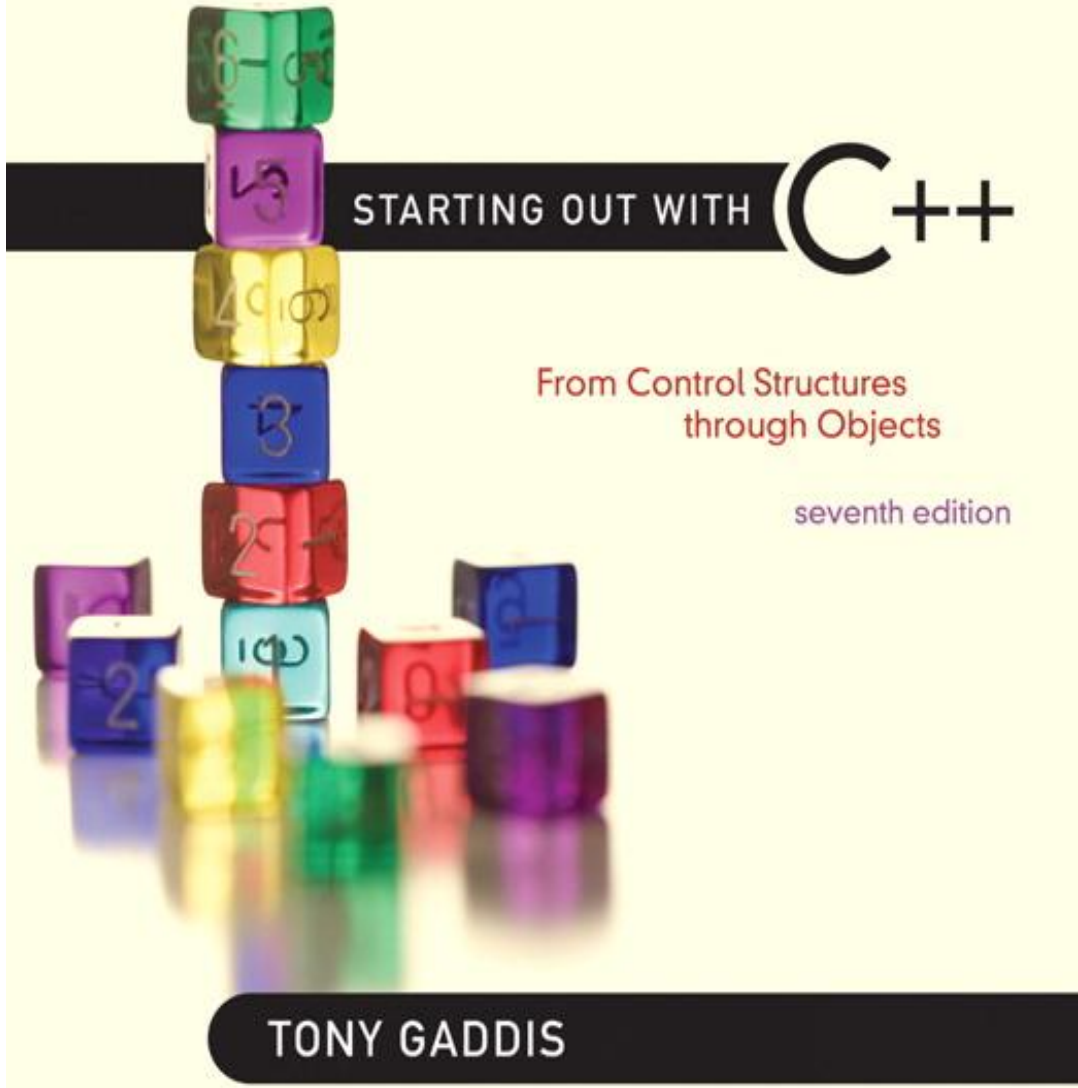
Chapter 16:

Exceptions, Templates, and the Standard Template Library (STL)



