Creative Software Programming

13– Exception Handling

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Today's Topics

- What are Exceptions & How to deal with Exceptions?
- C++ Exceptions: Basics
- try, catch, and throw
- Matching Catch Handlers
- Uncaught Exceptions
- Cleaning Up
- Unwinding the stack

Exceptions

- Exceptions are anomalous or ***exceptional situations*** requiring special processing – often changing the normal flow of program execution[wikipedia]
  - Memory allocation error
    - out of memory space
  - Divide by zero
    -
```
double x = 2.0;
double y = -2.0;
double harmonic_mean = 2.0 * (x * y) / (x + y);
```
  - File IO error
    - Try to open an unavailable file

How to Deal with Exceptions?

- Ignore them
  - Wrong thing to do for all but demo programs
- Abort processing
  - Detect but don't try to recover
  -
```
double harmonic_mean(double a, double b) {
  if (a == -b) {
    std::cout << "wrong arguments\n";
    std::abort();
  }
  return 2.0 * a * b / (a +
}
```
```
$ ./harmonic_mean
wrong arguments
Aborted (core dumped)
```
  - A little bit better, but still wrong for all but demo programs

How to Deal with Exceptions?

- **Returning error values**

```
ret = PerformTask()
If ret is 0 (or some error codes)
      Perform error processing

ret2 = PerformTask2()
If ret2 is 0 (or some error codes)
      Perform error processing
```

```
bool harmonic_mean(double a, double b,
                   double* ans) {
  if (a == -b){
    *ans = DBL_MAX;
    return false;
  } else{
    *ans = 2.0 * a * b / (a + b);
    return true;
  }
}
```

  - Difficult to read, modify, maintain and debug
    - Easy to miss a check
  - Impacts performance
    - Constantly spending CPU cycles looking for rare events
  - Traditional approach
    - e.g. malloc(), fopen() of C

How to Deal with Exceptions?

- **Use C++ Exceptions**
  - ```
    try {
       // protected code
    } catch( ExceptionName e1 ) {
       // catch block
    }
    ```
  - More maintainable
  - (Usually) More efficient: zero-cost model (popular strategy for major compilers):
    - if no exceptions are thrown, there's NO overhead.
    - if exceptions are thrown, there's more overhead to process them.
  - Modern approach
    - e.g. new, ifstream::open() of C++
    ```

C++ Exceptions: Basic

```
#include <iostream>
using namespace std;

double Division(int a, int b) {
  if (b == 0) {
    throw "Division by zero condition!";
  }
  return (a / (double) b);
}

int main () {
  int x, y;
  double z;
  cin >> x >> y;

  try {
    z = Division(x, y);
    cout << z << endl;
  }
  catch (const char* msg) {
    cerr << msg << endl;
  }
  return 0;
}
```

C++ Exceptions: Basic

```
#include <iostream>
using namespace std;

double Division(int a, int b) {
  if (b == 0) {
    throw "Division by zero condition!";
  }
  return (a / (double) b);
}

int main () {
  int x, y;
  double z;
  cin >> x >> y;

  try {
    z = Division(x, y);
    cout << z << endl;
  }
  catch (const char* msg) {
    cerr << msg << endl;
  }
  return 0;
}
```

- For a normal case (e.g. y != 0),
  1. All code in the try block is executed.
  2. Catch block is skipped.
  3. Computation resumes after the catch block.

C++ Exceptions: Basic

```
#include <iostream>
using namespace std;

double Division(int a, int b) {
  if (b == 0) {
    throw "Division by zero condition!";
  }
  return (a / (double) b);
}

int main () {
  int x, y;
  double z;
  cin >> x >> y;

  try {
    z = Division(x, y);
    cout << z << endl;
  }
  catch (const char* msg) {
    cerr << msg << endl;
  }
  return 0;
}
```

- For an exceptional case (e.g. y==0),
  1. **"Throw"** an exception.
  2. Remaining code in the try block is **skipped**.
  3. **Based on the type of the exception**, the matching catch block is executed, if found.
  4. Computation resumes after the last catch block.

C++ Exceptions: Basic

```
void SomeFunc1(){
   ...
   throw SomeException();  // when an exception occurs
   ...
}

void SomeFunc2() {
   try {
      // some code that may throw an exception
      SomeFunc1();
   }
   catch(SomeException &e) {
      // some processing to attempt to recover from error
   }
}
```

try, catch, and throw

```
#include <iostream>
using namespace std;

double Division(int a, int b) {
  if (b == 0) {
    throw "Division by zero condition!";
  }
  return (a / (double) b);
}

int main () {
  int x, y;
  double z;
  cin >> x >> y;

  try {
    z = Division(x, y);
    cout << z << endl;
  }
  catch (const char* msg) {
    cerr << msg << endl;
  }
  return 0;
}
```

- **try {…}:**
  - Consists of codes that may "throw" exceptions
  - Groups one or more statements that may throw with one or more catch blocks

try, catch, and throw

