Software Engineering 2 (C++)

CSY2006 (Week 18)

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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);
}
```

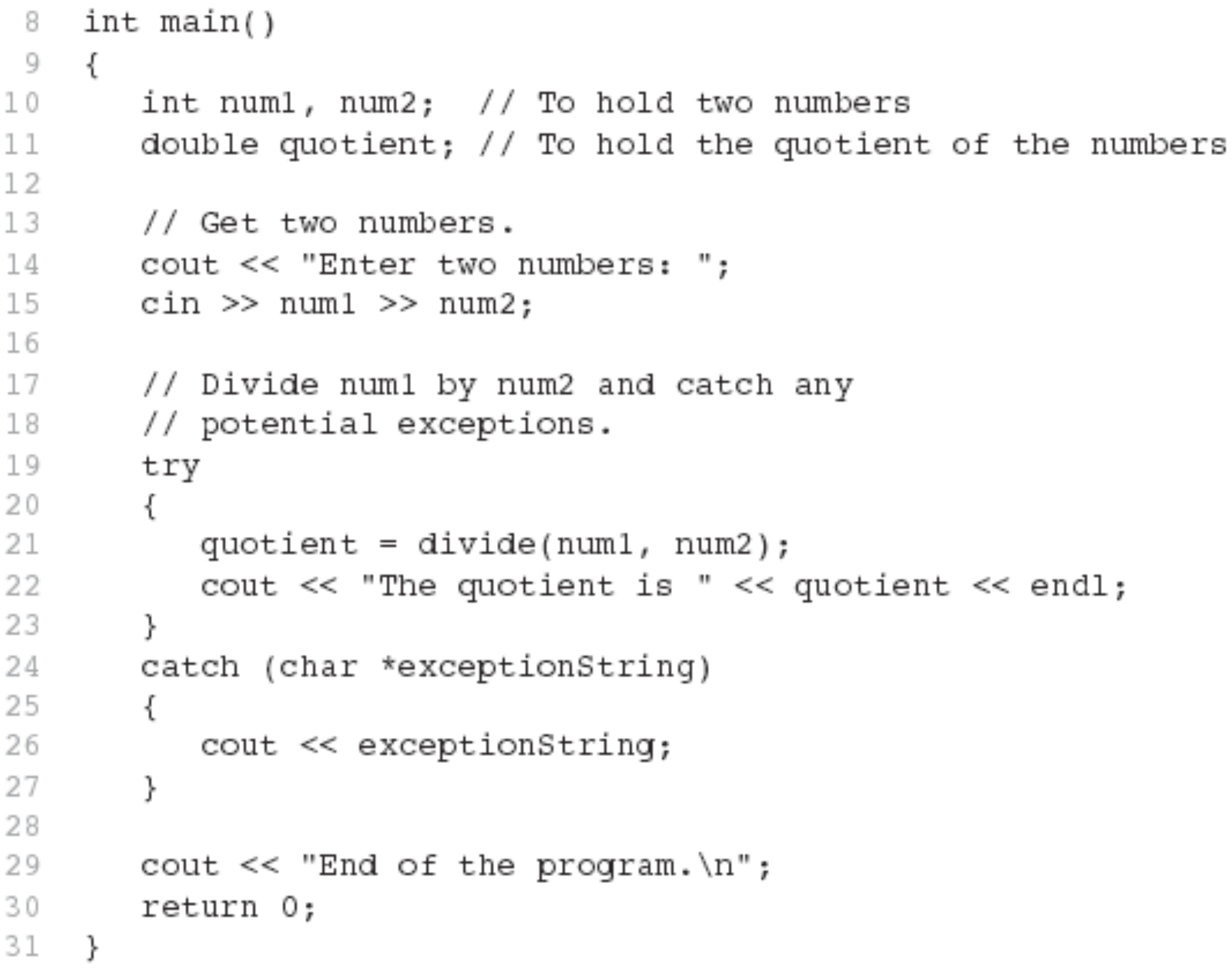
Exceptions – Example (2)

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

Exceptions – What Happens

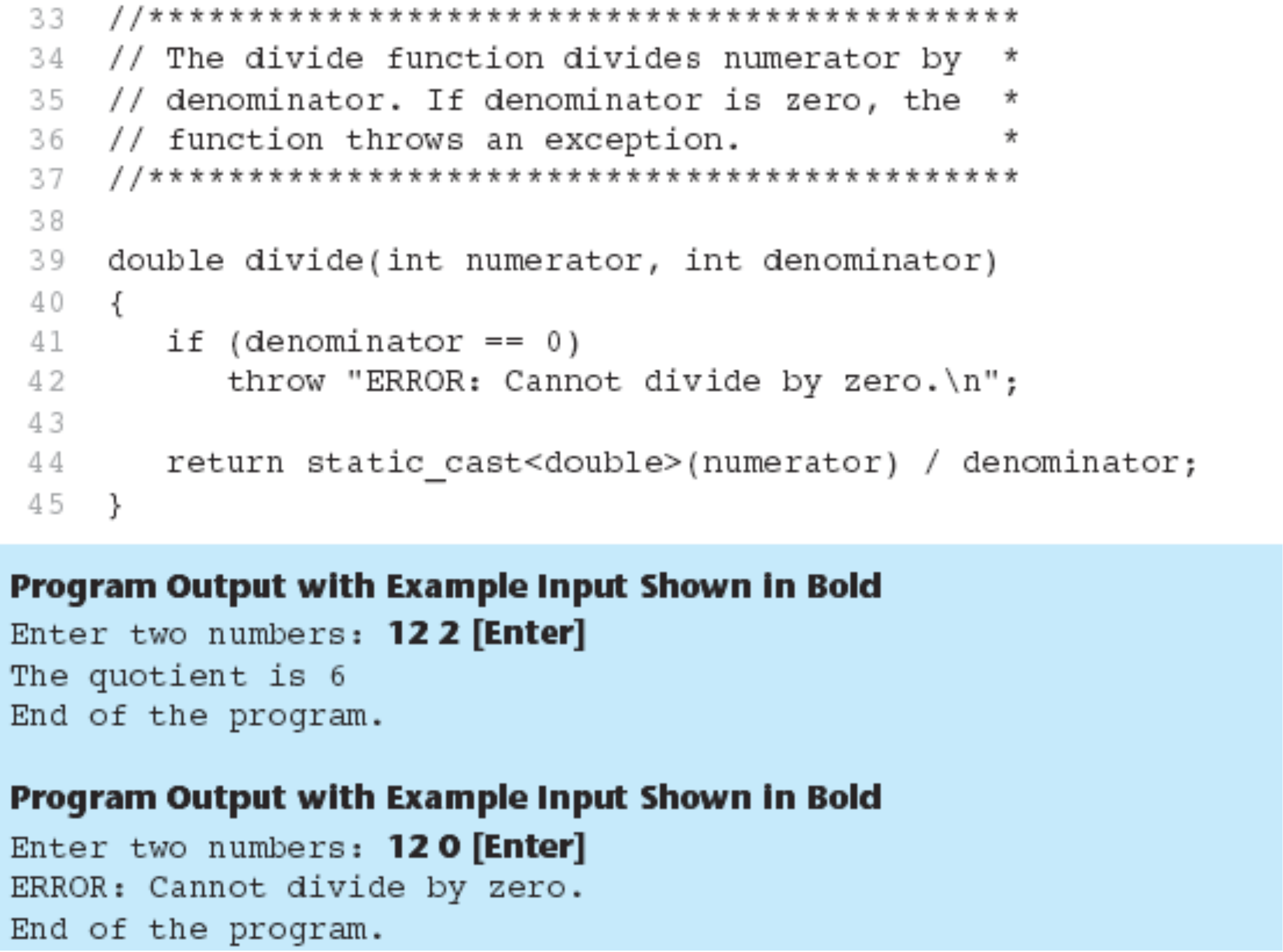
1) `try` block is entered. `totalDays` function is called
2) If 1st parameter is between 0 and 7, total number of days is returned and `catch` block is skipped over (no exception thrown)
3) If exception is thrown, function and `try` block are exited, `catch` blocks are scanned for 1st one that matches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

From Program 16-1



