CSCI-1200 Computer Science II — Fall 2006
Lecture 7 — Lists & Iterators: More Examples

Review from Lecture 6

- We wrote several versions of a program to maintain a class enrollment list and an associated waiting list.
  - The first version used vectors to store the information. Unfortunately, erasing items from vectors is inefficient.
  - In the second version, we explored iterators and iterator operations as a different means of manipulating the contents of the vector.
  - This allows us to replace the vector with a list in the third version. There is an `erase` function for both vectors and lists. The vector erase function does pretty much what we did in our enrollment example program. The list erase function is much more efficient.
- For the enrollment problem, the list is a better sequential container class than the vector.

Today's Class

- Returning references to member variables from member functions
- Lists
- Review of iterators and iterator operations
- Differences between indices and iterators
- Differences between lists and vectors
- Prime number programming example

7.1 References and Return Values

- A reference is an *alias* for another variable. For example:

```
string a = "Tommy";
string b = a;       // a new string is created using the string copy constructor
string& c = a;      // c is an alias/referece to the string object a

b[1] = 'i';
cout << a << " " << b << " " << c << endl;    // outputs:  Tommy Timmy Tommy

c[1] = 'a';
cout << a << " " << b << " " << c << endl;    // outputs:  Tammy Timmy Tammy
```

  The reference variable `c` refers to the same string as variable `a`. Therefore, when we change `c`, we change `a`.

- Exactly the same thing occurs with reference parameters to functions and the return values of functions. Let's look at the `Student` class from Lecture 6 again:

```
class Student {
public:
  const string& first_name() const { return first_name_; }
  const string& last_name() const { return last_name_; }
  //  etc....

private:
  string first_name_;
  string last_name_;
  //  etc...
};
```

- In the main function we had a vector of students:

```
vector<Student> students;
```

  Based on our discussion of references above and looking at the class declaration, what if we wrote:

```
string & fname = students[i].first_name();
fname[1] = 'i'
```

  Would the code then be changing the internal contents of the i-th Student object?

- The answer is NO! The `Student` class member function `first_name` returns a **const** reference. The compiler will complain that the above code is attempting to assign a const reference to a non-const reference variable.

- If we instead wrote:

```
const string & fname = students[i].first_name();
fname[1] = 'i'
```

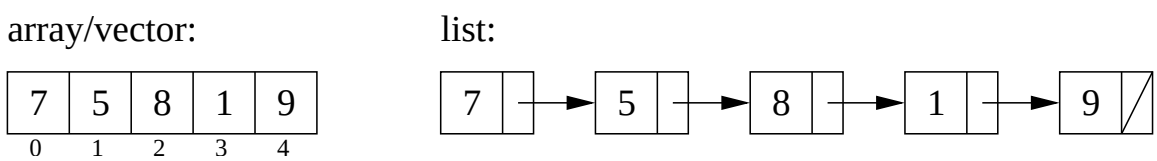
  Then compiler would complain that you are trying to change a const object.

- Hence in both cases the Student class would be "safe" from attempts at external modification.

- However, the author of the `Student` class would get into trouble if the member function return type was only a reference, and not a const reference. Then external users could access and change the internal contents of an object! This is a bad idea in most cases.

7.2 The `list` Standard Library Container Class

- Lists are formed as a sequentially linked structure instead of the array-like, random-access / indexing structure of vectors.



- Lists have `push_front` and `pop_front` functions in addition to the `push_back` and `pop_back` functions of vectors.

- Erase is very efficient for a list, independent of the size of the list (we'll see why when we learn the implementation details later in the semester).

- We can't use the standard `sort` function; we must use a special `sort` function defined by the list type.

- Lists have no subscripting operation (a.k.a. they do not allow "random-access").

7.3 Iterators and Iterator Operations — General

- An iterator type is defined by each 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*:

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

  In the first and third lines, `*v_itr` and `*l_itr` are l-values. In the second, `*s_itr` is an r-value.

- 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!

7.4 Iterators and Iterator Operations — Vector Iterators

Vector (and string) iterators have special capabilities that most other container iterators do not have:

- Initialization at a random spot in the vector:

```
p = v.begin() + i;
```

- Jumping around inside the vector through addition and subtraction of location counts:

```
p = p + 5;
```

  moves `p` 5 locations further in the vector.

- Neither of these is allowed for list iterators (and most other iterators, for that matter) because of the way containers are built.

7.5 Iterators vs. Indices for Vectors and Strings

Students are often confused by the difference between iterators and indices for vectors.

- Consider the following declarations:

```
vector<double> a(10, 2.5);
vector<double>::iterator p = a.begin() + 5;
unsigned int i=5;
```

- Iterator `p` refers to location 5 in vector `a`. The value stored there is directly accessed through the `*` operator:

```
*p = 6.0;
cout << *p << endl;
```

  This has **changed the contents** of vector `a`.