```
#include <iostream>
using namespace std;

double Division(int a, int b) {
  if (b == 0) {
    throw "Division by zero condition!";
  }
  return (a / (double) b);
}

int main () {
  int x, y;
  double z;
  cin >> x >> y;

  try {
    z = Division(x, y);
    cout << z << endl;
  }
  catch (const char* msg) {
    cerr << msg << endl;
  }
  return 0;
}
```

- **catch(E e) {…}:**
  - Catchs the exception of the given type, thrown from a throw statement inside try block
  - Exception type can be any built-in type or user-defined class
  - Exceptions are handled inside the catch block

try, catch, and throw

```
#include <iostream>
using namespace std;

double Division(int a, int b) {
  if (b == 0) {
    throw "Division by zero condition!";
  }
  return (a / (double) b);
}

int main () {
  int x, y;
  double z;
  cin >> x >> y;

  try {
    z = Division(x, y);
    cout << z << endl;
  }
  catch (const char* msg) {
    cerr << msg << endl;
  }
  return 0;
}
```

- **throw e:**
  - "Throw" an exception
  - Exception type can be any built-in type or user-defined class
  - Program immediately jumps to the matching catch block

Matching Catch Handlers

- A catch handler matches an exception based on its type.

- A try block can be followed by multiple catch blocks.
  - Matching attempts are performed in the order of catch handler declaration.

```
try {
  // some code that may throw an exception
}
catch(T1 t1) {
  // processing for type T1
}
catch(T2 t2) {
 // processing for type T2
}
```

```cpp
#include <iostream>
#include <string>
using namespace std;

double Division(int a, int b) {
  if (b == 0) {
    throw -1;                          // "catch int"
    // throw "exception";               // "catch const char*"
    // throw string("exception");       // "catch string&"
  }
  return (a / (double) b);
}

int main () {
  int x, y;
  cin >> x >> y;

  try {
    double z = Division(x, y);
    cout << z << endl;
  }
  catch (int e) {
    cout << "catch int " << e << endl;
  }
  catch (const char* e) {
    cout << "catch const char* " << e << endl;
  }
  catch (string& e) {
    cout << "catch string& " << e << endl;
  }
  return 0;
}
```

Matching Catch Handlers

- The conventional way to throw and catch exceptions is:
  - throw an exception **object**
  - catch it by **reference** (or const reference)

- A **derived class object** can be caught by **base class reference**.
  - But the opposite does not work.
  - Caution: If a derived class object is passed **by value of base class type**, *object slicing* occurs.

Matching Catch Handlers

- **std::exception** : Base class for standard exceptions.
  - All exceptions thrown by C++ standard library are derived from this class.
  - Therefore, all standard exceptions can be caught by catching this type by reference.

```
#include <iostream>
using namespace std;
class ExceptionA: public std::exception {};
class ExceptionB: public ExceptionA {};

double Division(int a, int b) {
  if (b == 0) {
    throw ExceptionA();          // "catch ExceptionA&"
    //throw ExceptionB();        // "catch ExceptionA&"
    //throw std::exception();    // "catch std::exception&"
  }
  return (a / (double) b);
}

int main () {
  int x = 2, y = 0;

  try {
    double z = division(x, y);
    cout << z << endl;
  }
  catch (ExceptionA& e) {
    cout << "catch ExceptionA&" << endl;
  }
  catch (std::exception& e) {
    cout << "catch std::exception&" << endl;
  }
  return 0;
}
```

Quiz #1

- What is the expected output of this program for each throw statement (a), (b), (c)? Write down three answers.

```
#include <iostream>
using namespace std;

class ExceptionA
    : public std::exception {};
class ExceptionB
    : public ExceptionA {};

double Division(int a, int b) {
  if (b == 0) {
    throw ExceptionA(); // (a)
    throw ExceptionB(); // (b)
    throw std::exception();// (c)
  }
  return (a / (double) b);
}

int main () {
  int x=2, y=0;

  try {
    double z = division(x, y);
    cout << z << endl;
  }
  catch (std::exception& e) {
    cout << "1" << endl;
  }
  catch (ExceptionA& e) {
    cout << "2" << endl;
  }
  return 0;
}
```

```
class ExceptionA
    : public std::exception {
  ...
};

class ExceptionB : public ExceptionA {
  ...
};
```

To catch each exception types in a hierarchy:

- Most-derived type should be caught first
- Most-base type should be caught last

```
using namespace std;

int main() {
  try {
    // This may throw
    // ...
  } catch (ExceptionB& e) {
    // ...
  } catch (ExceptionA& e) {
    // ...
  } catch (exception& e) {
    // ...
  }
  return 0;
}
```

Nested Try Blocks

- Try blocks can be nested.
- If a throw occurs in an inner try block, the exception moves outward through the nested try blocks until the first matching catch block is found.
  - If one of the inner catch blocks catches the exception, it will not get caught by the outer catch blocks.
  - If the inner catch blocks do not catch the exception, it will try to find a matching one in the outer catch blocks.

