Announcements

- HW 1 is available on-line through the website (on the “Calendar”).
- Be sure to read through this information as you start implementation of HW1: “Misc Programming Information” (a link at the bottom of the left bar of the website).
- TA & instructor office hours are posted on website (“Weekly Schedule”).
- Please use TA office hours and your lab time tomorrow to sort out any remaining installation problems with the C++ environment on your laptop.

Today

- Finish Lecture 1
- STL Strings, char arrays (C-style Strings), & converting between these two types
- L-values vs. R-values
- STL Vectors as “smart arrays”

2.1 String Concatenation and Creation of Temporary String Object

- The following statement creates a new string by “adding” (concatenating) other strings together:
  ```cpp
  std::string my_line = "*" + std::string(first.size()+2,' ') + \\
  "*";
  ```
- The expression `std::string(first.size()+2, ' ')` within this statement creates a temporary STL string but does not associate it with a variable.

2.2 Character Arrays and String Literals

- In the line below "Hello!" is a string literal and it is also an array of characters (with no associated variable name).
  ```cpp
  cout << "Hello!" << endl;
  ```
- A char array can be initialized as: `char h[] = {'H', 'e', 'l', 'l', 'o', '!', '\0'};`
  or as: `char h[] = "Hello!";`
  In either case, array h has 7 characters, the last one being the null character.
- The C language provides many functions for manipulating these “C-style strings”. We don’t study them much anymore because the “C++ style” STL string library is much more logical and easier to use.
- One place we do use them is in file names and command-line arguments, which you will use in Homework 1.

2.3 Conversion Between Standard Strings and C-Style String Literals

- We regularly convert/cast between C-style & C++-style (STL) strings. For example:
  ```cpp
  std::string s1( "Hello!" );
  std::string s2( h );
  ```
  where h is as defined above.
- You can obtain the C-style string from a standard string using the member function `c_str`, as in `s1.c_str()`.
2.4 L-Values and R-Values

- Consider the simple code below. String `a` becomes "Tim". No big deal, right?
  ```cpp
  std::string a = "Kim";
  std::string b = "Tom";
  a[0] = b[0];
  ```
- Let's look more closely at the line: `a[0] = b[0]` and think about what happens.
  In particular, what is the difference between the use of `a[0]` on the left hand side of the assignment statement and `b[0]` on the right hand side?
- Syntactically, they look the same. But,
  - The expression `b[0]` gets the char value, 'T', from string location 0 in b. This is an *r-value*.
  - The expression `a[0]` gets a reference to the memory location associated with string location 0 in a. This is an *l-value*.
- The assignment operator stores the value in the referenced memory location.

The difference between an *r-value* and an *l-value* will be especially significant when we get to writing our own operators later in the semester.

- What's wrong with this code?
  ```cpp
  std::string foo = "hello";
  foo[2] = 'X';
  cout << foo;
  'X' = foo[3];
  cout << foo;
  ```
  Your C++ compiler will complain with something like: “non-lvalue in assignment”

2.5 Standard Template Library (STL) Vectors: Motivation

- Example Problem: Read an unknown number of grades and compute some basic statistics such as the mean (average), standard deviation, median (middle value), and mode (most frequently occurring value).
- Our solution to this problem will be much more elegant, robust, & less error-prone if we use the STL `vector` class. Why would it be more difficult/wasteful/buggy to try to write this using C-style (dumb) arrays?

2.6 STL Vectors: a.k.a. “C++-Style”, “Smart” Arrays

- Standard library “container class” to hold sequences.
- A vector acts like a dynamically-sized, one-dimensional array.
- Capabilities:
  - Holds objects of any type
  - Starts empty unless otherwise specified
  - Any number of objects may be added to the end — there is no limit on size.
  - It can be treated like an ordinary array using the subscripting operator.
  - A vector knows how many elements it stores! (unlike C arrays)
  - There is NO automatic checking of subscript bounds.
- Here's how we create an empty vector of integers:
  ```cpp
  std::vector<int> scores;
  ```
- Vectors are an example of a *templated container class*. The angle brackets `< >` are used to specify the type of object (the “template type”) that will be stored in the vector.
• push_back is a vector function to append a value to the end of the vector, increasing its size by one. This is an \( O(1) \) operation (on average).
  – There is NO corresponding push_front operation for vectors.
• size is a function defined by the vector type (the vector class) that returns the number of items stored in the vector.
• After vectors are initialized and filled in, they may be treated just like arrays.
  – In the line
    
    ```cpp
    sum += scores[i];
    ```
    
    scores[i] is an “r-value”, accessing the value stored at location \( i \) of the vector.
  – We could also write statements like
    
    ```cpp
    scores[4] = 100;
    ```
    
    to change a score. Here scores[4] is an “l-value”, providing the means of storing 100 at location 4 of the vector.
  – It is the job of the programmer to ensure that any subscript value \( i \) that is used is legal — at least 0 and strictly less than scores.size().

