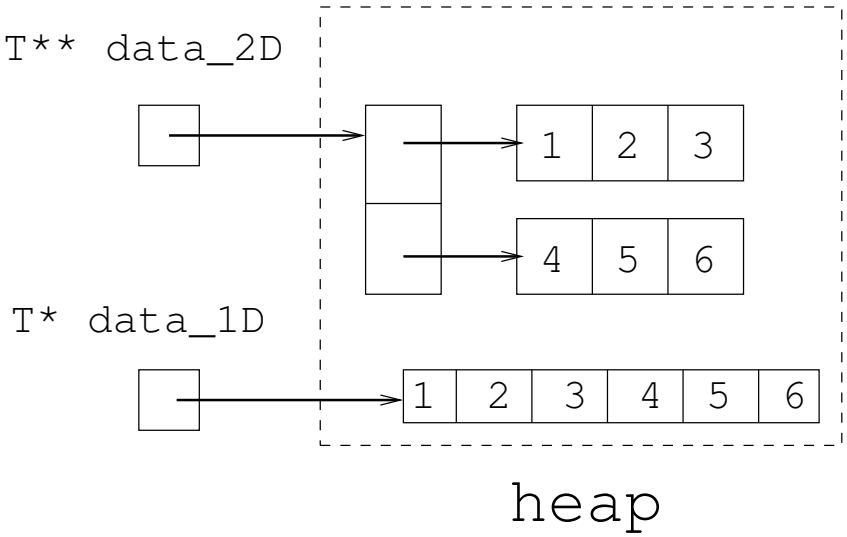
```
    tmp->next = NULL;
    merged_list = tmp;
    merge(list1, list2->next, merged_list->next);
  }
}
```

12 Templating and Flattened Matrices [/19]

In Homework 3 we explored a matrix based around a 2D data structure. We will not be using the *Matrix* class we designed, but instead will be using a templated T^{**} `data_2D` data structure to represent a matrix. The layout should look familiar.

In addition to the 2D representation, we would like to have the option to work on a "flattened" version of the matrix, which is implemented in a T^{*} `data_1D` structure. Both structures are depicted below. We would like to be able to go between the two data structures.

$$\begin{bmatrix} 1 & 2 & 3 \\ 4 & 5 & 6 \end{bmatrix} \Longleftrightarrow$$



Below is an example of how the two functions we will write might be used, along with the output from this code fragment.

```
int** data_2D = new int*[2];
data_2D[0] = new int[3];
data_2D[1] = new int[3];
data_2D[0][0] = 1; data_2D[0][1] = 2;
data_2D[0][2] = 3; data_2D[1][0] = 4;
data_2D[1][1] = 5; data_2D[1][2] = 6;

int* data_1D = Flatten(data_2D,2,3);

for(int i=0; i<2; i++){
  for(int j=0; j<3; j++){
    int index;
    int readval = Read1D(data_1D,2,3,i,j,index,-1);
    std::cout << "(" << index << "," << readval << ") ";
  }
}

//Assume and Delete1D/2D are already written
Delete2D(data_2D,2,3);
Delete1D(data_1D);

Output:
(0,1) (1,2) (2,3) (3,4) (4,5) (5,6)
```

12.1 Flattening the Matrix [/10]

Your first task is to implement the templated *flatten* function. *flatten* should take in `data_2D` as shown on the previous page, and two integers `m` and `n`, which are the number of rows and the number of columns in the data respectively. *flatten* should return a pointer to an equivalent 1D data structure.

If either the number of rows or columns is non-positive, the function should return a NULL pointer.

Do not change `data_2D`. **Only** use const and & when needed. Remember that since *flatten* is templated it should work with **any** datatype. Do not leak any memory, any memory still allocated must be reachable from the returned pointer.

Solution:

```
template <class T>
T* Flatten(T** data_2D, int m, int n){
  if(m <= 0 || n <= 0){
    return NULL;
  }

  T* ret = new T[m*n];
  for (int i=0; i<m; i++){
    for (int j=0; j<n; j++){
      ret[(i*n) + j] = data_2D[i][j];
    }
  }
  return ret;
}
```

If the 2D matrix reprensentation contains m rows and n columns, what is the running time of the *flatten* function?

