Chapter 18

Exception Handling

Learning Objectives

- Exception Handling Basics
  - Defining exception classes
  - Multiple throws and catches
  - Exception specifications
- Programming Techniques for Exception Handling
  - When to throw exceptions
  - Exception class hierarchies

Introduction

- Typical approach to development:
  - Write programs assuming things go as planned
  - Get "core" working
  - Then take care of "exceptional" cases
- C++ exception-handling facilities
  - Handle "exceptional" situations
  - Mechanism "signals" unusual happening
  - Another place in code "deals" with exception

Exception-Handling Basics

- Meant to be used sparingly
  - In "involved" situations
- Difficult to teach such large examples
- Approach:
  - Simple toy examples, that would not normally use exception-handling
  - Keep in mind "big picture"

Toy Example

- Imagine: people rarely run out of milk:

```
cout << "Enter number of donuts:";
cin >> donuts;
cout << "Enter number of glasses of milk:";
cin >> milk;
dpg = donuts/static_cast<double>(milk);
cout       << donuts << "donuts.\n";
           << milk << "glasses of milk.\n";
           << "You have " << dpg
           << "donuts for each glass of milk.\n";
```

- Basic code assumes never run out of milk

Toy Example if-else

- Notice: If no milk→divide by zero error!
- Program should accommodate unlikely situation of running out of milk
  - Can use simple if-else structure:

```
if (milk <= 0)
 cout << "Go buy some milk!\n";
else
 {…}
```

- Notice: no exception-handling here

Toy Example with Exception Handling: **Display 18.2** Same Thing Using Exception Handling

```
 9       try
10       {
11           cout << "Enter number of donuts:\n";
12           cin >> donuts;
13           cout << "Enter number of glasses of milk:\n";
14           cin >> milk;
15
16           if (milk <= 0)
17                 throw donuts;

18           dpg = donuts/static_cast<double>(milk);
19           cout << donuts << " donuts.\n"
20                << milk << " glasses of milk.\n"
21                << "You have " << dpg
22                << " donuts for each glass of milk.\n";
23       }
24       catch(int e)
25       {
26           cout << e << " donuts, and No Milk!\n"
27                << "Go buy some milk.\n";
28       }
```

Toy Example Discussion

- Code between keywords *try* and *catch*
  - Same code from ordinary version, except if statement simpler:

```
if (milk <= 0)
 throw donuts;
```

  - Much cleaner code
  - If "no milk" → do something exceptional
- The "something exceptional" is provided after keyword *catch*

Toy Example try-catch

- Try block
  - Handles "normal" situation
- Catch block
  - Handles "exceptional" situations
- Provides separation of normal from exceptional
  - Not big deal for this simple example, but important concept

try block

- Basic method of exception-handling is try-throw-catch
- Try block:

```
try
{
    Some_Code;
}
```

  - Contains code for basic algorithm when all goes smoothly

throw

- Inside try-block, when something unusual happens:

```
try
{
    Code_To_Try
    if (exceptional_happened)
        throw donuts;
    More_Code
}
```

  - Keyword *throw* followed by exception type
  - Called "throwing an exception"

catch-block

- When something thrown → goes somewhere
  - In C++, flow of control goes from try-block to catch-block
    - try-block is "exited" and control passes to catch-block
  - Executing catch block called "catching the exception"
- Exceptions must be "handled" in some catch block

catch-block More

- Recall:

```
catch(int e)
{
    cout << e << " donuts, and no milk!\n";
         << " Go buy some milk.\n";
}
```

- Looks like function definition with int parameter!
  - Not a function, but works similarly
  - Throw like "function call"

catch-block Parameter

- Recall: catch(int e)
- "e" called catch-block parameter
  - Each catch block can have at most ONE catch-block parameter
- Does two things:
  1. type name specifies what kind of thrown value the catch-block can catch
  2. Provides name for thrown value caught; can "do things" with value

Defining Exception Classes

- throw statement can throw value of any type
- Exception class
  - Contains objects with information to be thrown
  - Can have different types identifying each possible exceptional situation
  - Still just a class
    - An "exception class" due to how it's used

Exception Class for Toy Example

- Consider:

```
class NoMilk
{
public:
    NoMilk() { }
    NoMilk(int howMany) : count(howMany) { }
    int getcount() const { return count; }
private:
    int count;
};
```

