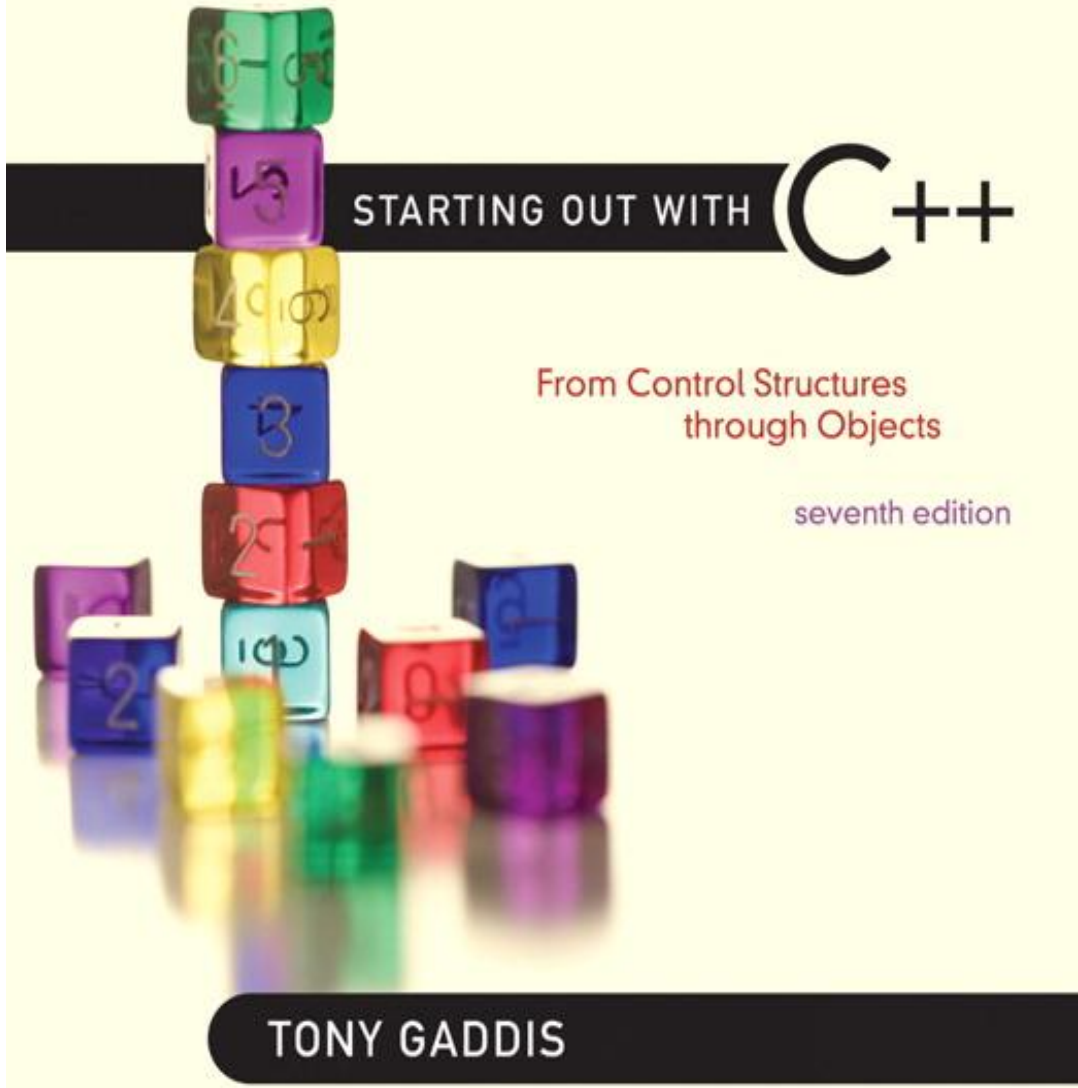
Chapter 16:

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



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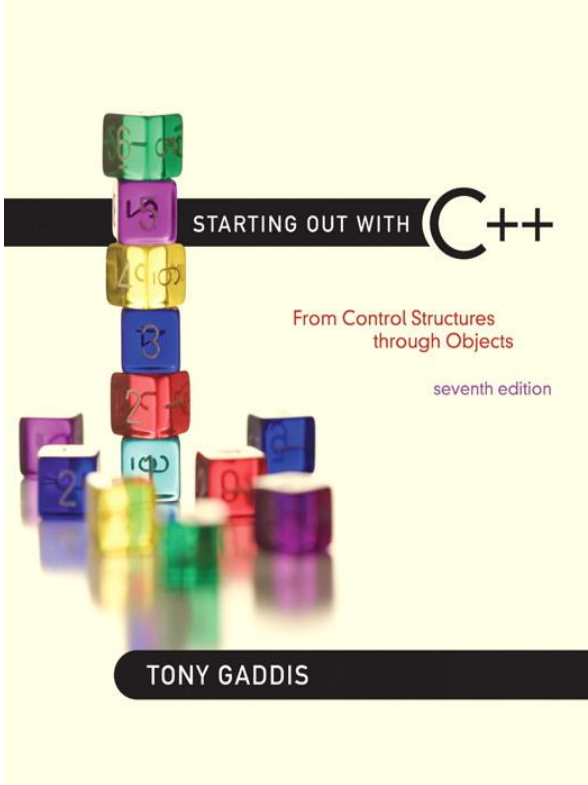


16.1

Exceptions

Exceptions

- Indicate that something unexpected has occurred or been detected
- Allows a 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 primitive value that signals an error
- Throw an exception:
  - send a signal that an error has occurred
  - throw 0;
  - throw index_error;
- Catch/Handle an exception:
  - process the exception

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 may throw 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))
       // the argument to throw is a string
       throw "invalid number of days";
    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  }
```

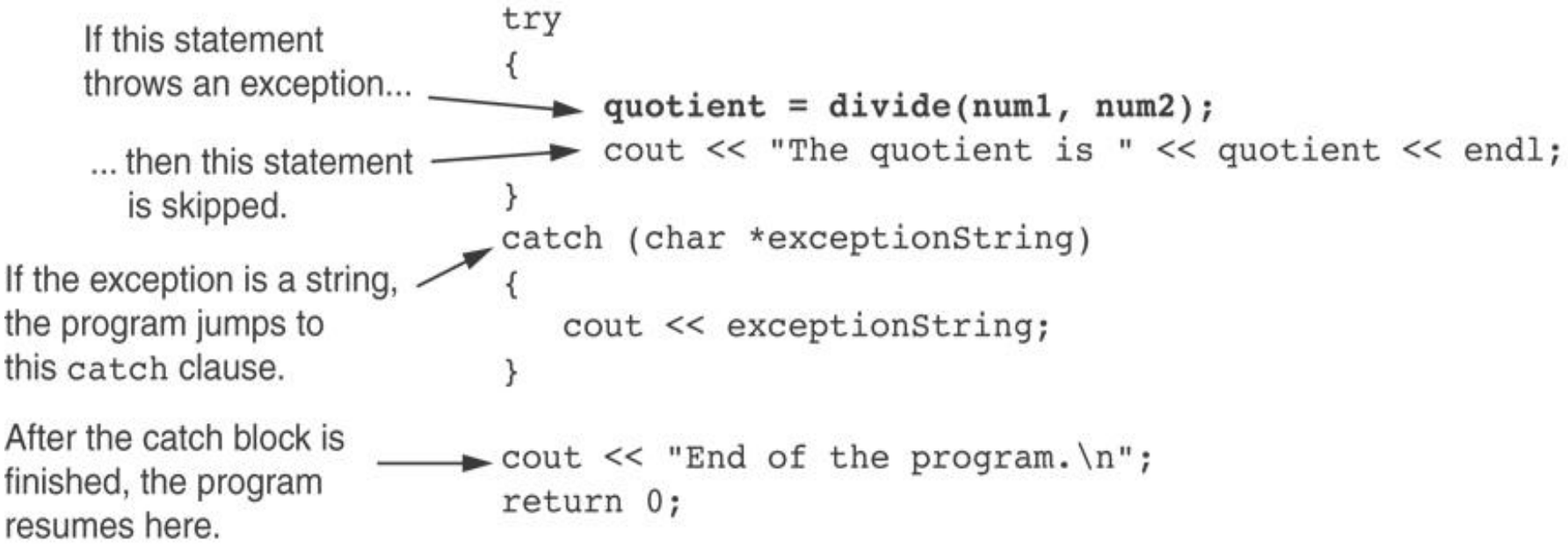
Program Output with Example Input Shown in Bold