Solution: O(m*n)

12.2 Reading From the Flattened Matrix [/9]

Another important task is to be able to read from the data structure. Write a function *Read1D* that takes in a 1D representation of data `data_1D`, two integers `m` and `n` which are the number of rows and columns respectively, two integers `row` and `col` which are the row and column position we are trying to extract data from, a reference to an integer `index`, and a failure_value which will be returned in case of an error.

Just like in Homework 3, we will number the upper left corner of a 2D structure as $(0, 0)$ or `row`$= 0$, `col`$= 0$.

The function should do two things. If the dimensions are legal (i.e. there are a positive number of rows and columns), and the requested position can exist within the given bounds, then the function should return the data stored at that position and set `index` to the index in `data_1D` where the data came from. If the dimensions are illegal or the requested position is out of bounds, the index should be set to -1 and `failure_value` should be returned.

Keep in mind that the same `data_1D` object can be viewed different ways. For example, if there is a 2×3 `data_2D_example` and `data_1D_example` = *flatten*(`data_2D_example`,...), then after calling *Read1D*(`data_1D_example`,1,6,1,1,index,-1), `index` will be -1, because in this example call we specified that `m`$= 1$, `n`$= 6$, and there is no position $(1, 1)$ inside of a 1×6 matrix.

On the other hand, using the same `data_1D_example`, *Read1D*(`data_1D_example`,2,3,1,1,index,-1) would set `index`$= 4$.

Do not call any STL functions. **Only** use const and & when needed. Remember that since *Read1D* is templated it should work with **any** datatype.

Solution:

```
template<class T>
const T& Read1D(T* data_1D, int m, int n, int row, int col, int& index, const T& failure_value){
  if(row < 0 || col < 0 || row >= m || col >= n ){
    index = -1;
    return failure_value;
  }

  index = (row*n) + col;

  return data_1D[index];
```

```
}
```

13 Memory Errors [/9]

For each function or pair of functions below, choose the letter that best describes the memory error that you would find. You can assume `using namespace std` and any necessary `#include` statements.

A) use of uninitialized memory
B) mismatched new/delete/delete[]
C) memory leak
D) already freed memory
E) no memory error
F) invalid write

Solution: B

```
char* a = new char[6];
a[0] = 'B';  a[1] = 'y';
a[2] = 'e';  a[3] = '\0';
cout << a << endl;
delete a;
```

Solution: A

```
int a[10];
int b[5];
for(int i=10; i>5; i--){
  a[((i-6)*2+1)] = i*2;
  a[((i-6)*2)] = b[i-6];
  cout << a[(i-6)*2] << endl;
}
```

Solution: F

```
bool* is_even = new bool[10];
for(int i=0; i<=10; i++){
  is_even[i] = ((i%2)==0);
}
delete [] is_even;
```

Solution: C

```
int a[2];
float** b = new float*[2];
b[0] = new float[1];
a[0] = 5; a[1] = 2;
b[0][0] = a[0]*a[1];
delete [] b[0];
b[0] = new float[0];
delete [] b;
```

Solution: D

```
string* str1 = new string;
string* str2;
string* str3 = new string;
*str1 = "Hello";
str2 = str1;
*str3 = *str1;
delete str1;
delete str3;
delete str2;
```

Solution: E

```
int x[3];
int* y = new int[3];
for (int i=3; i>=1; i--){
  y[i-1] = i*i;
  x[i-1] = y[i-1]*y[i-1];
}
delete [] y;
```

14 Complexity Code Writing [/ 9]

For each of the problems below, write a function `void complexity(int n)` that satisfies the big-O running time. Assume that the input is size n. You should not use anything that requires a `#include` statement. You should write no more than 7 lines of code per box (including the function prototype).

```
//O(1)
void complexity(int n){
  return;
}

//O(n^2)
void complexity(int n){
  for (int i=0; i<n; i++){ //n
    for (int j=0; j<n; j++){ //n
      continue;
    }
  }
}

//O(log n)
void complexity(int n){
  if(n == 0){
    return;
  }
  complexity(n/2);
}
```