```
#include <iostream>
using namespace std;

class ExceptionA: public std::exception {};
class ExceptionB: public ExceptionA {};

double Division(int a, int b) {
  if (b == 0) {
    throw ExceptionA();     // "catch std::exception&"
    // throw ExceptionB();     // "catch ExceptionB&"
  }
  return (a / (double) b);
}

int main () {
  int x = 2, y = 0;
  double z;
  try {
    try{
      z = Division(x, y);
    }
    catch (ExceptionB& e) {
      cout << "catch ExceptionB&" << endl;
    }
    cout << z << endl;
  }
  catch (std::exception& e) {
    cout << "catch std::exception&" << endl;
  }
  return 0;
}
```

Re-throw Exceptions

- If your catch handler does not completely handle an exception,
- you may re-throw it to the next outer catch blocks.

```
catch (E e) {
  // if the processing to handle e is incomplete,
  throw;
}
```

```
#include <iostream>
using namespace std;

class ExceptionA: public exception {};
class ExceptionB: public ExceptionA {};

double Division(int a, int b) {
  if (b == 0) {
    throw ExceptionB();  // "catch ExceptionB&",
                         // then "catch std::exception&"
  }
  return (a / (double) b);
}

int main () {
  int x = 2, y = 0;
  double z;
  try {
    try {
      z = Division(x, y);
    }
    catch (ExceptionB& e) {
      cout << "catch ExceptionB&" << endl;
      throw;
    }
    cout << z << endl;
  }
  catch (std::exception& e) {
    cout << "catch std::exception&" << endl;
  }
  return 0;
}
```

Uncaught Exceptions

- If there is ***no matching catch handler*** in all of the nested try block,
  - Exception is ***uncaught***
  - If an exception is uncaught, the special function **terminate**() is called

```
$ ./test
terminate called after throwing an instance of 'std::exception'
  what():  std::exception
Aborted (core dumped)
```

- Use "**catch(…)**", an *ellipsis* handler, to avoid uncaught exceptions.
  - It catches any exception not caught earlier.

Uncaught Exceptions: Example

- If none of the catch handlers matches,
  - Exception moves to the next enclosing try block

```
void ThrowsException() {
  throw string("Exception!");
}

void CallsOne() {
  ThrowsException();
}

void CallsTwo() {
  try {
    CallsOne();
  } catch (const char* e) {
    cout << "Caught in CallsTwo";
  }
}
```

```
int main() {
  try {
    CallsTwo();
  }
  catch (string e) {
    cout << "Caught "
         "an exception in main";
  }
  return 0;
}
```

Output:

```
Caught an exception in main
```

Uncaught Exceptions: Example

- If an exception is uncaught,
  - The special function **terminate**() is called

```
void ThrowsException() {
  throw string("Exception!");
}

void CallsOne() {
  ThrowsException();
}

void CallsTwo() {
  try {
    CallsOne();
  } catch (const char* e) {
    cout << "Caught in CallsTwo";
  }
}
```

```
int main() {
  try {
    CallsTwo();
  }
  catch (const char* e) {
    cout << "Caught "
         "an exception in main";
  }
  return 0;
}
```

Output:

```
terminate called after ...
Aborted (core dumped)
```

Cleaning Up

- As an exception leaves a scope, ***destructors*** of all the objects in that scope will be called.

- Make all allocations within objects deallocate in their destructors.

Cleaning Up: Example

