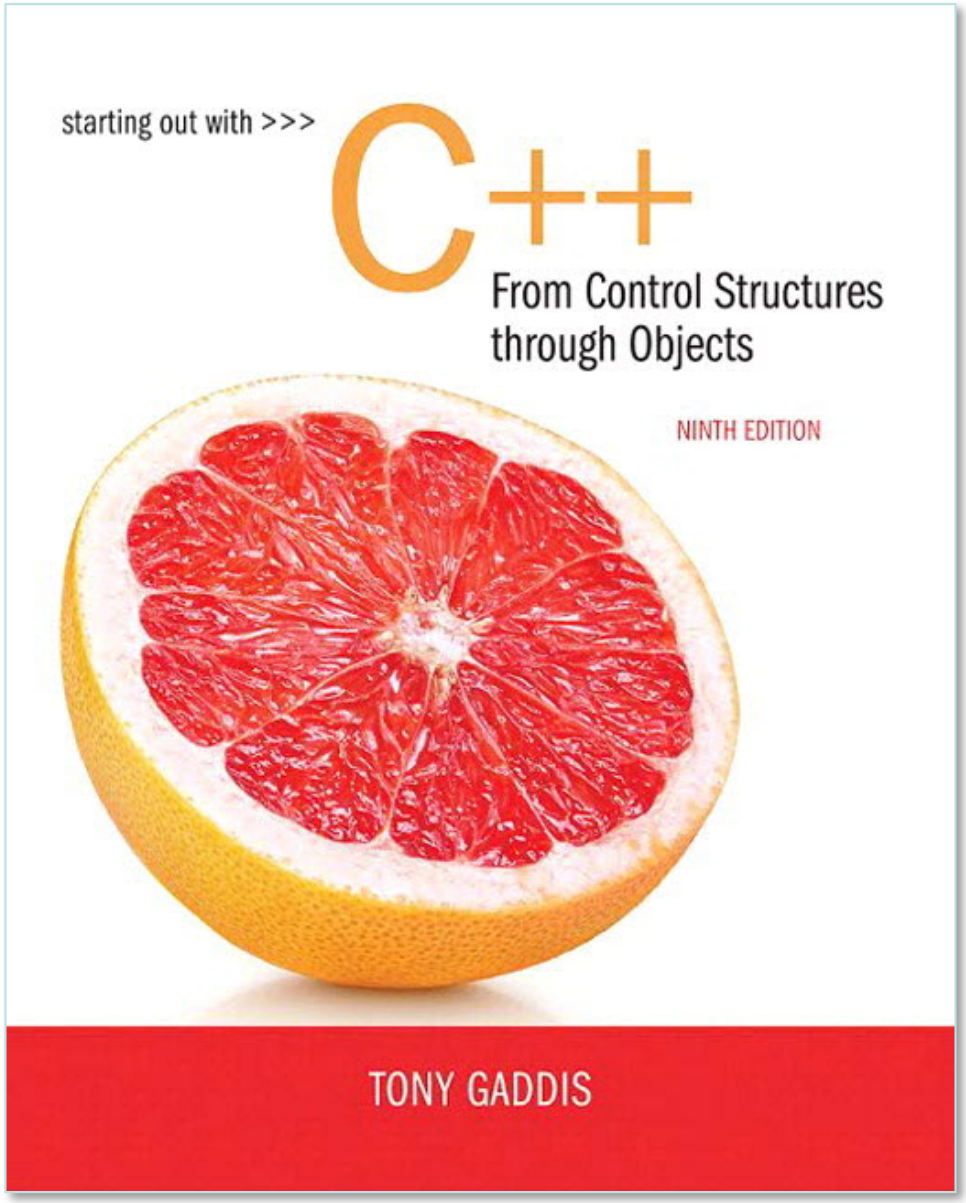
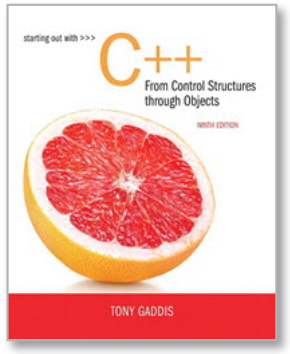
Chapter 17:

The Standard Template Library



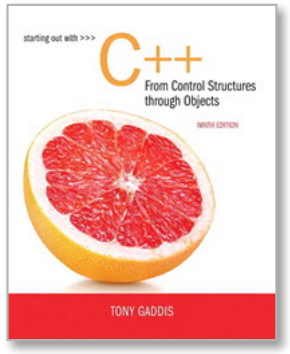


17.1

Introduction to the Standard Template Library

The Standard Template Library

- **The Standard Template Library (STL)**: an extensive library of generic templates for classes and functions.
- Categories of Templates:
  - **Containers**: Class templates for objects that store and organize data
  - **Iterators**: Class templates for objects that behave like pointers, and are used to access the individual data elements in a container
  - **Algorithms**: Function templates that perform various operations on elements of containers



17.2

STL Container and Iterator Fundamentals

Containers

- **Sequence Containers**
  - Stores data sequentially in memory, in a fashion similar to an array
- **Associative Containers**
  - Stores data in a nonsequential way that makes it faster to locate elements

Containers

Table 17-1 Sequence Containers

Container Class	Description
`array`	A fixed-size container that is similar to an array
`deque`	A double-ended queue. Like a `vector`, but designed so that values can be quickly added to or removed from the front and back. (This container will be discussed in Chapter 19.)
`forward_list`	A singly linked list of data elements. Values may be inserted to or removed from any position. (This container will be discussed in Chapter 18.)
`list`	A doubly linked list of data elements. Values may be inserted to or removed from any position. (This container will be discussed in Chapter 18.)
`vector`	A container that works like an expandable array. Values may be added to or removed from a `vector`. The `vector` automatically adjusts its size to accommodate the number of elements it contains.

Containers

Table 17-2 Associative Containers

Container Class	Description
`set`	Stores a set of unique values that are sorted. No duplicates are allowed.
`multiset`	Stores a set of unique values that are sorted. Duplicates are allowed.
`map`	Maps a set of keys to data elements. Only one key per data element is allowed. Duplicates are not allowed. The elements are sorted in order of their keys.
`multimap`	Maps a set of keys to data elements. Many keys per data element are allowed. Duplicates are allowed. The elements are sorted in order of their keys.
`unordered_set`	Like a `set`, except that the elements are not sorted
`unordered_multiset`	Like a `multiset`, except that the elements are not sorted
`unordered_map`	Like a `map`, except that the elements are not sorted
`unordered_multimap`	Like a `multimap`, except that the elements are not sorted

Container Adapters

Table 17-3 Container Adapter Classes

Container Adapter Class	Description
`stack`	An adapter class that stores elements in a `deque` (by default). A `stack` is a last-in, first-out (LIFO) container. When you retrieve an element from a `stack`, the `stack` always gives you the last element that was inserted. (This class will be discussed in Chapter 19.)
`queue`	An adapter class that stores elements in a `deque` (by default). A `queue` is a first-in, first-out (FIFO) container. When you retrieve an element from a `stack`, the `stack` always gives you the first, or earliest, element that was inserted. (This class will be discussed in Chapter 19.)
`priority_queue`	An adapter class that stores elements in a `vector` (by default). A data structure in which the element that you retrieve is always the element with the greatest value. (This class will be discussed in Chapter 19.)

STL Header Files

Table 17-4 Header Files

Header File	Classes
<array>	array
<deque>	deque
<forward_list>	forward_list
<list>	list
<map>	map, multimap
<queue>	queue, priority_queue
<set>	set, multiset
<stack>	stack
<unordered_map>	unordered_map, unordered_multimap
<unordered_set>	unordered_set, unordered_multiset
<vector>	vector

The `array` Class Template

- An `array` object works very much like a regular array
- A fixed-size container that holds elements of the same data type.
- `array` objects have a `size()` member function that returns the number of elements contained in the object.

The array Class Template

- The array class is declared in the <array> header file.
- When defining an array object, you specify the data type of its elements, and the number of elements.
- Examples:

```
array<int, 5> numbers;

array<string, 4> names;
```

The array Class Template

- Initializing an array object:

```
array<int, 5> numbers = {1, 2, 3, 4, 5};

array<string, 4> names = {"Jamie", "Ashley", "Doug",
                          "Claire"};
```

The `array` Class Template

- The `array` class overloads the `[]` operator.
- You can use the `[]` operator to access elements using a subscript, just as you would with a regular array.
- The `[]` operator does not perform bounds checking. Be careful not to use a subscript that is out of bounds.