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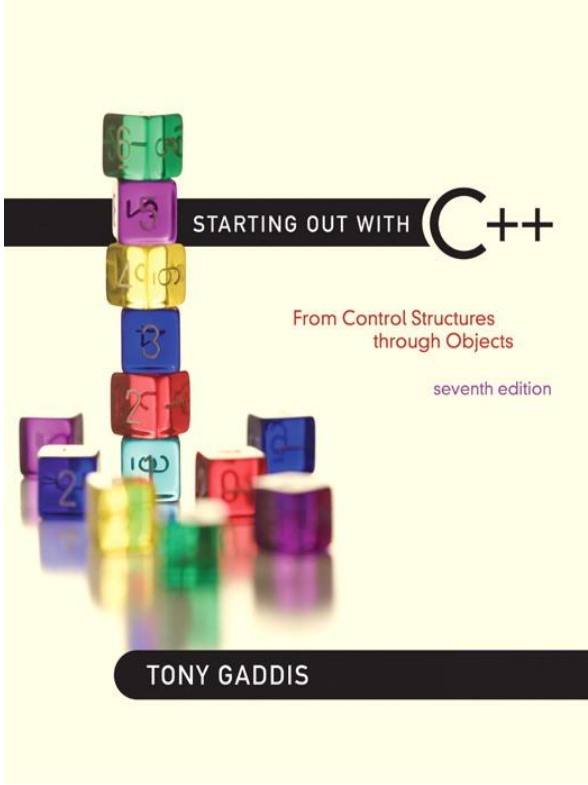


6.1

Exceptions

Exceptions

- Indicate that something unexpected has occurred or been detected
- Allow program to deal with the problem in a controlled manner
- Can be as simple or complex as program design requires

Exceptions - Terminology

- Exception: object or value that signals an error
- Throw an exception: send a signal that an error has occurred
- Catch/Handle an exception: process the exception; interpret the signal

Exceptions – Key Words

- `throw` – followed by an argument, is used to throw an exception
- `try` – followed by a block `{ }`, is used to invoke code that throws an exception
- `catch` – followed by a block `{ }`, is used to detect and process exceptions thrown in preceding `try` block. Takes a parameter that matches the type thrown.

Exceptions – Flow of Control

1) A function that throws an exception is called from within a try block
2) If the function throws an exception, the function terminates and the try block is immediately exited. A catch block to process the exception is searched for in the source code immediately following the try block.
3) If a catch block is found that matches the exception thrown, it is executed. If no catch block that matches the exception is found, the program terminates.

Exceptions – Example (1)

```
// function that throws an exception
int totalDays(int days, int weeks)
{
   if ((days < 0) || (days > 7))
     throw "invalid number of days";
// the argument to throw is the
// character string
  else
     return (7 * weeks + days);
}
```

Exceptions – Example (2)

```
try // block that calls function
{
     totDays = totalDays(days, weeks);
   cout << "Total days: " << days;
}
catch (char *msg) // interpret
                  //  exception
{
   cout << "Error: " << msg;
}
```

Exceptions – What Happens

1) `try` block is entered. `totalDays` function is called
2) If 1st parameter is between 0 and 7, total number of days is returned and `catch` block is skipped over (no exception thrown)
3) If exception is thrown, function and `try` block are exited, `catch` blocks are scanned for 1st one that matches the data type of the thrown exception. `catch` block executes

From Program 16-1

```
 8  int main()
 9  {
10     int num1, num2;  // To hold two numbers
11     double quotient; // To hold the quotient of the numbers
12
13     // Get two numbers.
14     cout << "Enter two numbers: ";
15     cin >> num1 >> num2;
16
17     // Divide num1 by num2 and catch any
18     // potential exceptions.
19     try
20     {
21        quotient = divide(num1, num2);
22        cout << "The quotient is " << quotient << endl;
23     }
24     catch (char *exceptionString)
25     {
26        cout << exceptionString;
27     }
28
29     cout << "End of the program.\n";
30     return 0;
31  }
```

From Program 16-1

```
33  //*********************************************
34  // The divide function divides numerator by  *
35  // denominator. If denominator is zero, the  *
36  // function throws an exception.             *
37  //*********************************************
38
39  double divide(int numerator, int denominator)
40  {
41     if (denominator == 0)
42        throw "ERROR: Cannot divide by zero.\n";
43
44     return static_cast<double>(numerator) / denominator;
45  }
```

