Review from Lecture 8

- Explored a program to maintain a class enrollment list and an associated waiting list.
- Unfortunately, erasing items from the front or middle of vectors is inefficient.
- Iterators can be used to access elements of a vector

Today’s Class

- Review of iterators and iterator operations
- STL lists, erase and insert on STL lists
- Differences between indices and iterators, differences between STL list and STL vector.
- Building our own basic linked lists:
  - Stepping through a list
  - Push back
  - ... & even more next week!

9.1 Review: Iterators and Iterator Operations

- An iterator type is defined by each STL container class. For example:

  ```
  vector<double>::iterator v_itr;
  list<string>::iterator l_itr;
  string::iterator s_itr;
  ```

- An iterator is assigned to a specific location in a container. For example:

  ```
  v_itr = vec.begin() + i; // i-th location in a vector
  l_itr = lst.begin(); // first entry in a list
  s_itr = str.begin(); // first char of a string
  ```

  Note: We can add an integer to vector and string iterators, but not to list iterators.

- The contents of the specific entry referred to by an iterator are accessed using the * dereference operator:
  In the first and third lines, *v_itr and *l_itr are l-values. In the second, *s_itr is an r-value.

  ```
  *v_itr = 3.14;
  cout << *s_itr << endl;
  *l_itr = "Hello";
  ```

- Stepping through a container, either forward and backward, is done using increment (++) and decrement (--) operators:

  ```
  ++itr; itr++; --itr; itr--;
  ```

  These operations move the iterator to the next and previous locations in the vector, list, or string. The operations do not change the contents of container!

- Finally, we can change the container that a specific iterator is attached to as long as the types match. Thus, if v and w are both vector<double>, then the code:

  ```
  v_itr = v.begin();
  *v_itr = 3.14; // changes 1st entry in v
  v_itr = w.begin(); + 2;
  *v_itr = 2.78; // changes 3rd entry in w
  ```

  works fine because v_itr is a vector<double>::iterator, but if a is a vector<string> then

  ```
  v_itr = a.begin();
  ```

  is a syntax error because of a type clash!
9.2 Additional Iterator Operations for Vector (& String) Iterators

- Initialization at a random spot in the vector:
  \[ v_{itr} = v\text{.begin()} + i; \]

- Jumping around inside the vector through addition and subtraction of location counts:
  \[ v_{itr} = v_{itr} + 5; \]

  moves \( p \) 5 locations further in the vector. These operations are constant time, \( O(1) \) for vectors.

- These operations are \textit{not allowed} for list iterators (and most other iterators, for that matter) because of the way the corresponding containers are built. These operations would be linear time, \( O(n) \), for lists, where \( n \) is the number of slots jumped forward/backward. Thus, they are not provided by STL for lists.

- Students are often confused by the difference between iterators and indices for vectors. Consider the following declarations:

  \[
  \text{vector<double> } a(10, 2.5); \\
  \text{vector<double>::iterator } p = a\text{.begin()} + 5; \\
  \text{unsigned int } i=5;
  \]

  - Iterator \( p \) refers to location 5 in vector \( a \). The value stored there is directly accessed through the \(*\) operator:
    \[
    \ast p = 6.0; \\
    \text{cout } \ll \ast p \ll \text{endl;}
    \]

    - The above code has \textbf{changed the contents} of vector \( a \). Here’s the equivalent code using subscripting:
      \[
      a[i] = 6.0; \\
      \text{cout } \ll a[i] \ll \text{endl;}
      \]

9.3 The list Standard Library Container Class

- Both lists & vectors store sequential data that can shrink or grow.

- However, the use of memory is fundamentally different. Vectors are formed as a single contiguous array-like block of memory. Lists are formed as a chain of separate memory blocks (not necessarily next to each other or in a particular order in memory), connected by pointers.

\[
\begin{array}{cccccc}
\text{array/vector:} & 7 & 5 & 8 & 1 & 9 \\
0 & 1 & 2 & 3 & 4
\end{array}
\quad
\begin{array}{cccccc}
\text{list:} & 7 & \rightarrow & 5 & \rightarrow & 8 & \rightarrow & 1 & \rightarrow & 9
\end{array}
\]

- STL lists have no subscripting operation (we can’t use \([\]) to access data). That is, they do not allow “random-access” or indexing. The only way to get to the middle of a list is to follow pointers one link at a time. Vectors do allow indexing (we can directly jump to the middle of the vector).

- STL lists have \texttt{push_front} and \texttt{pop_front} functions in addition to \texttt{push_back} and \texttt{pop_back}.

- \textbf{erase} and \textbf{insert} in the middle of the STL list is very efficient, independent of the size of the list. Both are implemented by rearranging pointers between the small blocks of memory.