Program 17-1

```
 1  #include <iostream>
 2  #include <string>
 3  #include <array>
 4  using namespace std;
 5
 6  int main()
 7  {
 8      const int SIZE = 4;
 9
10      // Store some names in an array object.
11      array<string, SIZE> names = {"Jamie", "Ashley", "Doug", "Claire"};
12
13      // Display the names.
14      cout << "Here are the names:\n";
15      for (int index = 0; index < names.size(); index++)
16         cout << names[index] << endl;
17
18      return 0;
19  }
```

Program Output

```
Here are the names:
Jamie
Ashley
Doug
Claire
```

Iterators

- Objects that work like pointers
- Used to access data in STL containers
- Five categories of iterators:

Table 17-6 Categories of Iterators

Iterator Category	Description
Forward	Can only move forward in a container (uses the ++ operator).
Bidirectional	Can move forward or backward in a container (uses the ++ and -- operators).
Random access	Can move forward and backward, and can jump to a specific data element in a container.
Input	Can be used with an input stream to read data from an input device or a file.
Output	Can be used with an output stream to write data to an output device or a file.

Similarities between Pointers and Iterators

	Pointers	Iterators
Use the * and -> operators to dereference	Yes	Yes
Use the = operator to assign to an element	Yes	Yes
Use the == and != operators to compare	Yes	Yes
Use the ++ operator to increment	Yes	Yes
Use the -- operator to decrement	Yes	Yes (bidirectional and random-access iterators)
Use the + operator to move forward a specific number of elements	Yes	Yes
Use the - operator to move backward a specific number of elements	Yes	Yes Yes (bidirectional and random-access iterators)

Iterators

- To define an iterator, you must know what type of container you will be using it with.

- The general format of an iterator definition:

  containerType`::iterator` *iteratorName*`;`

  Where *containerType* is the STL container type, and *iteratorName* is the name of the iterator variable that you are defining.

Iterators

- For example, suppose we have defined an `array` object, as follows:

```
array<string, 3> names = {"Sarah", "William", "Alfredo"};
```

We can define an iterator that is compatible with the array object as follows:

```
array<string, 3>::iterator it;
```

This defines an iterator named `it`. The iterator can be used with an `array<string, 3>` object.

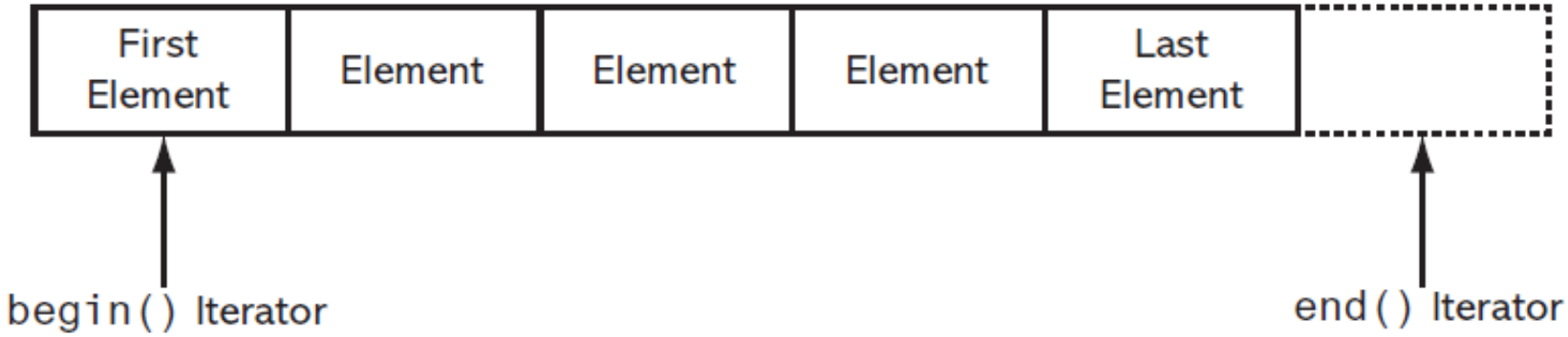
Iterators

- All of the STL containers have a `begin()` member function that returns an iterator pointing to the container's first element.

```
// Define an array object.
array<string, 3> names = {"Sarah", "William", "Alfredo"};

// Define an iterator for the array object.
array<string, 3>::iterator it;

// Make the iterator point to the array object's first element.
it = names.begin();

// Display the element that the iterator points to.
cout << *it << endl;
```

Iterators

- All of the STL containers have a `end()` member function that returns an iterator pointing to the position *after* the container's last element.



Iterators

- You typically use the `end()` member function to know when you have reached the end of a container.

```
// Define an array object.
array<string, 3> names = {"Sarah", "William", "Alfredo"};

// Define an iterator for the array object.
array<string, 3>::iterator it;

// Make the iterator point to the array object's first element.
it = names.begin();

// Display the array object's contents.
while (it != names.end())
{
   cout << *it << endl;
   it++;
}
```

Program 17-2

```
 1  #include <iostream>
 2  #include <string>
 3  #include <array>
 4  using namespace std;
 5
 6  int main()
 7  {
 8      const int SIZE = 3;
 9
10      // Store some names in an array object.
11      array<string, SIZE> names = {"Sarah", "William", "Alfredo"};
12
13      // Create an iterator for the array object.
14      array<string, SIZE>::iterator it;
15
16      // Display the names.
17      cout << "Here are the names:\n";
18      for (it = names.begin(); it != names.end(); it++)
19          cout << *it << endl;
20
21      return 0;
22  }
```

Program Output

```
Here are the names:
Sarah
William
Alfredo
```

Iterators

- You can use the `auto` keyword to simplify the definition of an iterator.

- Example:

```
array<string, 3> names = {"Sarah", "William", "Alfredo"};
auto it = names.begin();
```

Program 17-3

```
1  #include <iostream>
2  #include <string>
3  #include <array>
4  using namespace std;
5
6  int main()
7  {
8       const int SIZE = 4;
9
10      // Store some names in an array object.
11      array<string, SIZE> names = {"Jamie", "Ashley", "Doug", "Claire"};
12
13      // Display the names.
14      cout << "Here are the names:\n";
15      for (auto it = names.begin(); it != names.end(); it++)
16         cout << *it << endl;
17
18      return 0;
19 }
```

Mutable Iterators

- An iterator of the `iterator` type gives you read/write access to the element to which the iterator points.
- This is commonly known as a mutable iterator.

```
// Define an array object.
array<int, 5> numbers = {1, 2, 3, 4, 5};

// Define an iterator for the array object.
array<int, 5>::iterator it;

// Make the iterator point to the array object's first element.
it = numbers.begin();

// Use the iterator to change the element.
*it = 99;
```

Constant Iterators

- An iterator of the `const_iterator` type provides read-only access to the element to which the iterator points.
- The STL containers provide a `cbegin()` member function and a `cend()` member function.
  - The `cbegin()` member function returns a `const_iterator` pointing to the first element in a container.
  - The `cend()` member function returns a `const_iterator` pointing to the end of the container.
  - When working with `const_iterators`, simply use the container class's `cbegin()` and `cend()` member functions instead of the `begin()` and `end()` member functions.

Reverse Iterators

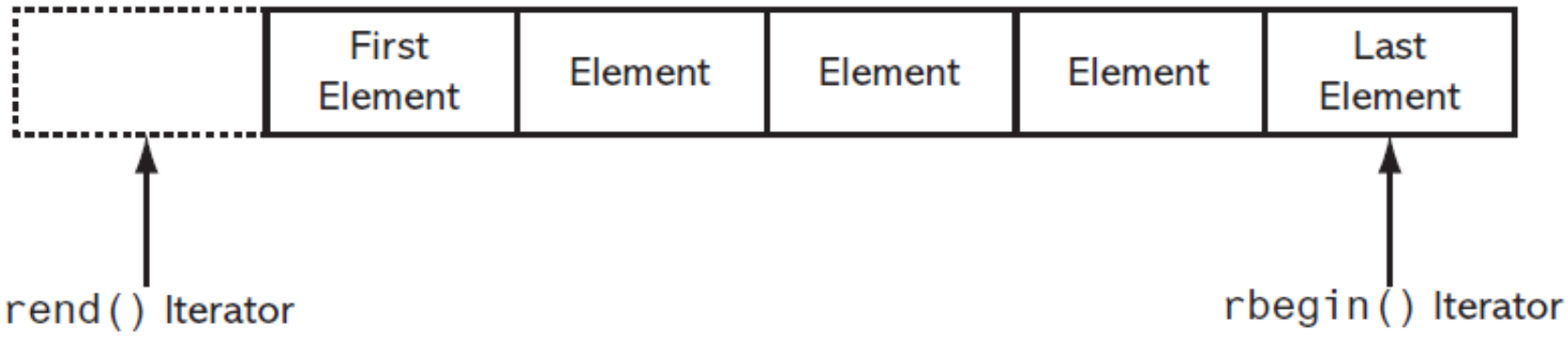
- A *reverse iterator* works in reverse, allowing you to iterate backward over the elements in a container.
- With a reverse iterator, the last element in a container is considered the first element, and the first element is considered the last element.
- The ++ operator moves a reverse iterator backward, and the –– operator moves a reverse iterator forward.