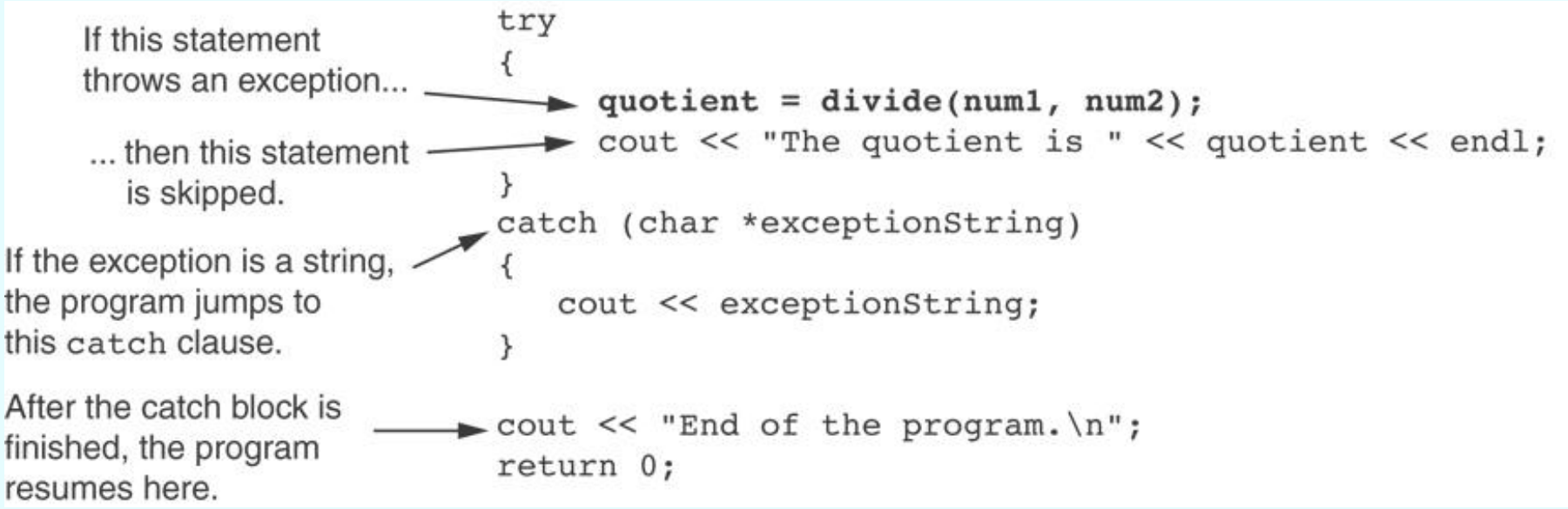
Program Output with Example Input Shown in Bold

```
Enter two numbers: 12 2 [Enter]
The quotient is 6
End of the program.
```

Program Output with Example Input Shown in Bold

```
Enter two numbers: 12 0 [Enter]
ERROR: Cannot divide by zero.
End of the program.
```

What Happens in theTry/Catch Construct



What if no exception is thrown?

If no exception is thrown in the try block, the program jumps to the statement that immediately follows the try/catch construct.

```
try
{
      quotient = divide(num1, num2);
      cout << "The quotient is " << quotient << endl;
}
catch (char *exceptionString)
{
   cout << exceptionString;
}

cout << "End of the program.\n";
return 0;
```

Exceptions - Notes

- Predefined functions such as `new` may throw exceptions
- The value that is thrown does not need to be used in `catch` block.
  - in this case, no name is needed in catch parameter definition
  - `catch` block parameter definition *does* need the type of exception being caught

Exception Not Caught?