```
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

- Operators such as `new` may throw exceptions
- The value that is thrown does not need to be used in `catch` block.
  - in this case, only the type need be specified
- `catch` block parameter definition does need the type of exception being caught
  - in this case, you need both the type and the parameter name

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   }
```

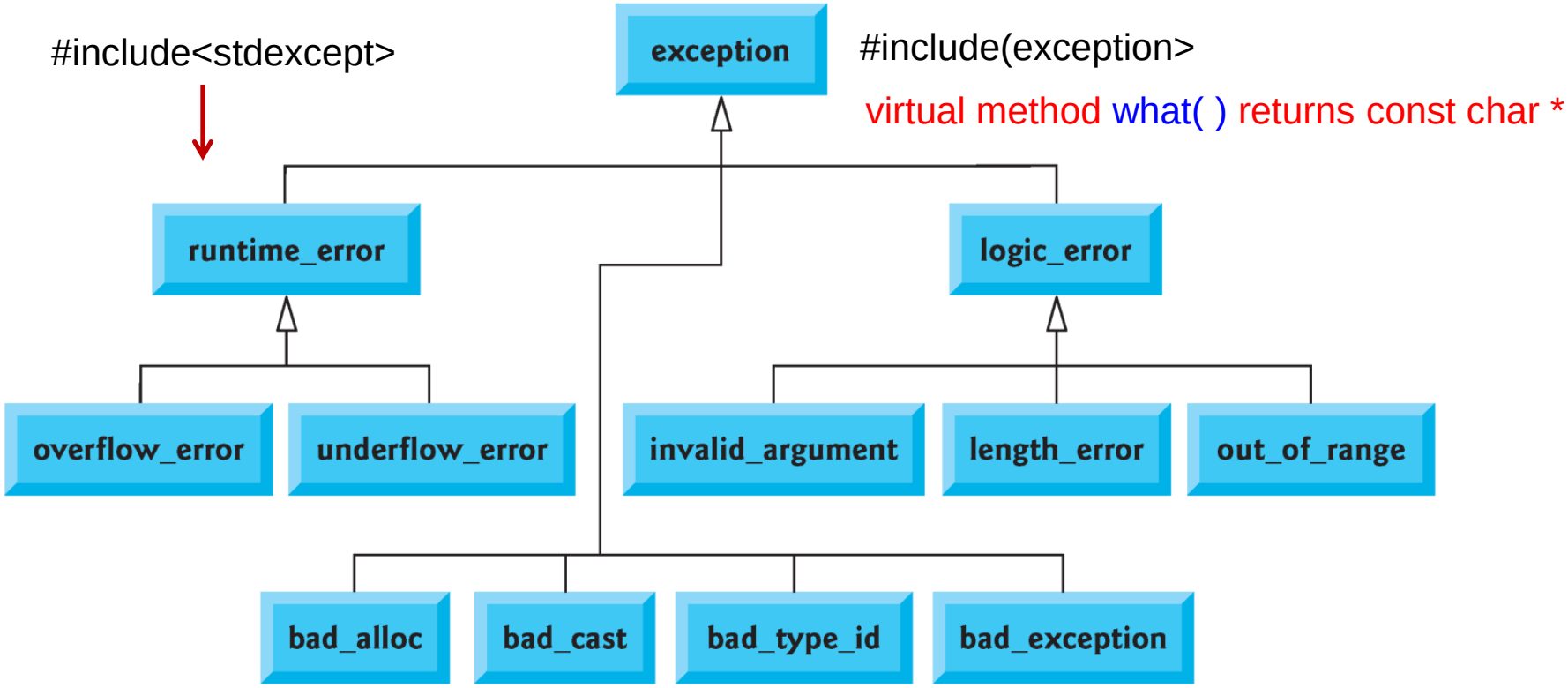
Program 16-2 (Continued)

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.
```