```
int main()
{
    int num1, num2;  // To hold two numbers
    double quotient; // To hold the quotient of the numbers

    // Get two numbers.
    cout << "Enter two numbers: ";
    cin >> num1 >> num2;

    // Divide num1 by num2 and catch any
    // potential exceptions.
    try
    {
        quotient = divide(num1, num2);
        cout << "The quotient is " << quotient << endl;
    }
    catch (char *exceptionString)
    {
        cout << exceptionString;
    }

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

From Program 16-1



```
//*****************************************************
// The divide function divides numerator by    *
// denominator. If denominator is zero, the    *
// function throws an exception.               *
//*****************************************************

double divide(int numerator, int denominator)
{
   if (denominator == 0)
      throw "ERROR: Cannot divide by zero.\n";

   return static_cast<double>(numerator) / denominator;
}
```

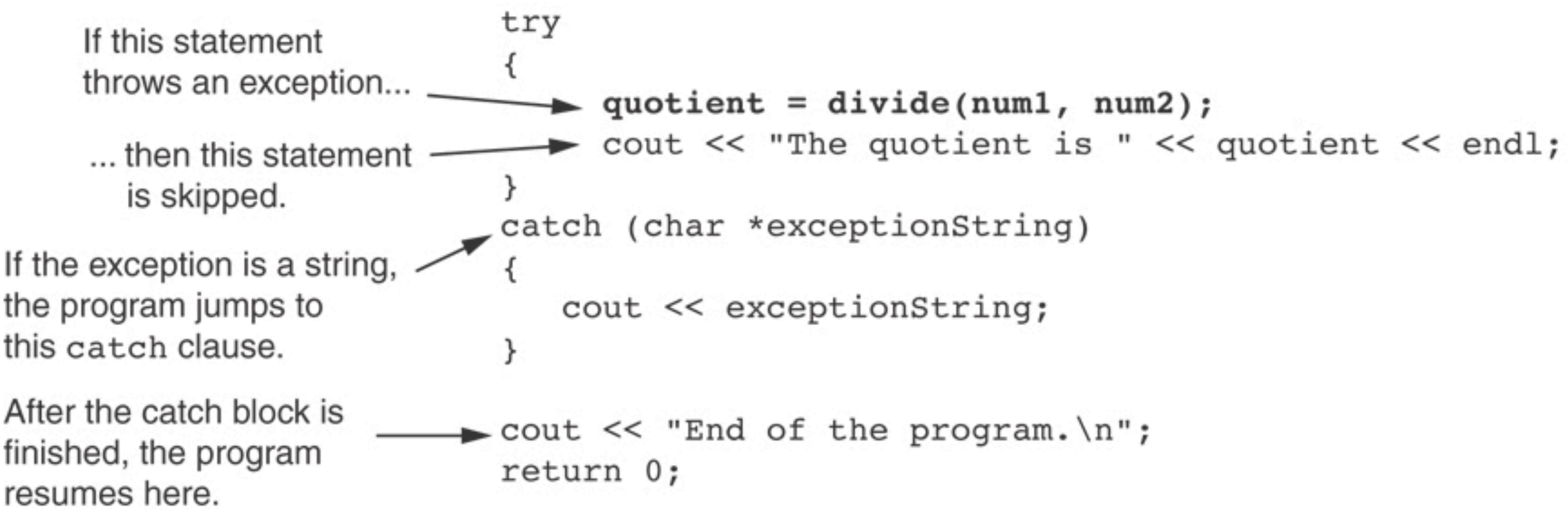
Program Output with Example Input Shown in Bold

```
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