2.7 Initializing a Vector — The Use of Constructors

Here are several different ways to initialize a vector:

• This “constructs” an empty vector of integers. Values must be placed in the vector using push_back.
  ```cpp
  std::vector<int> a;
  ```
• This constructs a vector of 100 doubles, each entry storing the value 3.14. New entries can be created using push_back, but these will create entries 100, 101, 102, etc.
  ```cpp
  int n = 100;
  std::vector<double> b( n, 3.14 );
  ```
• This constructs a vector of 10,000 ints, but provides no initial values for these integers. Again, new entries can be created for the vector using push_back. These will create entries 10000, 10001, etc.
  ```cpp
  std::vector<int> c( n*n );
  ```
• This constructs a vector that is an exact copy of vector \( b \).
  ```cpp
  std::vector<double> d( b );
  ```
• This is a compiler error because no constructor exists to create an int vector from a double vector. These are different types.
  ```cpp
  std::vector<int> e( b );
  ```

2.8 Exercises

1. After the above code constructing the three vectors, what will be output by the following statement?
  ```cpp
  cout << a.size() << endl << b.size() << endl << c.size() << endl;
  ```
2. Write code to construct a vector containing 100 doubles, each having the value 55.5.
3. Write code to construct a vector containing 1000 doubles, containing the values 0, 1, \( \sqrt{2}, \sqrt{3}, \sqrt{4}, \sqrt{5} \), etc. Write it two ways, one that uses push_back and one that does not use push_back.

2.9 Example: Using Vectors to Compute Standard Deviation

**Definition:** If \( a_0, a_1, a_2, \ldots, a_{n-1} \) is a sequence of \( n \) values, and \( \mu \) is the average of these values, then the standard deviation is

\[
\left( \frac{\sum_{i=0}^{n-1} (a_i - \mu)^2}{n - 1} \right)^{\frac{1}{2}}.
\]
// Compute the average and standard deviation of an input set of grades.
#include <fstream>
#include <iomanip>
#include <iostream>
#include <vector> // to access the STL vector class
#include <cmath> // to use standard math library and sqrt

int main(int argc, char* argv[]) {
  if (argc != 2) {
    std::cerr << "Usage: " << argv[0] << " grades-file\n";
    return 1;
  }
  std::ifstream grades_str(argv[1]);
  if (!grades_str.good()) {
    std::cerr << "Can not open the grades file " << argv[1] << "\n";
    return 1;
  }
  std::vector<int> scores; // Vector to hold the input scores; initially empty.
  int x; // Input variable

  // Read the scores, appending each to the end of the vector
  while (grades_str >> x) { scores.push_back(x); }

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

  // Compute and output the average value.
  int sum = 0;
  for (unsigned int i = 0; i < scores.size(); ++i) {
    sum += scores[i];
  }
  double average = double(sum) / scores.size();
  std::cout << "The average of " << scores.size() << " grades is " << std::setprecision(3) << average << std::endl;

  // Exercise: compute and output the standard deviation.
  double sum_sq_diff = 0.0;
  for (unsigned int i=0; i<scores.size(); ++i) {
    double diff = scores[i] - average;
    sum_sq_diff += diff*diff;
  }
  double std_dev = sqrt(sum_sq_diff / (scores.size()-1));
  std::cout << "The standard deviation of " << scores.size() << " grades is " << std::setprecision(3) << std_dev << std::endl;

  return 0; // everything ok
}

2.10 Standard Library Sort Function

- The standard library has a series of algorithms built to apply to container classes.
- The prototypes for these algorithms (actually the functions implementing these algorithms) are in header file algorithm.
- One of the most important of the algorithms is sort.
- It is accessed by providing the beginning and end of the container's interval to sort.
As an example, the following code reads, sorts and outputs a vector of doubles:

```cpp
double x;
std::vector<double> a;
while (std::cin >> x)
    a.push_back(x);
std::sort(a.begin(), a.end());
for (unsigned int i = 0; i < a.size(); ++i)
    std::cout << a[i] << \'n\';
```

- `a.begin()` is an iterator referencing the first location in the vector, while `a.end()` is an iterator referencing one past the last location in the vector.
  - We will learn much more about iterators in the next few weeks.
  - Every container has iterators: strings have `begin()` and `end()` iterators defined on them.
- The ordering of values by `std::sort` is least to greatest (technically, non-decreasing). We will see ways to change this.