```
class CleaningUp{
 private:
  string word;
 public:
  CleaningUp(const string & str) {
    word = str;
    cout << "Created word:"
         << word << endl;
  }
  ~CleaningUp() {
    cout << "Destroyed word:"
         << word << endl;
  }
};
void ThrowsException() {
  CleaningUp hi("HI");
  int* pi = new int;
  throw "Exception";
  delete pi;  // memory leak
  CleaningUp bye("BYE");
}
```

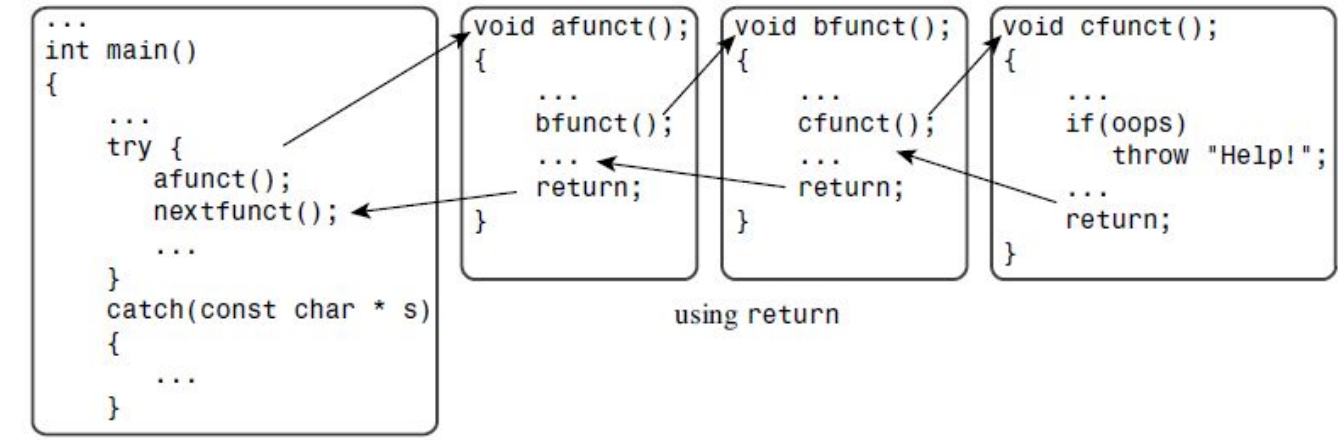
```
int main() {
  try {
    ThrowsException();
  }
  catch (const char* e) {
    cout << "Caught an exception"
         << endl;
  }
  return 0;
}
```

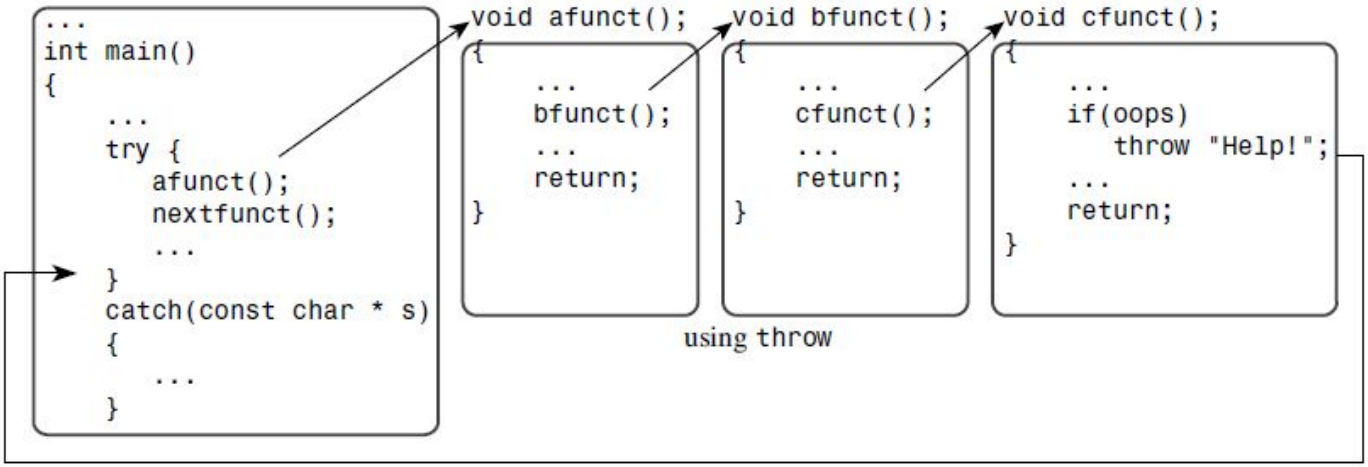
Output:

```
Created word:HI
Destroyed word:HI
Caught an exception
```

Unwinding the stack

- return vs. throw





Unwinding the stack

- Exceptions can be propagated through several levels of function calls if there is no try-catch block

```
void ThrowsException() {
  throw string("Exception!");
}

void DoSomething() {
  cout << "DoSomething called.\n";
  ThrowsException();
  cout << "DoSomething finished\n";
}

void DoSomethingMore() {
  cout << "DoSomethingMore called.\n";
  DoSomething();
  cout << "error in DoSomethingMore\n";
  throw string("error");
  cout << "DoSomethingMore "
      "finished.\n";
}
```

```
int main() {
  try {
    DoSomethingMore();
  }
  catch (string s) {
    cout << "Caught an exception "
        << s << "'" << endl;
  }
  cout << "All done." << endl;
  return 0;
}
```

Output:

```
DoSomethingMore called.
DoSomething called.
Caught an exception 'Exception!'
All done.
```