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

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

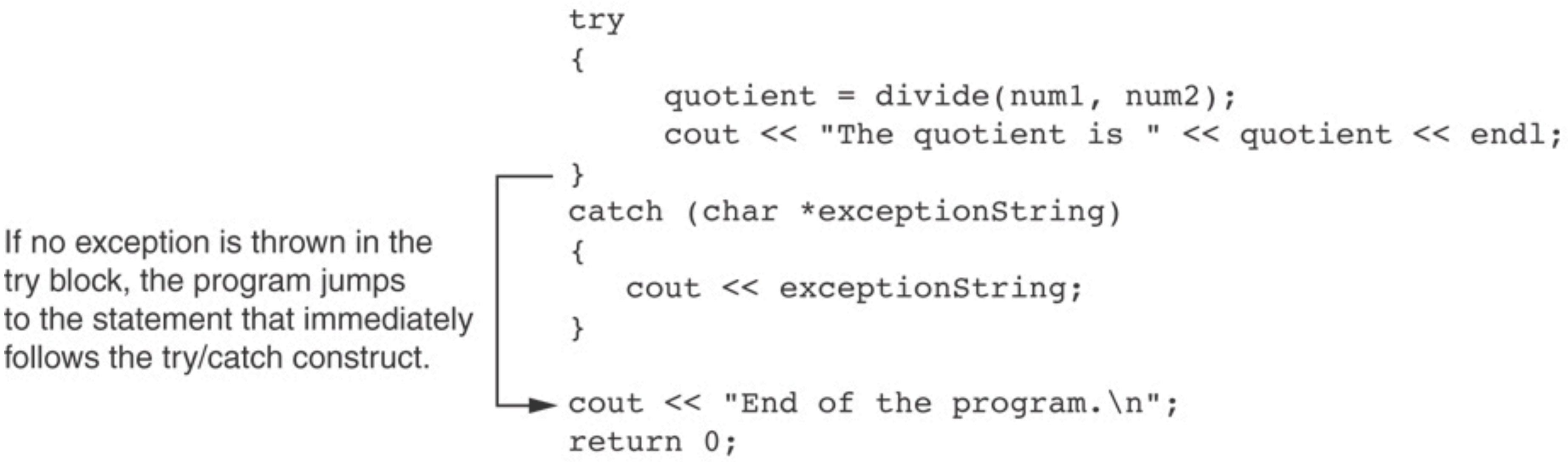
If this statement throws an exception...

... then this statement is skipped.

If the exception is a string, the program jumps to this catch clause.

After the catch block is finished, the program resumes here.

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

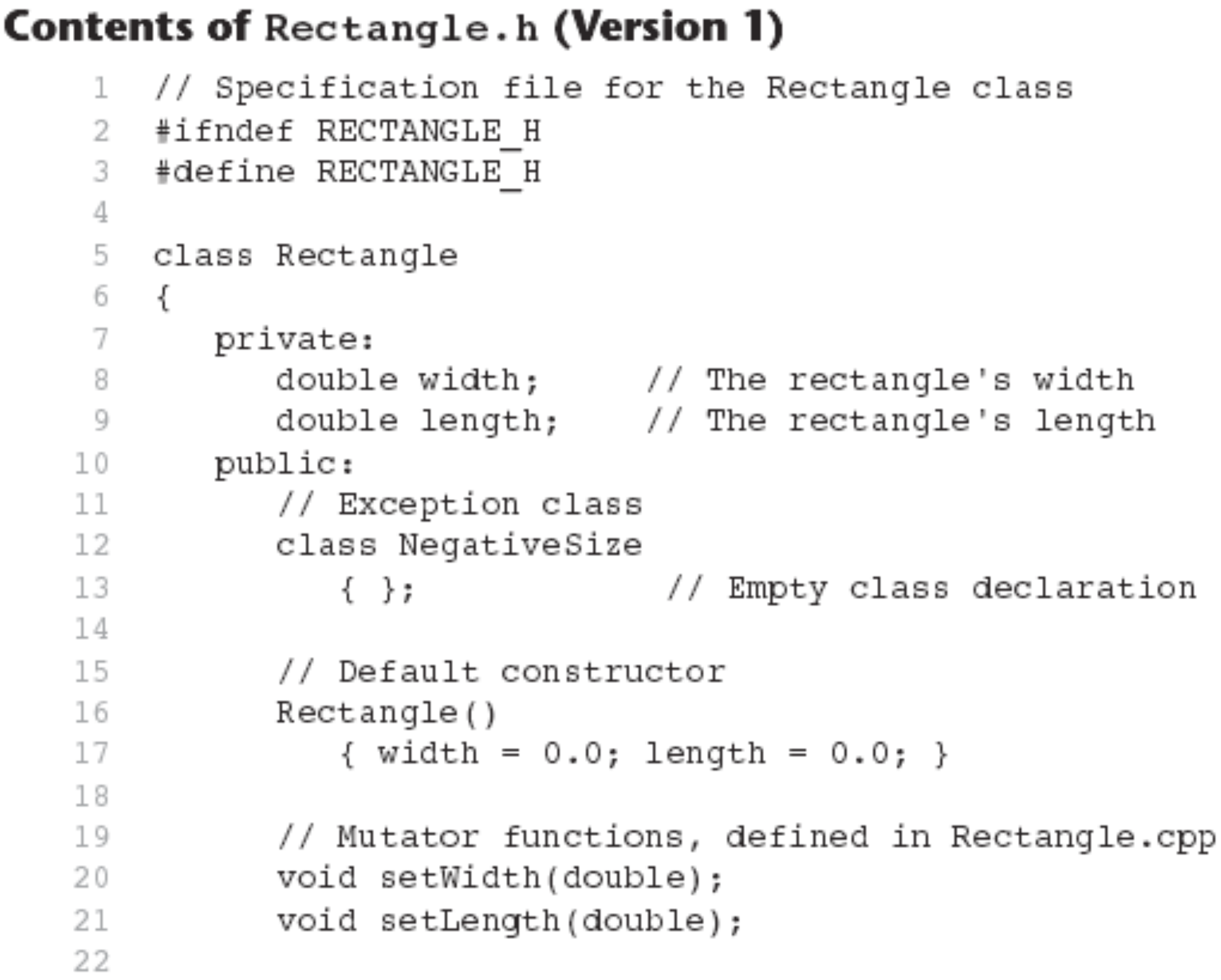
- Predefined functions such as `new` may throw exceptions
- The value that is thrown does not need to be used in `catch` block.
  - in this case, no name is needed in catch parameter definition
  - `catch` block parameter definition *does* need the type of exception being caught

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

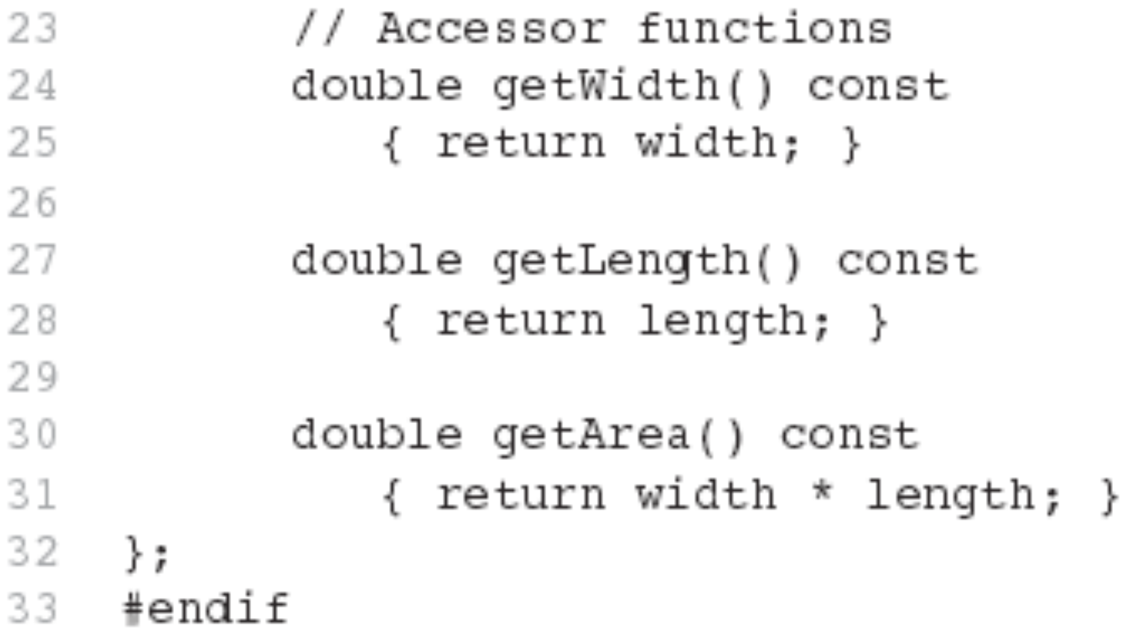
- An exception class can be defined in a class and thrown as an exception by a member function
- An exception class may have:
  - no members: used only to signal an error
  - members: pass error data to `catch` block
- A class can have more than one exception class



Contents of Rectangle.h (Version 1)