Reverse Iterators

- The following STL containers support reverse iterators:
  - `array`
  - `deque`
  - `list`
  - `map`
  - `multimap`
  - `multiset`
  - `set`
  - `vector`
- All of these classes provide an `rbegin()` member function and an `rend()` member function.

Reverse Iterators

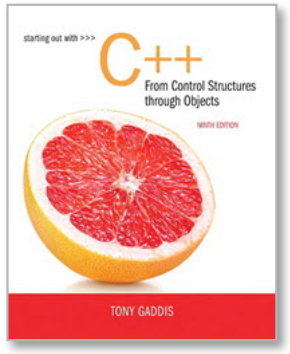
- The `rbegin()` member function returns a reverse iterator pointing to the last element in a container.
- The `rend()` member function returns an iterator pointing to the position *before* the first element.



Reverse Iterators

- To create a reverse iterator, define it as `reverse_iterator`

```
// Define an array object.
array<int, 5> numbers = {1, 2, 3, 4, 5};

// Define a reverse iterator for the array object.
array<int, 5>::reverse_iterator it;

// Display the elements in reverse order.
for (it = numbers.rbegin(); it != numbers.rend(); it++)
   cout << *it << endl;
```



17.3

The vector Class

The `vector` Class

- A `vector` is a sequence container that works like an array, but is dynamic in size.
- Overloaded `[ ]` operator provides access to existing elements
- The `vector` class is declared in the `<vector>` header file.

`vector` Class Constructors

Default Constructor	`vector<dataType> name;` Creates an empty `vector`.
Fill Constructor	`vector<dataType> name(size);` Creates a `vector` of *`size`* elements. If the elements are objects, they are initialized via their default constructor. Otherwise, initialized with 0.
Fill Constructor	`vector<dataType> name(size, value);` Creates a `vector` of *`size`* elements, each initialized with *`value`*.

`vector` Class Constructors

Range Constructor

```
vector<dataType> name(iterator1, iterator2);
```

Creates a `vector` that is initialized with a range of values from another container. *`iterator1`* marks the beginning of the range and *`iterator2`* marks the end.

Copy Constructor

```
vector<dataType> name(vector2);
```

Creates a `vector` that is a copy of *`vector2`*.

Program 17-4

```
1  #include <iostream>
2  #include <vector>
3  using namespace std;
4
5  int main()
6  {
7      const int SIZE = 10;
8
9      // Define a vector to hold 10 int values.
10     vector<int> numbers(SIZE);
11
12     // Store the values 0 through 9 in the vector.
13     for (int index = 0; index < numbers.size(); index++)
14        numbers[index] = index;
15
16     // Display the vector elements.
17     for (auto element : numbers)
18        cout << element << " ";
19     cout << endl;
20
21     return 0;
22 }
```

Subscript notation

Range-based for loop

Program Output

```
0 1 2 3 4 5 6 7 8 9
```

Initializing a `vector`

- In C++ 11 and later, you can initialize a `vector` object:

```
vector<int> numbers = {1, 2, 3, 4, 5};
```

or

```
vector<int> numbers {1, 2, 3, 4, 5};
```

Adding New Elements to a `vector`

- The `push_back` member function adds a new element to the end of a `vector`:

```
vector<int> numbers;
numbers.push_back(10);
numbers.push_back(20);
numbers.push_back(30);
```

Accessing Elements with the `at()` Member Function

- You can use the `at()` member function to retrieve a `vector` element by its index with bounds checking:

```
vector<string> names = {"Joe", "Karen", "Lisa"};
cout << names.at(0) << endl;
cout << names.at(1) << endl;
cout << names.at(2) << endl;
cout << names.at(3) << endl; // Throws an exception
```

Throws an `out_of_bounds` exception when given an invalid index

Using an Iterator With a `vector`

- `vectors` have `begin()` and `end()` member functions that return iterators pointing to the beginning and end of the container:

```
// Create a vector containing names.
vector<string> names = {"Joe", "Karen", "Lisa", "Jackie"};

// Create an iterator.
vector<string>::iterator it;

// Use the iterator to display each element in the vector.
for (it = names.begin(); it != names.end(); it++)
{
   cout << *it << endl;
}
```

Defines an iterator that is compatible with a `vector<string>` object

Displays the item that the iterator points to

Using an Iterator With a `vector`

- The `begin()` and `end()` member functions return a random-access iterator of the `iterator` type
- The `cbegin()` and `cend()` member functions return a random-access iterator of the `const_iterator` type
- The `rbegin()` and `rend()` member functions return a reverse iterator of the `reverse_iterator` type
- The `crbegin()` and `crend()` member functions return a reverse iterator of the `const_reverse_iterator` type

Inserting Elements with the `insert()` Member Function

- You can use the `insert()` member function, along with an iterator, to insert an element at a specific position.
- General format:

```
vectorName.insert(it, value);
```

Iterator pointing to an element in the `vector`

Value to insert before the element that *`it`* points to

Program 17-5

```
1  #include <iostream>
2  #include <vector>
3  using namespace std;
4
5  int main()
6  {
7       // Define a vector with 5 int values.
8       vector<int> numbers = {1, 2, 3, 4, 5};
9
10      // Define an iterator pointing to the second element.
11      auto it = numbers.begin() + 1;
12
13      // Insert a new element with the value 99.
14      numbers.insert(it, 99);
15
16      // Display the vector elements.
17      for (auto element : numbers)
18         cout << element << " ";
19      cout << endl;
20
21      return 0;
22 }
```

Program Output

```
1 99 2 3 4 5
```

Overloaded Versions of the `insert()` Member Function

`insert(`*`it, value`*`)`	Inserts *`value`* just before the element pointed to by *`it`*. The function returns an iterator pointing to the newly inserted element.
`insert(`*`it, n, value`*`)`	Inserts *`n`* elements just before the element pointed to by *`it`*. Each of the new elements will be initialized with *`value`*. The function returns an iterator pointing to the first element of the newly inserted elements.
`insert(`*`iterator1, iterator2, iterator3`*`)`	Inserts a range of new elements. *`iterator1`* points to an existing element in the container. The range of new elements will be inserted before the element pointed to by *`iterator1`*. *`iterator2`* and *`iterator3`* mark the beginning and end of a range of values that will be inserted. (The element pointed to by *`iterator3`* will not be included in the range.) The function returns an iterator pointing to the first element of the newly inserted range.

Storing Objects Of Your Own Classes in a `vector`

- STL containers are especially useful for storing objects of your own classes.
- Consider this `Product` class:

```
1  #ifndef PRODUCT_H
2  #define PRODUCT_H
3  #include <string>
4  using namespace std;
5
6  class Product
7  {
8  private:
9      string name;
10     int units;
11 public:
12     Product(string n, int u)
13     {  name = n;
14        units = u; }
15
16     void setName(string n)
17     {  name = n; }
18
19     void setUnits(int u)
20     {  units = u; }
21
22     string getName() const
23     {  return name; }
24
25     int getUnits() const
26     {  return units; }
27 };
28 #endif
```

Program 17-7

```
 1  #include <iostream>
 2  #include <vector>
 3  #include "Product.h"
 4  using namespace std;
 5
 6  int main()
 7  {
 8       // Create a vector of Product objects.
 9       vector<Product> products =
10       {
11            Product("T-Shirt", 20),
12            Product("Calendar", 25),
13            Product("Coffee Mug", 30)
14       };
15
16       // Display the vector elements.
17       for (auto element : products)
18       {
19            cout << "Product: " << element.getName() << endl
20                 << "Units: " << element.getUnits() << endl;
21       }
22
23       return 0;
24  }
```

This program initializes a `vector` with three `Product` objects.

A range-based `for` loop iterates over the `vector`.

Program Output

```
Product: T-Shirt
Units: 20
Product: Calendar
Units: 25
Product: Coffee Mug
Units: 30
```

Program 17-8

```
 1  #include <iostream>
 2  #include <string>
 3  #include <vector>
 4  #include "Product.h"
 5  using namespace std;
 6
 7  int main()
 8  {
 9      // Create Product objects.
10      Product prod1("T-Shirt", 20);
11      Product prod2("Calendar", 25);
12      Product prod3("Coffee Mug", 30);
13
14      // Create a vector to hold the Products
15      vector<Product> products;
16
17      // Add the products to the vector.
18      products.push_back(prod1);
19      products.push_back(prod2);
20      products.push_back(prod3);
21
22      // Use an iterator to display the vector contents.
23      for (auto it = products.begin(); it != products.end(); it++)
24      {
25          cout << "Product: " << it->getName() << endl
26               << "Units: " << it->getUnits() << endl;
27      }
28
29      return 0;
30  }
```

This program uses the `push_back` member function to store three `Product` objects in a `vector`.