C++ Exception Class Hierarchy

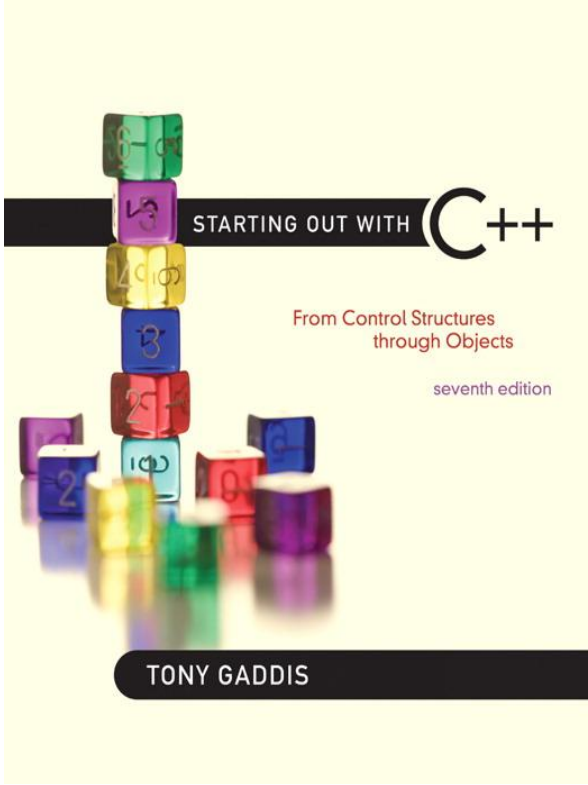
What Happens After catch Block?

- Once an exception is thrown, the program cannot return to the throw point. [ok in a loop]
- The function executing the `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 (rethrown)

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



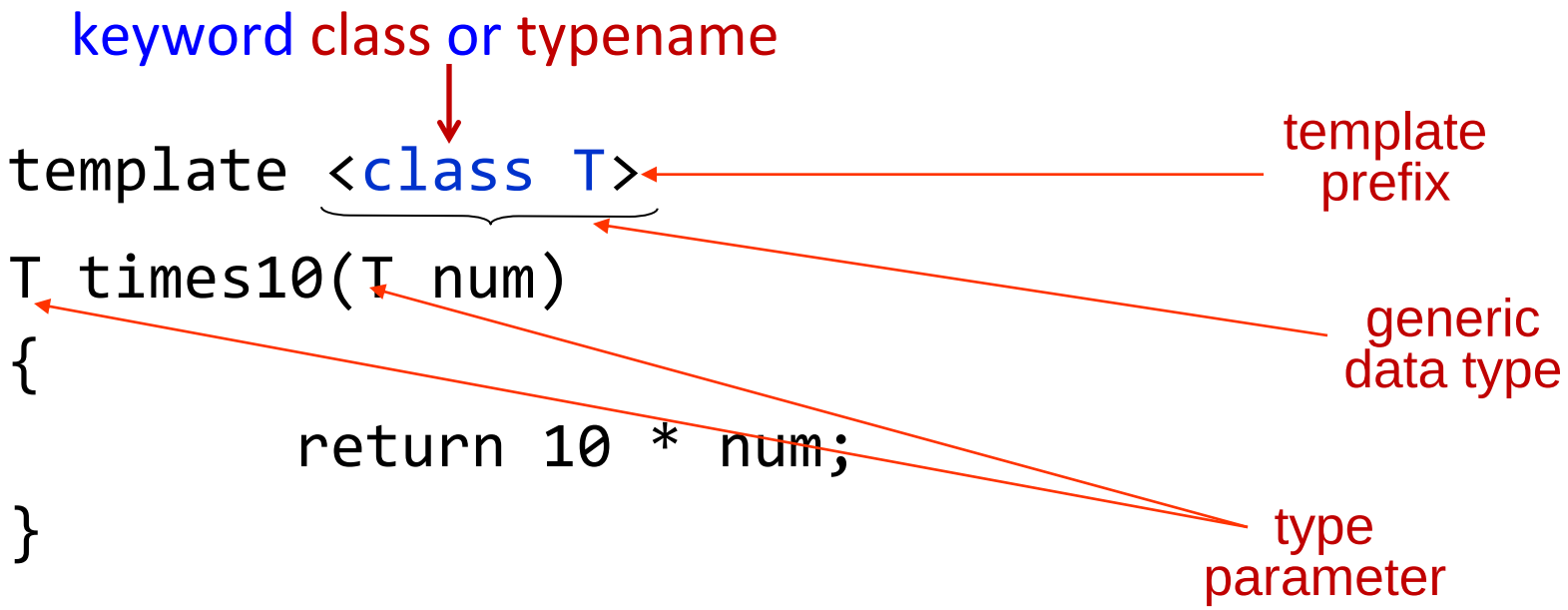
16.2

Function Templates

Function Templates

- Function template
  - a pattern for a function that can work with many data types
- When defined, type parameters are used for the data types
- When called, the compiler generates code for specific data types in function call (specialization)