```
// Specification file for the Rectangle class
#ifndef RECTANGLE_H
#define RECTANGLE_H

class Rectangle
{
   private:
      double width;     // The rectangle's width
      double length;    // The rectangle's length
   public:
      // Exception class
      class NegativeSize
         { };            // Empty class declaration

      // Default constructor
      Rectangle()
         { width = 0.0; length = 0.0; }

      // Mutator functions, defined in Rectangle.cpp
      void setWidth(double);
      void setLength(double);

```

Contents of Rectangle.h (Version1) (Continued)



```
      // Accessor functions
      double getWidth() const
         { return width; }

      double getLength() const
         { return length; }

      double getArea() const
         { return width * length; }
};
#endif
```

Contents of Rectangle.cpp (Version 1)

```
// Implementation file for the Rectangle class.
#include "Rectangle.h"

//***********************************************************
// setWidth sets the value of the member variable width.   *
//***********************************************************

void Rectangle::setWidth(double w)
{
   if (w >= 0)
      width = w;
   else
      throw NegativeSize();
}

//***********************************************************
// setLength sets the value of the member variable length.  *
//***********************************************************

void Rectangle::setLength(double len)
{
   if (len >= 0)
      length = len;
   else
      throw NegativeSize();
}
```

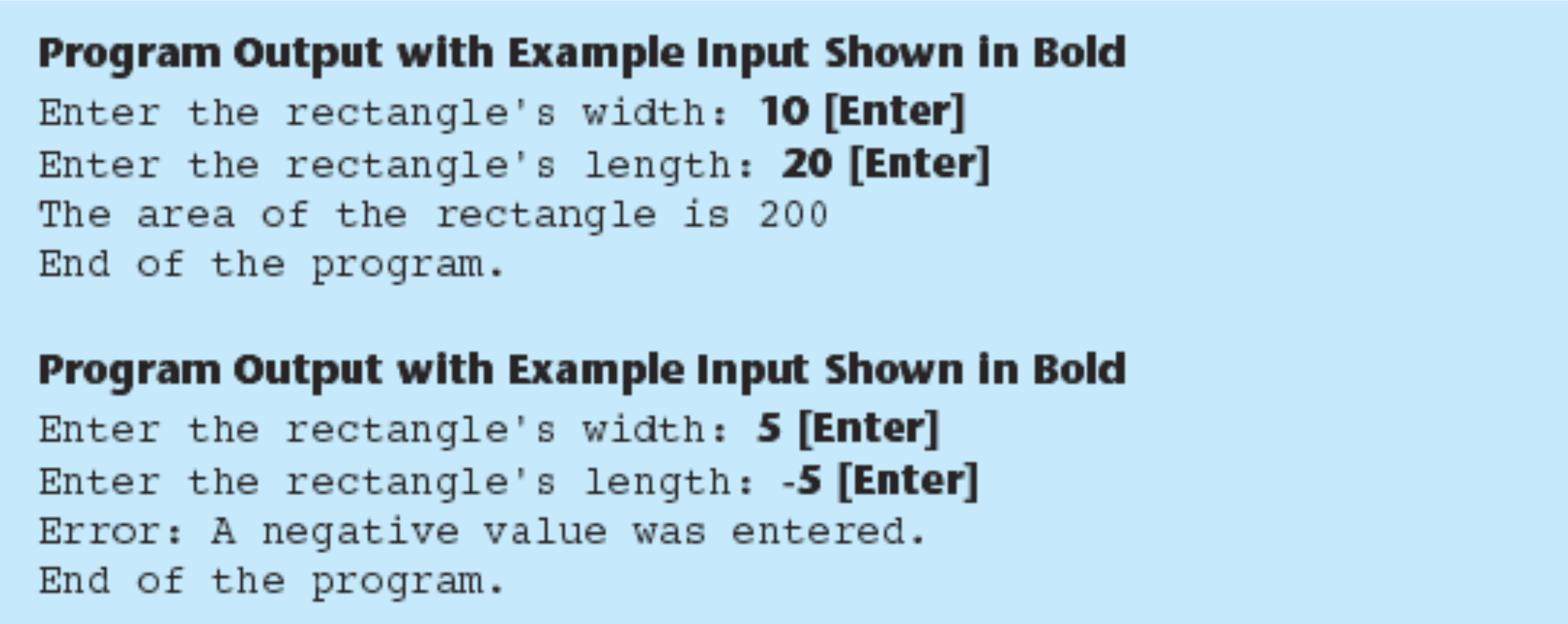
Program 16-2

```
// This program demonstrates Rectangle class exceptions.
#include <iostream>
#include "Rectangle.h"
using namespace std;

int main()
{
   int width;
   int length;

   // Create a Rectangle object.
   Rectangle myRectangle;

```

Program 16-2 *(continued)*

```
   // Get the width and length.
   cout << "Enter the rectangle's width: ";
   cin >> width;
   cout << "Enter the rectangle's length: ";
   cin >> length;