### 2.11 Example: Computing the Median

The median value of a sequence is less than half of the values in the sequence, and greater than half of the values in the sequence. If \(a_0, a_1, a_2, \ldots, a_{n-1}\) is a sequence of \(n\) values AND if the sequence is sorted such that \(a_0 \leq a_1 \leq a_2 \leq \cdots \leq a_{n-1}\) then the median is

\[
\begin{align*}
\text{median} = \begin{cases} 
\frac{a_{(n-1)/2}}{2} & \text{if } n \text{ is odd} \\
\frac{a_{n/2} + a_{n/2}}{2} & \text{if } n \text{ is even}
\end{cases}
\end{align*}
\]

```cpp
// Compute the median value of an input set of grades.
#include <algorithm>
#include <cmath>
#include <fstream>
#include <iomanip>
#include <iostream>
#include <vector>
void read_scores(std::vector<int> & scores, std::ifstream & grade_str) {
    int x; // input variable
    while (grade_str >> x) {
        scores.push_back(x);
    }
}
void compute_avg_and_std_dev(const std::vector<int>& s, double & avg, double & std_dev) {
    // Compute and output the average value.
    int sum=0;
    for (unsigned int i = 0; i < s.size(); ++ i) {
        sum += s[i];
    }
    avg = double(sum) / s.size();

    // Compute the standard deviation
    double sum_sq = 0.0;
    for (unsigned int i=0; i < s.size(); ++i) {
        sum_sq += (s[i]-avg) * (s[i]-avg);
    }
    std_dev = sqrt(sum_sq / (s.size()-1));
}
double compute_median(const std::vector<int> & scores) {
    // Create a copy of the vector
    std::vector<int> scores_to_sort(scores);
    // Sort the values in the vector. By default this is increasing order.
    return compute_median(scores);
}
```
std::sort(scores_to_sort.begin(), scores_to_sort.end());

// Now, compute and output the median.
unsigned int n = scores_to_sort.size();
if (n%2 == 0) // even number of scores
    return double(scores_to_sort[n/2] + scores_to_sort[n/2-1]) / 2.0;
else
    return double(scores_to_sort[n/2]); // same as (n-1)/2 because n is odd
}

int main(int argc, char* argv[]) {
    if (argc != 2) {
        std::cerr << "Usage: " << argv[0] << " grades-file\n";
        return 1;
    }
    std::ifstream grades_str(argv[1]);
    if (!grades_str) {
        std::cerr << "Can not open the grades file " << argv[1] << "\n";
        return 1;
    }
    std::vector<int> scores; // Vector to hold the input scores; initially empty.
    read_scores(scores, grades_str); // Read the scores, as before

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

    // Compute the average, standard deviation and median
    double average, std_dev;
    compute_avg_and_std_dev(scores, average, std_dev);
    double median = compute_median(scores);

    // Output
    std::cout << "Among " << scores.size() << " grades: \n"
             << " average = " << std::setprecision(3) << average << '\n'
             << " std_dev = " << std_dev << '\n'
             << " median = " << median << std::endl;
    return 0;
}

2.12 Passing Vectors (and Strings) As Parameters

The following outlines rules for passing vectors as parameters. The same rules apply to passing strings.

- If you are passing a vector as a parameter to a function and you want to make a (permanent) change to the vector, then you should pass it by reference.
  - This is illustrated by the function read_scores in the program median_grade.
  - This is very different from the behavior of arrays as parameters.

- What if you don’t want to make changes to the vector or don’t want these changes to be permanent?
  - The answer we’ve learned so far is to pass by value.
  - The problem is that the entire vector is copied when this happens! Depending on the size of the vector, this can be a considerable waste of memory.

- The solution is to pass by constant reference: pass it by reference, but make it a constant so that it can not be changed.
  - This is illustrated by the functions compute_avg_and_std_dev and compute_median in the program median_grade.

- As a general rule, you should not pass a container object, such as a vector or a string, by value because of the cost of copying.