A `for` loop uses an iterator to step through the `vector`.

Program Output

```
Product: T-Shirt
Units: 20
Product: Calendar
Units: 25
Product: Coffee Mug
Units: 30
```

Inserting Container Elements With Emplacement

- Member functions such as `insert()` and `push_back()` can cause temporary objects to be created in memory while the insertion is taking place.
- This is not a problem in programs that make only a few insertions.
- However, these functions can be inefficient for making a lot of insertions.

Inserting Container Elements With Emplacement

- C++11 introduced a new family of member functions that use a technique known as *emplacement* to insert new elements.
- Emplacement avoids the creation of temporary objects in memory while a new object is being inserted into a container.
- The emplacement functions are more efficient than functions such as `insert()` and `push_back()`

Inserting Container Elements With Emplacement

- The `vector` class provides two member functions that use emplacement:
  - `emplace()` - emplaces an element at a specific location
  - `emplace_back()`- emplaces an element at the end of the vector

- With these member functions, it is not necessary to instantiate, ahead of time, the object you are going to insert.
- Instead, you pass to the emplacement function any arguments that you would normally pass to the constructor of the object you are inserting.
- The emplacement function handles the construction of the object, forwarding the arguments to its constructor.

Program 17-9

```
1  #include <iostream>
2  #include <vector>
3  #include "Product.h"
4  using namespace std;
5
6  int main()
7  {
8      // Create a vector to hold Products.
9      vector<Product> products;
10
11     // Add Products to the vector.
12     products.emplace_back("T-Shirt", 20);
13     products.emplace_back("Calendar", 25);
14     products.emplace_back("Coffee Mug", 30);
15
16     // Use an iterator to display the vector contents.
17     for (auto it = products.begin(); it != products.end(); it++)
18     {
19         cout << "Product: " << it->getName() << endl
20              << "Units: " << it->getUnits() << endl;
21     }
22
23     return 0;
24 }
```

Define a `vector` to hold `Product` objects

Emplace three `Product` objects at the end of the `vector`

A `for` loop uses an iterator to step through the `vector`.

Program Output

```
Product: T-Shirt
Units: 20
Product: Calendar
Units: 25
Product: Coffee Mug
Units: 30
```

Program 17-10

```
1  #include <iostream>
2  #include <vector>
3  #include "Product.h"
4  using namespace std;
5
6  int main()
7  {
8      // Create a vector to hold Products.
9      vector<Product> products =
10     {
11         Product("T-Shirt", 20),
12         Product("Coffee Mug", 30)
13     };
14
15     // Get an iterator to the 2nd element.
16     auto it = products.begin() + 1;
17
18     // Insert another Product into the vector.
19     products.emplace(it, "Calendar", 25);
20
21     // Display the vector contents.
22     for (auto element : products)
23     {
24         cout << "Product: " << element.getName() << endl
25              << "Units: " << element.getUnits() << endl;
26     }
27
28     return 0;
29 }
```

Initializes a `vector` with two `Product` objects

Gets an iterator pointing to the 2nd element

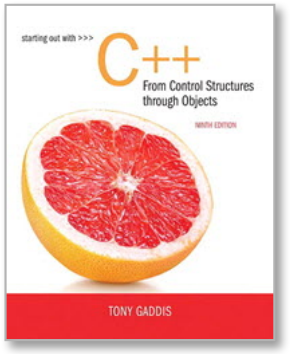
Emplaces a new `Product` object before the one pointed to by the iterator

Program Output

```
Product: T-Shirt
Units: 20
Product: Calendar
Units: 25
Product: Coffee Mug
Units: 30
```

The `vector` Class

- The `vector` class has many useful member functions.
- See Table 17-8 in your textbook.



17.4

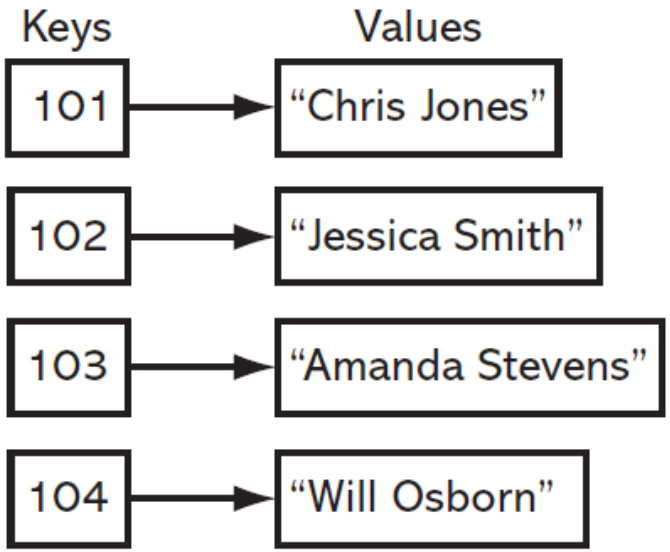
The `map`, `multimap`, and `unordered_map` Classes

Maps – General Concepts

- A *map* is an associative container.
- Each element that is stored in a map has two parts: a *key* and a *value*.
- To retrieve a specific value from a map, you use the key that is associated with that value.
- This is similar to the process of looking up a word in the dictionary, where the words are keys and the definitions are values.

Maps

- Example: a map in which employee IDs are the keys and employee names are the values.
- You use an employee's ID to look up that employee's name.



The `map` Class

- You can use the STL `map` class to store key-value pairs.
- The keys that are stored in a `map` container are unique – no duplicates.
- The `map` class is declared in the `<map>` header file.

map Class Constructors

Default Constructor	`map<keyDataType, valueDataType> name;` Creates an empty `map`.

Range Constructor	`map<keyDataType, valueDataType>`
	`    name(iterator1, iterator2);`
	Creates a `map` that is initialized with a range of values from another `map`. *`iterator1`* marks the beginning of the range and *`iterator2`* marks the end.

Copy Constructor	`map<keyDataType, valueDataType> name(map2);` Creates a `map` that is a copy of *`map2`*.

The map Class

- Example: defining a map container to hold employee ID numbers (as ints) and their corresponding employee names (as strings):

```
map<int, string> employees;
```

Initializing a map

```
map<int, string> employees =
{
   {101, "Chris Jones"}, {102, "Jessica Smith"},
   {103, "Amanda Stevens"}, {104, "Will Osborn"}
};
```

- In the first element, the key is 101 and the value is "Chris Jones".
- In the second element, the key is 102 and the value is "Jessica Smith".
- In the third element, the key is 103 and the value is "Amanda Stevens".
- In the fourth element, the key is 104 and the value is "Will Osborn".

The Overloaded [ ] Operator

- You can use the `[ ]` operator to add new elements to a `map`.
- General format:

  `mapName``[`*`key`*`] = `*`value`*`;`

- This adds the key-value pair to the `map`.
- If the key already exists in the `map`, it's associated value will be changed to *`value`*.

The Overloaded [ ] Operator

```
map<int, string> employees;
employees[110] = "Beth Young";
employees[111] = "Jake Brown";
employees[112] = "Emily Davis";
```

- After this code executes, the `employees` map will contain the following elements:
  - Key = 110, Value = "Beth Young"
  - Key = 111, Value = "Jake Brown"
  - Key = 112, Value = "Emily Davis"

The `pair` Type

- Internally, the elements of a `map` are stored as instances of the `pair` type.
- `pair` is a struct that has two member variables: `first` and `second`.
- The element's key is stored in `first`, and the element's value is stored in `second`.
- The `pair` struct is declared in the `<utility>` header file. When you `#include` the `<map>` header file, `<utility>` is automatically included as well.

Inserting Elements with the `insert()` Member Function

- The `map` class provides an `insert()` member function that adds a `pair` object as an element to the `map`.
- You can use the STL function template `make_pair` to construct a `pair` object.
- The `make_pair` function template is declared in the `<utility>` header file.

Inserting Elements with the `insert()` Member Function

```
map<int, string> employees;
employees.insert(make_pair(110, "Beth Young"));
employees.insert(make_pair(111, "Jake Brown"));
employees.insert(make_pair(112, "Emily Davis"));
```

- After this code executes, the `employees` map will contain the following elements:
  - Key = 110, Value = "Beth Young"
  - Key = 111, Value = "Jake Brown"
  - Key = 112, Value = "Emily Davis"

Note: If the element that you are inserting with the `insert()` member function has the same key as an existing element, the function will *not* insert the new element.