- An exception will not be caught if
  - it is thrown from outside of a `try` block
  - there is no `catch` block that matches the data type of the thrown exception
- If an exception is not caught, the program will terminate

Exceptions and Objects

- An exception class can be defined in a class and thrown as an exception by a member function
- An exception class may have:
  - no members: used only to signal an error
  - members: pass error data to `catch` block
- A class can have more than one exception class

Contents of `Rectangle.h` (Version 1)

```
1  // Specification file for the Rectangle class
2  #ifndef RECTANGLE_H
3  #define RECTANGLE_H
4
5  class Rectangle
6  {
7     private:
8        double width;     // The rectangle's width
9        double length;    // The rectangle's length
10    public:
11       // Exception class
12       class NegativeSize
13          { };            // Empty class declaration
14
15       // Default constructor
16       Rectangle()
17          { width = 0.0; length = 0.0; }
18
19       // Mutator functions, defined in Rectangle.cpp
20       void setWidth(double);
21       void setLength(double);
22
```

Contents of Rectangle.h (Version1) (Continued)

```
23          // Accessor functions
24          double getWidth() const
25             { return width; }
26
27          double getLength() const
28             { return length; }
29
30          double getArea() const
31             { return width * length; }
32    };
33    #endif
```

Contents of `Rectangle.cpp` (Version 1)

```
1  // Implementation file for the Rectangle class.
2  #include "Rectangle.h"
3
4  //***********************************************************
5  // setWidth sets the value of the member variable width.    *
6  //***********************************************************
7
8  void Rectangle::setWidth(double w)
9  {
10    if (w >= 0)
11       width = w;
12    else
13       throw NegativeSize();
14 }
15
16 //***********************************************************
17 // setLength sets the value of the member variable length.  *
18 //***********************************************************
19
20 void Rectangle::setLength(double len)
21 {
22    if (len >= 0)
23       length = len;
24    else
25       throw NegativeSize();
26 }
```

Program 16-2

```
1  // This program demonstrates Rectangle class exceptions.
2  #include <iostream>
3  #include "Rectangle.h"
4  using namespace std;
5
6  int main()
7  {
8     int width;
9     int length;
10
11    // Create a Rectangle object.
12    Rectangle myRectangle;
13
```

Program 16-2 *(continued)*

```
14      // Get the width and length.
15      cout << "Enter the rectangle's width: ";
16      cin >> width;
17      cout << "Enter the rectangle's length: ";
18      cin >> length;
19
20      // Store these values in the Rectangle object.
21      try
22      {
23         myRectangle.setWidth(width);
24         myRectangle.setLength(length);
25         cout << "The area of the rectangle is "
26              << myRectangle.getArea() << endl;
27      }
28      catch (Rectangle::NegativeSize)
29      {
30         cout << "Error: A negative value was entered.\n";
31      }
32      cout << "End of the program.\n";
33
34      return 0;
35  }
```

Program 16-2 (Continued)

Program Output with Example Input Shown in Bold

```
Enter the rectangle's width: 10 [Enter]
Enter the rectangle's length: 20 [Enter]
The area of the rectangle is 200
End of the program.
```

Program Output with Example Input Shown in Bold

```
Enter the rectangle's width: 5 [Enter]
Enter the rectangle's length: -5 [Enter]
Error: A negative value was entered.
End of the program.
```

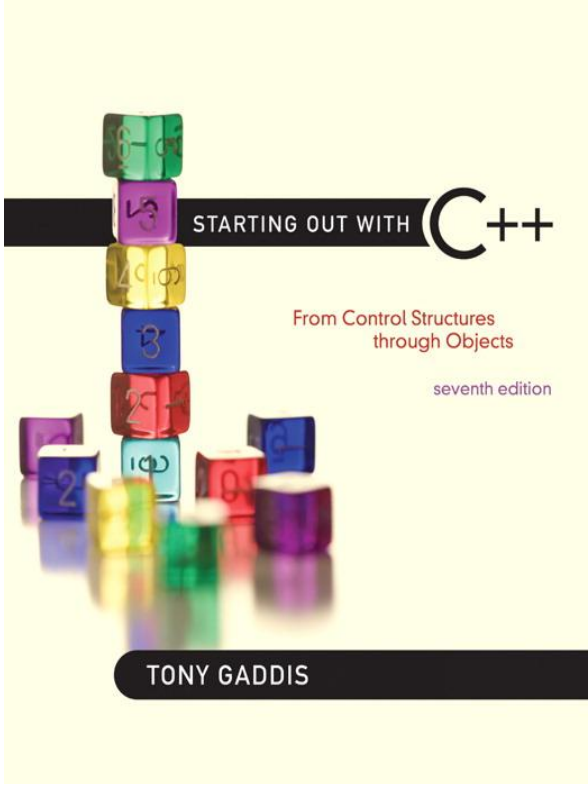
What Happens After `catch` Block?