Function Template Example



What gets generated when `times10` is called with an `int`: [template specialization]	What gets generated when `times10` is called with a `double`: [template specialization]

`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 i_val = 3;
double d_val = 2.55;
cout << times10(i_val); // displays 30
cout << times10(d_val); // displays 25.5
```

Function Template Notes

- Can define a template to use multiple data types:

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

- Example: T1 and T2 will be replaced in the called function with the data types of the arguments.

```
template<class T1, class T2>
double mpg(T1 miles, T2 gallons)
{
   return miles / gallons;
}
```

Function Template Notes

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

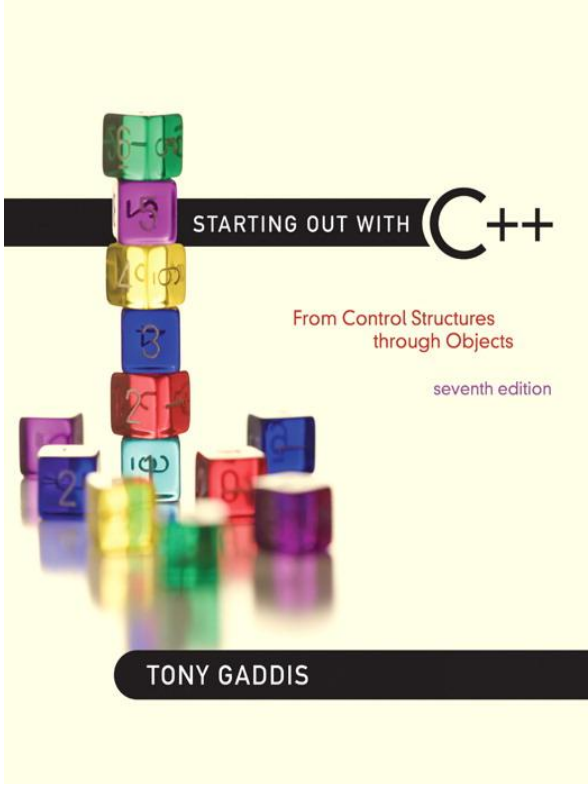
```
template <class T>
T sumAll(T num) ...

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 (then a template specialization is created).
- A function template uses no memory
- When passing an object to a function template, ensure that all operators in the template are defined or overloaded in the class definition



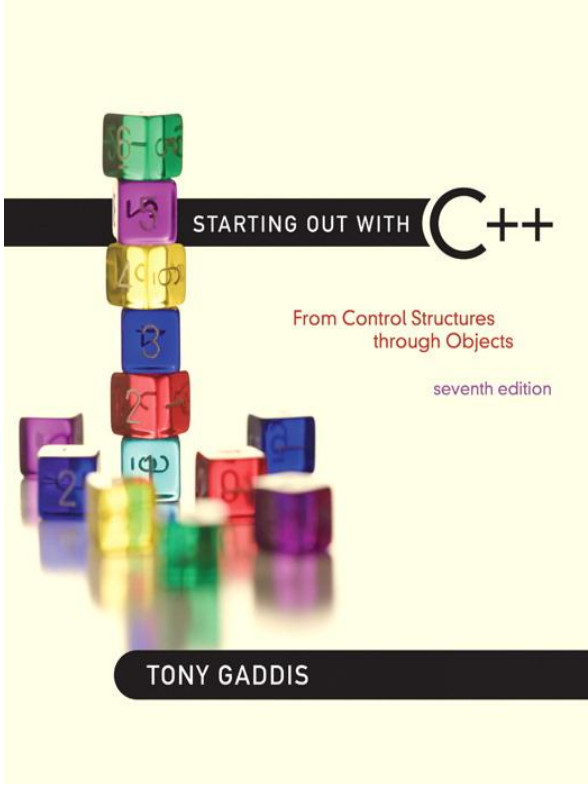
16.3

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 the function using the usual data types first, then convert to a template:
  - add template prefix `template`
  - 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 actual 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 creating objects:

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

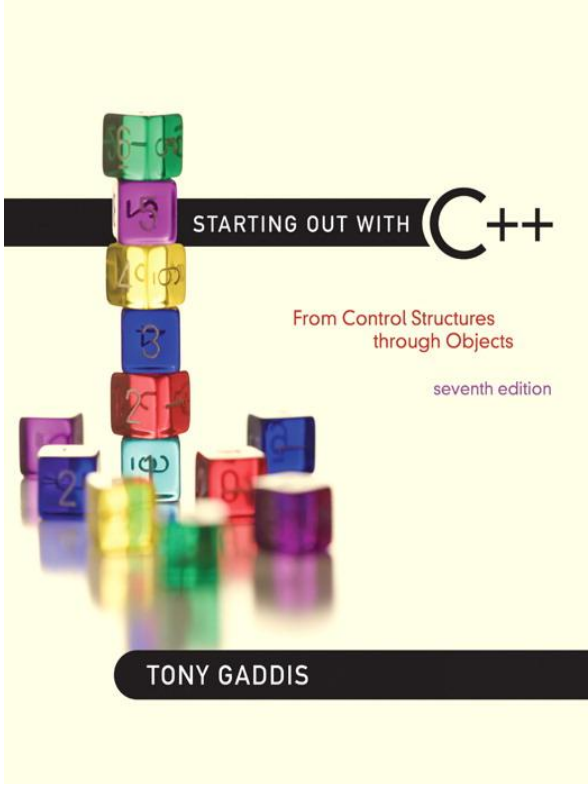
- Use as ordinary objects once defined

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

Standard Library container class	Description
Sequence containers	
`vector`	Rapid insertions and deletions at back. Direct access to any element.
`deque`	Rapid insertions and deletions at front or back. Direct access to any element.
`list`	Doubly linked list, rapid insertion and deletion anywhere.
Associative containers	
`set`	Rapid lookup, no duplicates allowed.
`multiset`	Rapid lookup, duplicates allowed.
`map`	One-to-one mapping, no duplicates allowed, rapid key-based lookup.
`multimap`	One-to-many mapping, duplicates allowed, rapid key-based lookup.

Standard Library container class	Description
Container adapters	
`stack`	Last-in, first-out (LIFO).
`queue`	First-in, first-out (FIFO).
`priority_queue`	Highest-priority element is always the first element out.

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 and values to allow data elements to be quickly accessed by searching.
  - These include set, multiset, map, and multimap

Member function	Description
default constructor	A constructor that initializes an empty container. Normally, each container has several constructors that provide different initialization methods for the container.
copy constructor	A constructor that initializes the container to be a copy of an existing container of the same type.
destructor	Destructor function for cleanup after a container is no longer needed.
`empty`	Returns `true` if there are no elements in the container; otherwise, returns `false`.
`insert`	Inserts an item in the container.
`size`	Returns the number of elements currently in the container.
`operator=`	Assigns one container to another.
`operator<`	Returns `true` if the contents of the first container is less than the second; otherwise, returns `false`.

Fig. 22.2 | Common member functions for most STL containers. (Part 1 of 3.)

Member function	Description
`operator<=`	Returns `true` if the contents of the first container is less than or equal to the second; otherwise, returns `false`.
`operator>`	Returns `true` if the contents of the first container is greater than the second; otherwise, returns `false`.
`operator>=`	Returns `true` if the contents of the first container is greater than or equal to the second; otherwise, returns `false`.
`operator==`	Returns `true` if the contents of the first container is equal to the second; otherwise, returns `false`.
`operator!=`	Returns `true` if the contents of the first container is not equal to the second; otherwise, returns `false`.
`swap`	Swaps the elements of two containers.

Fig. 22.2 | Common member functions for most STL containers. (Part 2 of 3.)