Inserting Elements with the `emplace()` Member Function

- The `map` class also provides an `emplace()` member function that adds an element to the `map`.

```
map<int, string> employees;
employees.emplace(110, "Beth Young");
employees.emplace(111, "Jake Brown");
employees.emplace(112, "Emily Davis");
```

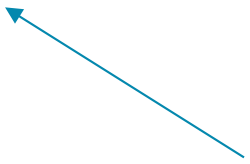
  - After this code executes, the `employees` map will contain the following elements:
    - Key = 110, Value = "Beth Young"
    - Key = 111, Value = "Jake Brown"
    - Key = 112, Value = "Emily Davis"

Note: If the element that you are inserting with the `emplace()` member function has the same key as an existing element, the function will *not* insert the new element.

Retrieving Elements with the at() Member Function

- You can use the at() member function to retrieve a map element by its key:

```
// Create a map containing employee IDs and names.
map<int, string> employees =
{
   {101, "Chris Jones"}, {102, "Jessica Smith"},
   {103, "Amanda Stevens"}, {104, "Will Osborn"}
};

// Retrieve a value from the map.
cout << employees.at(103) << endl;
```



Displays "Amanda Stevens"

Retrieving Elements with the at() Member Function

- To prevent the at() member function from throwing an exception (if the specified key does not exist), use the count member function to determine whether it exists:

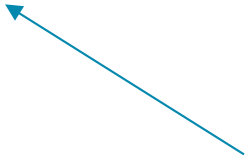
```
// Create a map containing employee IDs and names.
map<int, string> employees =
{
   {101, "Chris Jones"}, {102, "Jessica Smith"},
   {103, "Amanda Stevens"}, {104, "Will Osborn"}
};

// Retrieve a value from the map.
if (employees.count(103))
   cout << employees.at(103) << endl;
else
   cout << "Employee not found.\n";
```

The count() member function returns 1 if the specified key exists, or 0 otherwise.

Deleting Elements

- You can use the `erase()` member function to retrieve a `map` element by its key:

```
// Create a map containing employee IDs and names.
map<int, string> employees =
{
   {101, "Chris Jones"}, {102, "Jessica Smith"},
   {103, "Amanda Stevens"}, {104, "Will Osborn"}
};

// Delete the employee with ID 102.
employees.erase(102);
```



Deletes Jessica Smith from the map

Stepping Through a map with the Range-Based for Loop

```
// Create a map containing employee IDs and names.
map<int, string> employees =
{
   {101, "Chris Jones"}, {102, "Jessica Smith"},
   {103, "Amanda Stevens"}, {104, "Will Osborn"}
};

// Display each element.
for (pair<int, string> element : employees)
{
   cout << "ID: " << element.first << "\tName: "
        << element.second << endl;
}
```

Remember, each element is a `pair`.

Stepping Through a map with the Range-Based for Loop

```
// Create a map containing employee IDs and names.
map<int, string> employees =
{
   {101, "Chris Jones"}, {102, "Jessica Smith"},
   {103, "Amanda Stevens"}, {104, "Will Osborn"}
};

// Display each element.
for (auto element : employees)
{
   cout << "ID: " << element.first << "\tName: "
        << element.second << endl;
}
```

auto simplifies this

Using an Iterator With a `map`

- The `begin()` and `end()` member functions return a bidirectional iterator of the `iterator` type
- The `cbegin()` and `cend()` member functions return a bidirectional iterator of the `const_iterator` type
- The `rbegin()` and `rend()` member functions return a reverse bidirectional iterator of the `reverse_iterator` type
- The `crbegin()` and `crend()` member functions return a reverse bidirectional iterator of the `const_reverse_iterator` type

Using an Iterator With a `map`

- When an iterator points to a `map` element, it points to an instance of the `pair` type.
- The element has two member variables: `first` and `second`.
- The element's key is stored in `first`, and the element's value is stored in `second`.

Program 17-11

```
1  // This program demonstrates an iterator with a map.
2  #include <iostream>
3  #include <string>
4  #include <map>
5  using namespace std;
6
7  int main()
8  {
9       // Create a map containing employee IDs and names.
10      map<int, string> employees =
11         { {101,"Chris Jones"}, {102,"Jessica Smith"},
12           {103,"Amanda Stevens"},{104,"Will Osborn"} };
13
14      // Create an iterator.
15      map<int, string>::iterator iter;
16
17      // Use the iterator to display each element in the map.
18      for (iter = employees.begin(); iter != employees.end(); iter++)
19      {
20           cout << "ID: " << iter->first
21                << "\tName: " << iter->second << endl;
22      }
23
24      return 0;
25 }
```

Program Output

```
ID: 101 Name: Chris Jones
ID: 102 Name: Jessica Smith
ID: 103 Name: Amanda Stevens
ID: 104 Name: Will Osborn
```

Storing Objects Of Your Own Classes as *Values* in a `map`

- If you want to store an object as a value in a map, there is one requirement for that object's class:

  It must have a default constructor.

- Consider the following `Contact` class...

```
1  #ifndef CONTACT_H
2  #define CONTACT_H
3  #include <string>
4  using namespace std;
5
6  class Contact
7  {
8  private:
9       string name;
10      string email;
11 public:
12      Contact()
13      {  name = "";
14         email = ""; }
15
16      Contact(string n, string em)
17      {  name = n;
18         email = em; }
19
20      void setName(string n)
21      {  name = n; }
22
23      void setEmail(string em)
24      {  email = em; }
25
26      string getName() const
27      {  return name; }
28
29      string getEmail() const
30      {  return email; }
31 };
32 #endif
```

Default constructor

Program 17-14

```
1  #include <iostream>
2  #include <string>
3  #include <map>
4  #include "Contact.h"
5  using namespace std;
6
7  int main()
8  {
9       string searchName;    // The name to search for
10
11      // Create some Contact objects
12      Contact contact1("Ashley Miller", "amiller@faber.edu");
13      Contact contact2("Jacob Brown", "jbrown@gotham.edu");
14      Contact contact3("Emily Ramirez", "eramirez@coolidge.edu");
15
16      // Create a map to hold the Contact objects.
17      map<string, Contact> contacts;
18
19      // Create an iterator for the map.
20      map<string, Contact>::iterator iter;
21
22      // Add the contact objects to the map.
23      contacts[contact1.getName()] = contact1;
24      contacts[contact2.getName()] = contact2;
25      contacts[contact3.getName()] = contact3;
```

In the map, the keys are the contact names, and the values are the `Contact` objects.

Continued…

```
26
27      // Get the name to search for.
28      cout << "Enter a name: ";
29      getline(cin, searchName);
30
31      // Search for the name.
32      iter = contacts.find(searchName);
33
34      // Display the results.
35      if (iter != contacts.end())
36      {
37          cout << "Name: " << iter->second.getName() << endl;
38          cout << "Email: " << iter->second.getEmail() << endl;
39      }
40      else
41      {
42          cout << "Contact not found.\n";
43      }
44
45      return 0;
46  }
```

Program Output (with Example Input Shown in Bold)

```
Enter a name: Emily Ramirez Enter
Name: Emily Ramirez
Email: eramirez@coolidge.edu
```

Program Output (with Example Input Shown in Bold)

```
Enter a name: Billy Clark Enter
Contact not found.
```

Storing Objects Of Your Own Classes as *Keys* in a `map`

- If you want to store an object as a key in a map, there is one requirement for that object's class:

  It must overload the `<` operator.

- Consider the following `Customer` class...

```
#ifndef CUSTOMER_H
#define CUSTOMER_H
#include<string>
using namespace std;

class Customer
{
private:
     int custNumber;
     string name;
public:
     Customer(int cn, string n)
     {  custNumber = cn;
        name = n; }

     void setCustNumber(int cn)
     {  custNumber = cn; }

     void setName(string n)
     {  name = n; }

     int getCustNumber() const
     {  return custNumber; }

     string getName() const
     {  return name; }

     bool operator < (const Customer &right) const
     {  bool status = false;

        if (custNumber < right.custNumber)
           status = true;

        return status; }
};
#endif
```

Program 17-17

```
#include <iostream>
#include <string>
#include <map>
#include "Customer.h"
using namespace std;

int main()
{
   // Create some Customer objects.
   Customer customer1(1001, "Sarah Scott");
   Customer customer2(1002, "Austin Hill");
   Customer customer3(1003, "Megan Cruz");

   // Create a map to hold the seat assignments.
   map<Customer, string> assignments;

   // Use the map to store the seat assignments.
   assignments[customer1] = "1A";
   assignments[customer2] = "2B";
   assignments[customer3] = "3C";

   // Display all objects in the map.
   for (auto element : assignments)
   {
      cout << element.first.getName() << "\t"
           << element.second << endl;
   }

   return 0;
}
```

Program Output

```
Sarah Scott     1A
Austin Hill     2B
Megan Cruz      3C
```

This program assigns seats in a theater to customers. The map uses Customer objects as keys, and seat numbers as values.