- Once an exception is thrown, the program cannot return to throw point. The function executing `throw` terminates (does not return), other calling functions in `try` block terminate, resulting in unwinding the stack
- If objects were created in the `try` block and an exception is thrown, they are destroyed.

Nested `try` Blocks

- `try/catch` blocks can occur within an enclosing `try` block
- Exceptions caught at an inner level can be passed up to a `catch` block at an outer level:

```
catch ( )
{
   ...
   throw;  // pass exception up
}          // to next level
```



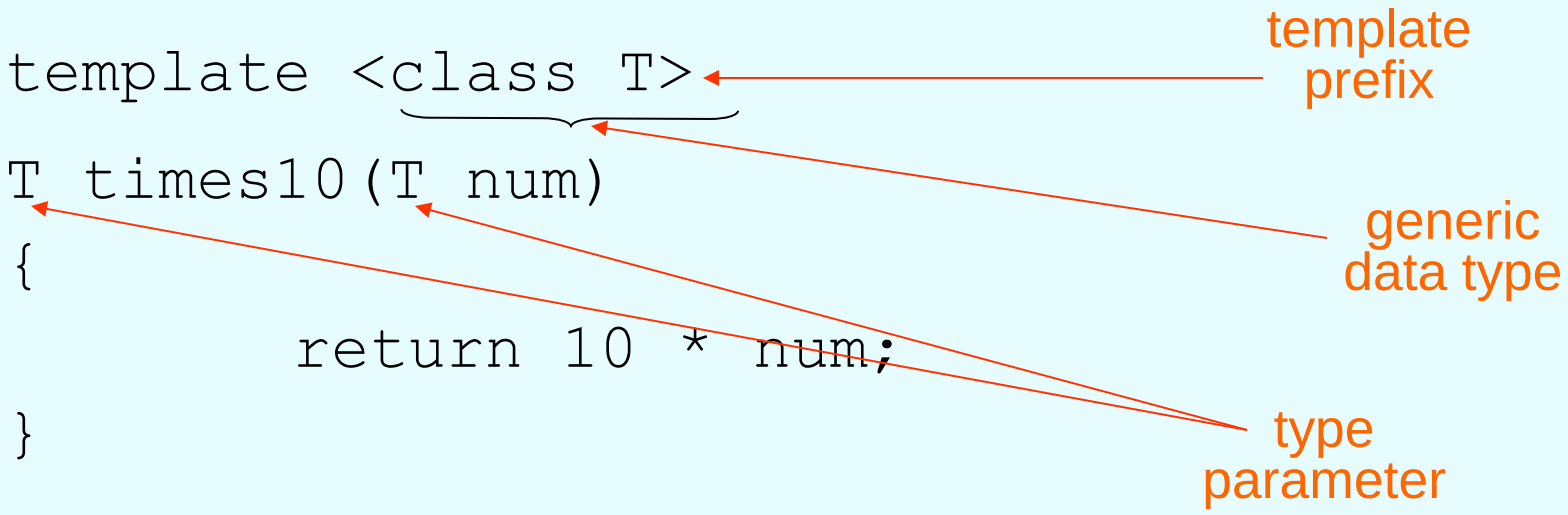
16.2

Function Templates

Function Templates

- Function template: a pattern for a function that can work with many data types
- When written, parameters are left for the data types
- When called, compiler generates code for specific data types in function call

Function Template Example



What gets generated when `times10` is called with an `int`:	What gets generated when `times10` is called with a `double`:

`int times10(int num)`
`{`
`  return 10 * num;`
`}`
	`double times10(double num)`
	`{`
	`  return 10 * num;`
	`}`