- throw NoMilk(donuts);
  - Invokes constructor of NoMilk class

Multiple Throws and Catches

- try-block typically throws any number of exception values, of differing types
- Of course only one exception thrown
  - Since throw statement ends try-block
- But different types can be thrown
  - Each catch block only catches "one type"
  - Typical to place many catch-blocks after each try-block
    - To catch "all-possible" exceptions to be thrown

Catching

- Order of catch blocks important
- Catch-blocks tried "in order" after try-block
  - First match handles it!
- Consider:
  catch (…) { }
  - Called "catch-all", "default" exception handler
  - Catches any exception
  - Ensure catch-all placed AFTER more specific exceptions!
    - Or others will never be caught!

Trivial Exception Classes

- Consider:

```
class DivideByZero
{ }
```

- No member variables
- No member functions (except default constructor)
- Nothing but it’s name, which is enough
  - Might be "nothing to do" with exception value
  - Used simply to "get to" catch block
  - Can omit catch block parameter

Throwing Exception in Function

- Function might throw exception
- Callers might have different "reactions"
  - Some might desire to "end program"
  - Some might continue, or do something else
- Makes sense to "catch" exception in calling function's try-catch-block
  - Place call inside try-block
  - Handle in catch-block after try-block

Throwing Exception in Function Example

- Consider:

```
try
{
    quotient = safeDivide(num, den);
}
catch (DivideByZero)
{ … }
```

- safeDivide() function throws DividebyZero exception
  - Handled back in caller's catch-block

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

Example – High Score

- Throwing an exception in a function is especially helpful when the exception has no relation to the return value of the function.
- Consider a function that scans through a text file of high scores and returns the highest score.
  - What should the function return if the file cannot be opened?
  - One strategy is to return a special value, such as a negative number.

High Score – No Exception Handling (1 of 3)

```
// Program that outputs the high score from a high scores file.
// Does not use exception handling.
#include <iostream>
#include <fstream>
#include <string>
using std::cout;
using std::endl;
using std::ifstream;

//Function prototypes
int getHighscore();
```

High Score – No Exception Handling (2 of 3)

```
// Returns the high score in the scores.txt file
int getHighscore()
{
  ifstream f;
  int high = -1;

  f.open("scores.txt");
  // Check if the file did not open
  if (f.fail())
  {
        cout << "File could not be opened." << endl;
        return -1;
  }
  int num;
  // Scan through each number in the file and return the largest
  f >> high;
  while (f >> num)
  {
        if (num > high)
              high = num;
  }
  f.close();
  return high;
}
```

High Score – No Exception Handling (3 of 3)

```
int main()
{
  int highscore = getHighscore();
  cout << "The high score is " << highscore << endl;
  return 0;
}
```

Sample Dialogue 1 (file exists with values 10, 50, 30)

```
The high score is 50
```

Sample Dialogue 2 (the file does not exist)

```
File could not be opened.
The high score is -1
```

But what if negative scores are possible? No way to distinguish high scores from no scores!

High Score Solution – Throw Exception (1 of 3)

- Throw an exception if there is an IO error and catch it in main

```
// Program that outputs the high score from a high scores
file.
// Uses exception handling.
#include <iostream>
#include <fstream>
#include <string>
using std::cout;
using std::endl;
using std::ifstream;

class FileIOError
{};

//Function prototypes
int getHighscore() throw (FileIOError);
```

High Score Solution – Throw Exception (2 of 3)

```
/ Returns the high score in the scores.txt file
// but throws an exception if the file could not be opened.
// This eliminates possible confusion over the return value.
int getHighscore() throw (FileIOError)
{
  ifstream f;
  int high = -1;

  f.open("cores.txt");
  // Check if the file did not open
  if (f.fail())
  {
        throw FileIOError();
  }
  int num;
  // Scan through each number in the file and return the largest
  f >> high;
  while (f >> num)
  {
        if (num > high)
              high = num;
  }
  f.close();
  return high;
}
```

High Score Solution – Throw Exception (3 of 3)

```
int main()
{
  try
  {
    int highscore = getHighscore();
    cout << "The high score is " << highscore << endl;
  }
  catch (FileIOError)
  {
    cout << "Could not open the scores file." << endl;
  }
  return 0;
}
```

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