The unordered_map Class

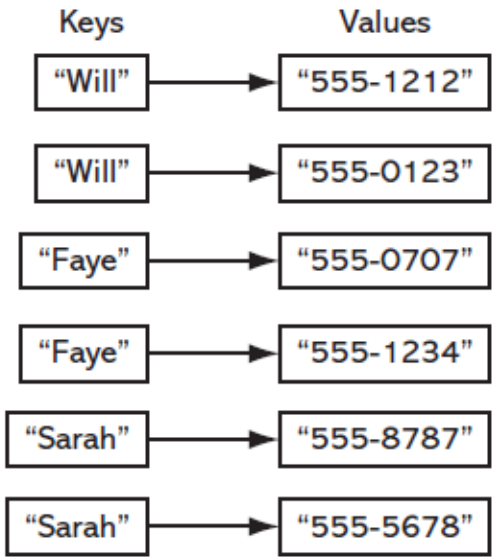
- The unordered_map class is similar to the map class, except in two regards:
  - The keys in an unordered_map are not sorted
  - The unordered_map class has better performance
- You should use the unordered_map class instead of the map class if:
  - You will be making a lot of searches on a large number of elements
  - You are not concerned with retrieving them in key order
- The unordered_map class is declared in the <unordered_map> header file

The `multimap` Class

- The `mulitmap` class is a map that allows duplicate keys
- The `mulitmap` class has most of the same member functions as the map class (see Table 17-11 in your textbook)
- The `multimap` class is declared in the `<map>` header file

The `multimap` Class

- Consider a phonebook application where the key is a person's name and the value is that person's phone number.
- A `multimap` container would allow each person to have multiple phone numbers



Program 17-19

```
 1  #include <iostream>
 2  #include <string>
 3  #include <map>
 4  using namespace std;
 5
 6  int main()
 7  {
 8     // Define a phonebook multimap.
 9     multimap<string, string> phonebook =
10        { {"Will", "555-1212"},  {"Will", "555-0123"},
11          {"Faye", "555-0707"},  {"Faye", "555-1234"},
12          {"Sarah", "555-8787"}, {"Sarah", "555-5678"} };
13
14     // Display the elements in the multimap.
15     for (auto element : phonebook)
16     {
17        cout << element.first << "\t"
18             << element.second << endl;
19     }
20     return 0;
21  }
```

Program Output

```
Faye    555-0707
Faye    555-1234
Sarah   555-8787
Sarah   555-5678
Will    555-1212
Will    555-0123
```

Adding Elements to a `multimap`

- The `multimap` class does not overload the `[]` operator.
  - So, you cannot use an assignment statement to add a new element to a `multimap`.
- Instead, you will use either the `emplace()` or the `insert()` member functions.

Adding Elements to a `multimap`

```
multimap<string, string> phonebook;
phonebook.emplace("Will", "555-1212");
phonebook.emplace("Will", "555-0123");
phonebook.emplace("Faye", "555-0707");
phonebook.emplace("Faye", "555-1234");
phonebook.emplace("Sarah", "555-8787");
phonebook.emplace("Sarah", "555-5678");
```

Adding Elements to a `multimap`

```
multimap<string, string> phonebook;
phonebook.insert(make_pair("Will", "555-1212"));
phonebook.insert(make_pair("Will", "555-0123"));
phonebook.insert(make_pair("Faye", "555-0707"));
phonebook.insert(make_pair("Faye", "555-1234"));
phonebook.insert(make_pair("Sarah", "555-8787"));
phonebook.insert(make_pair("Sarah", "555-5678"));
```

Getting the Number of Elements With a Specified Key

- The `multimap` class's `count()` member function accepts a key as its argument, and returns the number of elements that match the specified key.

Program 17-20

```
 1  #include <iostream>
 2  #include <string>
 3  #include <map>
 4  using namespace std;
 5
 6  int main()
 7  {
 8     // Define a phonebook multimap.
 9     multimap<string, string> phonebook =
10        { {"Will", "555-1212"},  {"Will", "555-0123"},
11          {"Faye", "555-0707"},  {"Faye", "555-1234"},
12          {"Sarah", "555-8787"}, {"Sarah", "555-5678"} };
13
14     // Display the number of elements that match "Faye".
15     cout << "Faye has " << phonebook.count("Faye") << " elements.\n";
16     return 0;
17  }
```

Program Output

```
Faye has 2 elements.
```

Retrieving Elements with a Specified Key

- The `multimap` class has a `find()` member function that searches for an element with a specified key.
- The `find()` function returns an iterator to the first element matching it.
- If the element is not found, the `find()` function returns an iterator to the end of the `multimap`.

Retrieving Elements with a Specified Key

- To retrieve all elements matching a specified key, use the `equal_range` member function.

- The `equal_range` member function returns a pair object.
  - The `pair` object's `first` member is an iterator pointing to the first element that matches the specified key.
  - The `pair` object's `second` member is an iterator pointing to the position *after* the last element that matches the specified key.

```
// Define a phonebook multimap.
multimap<string, string> phonebook =
   { {"Will", "555-1212"},  {"Will", "555-0123"},
     {"Faye", "555-0707"},  {"Faye", "555-1234"},
     {"Sarah", "555-8787"}, {"Sarah", "555-5678"} };

// Define a pair variable to receive the object that
// is returned from the equal_range member function.
pair<multimap<string, string>::iterator,
     multimap<string, string>::iterator> range;

// Define an iterator for the multimap.
multimap<string, string>::iterator iter;

// Get the range of elements that match "Faye".
range = phonebook.equal_range("Faye");

// Display all of the elements that match "Faye".
for (iter = range.first; iter != range.second; iter++)
{
   cout << iter->first << "\t" << iter->second << endl;
}
```

Program Output

```
Faye    555-0707
Faye    555-1234
```

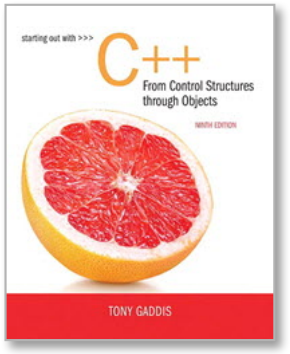
Deleting Elements with a Specified Key

- To delete all elements matching a specified key, use the `erase()` member function.

```
// Define a phonebook multimap.
multimap<string, string> phonebook =
   { {"Will", "555-1212"},  {"Will", "555-0123"},
     {"Faye", "555-0707"},  {"Faye", "555-1234"},
     {"Sarah", "555-8787"}, {"Sarah", "555-5678"} };

// Delete Will's phone numbers from the multimap.
phonebook.erase("Will");
```

The unordered_multimap Class

- The unordered_multimap class is similar to the multimap class, except:
  - The keys in an unordered_multimap are not sorted
  - The unordered_multimap class has better performance
- You should use the unordered_multimap class instead of the multimap class if:
  - You will be making a lot of searches on a large number of elements
  - You are not concerned with retrieving them in key order
- The unordered_multimap class is declared in the <unordered_multimap> header file



17.5

The `set`, `multiset`, and `unordered_set` Classes

Sets

- A *set* is an associative container that is similar to a mathematical set.
- You can use the STL `set` class to create a set container.
- All the elements in a `set` must be unique. No two elements can have the same value.
- The elements in a set are automatically sorted in ascending order.
- The `set` class is declared in the `<set>` header file.

The `set` Class

- You can use the STL `set` class to create a set container.
- The keys that are stored in a `map` container are unique – no duplicates.
- The `map` class is declared in the `<map>` header file.

`set` Class Constructors

Default Constructor	`set<dataType> name;` Creates an empty `set`.
Range Constructor	`set<dataType> name(iterator1, iterator2);` Creates a `set` that is initialized with a range of values. *`iterator1`* marks the beginning of the range and *`iterator2`* marks the end.
Copy Constructor	`set<dataType> name(set2);` Creates a `set` that is a copy of *`set2`*.