Function Template Example

```
template <class T>
T times10(T num)
{
        return 10 * num;
}
```

- Call a template function in the usual manner:

```
int ival = 3;
double dval = 2.55;
cout << times10(ival); // displays 30
cout << times10(dval); // displays 25.5
```

Function Template Notes

- Can define a template to use multiple data types:

```
template<class T1, class T2>
```

- Example:

```
template<class T1, class T2>      // T1 and T2 will be
double mpg(T1 miles, T2 gallons) // replaced in the
{                                 // called function
return miles / gallons          // with the data
}                                 // types of the
                                  // arguments
```

Function Template Notes

- Function templates can be overloaded Each template must have a unique parameter list

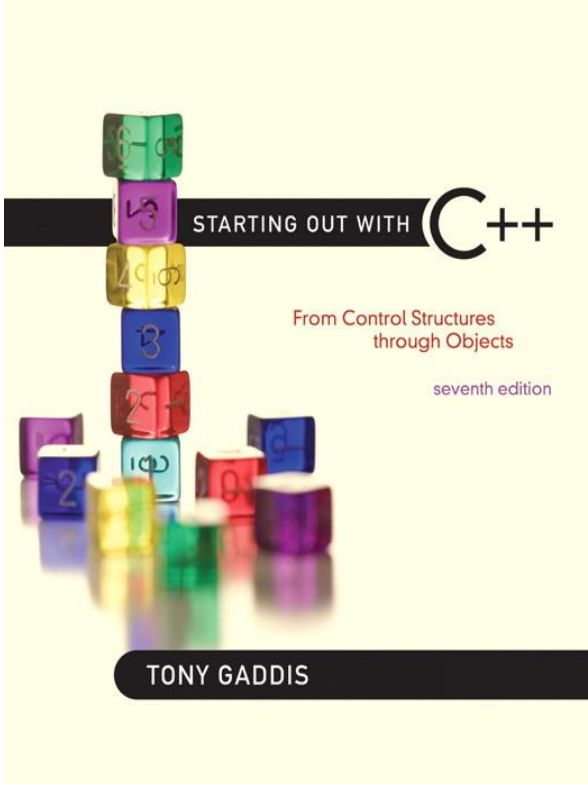
```
template <class T>
T sumAll(T num) ...
template <class T1, class T2>
T1 sumall(T1 num1, T2 num2) ...
```

Function Template Notes

- All data types specified in template prefix must be used in template definition
- Function calls must pass parameters for all data types specified in the template prefix
- Like regular functions, function templates must be defined before being called

Function Template Notes

- A function template is a pattern
- No actual code is generated until the function named in the template is called
- A function template uses no memory
- When passing a class object to a function template, ensure that all operators in the template are defined or overloaded in the class definition

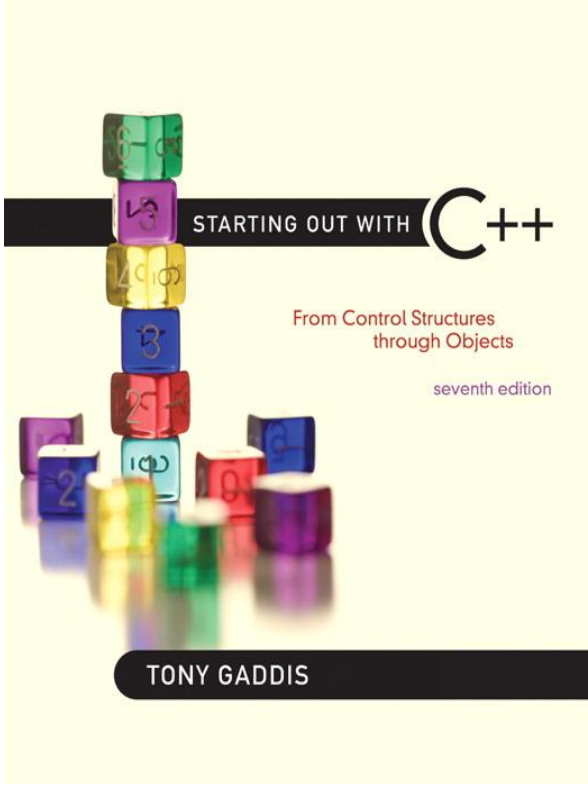


16.3

Where to Start When Defining Templates

Where to Start When Defining Templates

- Templates are often appropriate for multiple functions that perform the same task with different parameter data types
- Develop function using usual data types first, then convert to a template:
  - add template prefix
  - convert data type names in the function to a type parameter (*i.e.*, a T type) in the template