   // Store these values in the Rectangle object.
   try
   {
      myRectangle.setWidth(width);
      myRectangle.setLength(length);
      cout << "The area of the rectangle is "
           << myRectangle.getArea() << endl;
   }
   catch (Rectangle::NegativeSize)
   {
      cout << "Error: A negative value was entered.\n";
   }
   cout << "End of the program.\n";

   return 0;
}
```

Program 16-2 (Continued)



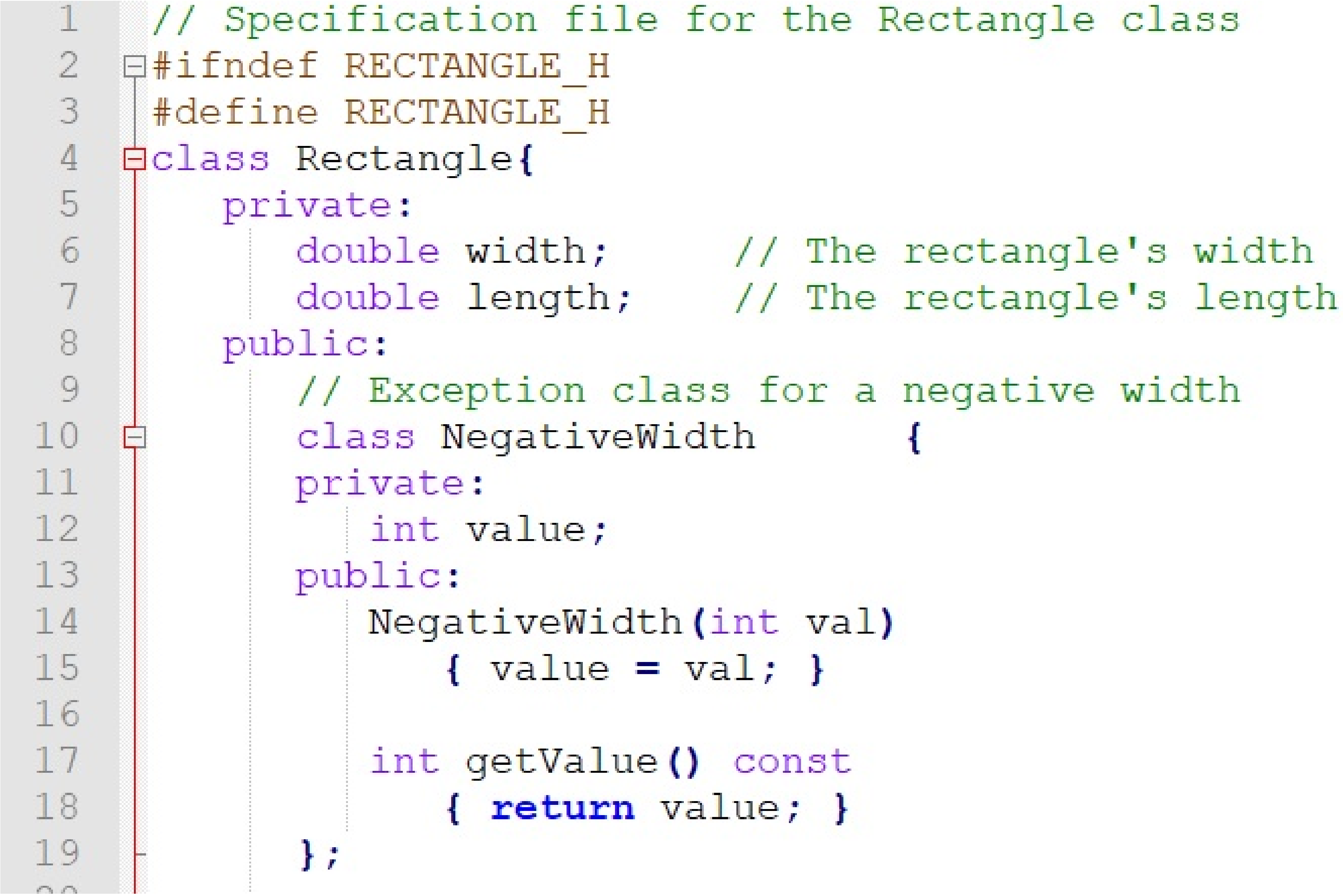
Program Output with Example Input Shown in Bold