The `set` Class

- Example: defining a `set` container to hold integers:

```
set<int> numbers;
```

- Example: defining and initializing a `set` container to hold integers:

```
set<int> numbers = {1, 2, 3, 4, 5};
```

The `set` Class

- A set cannot contain duplicate items.
- If the same value appears more than once in an initialization list, it will be added to the set only one time.
- For example, the following set will contain the values 1, 2, 3, 4, and 5:

```
set<int> numbers = {1, 1, 2, 2, 3, 4, 5, 5, 5};
```

Adding New Elements to a `set`

- The `insert()` member function adds a new element to a `set`:

```
set<int> numbers;
numbers.insert(10);
numbers.insert(20);
numbers.insert(30);
```

Stepping Through a `set` With the Range-Based `for` Loop

```
// Create a set containing names.
set<string> names = {"Joe", "Karen", "Lisa", "Jackie"};

// Display each element.
for (string element : names)
{
    cout << element << endl;
}
```

Using an Iterator With a `set`

- The `begin()` and `end()` member functions return a bidirectional iterator of the `iterator` type
- The `cbegin()` and `cend()` member functions return a bidirectional iterator of the `const_iterator` type
- The `rbegin()` and `rend()` member functions return a reverse bidirectional iterator of the `reverse_iterator` type
- The `crbegin()` and `crend()` member functions return a reverse bidirectional iterator of the `const_reverse_iterator` type

Using an Iterator With a `set`

```
// Create a set containing names.
set<string> names = {"Joe", "Karen", "Lisa", "Jackie"};

// Create an iterator.
set<string>::iterator iter;

// Use the iterator to display each element in the set.
for (iter = names.begin(); iter != names.end(); iter++)
{
   cout << *iter << endl;
}
```

Determining Whether an Element Exists

- The `set` class's `count()` member function accepts a value as its argument, and returns 1 if that value exists in the set. The function returns 0 otherwise.

```
set<string> names = {"Joe", "Karen", "Lisa", "Jackie"};
if (names.count("Lisa"))
   cout << "Lisa was found in the set.\n";
else
   cout << "Lisa was not found.\n";
```

Retrieving an Element

- The `set` class has a `find()` member function that searches for an element with a specified value.
- The `find()` function returns an iterator to the element matching it.
- If the element is not found, the `find()` function returns an iterator to the end of the `set`.

Retrieving an Element

```
// Create a set containing names.
set<string> names = {"Joe", "Karen", "Lisa", "Jackie"};

// Create an iterator.
set<string>::iterator iter;

// Find "Karen".
iter = names.find("Karen");

// Display the result.
if (iter != names.end())
{
   cout << *iter << " was found.\n";
}
else
{
   cout << "Karen was not found.\n";
}
```

Storing Objects Of Your Own Classes in a `set`

- If you want to store an object in a `set`, there is one requirement for that object's class:

  It must overload the < operator.

- Consider the following `Customer` class...

```
#ifndef CUSTOMER_H
#define CUSTOMER_H
#include<string>
using namespace std;

class Customer
{
private:
     int custNumber;
     string name;
public:
     Customer(int cn, string n)
     {  custNumber = cn;
        name = n; }

     void setCustNumber(int cn)
     {  custNumber = cn; }

     void setName(string n)
     {  name = n; }

     int getCustNumber() const
     {  return custNumber; }

     string getName() const
     {  return name; }

     bool operator < (const Customer &right) const
     {  bool status = false;

        if (custNumber < right.custNumber)
           status = true;

        return status; }
};
#endif
```

Program 17-22

```
#include <iostream>
#include <set>
#include "Customer.h"
using namespace std;

int main()
{
    // Create a set of Customer objects.
    set<Customer> customerset =
      { Customer(1003, "Megan Cruz"),
        Customer(1002, "Austin Hill"),
        Customer(1001, "Sarah Scott")
      };

    // Try to insert a duplicate customer number.
    customerset.emplace(1001, "Evan Smith");

    // Display the set elements
    cout << "List of customers:\n";
    for (auto element : customerset)
    {
       cout << element.getCustNumber() << " "
            << element.getName() << endl;
    }

```

Continued…

```
26     // Search for customer number 1002.
27     cout << "\nSearching for Customer Number 1002:\n";
28     auto it = customerset.find(Customer(1002, ""));
29
30     if (it != customerset.end())
31        cout << "Found: " << it->getName() << endl;
32     else
33        cout << "Not found.\n";
34
35     return 0;
36  }
```

Program Output

```
List of customers:
1001 Sarah Scott
1002 Austin Hill
1003 Megan Cruz

Searching for Customer Number 1002:
Found: Austin Hill
```

The `multiset` Class

- The `mulitset` class is a set that allows duplicate items.
- The `mulitset` class has the same member functions as the `set` class (see Table 17-13 in your textbook).
- The `multiset` class is declared in the `<set>` header file.

The `multiset` Class

- In the `set` class, the `count()` member function returns either 0 or 1. In the `multiset` class, the `count()` member function can return values greater than 1.

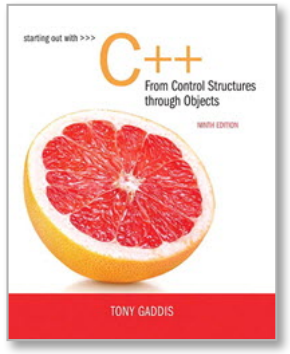
- In the `set` class, the `equal_range()` member function returns a range with, at most, one element. In the `multiset` class, the `equal_range()` member function can return a range with multiple elements.

The unordered_set Class

- The unordered_set class is similar to the set class, except in two regards:
  - The values in an unordered_set are not sorted
  - The unordered_set class has better performance
- You should use the unordered_set class instead of the set class if:
  - You will be making a lot of searches on a large number of elements
  - You are not concerned with retrieving them in ascending order
- The unordered_set class is declared in the <unordered_set> header file

The unordered_multiset Class

- The unordered_multiset class is similar to the multiset class, except in two regards:
  - The values in an unordered_multiset are not sorted
  - The unordered_multiset class has better performance
- You should use the unordered_multiset class instead of the multiset class if:
  - You will be making a lot of searches on a large number of elements
  - You are not concerned with retrieving them in ascending order
- The unordered_multiset class is declared in the <unordered_set> header file



17.6

Algorithms

STL Algorithms

- The STL provides a number of algorithms, implemented as function templates, in the `<algorithm>` header file.
- These functions perform various operations on ranges of elements.
- A range of elements is a sequence of elements denoted by two iterators:
  - The first iterator points to the first element in the range
  - The second iterator points to the end of the range (the element to which the second iterator points is not included in the range).

Categories of Algorithms in the STL

- Min/max algorithms
- Sorting algorithms
- Search algorithms
- Read-only sequence algorithms
- Copying and moving algorithms
- Swapping algorithms
- Replacement algorithms
- Removal algorithms
- Reversal algorithms
- Fill algorithms
- Rotation algorithms
- Shuffling algorithms
- Set algorithms
- Transformation algorithm
- Partition algorithms
- Merge algorithms
- Permutation algorithms
- Heap algorithms
- Lexicographical comparison algorithm

Sorting

- The `sort` function:

  `sort(`*`iterator1`*`, `*`iterator2`*`);`

  `iterator1` and *`iterator2`* mark the beginning and end of a range of elements. The function sorts the range of elements in ascending order.

Searching

- The `binary_search` function:

```
binary_search(iterator1, iterator2, value);
```

`iterator1` and *`iterator2`* mark the beginning and end of a range of elements that are sorted in ascending order. value is the value to search for. The function returns `true` if value is found in the range, or `false` otherwise.

Program 17-23

```
1  #include <iostream>
2  #include <vector>
3  #include <algorithm>
4  using namespace std;
5
6  int main()
7  {
8     int searchValue;    // Value to search for
9
10    // Create a vector of unsorted integers.
11    vector<int> numbers = {10, 1, 9, 2, 8, 3, 7, 4, 6, 5};
12
13    // Sort the vector.
14    sort(numbers.begin(), numbers.end());
15
```

Continued…

```
16      // Display the vector.
17      cout << "Here are the sorted values:\n";
18      for (auto element : numbers)
19         cout << element << " ";
20      cout << endl;
21
22      // Get the value to search for.
23      cout << "Enter a value to search for: ";
24      cin >> searchValue;
25
26      // Search for the value.
27      if (binary_search(numbers.begin(), numbers.end(), searchValue))
28         cout << "That value is in the vector.\n";
29      else
30         cout << "That value is not in the vector.\n";
31
32      return 0;
33   }
```

Program Output

```
Here are the sorted values:
1 2 3 4 5 6 7 8 9 10
Enter a value to search for: 8
That value is in the vector.
```

Program Output

```
Here are the sorted values:
1 2 3 4 5 6 7 8 9 10
Enter a value to search for: 99
That value is not in the vector.
```

Detecting Permutations

- If a range has *N* elements, there are *N*! possible arrangements, or permutations, of those elements.
- For example, the range of integers 1, 2, 3 has six possible permutations:

1, 2, 3
1, 3, 2
2, 1, 3
2, 3, 1
3, 1, 2
3, 2, 1

Detecting Permutations

- The `is_permutation()` function determines whether one range of elements is a permutation of another range of elements.

  `is_permutation(`*`iterator1, iterator2, iterator3`*`)`

  - *`iterator1`* and *`iterator2`* mark the beginning and end of the first range of elements.
  - *`iterator3`* marks the beginning of the second range of elements, assumed to have the same number of elements as the first range.
  - The function returns `true` if the second range is a permutation of the first range, or `false` otherwise.
  - See Program 17-25 in your textbook for an example.