- Note: We can’t use the standard \texttt{sort} function; we must use a special \texttt{sort} member function defined by the STL list type:

\[
\text{std::vector<int>} \ my\text{-vec;} \\
\text{std::list<int>} \ my\_lst; \\
\text{// ... put some data in my\_vec \& my\_lst} \\
\text{std::sort(my\_vec.begin(),my\_vec.end(),optional\_compare\_function);} \\
\text{my\_lst.sort(optional\_compare\_function);} \\
\]

Note: STL list \texttt{sort} member function is just as efficient efficient, \( O(n \log n) \), and will also take the same optional compare function as STL \texttt{vector}.
9.4 Erase & Iterators

- STL lists and vectors each have a special member function called erase. In particular, given list of ints $s$, consider the example:

```cpp
list<int>::iterator p = s.begin();
++p;
list<int>::iterator q = s.erase(p);
```

- After the code above is executed:
  - The integer stored in the second entry of the list has been removed.
  - The size of the list has shrunk by one.
  - The iterator $p$ does not refer to a valid entry.
  - The iterator $q$ refers to the item that was the third entry and is now the second.

- To reuse the iterator $p$ and make it a valid entry, you will often see the code written:

```cpp
list<int>::iterator p = s.begin();
++p;
p = s.erase(p);
```

- Even though the erase function has the same syntax for vectors and for list, the vector version is $O(n)$, whereas the list version is $O(1)$.

9.5 Insert

- Similarly, there is an insert function for STL lists that takes an iterator and a value and adds a link in the chain with the new value immediately before the item pointed to by the iterator.

- The call returns an iterator that points to the newly added element. Variants on the basic insert function are also defined.

9.6 Exercise: Using STL list Erase & Insert

Write a function that takes an STL list of integers, $lst$, and an integer, $x$. The function should 1) remove all negative numbers from the list, 2) verify that the remaining elements in the list are sorted in increasing order, and 3) insert $x$ into the list such that the order is maintained.
9.7 Working towards our own version of the STL list

- Our discussion of how the STL list<T> is implemented has been intuitive: it is a “chain” of objects.
- Now we will study the underlying mechanism — linked lists.
- This will allow us to build custom classes that mimic the STL list class, and add extensions and new features (more next week!).

9.8 Objects with Pointers, Linking Objects Together

- The two fundamental mechanisms of linked lists are:
  - creating objects with pointers as one of the member variables, and
  - making these pointers point to other objects of the same type.
- These mechanisms are illustrated in the following program:

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

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

int main() {
    Node<int>* ll; // ll is a pointer to a (non-existent) Node
    ll = new Node<int>; // Create a Node and assign its memory address to ll
    ll->value = 6; // This is the same as (*ll).value = 6;
    ll->ptr = NULL; // NULL == 0, which indicates a "null" pointer

    Node<int>* q = new Node<int>;
    q->value = 8;
    q->ptr = NULL;

    // set ll’s ptr member variable to
    // point to the same thing as variable q
    ll->ptr = q;

    cout << "1st value: " << ll->value << "\n"
        << "2nd value: " << ll->ptr->value << endl;
}
```

9.9 Definition: A Linked List

- The definition is recursive: A linked list is either:
  - Empty, or
  - Contains a node storing a value and a pointer to a linked list.
- The first node in the linked list is called the head node and the pointer to this node is called the head pointer. The pointer’s value will be stored in a variable called head.
9.10 Visualizing Linked Lists

- The `head` pointer variable is drawn with its own box. It is an individual variable. It is important to have a separate pointer to the first node, since the “first” node may change.

- The objects (nodes) that have been dynamically allocated and stored in the linked lists are shown as boxes, with arrows drawn to represent pointers.
  - Note that this is a conceptual view only. The memory locations could be anywhere, and the actual values of the memory addresses aren’t usually meaningful.

- The last node MUST have NULL for its pointer value — you will have all sorts of trouble if you don’t ensure this!

- You should make a habit of drawing pictures of linked lists to figure out how to do the operations.

9.11 Basic Mechanisms: Stepping Through the List

- We’d like to write a function to determine if a particular value, stored in `x`, is also in the list.

- We can access the entire contents of the list, one step at a time, by starting just from the `head` pointer.
  - We will need a separate, local pointer variable to point to nodes in the list as we access them.
  - We will need a loop to step through the linked list (using the pointer variable) and a check on each value.

9.12 Exercise: Write `is_there`

```cpp
template <class T> bool is_there(Node<T>* head, const T& x) {
```

9.13 Basic Mechanisms: Pushing on the Back

- Goal: place a new node at the end of the list.

- We must step to the end of the linked list, remembering the pointer to the last node.
  - This is an $O(n)$ operation and is a major drawback to the ordinary linked-list data structure we are discussing now. We will correct this drawback by creating a slightly more complicated linking structure in our next lecture.

- We must create a new node and attach it to the end.

- We must remember to update the `head` pointer variable’s value if the linked list is initially empty.
  - Hence, in writing the function, we must pass the pointer variable by reference.

9.14 Exercise: Write `push_back`

```cpp
template <class T> void push_back( Node<T>* & head, T const& value ) {
```