16.4

Class Templates

Class Templates

- Classes can also be represented by templates. When a class object is created, type information is supplied to define the type of data members of the class.
- Unlike functions, classes are instantiated by supplying the type name (`int`, `double`, `string`, etc.) at object definition

Class Template Example

```
template <class T>
class grade
{
    private:
        T score;
    public:
        grade(T);
        void setGrade(T);
        T getGrade()
};
```

Class Template Example

- Pass type information to class template when defining objects:

```
grade<int> testList[20];

grade<double> quizList[20];
```

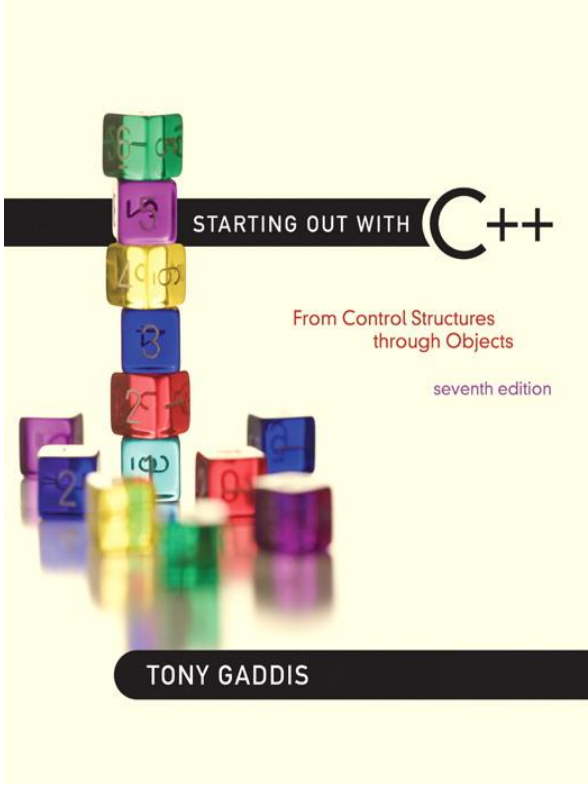
- Use as ordinary objects once defined

Class Templates and Inheritance

- Class templates can inherit from other class templates:

```
template <class T>
class Rectangle
  { ... };
template <class T>
class Square : public Rectangle<T>
  { ... };
```

- Must use type parameter `T` everywhere base class name is used in derived class



16.5

Introduction to the Standard Template Library

Introduction to the Standard Template Library

- Standard Template Library (STL): a library containing templates for frequently used data structures and algorithms
- Not supported by many older compilers

Standard Template Library

- Two important types of data structures in the STL:
  - containers: classes that stores data and imposes some organization on it
  - iterators: like pointers; mechanisms for accessing elements in a container

Containers

- Two types of container classes in STL:
  - sequence containers: organize and access data sequentially, as in an array. These include `vector`, `dequeue`, and `list`
  - associative containers: use keys to allow data elements to be quickly accessed. These include `set`, `multiset`, `map`, and `multimap`

Iterators

- Generalization of pointers, used to access information in containers
- Four types:
  - forward (uses `++`)
  - bidirectional (uses `++` and `--`)
  - random-access
  - input (can be used with `cin` and `istream` objects)
  - output (can be used with `cout` and `ostream` objects)

Algorithms

- STL contains algorithms implemented as function templates to perform operations on containers.
- Requires `algorithm` header file
- `algorithm` includes

`binary_search`	`count`
`for_each`	`find`
`find_if`	`max_element`
`min_element`	`random_shuffle`
`sort`	and others