Plugging Your Own Functions into an Algorithm

- Many of the function templates in the STL are designed to accept function pointers as arguments.
- This allows you to "plug" one of your own functions into the algorithm.
- For example:

```
for_each(iterator1, iterator2, function)
```

  - *iterator1* and *iterator2* mark the beginning and end of a range of elements.
  - *function* is the name of a function that accepts an element as its argument.
  - The `for_each()` function iterates over the range of elements, passing each element as an argument to *function*.

Plugging Your Own Functions into an Algorithm

- For example, consider this function:

```
void doubleNumber(int &n)
{
   n = n * 2;
}
```

Plugging Your Own Functions into an Algorithm

- And this code snippet:

```
vector<int> numbers = { 1, 2, 3, 4, 5 };

// Display the numbers before doubling.
for (auto element : numbers)
   cout << element << " ";
cout << endl;

// Double the value of each vector element.
for_each(numbers.begin(), numbers.end(), doubleNumber);

// Display the numbers before doubling.
for (auto element : numbers)
   cout << element << " ";
cout << endl;
```

This passes each element of the `numbers` vector to the `doubleNumber` function.

Plugging Your Own Functions into an Algorithm

- Another example:

```
count_if(iterator1, iterator2, function)
```

  - *iterator1* and *iterator2* mark the beginning and end of a range of elements.
  - *function* is the name of a function that accepts an element as its argument, and returns either `true` or `false`.
  - The `count_if()` function iterates over the range of elements, passing each element as an argument to *function*.
  - The `count_if` function returns the number of elements for which function returns `true`.

```
 1 #include <iostream>
 2 #include <vector>
 3 #include <algorithm>
 4 using namespace std;
 5
 6 // Function prototypes
 7 bool isNegative(int);
 8
 9 int main()
10 {
11    // Create a vector of ints.
12    vector<int> numbers = { 0, 99, 120, -33, 10, 8, -1, 101 };
13
14    // Get the number of elements that are negative.
15    int negatives = count_if(numbers.begin(), numbers.end(), isNegative);
16
17    // Display the results.
18    cout << "There are " << negatives << " negative elements.\n";
19    return 0;
20 }
21
22 // isNegative function
23 bool isNegative(int n)
24 {
25    bool status = false;
26
27    if (n < 0)
28       status = true;
29
30    return status;
31 }
```

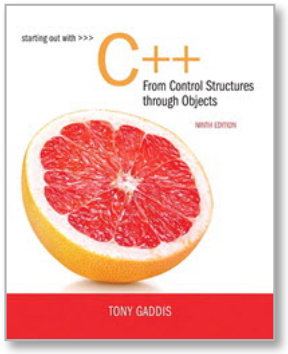
Program Output

```
There are 2 negative elements.
```

Algorithms for Set Operations

- The STL provides function templates for basic mathematical set operations.

STL Function Template	Description
`set_union`	Finds the union of two sets, which is a set that contains all the elements of both sets, excluding duplicates.
`set_intersection`	Finds the intersection of two sets, which is a set that contains only the elements that are found in both sets.
`set_difference`	Finds the difference of two sets, which is the set of elements that appear in one set, but not the other.
`set_symmetric_difference`	Finds the symmetric difference of two sets, which is the set of elements that appear in one set, but not both.
`set_includes`	Determines whether one set includes another.



17.7

Introduction to Function Objects and Lambda Expressions

Function Objects

- A function object is an object that acts like a function.
  - It can be called
  - It can accept arguments
  - It can return a value
- Function objects are also known as *functors*

Function Objects

- To create a function object, you write a class that overloads the ( ) operator.

```
1   #ifndef SUM_H
2   #define SUM_H
3
4   class Sum
5   {
6   public:
7      int operator()(int a, int b)
8      { return a + b; }
9   };
10  #endif
```

Accepts two `int` arguments

Returns an `int`

Program 17-34

```
 1  #include <iostream>
 2  #include "Sum.h"
 3  using namespace std;
 4
 5  int main()
 6  {
 7     // Local variables
 8     int x = 10;
 9     int y = 2;
10     int z = 0;
11
12     // Create a Sum object.
13     Sum sum;
14
15     // Call the sum function object.
16     z = sum(x, y);
17
18     // Display the result.
19     cout << z << endl;
20
21     return 0;
22  }
```

Program Output

```
12
```

Anonymous Function Objects

- Function objects can be called at the point of their creation, without being given a name. Consider this class:

```
1   #ifndef IS_EVEN_H
2   #define IS_EVEN_H
3
4   class IsEven
5   {
6   public:
7       bool operator()(int x)
8       { return x % 2 == 0; }
9   };
10  #endif
```

Program 17-36

```
1  #include <iostream>
2  #include <vector>
3  #include <algorithm>
4  #include "IsEven.h"
5  using namespace std;
6
7  int main()
8  {
9     // Create a vector of ints.
10    vector<int> v = { 1, 2, 3, 4, 5, 6, 7, 8 };
11
12    // Get the number of elements that even.
13    int evenNums = count_if(v.begin(), v.end(), IsEven());
14
15    // Display the results.
16    cout << "The vector contains " << evenNums << " even numbers.\n";
17    return 0;
18 }
```

An `IsEven` object is created here, but not given a name. It is anonymous.

Program Output

```
The vector contains 4 even numbers.
```

Predicate Terminology

- A function or function object that returns a Boolean value is called a *predicate*.
- A predicate that takes only one argument is called a *unary predicate*.
- A predicate that takes two arguments is called a *binary predicate*.
- This terminology is used in much of the available C++ documentation and literature.

Lambda Expressions

- A lambda expression is a compact way of creating a function object without having to write a class declaration.
- It is an expression that contains only the logic of the object's `operator()` member function.
- When the compiler encounters a lambda expression, it automatically generates a function object in memory, using the code that you provide in the lambda expression for the `operator()` member function.

Lambda Expressions

- General format:

  `[](`*`parameter list`*`) { `*`function body`*` }`

- The `[]` is known as the lambda introducer. It marks the beginning of a lambda expression.
- *`parameter list`* is a list of parameter declarations for the function object's `operator()` member function.
- *`function body`* is the code that should be the body of the object's `operator()` member function.

Lambda Expressions

- Example: a lambda expression for a function object that computes the sum of two integers:

```
[](int a, int b) { return x + y; }
```

Lambda Expressions

- Example: a lambda expression for a function object that determines whether an integer is even is:

```
[](int x) { return x % 2 == 0; }
```

Lambda Expressions

- Example: a lambda expression for a function object that takes an integer as input and prints the square of that integer:

```
[](int a) { cout << a * a << " "; }
```

Lambda Expressions

- When you call a lambda expression, you write a list of arguments, enclosed in parentheses, right after the expression.
- For example, the following code snippet displays 7, which is the sum of the variables x and y:

```
int x = 2;
int y = 5;
cout << [](int a, int b) {return a + b;}(x, y) << endl;
```

Lambda Expressions

- The following code segment counts the even numbers in a `vector`:

```
// Create a vector of ints.
vector<int> v = { 1, 2, 3, 4, 5, 6, 7, 8 };

// Get the number of elements that are even.
int evenNums = count_if(v.begin(), v.end(), [](int x) {return x % 2 == 0;});

// Display the results.
cout << "The vector contains " << evenNums << " even numbers.\n";
```

Lambda Expressions

- Because lambda expressions generate function objects, you can assign a lambda expression to a variable and then call it through the variable's name:

```
auto sum = [](int a, int b) {return a + b;};
int x = 2;
int y = 5;
int z = sum(x, y);
```

Program 17-37

```
 1  #include <iostream>
 2  #include <vector>
 3  #include <algorithm>
 4  using namespace std;
 5
 6  int main()
 7  {
 8     // Create a vector of ints.
 9     vector<int> v = { 1, 2, 3, 4, 5, 6, 7, 8 };
10
11     // Use a lambda expression to create a function object.
12     auto isEven = [](int x) { return x % 2 == 0; };
13
14     // Get the number of elements that even.
15     int evenNums = count_if(v.begin(), v.end(), isEven);
16
17     // Display the results.
18     cout << "The vector contains " << evenNums << " even numbers.\n";
19     return 0;
20  }
```

Program Output

```
The vector contains 4 even numbers.
```

Functional Classes in the STL

- The STL library defines a number of classes that you can instantiate to create function objects in your program.
- To use these classes, you must `#include` the `<functional>` header file.
- Table 17-15 in your textbook lists a few of the functional classes:

Table 17-15 STL Function Object Classes

Functional Class	Description
`less<T>`	`less<T>()(T a, T b)` is true if and only if `a < b`
`less_equal<T>`	`less_equal()(T a, T b)` is true if an only if `a <= b`
`greater<T>`	`greater<T>()(T a, T b)` is true if and only if `a > b`
`greater_equal<T>`	`greater_equal<T>()(T a, T b)` is true if and only if `a >= b`