- And here's the equivalent code using subscripting:

```
a[i] = 6.0;
cout << a[i] << endl;
```

7.6 Lists vs. Vectors

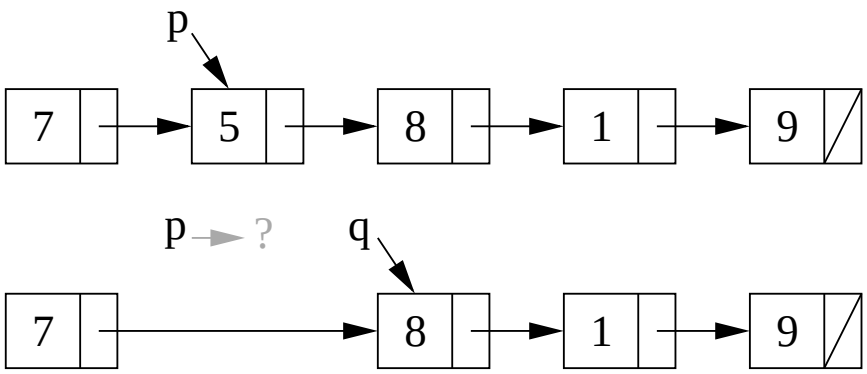
- Lists are a chain of separate memory blocks, one block for each entry.
- Vectors are formed as a contiguous (and bigger) block of memory.
- Lists therefore allow easy/fast insert and remove in the middle, but not indexing.
- Vectors therefore allow indexing (which depends on jumping around inside the block of memory), but slow insert and remove in the middle.

7.7 Erase

- Lists and vectors each have a special member function called `erase`.
- In particular, given list of ints `s`, consider the example

```
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:

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

- Now we can rewrite the `erase_from_vector` function from the Lecture 7 enrollment example:

```
p = v.erase(p);
```

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

7.8 Prime Numbers: Sieve of Eratosthenes

- We will explore the problem of finding all primes less than a given integer, n, and introduce the Sieve of Eratosthenes algorithm.
- The algorithm is a "casting out" algorithm: each new prime is used to cast out all of its multiples from a list of potential primes.
- Finish the skeleton code below which uses lists and iterators.
- Why did we choose to use a `list` rather than a `vector`?

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

int main() {

  int n;
  cout << "Enter the upper bound on the set of primes you are interested in: ";
  cin >> n;

  list<int> primes;

  // Initialize with everything from 2 to n
  for (unsigned int i=2; i<=n; ++i)
    primes.push_back(i);

  // p will indicate the current prime
  list<int>::iterator p = primes.begin();


  // step through primes list until it is exhausted
  while (p != primes.end()) {

    // throw out all the numbers that are divisible by the current prime









  }


  // output out all the primes
  cout << primes.size() << " primes: " << endl;
  for (p = primes.begin(); p != primes.end(); p++) {
    cout << *p << " ";
  }
  cout << endl;

  return 0;
}
```

7.9 Another Iterator Example: Compute Mode

```
#include <algorithm>
#include <cmath>
#include <iomanip>
#include <iostream>
#include <vector>

using namespace std;

int main() {

  //  Input the scores
  cout << "Enter each of the grades, followed by end-of-file: " << endl;
  vector<int> scores;
  int x;
  while (cin >> x) {
    scores.push_back(x);
  }

  //  Quit with an error message if too few scores.
  if (scores.size() == 0) {
    cout << "No scores entered.  Please try again!" << endl;
    return 1;
  }

  // Sort the values in the vector
  sort(scores.begin(), scores.end());

  //  Compute the mode.
  int current_count = 1;
  int mode;
  int mode_count = 0;
  vector<int>::iterator current = scores.begin();
  ++current;
  vector<int>::iterator previous = scores.begin();
  //  Loop invariants:
  //  (a) current_count == number of occurrences of *previous in the
  //      interval of the vector up until previous
  //  (b) mode is the most frequently occurring score that is also less
  //      than *previous in the interval up to previous
  //  (c) mode_count is the number of times mode occurs
  for (; current != scores.end(); ++current, ++previous) {
      if (*current == *previous) {
        current_count++;
      } else if (current_count >= mode_count) {
        //  Change in the score
        mode = *previous;
        mode_count = current_count;
        current_count = 1;
      } else {
        current_count = 1;
      }
  }

  // Handle the possibility of the last score being the most frequent.
  // The statement of the loop invariant makes it clear that the loop
  // ends without checking if the last value is the mode.
  if (current_count >= mode_count) {
    mode = *previous;
    mode_count = current_count;
  }

  cout << "The most frequent grade, occurring " << mode_count << " times, is " << mode << endl;
  return 0;  //  Everything ok
}
```