```
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.
```

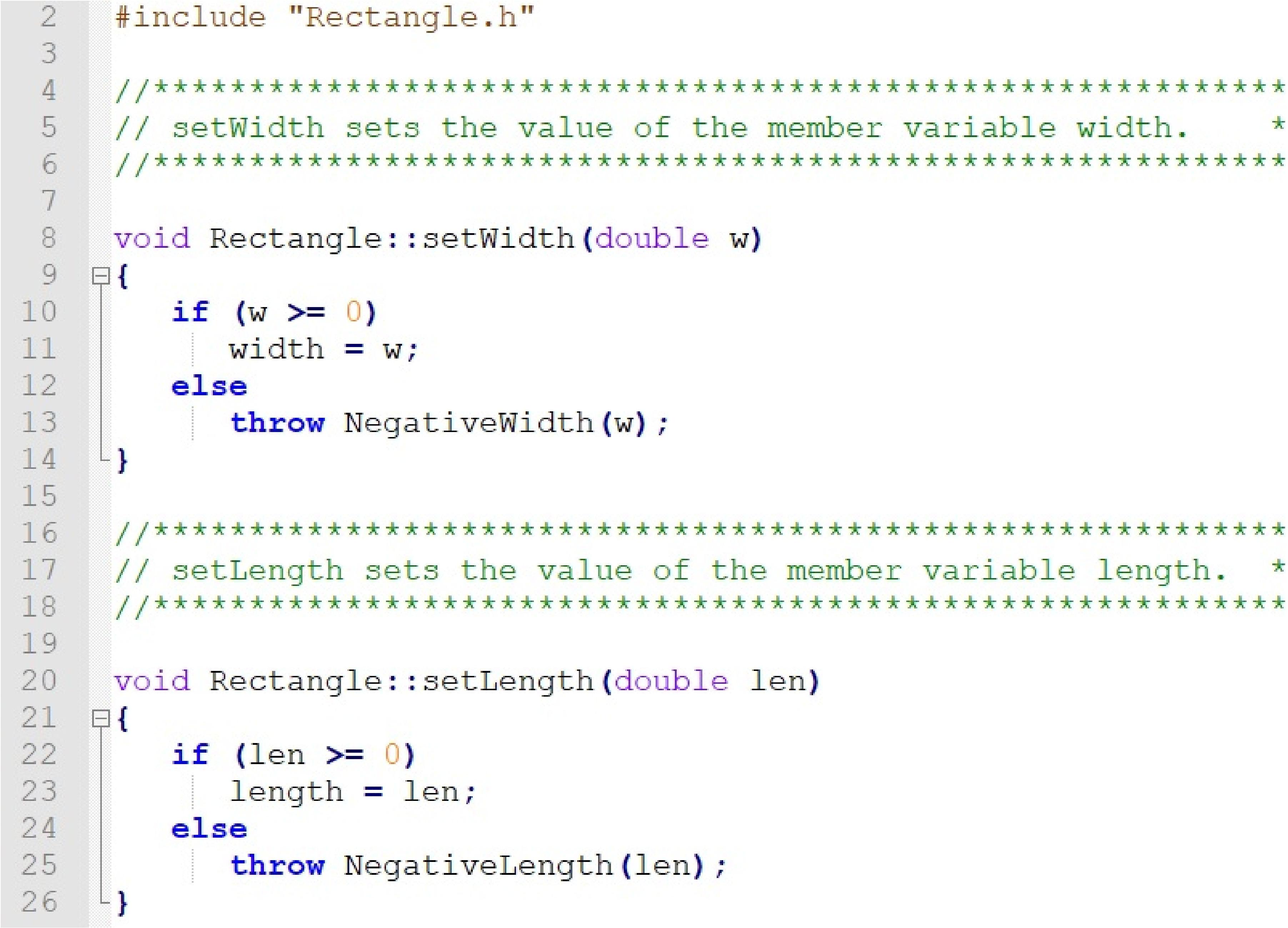
Program Output with Example Input Shown in Bold

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

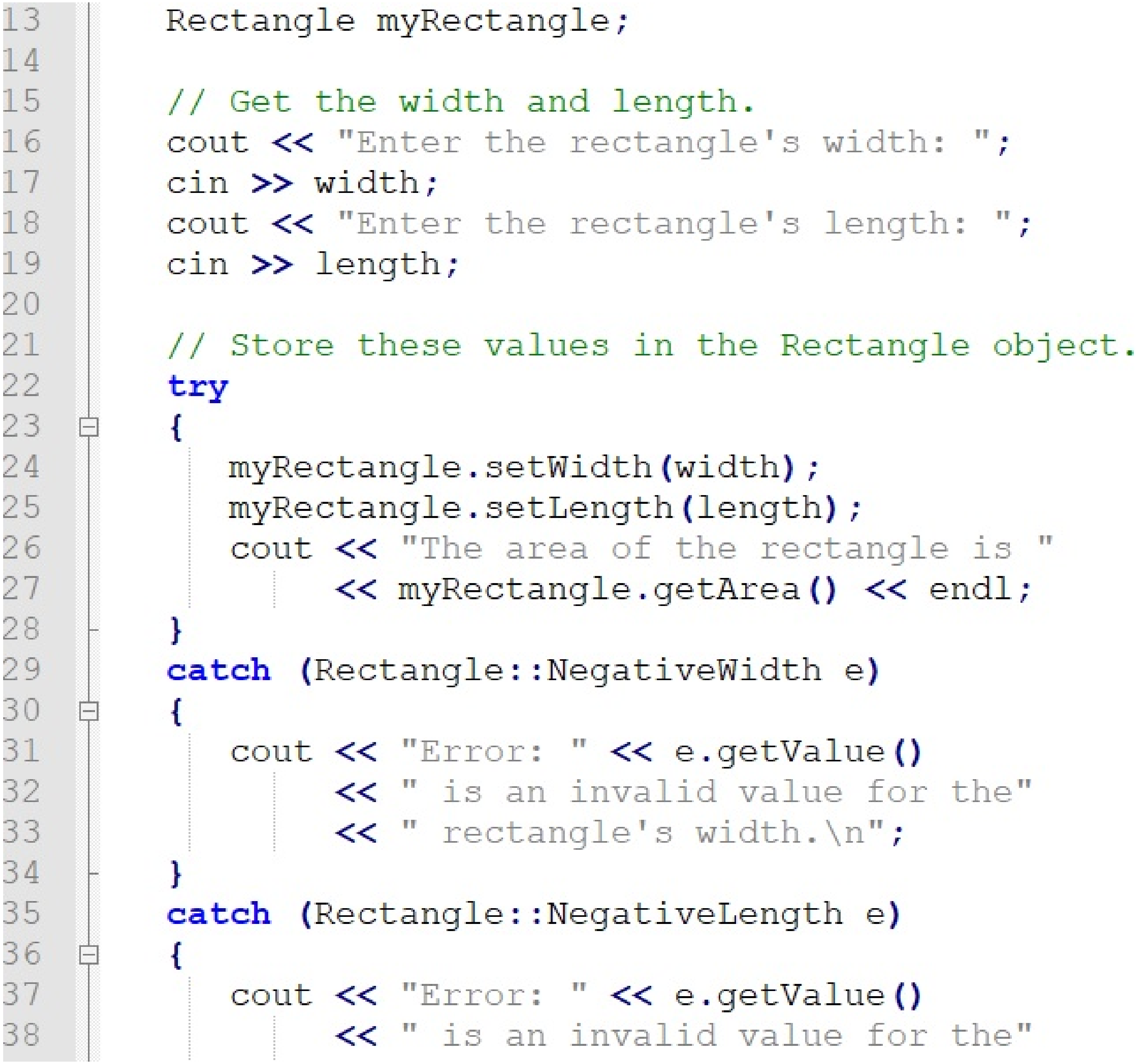
See: Pr 16-3: Multiple Exceptions (separate exception class for negative length, negative width)
Pr 16-4: Better Exception Handling
Pr 16-5: Passing parameter to Exception class



```
// Specification file for the Rectangle class
#ifndef RECTANGLE_H
#define RECTANGLE_H
class Rectangle{
   private:
      double width;     // The rectangle's width
      double length;    // The rectangle's length
   public:
      // Exception class for a negative width
      class NegativeWidth      {
      private:
         int value;
      public:
         NegativeWidth(int val)
            { value = val; }

         int getValue() const
            { return value; }
      };
```



```
#include "Rectangle.h"

//************************************************************
// setWidth sets the value of the member variable width.    *
//************************************************************

void Rectangle::setWidth(double w)
{
   if (w >= 0)
      width = w;
   else
      throw NegativeWidth(w);
}

//************************************************************
// setLength sets the value of the member variable length.  *
//************************************************************

void Rectangle::setLength(double len)
{
   if (len >= 0)
      length = len;
   else
      throw NegativeLength(len);
}
```



```
    Rectangle myRectangle;

    // Get the width and length.
    cout << "Enter the rectangle's width: ";
    cin >> width;
    cout << "Enter the rectangle's length: ";
    cin >> length;

    // Store these values in the Rectangle object.
    try
    {
       myRectangle.setWidth(width);
       myRectangle.setLength(length);
       cout << "The area of the rectangle is "
            << myRectangle.getArea() << endl;
    }
    catch (Rectangle::NegativeWidth e)
    {
       cout << "Error: " << e.getValue()
            << " is an invalid value for the"
            << " rectangle's width.\n";
    }
    catch (Rectangle::NegativeLength e)
    {
       cout << "Error: " << e.getValue()
            << " is an invalid value for the"
```

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
```