Member function	Description
Functions found only in first-class containers	
`max_size`	Returns the maximum number of elements for a container.
`begin`	The two versions of this function return either an `iterator` or a `const_iterator` that refers to the first element of the container.
`end`	The two versions of this function return either an `iterator` or a `const_iterator` that refers to the next position after the end of the container.
`rbegin`	The two versions of this function return either a `reverse_iterator` or a `const_reverse_iterator` that refers to the last element of the container.
`rend`	The two versions of this function return either a `reverse_iterator` or a `const_reverse_iterator` that refers to next position after the last element of the container.
`erase`	Erases one or more elements from the container.
`clear`	Erases all elements from the container.

Fig. 22.2 | Common member functions for most STL containers. (Part 3 of 3.)

Standard Library container headers	
`<vector>`	
`<list>`	
`<deque>`	
`<queue>`	Contains both `queue` and `priority_queue`.
`<stack>`	
`<map>`	Contains both `map` and `multimap`.
`<set>`	Contains both `set` and `multiset`.
`<valarray>`	
`<bitset>`	

Fig. 22.3 | Standard Library container headers.

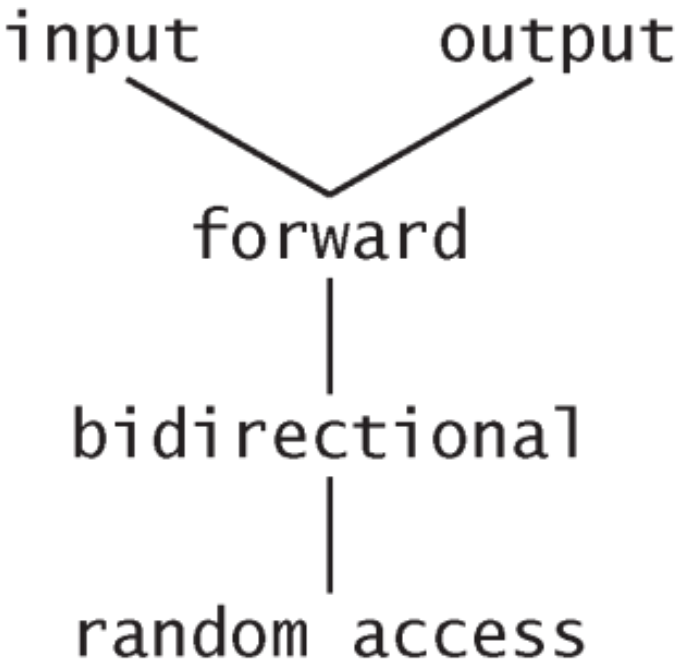
Iterators

- Generalization of pointers
  - used to access information in containers

- Five 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)

Category	Description
input	Used to read an element from a container. An input iterator can move only in the forward direction (i.e., from the beginning of the container to the end) one element at a time. Input iterators support only one-pass algorithms—the same input iterator cannot be used to pass through a sequence twice.
output	Used to write an element to a container. An output iterator can move only in the forward direction one element at a time. Output iterators support only one-pass algorithms—the same output iterator cannot be used to pass through a sequence twice.
forward	Combines the capabilities of *input and output iterators* and retains their position in the container (as state information).
bidirectional	Combines the capabilities of a *forward iterator* with the ability to move in the backward direction (i.e., from the end of the container toward the beginning). Bidirectional iterators support multipass algorithms.
random access	Combines the capabilities of a *bidirectional iterator* with the ability to directly access any element of the container, i.e., to jump forward or backward by an arbitrary number of elements.

Fig. 22.6 | Iterator categories.



Container	Type of iterator supported
Sequence containers (first class)	
`vector`	random access
`deque`	random access
`list`	bidirectional
Associative containers (first class)	
`set`	bidirectional
`multiset`	bidirectional
`map`	bidirectional
`multimap`	bidirectional

Fig. 22.8 | Iterator types supported by each container. (Part 1 of 2.)

Container	Type of iterator supported
Container adapters	
`stack`	no iterators supported
`queue`	no iterators supported
`priority_queue`	no iterators supported

Fig. 22.8 | Iterator types supported by each container. (Part 2 of 2.)

Container	Type of iterator supported
Container adapters	
`stack`	no iterators supported
`queue`	no iterators supported
`priority_queue`	no iterators supported

Fig. 22.8 | Iterator types supported by each container. (Part 2 of 2.)

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
```