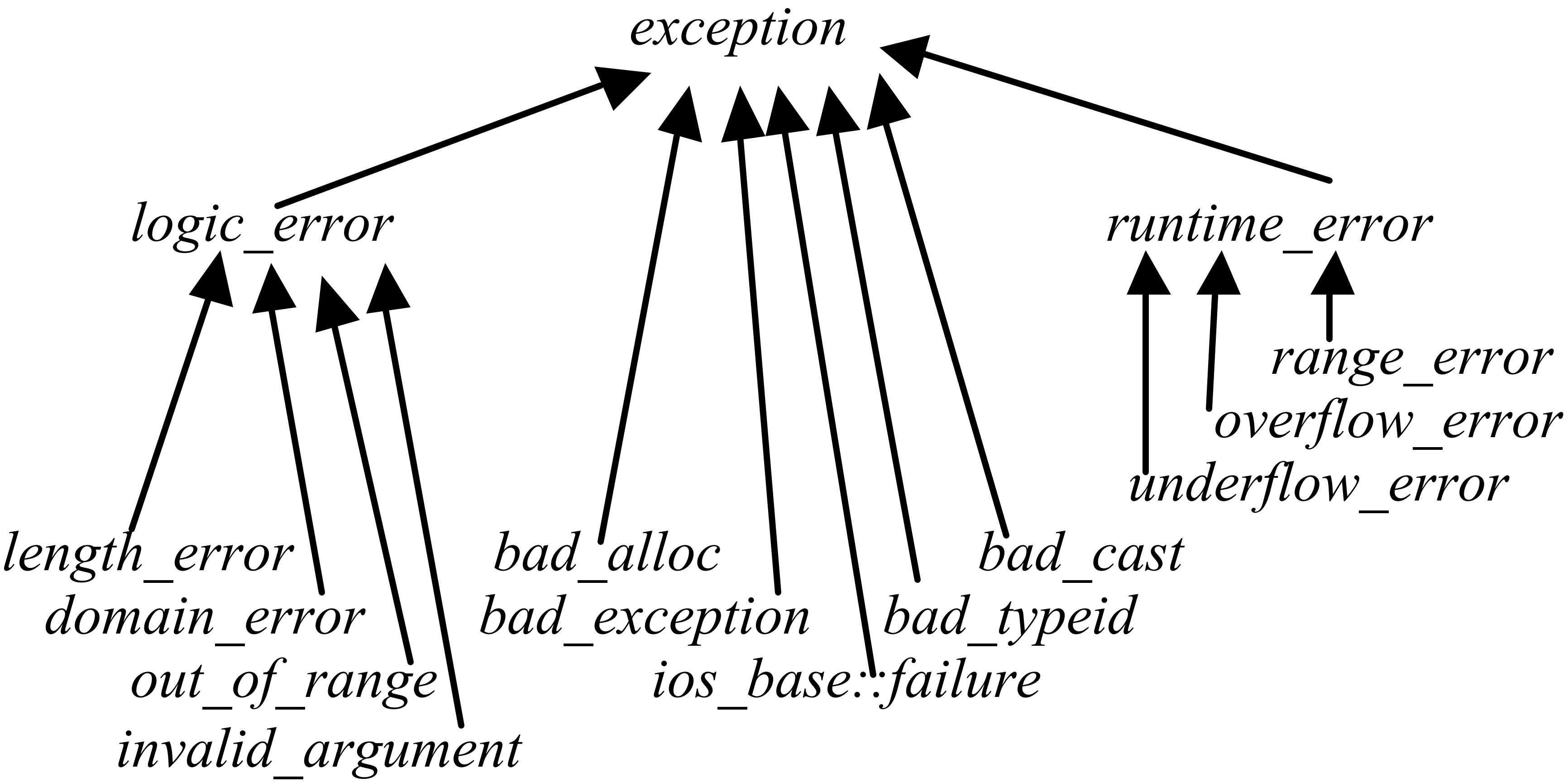
Testing Available Memory

- new operator throws bad_alloc exception if insufficient memory:

  ```
  try
  {
  	NodePtr pointer = new Node;
  }
  catch (bad_alloc)
  {
  	cout << "Ran out of memory!";
  	// Can do other things here as well…
  }
  ```

- In library <new>, std namespace
- See: Pr 16-6

Exceptions Hierarchy



exception

logic_error

runtime_error

length_error

domain_error

out_of_range

invalid_argument

bad_alloc

bad_exception

ios_base::failure

bad_typeid

bad_cast

range_error

overflow_error

underflow_error

Further Reading/Reference

- See Extra Resources Folder (NILE)
  - Exception Notes
  - Notes and Examples from comparison of Java versus C++

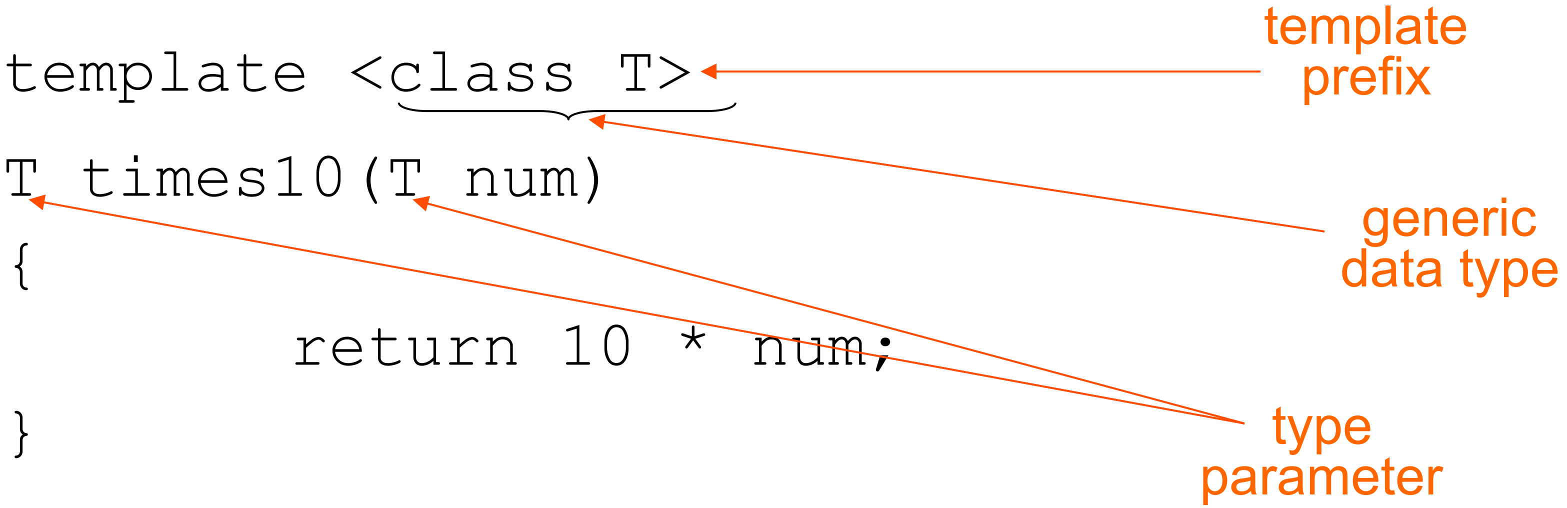
Function Templates

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

Examples: Pr 16-7 to Pr 16-10

Function Template Example



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

template prefix

generic data type

type parameter

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

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

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

More examples: Pr 16-11 and Pr 16-12 use user-defined class templates

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

See examples:

16-11 and 16-12 are implementations of user-defined class templates

16-13 to 16-19 are examples of uses of pre-defined templates (STL Library)

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

Introduction to the STL vector

Introduction to the STL vector

- A data type defined in the Standard Template Library
- Can hold values of any type:

```
vector<int> scores;
```

- Automatically adds space as more is needed – no need to determine size at definition
- Can use `[]` to access elements

See: examples Pr7-21 to Pr7-26

Declaring Vectors

- You must `#include<vector>`
- Declare a vector to hold `int` element:

```
vector<int> scores;
```

- Declare a vector with initial size 30:

```
vector<int> scores(30);
```

- Declare a vector and initialize all elements to 0:

```
vector<int> scores(30, 0);
```

- Declare a vector initialized to size and contents of another vector:

```
vector<int> finals(scores);
```

Adding Elements to a Vector

- Use `push_back` member function to add element to a full array or to an array that had no defined size:

```
scores.push_back(75);
```

- Use `size` member function to determine size of a vector:

```
howbig = scores.size();
```

Removing Vector Elements

- Use `pop_back` member function to remove last element from vector:

```
   scores.pop_back();
```

- To remove all contents of vector, use `clear` member function:

```
   scores.clear();
```

- To determine if vector is empty, use `empty` member function:

```
   while (!scores.empty()) ...
```

Other Useful Member Functions

Member Function	Description	Example
`at(elt)`	Returns the value of the element at position `elt` in the vector	`cout << vec1.at(i);`
`capacity()`	Returns the maximum number of elements a vector can store without allocating more memory	`maxelts = vec1.capacity();`
`reverse()`	Reverse the order of the elements in a vector	`vec1.reverse();`
`resize (elts,val)`	Add elements to a vector, optionally initializes them	`vec1.resize(5,0);`
`swap(vec2)`	Exchange the contents of two vectors	`vec1.swap(vec2);`

Miscellaneous
(Notes)

Exception Specification

- Functions that don’t catch exceptions
  - Should "warn" users that it could throw
  - But it won’t catch!
- Should list such exceptions:

```
double safeDivide(int top, int bottom)
                              throw (DividebyZero);
```

  - Called "exception specification" or "throw list"
  - Should be in declaration and definition
  - All types listed handled "normally"
  - If no throw list → all types considered there

Throw List

- If exception thrown in function NOT in throw list:
  - No errors (compile or run-time)
  - Function unexpected() automatically called
    - Default behavior is to terminate
    - Can modify behavior
- Same result if no catch-block found

Throw List Summary

- void someFunction()
  throw(DividebyZero, OtherException);
  //Exception types DividebyZero or OtherException
  //treated normally. All others invoke unexpected()
- void someFunction() throw ();
  //Empty exception list, all exceptions invoke unexpected()
- void someFunction();
  //All exceptions of all types treated normally

Derived Classes

- Remember: derived class objects also objects of base class
- Consider:
  D is derived class of B
- If B is in exception specification →
  - Class D thrown objects will also be treated normally, since it’s also object of class B
- Note: does not do automatic type cast:
  - double will not account for throwing an int

unexpected()

- Default action: terminates program
  - No special includes or using directives
- Normally no need to redefine
- But you can:
  - Use set_unexpected
  - Consult compiler manual or advanced text for details

When to Throw Exceptions

- Typical to separate throws and catches
  - In separate functions
- Throwing function:
  - Include throw statements in definition
  - List exceptions in throw list
    - In both declaration and definition
- Catching function:
  - Different function, perhaps even in different file

Preferred throw-catch Triad: throw

-
  ```
  void functionA() throw (MyException)
  {
      …
      throw MyException(arg);
      …
  }
  ```

- Function throws exception as needed

Preferred throw-catch Triad: catch

- Then some other function:

```
void functionB()
{
        …
        try
        {
                …
                functionA();
                …
        }
        catch (MyException e)
        { // Handle exception
        }
        …
}
```

Uncaught Exceptions

- Should catch every exception thrown
- If not → program terminates
  - terminate() is called
- Recall for functions
  - If exception not in throw list: unexpected() is called
    - It in turn calls terminate()
- So same result

Overuse of Exceptions

- Exceptions alter flow of control
  - Similar to old "goto" construct
  - "Unrestricted" flow of control
- Should be used sparingly
- Good rule:
  - If desire a "throw": consider how to write program without throw
  - If alternative reasonable → do it

Exception Class Hierarchies

- Useful to have; consider:
  DivideByZero class derives from:

  ArithmeticError exception class
  - All catch-blocks for ArithmeticError also catch DivideByZero
  - If ArithmeticError in throw list, then DividebyZero also considered there

Testing Available Memory

- new operator throws bad_alloc exception if insufficient memory:

  ```
  try
  {
        NodePtr pointer = new Node;
  }
  catch (bad_alloc)
  {
        cout << "Ran out of memory!";
        // Can do other things here as well…
  }
  ```

- In library <new>, std namespace

Rethrowing an Exception

- Legal to throw exception IN catch-block!
  - Typically only in rare cases
- Throws to catch-block "farther up chain"
- Can re-throw same or new exception
  - rethrow;
    - Throws same exception again
  - throw newExceptionUp;
    - Throws new exception to next catch-block

Summary 1

- Exception handling allows separation of "normal" cases and "exceptional" cases
- Exceptions thrown in try-block
  - Or within a function whose call is in try-block
- Exceptions caught in catch-block
- try-blocks typically followed by more than one catch-block
  - List more specific exceptions first

Summary 2

- Best used with separate functions
  - Especially considering callers might handle differently
- Exceptions thrown in but not caught in function, should be listed in throw list
- Exceptions thrown but never caught → program terminates
- Resist overuse of exceptions
  - Unrestricted flow of control