Creative Software Design

13 – Exception Handling

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Final Exam

- Date & time: **Dec 19, AM 09:30 ~ 10:30**
- Place: **IT.BT 609**
- Scope: Lecture 8 ~ 13

- **You cannot leave until 30 minutes after the start of the exam** even if you finish the exam earlier.

- That means, **you cannot enter the room after 30 minutes from the start of the exam** (do not be late, never too late!).

- Please bring your **student ID card** to the exam.

- We will not accept questions unless the error in the problem is clearly evident. You should solve the problem based on the information provided in the question.

- Problem types: true/false, single choice, multiple choices, short answer, fill-in-blank, ...

Outline

- What are Exceptions & How to deal with Exceptions?
- C++ Exceptions: Basics
  - try, catch, and throw
- More about C++ Exceptions
  - Matching Catch Handlers
  - Uncaught Exceptions
  - Unwinding the stack
  - ...
- Course Wrap-up

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.;
double y = -2.;
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 exceptions but do nothing other than aborting the program
  -
```
double harmonic_mean(double a, double b){
    if (a == -b)
    {
            std::cout << “wrong arguments\n";
            std::abort();
    }
    return 2.0 * a * b / (a + b);
}
```
```
$ ./harmonic_mean
wrong arguments
Aborted (core dumped)
```
  - A little bit better, but still wrong for all but demo programs

How to Deal with Exceptions?

```
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;
    }
}
```

- **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
    ```
  - Difficult to read, modify, maintain and debug
    - Easy to miss a check
  - Impacts performance
    - Constantly spending CPU cycles looking for rare "exceptional" 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
  - 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 divide(int a, int b) {
   if( b == 0 ) {
      throw "Division by zero condition!";
   }
   return (a/b);
}

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

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

   return 0;
}
```

C++ Exceptions: Basic

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

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

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

   try {
      z = divide(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. Program execution resumes after the last catch block.

C++ Exceptions: Basic

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

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

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

    try {
        z = divide(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. Program execution 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 divide(int a, int b) {
    if( b == 0 ) {
        throw "Division by zero condition!";
    }
    return (a/b);
}

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

    try {
        z = divide(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 exceptions) with one or more catch blocks

try, catch, and throw

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

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

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

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

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

    try {
        z = divide(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

Quiz 1

- Go to https://www.slido.com/
- Join #**csd-ys**
- Click "Polls"

- Submit your answer in the following format:
  - **Student ID: Your answer**
  - **e.g. 2022123456: 4)**

- Note that your quiz answer must be submitted **in the above format** to receive a quiz score!

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 de claration.**

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

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

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

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

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

Matching Catch Handlers

- The conventional way to throw and catch exceptions is:
  - throw an exception **object**
  - catch it by **const reference**
    - to avoid copying the object & modifying it in catch handler

- Polymorphism can be employed: A **derived class object** ca n 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 ty pe**, ***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 ty pe by reference (`catch(std::exception& e)`).

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

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

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

    try {
        z = divide(x, y);
        cout << z << endl;
    }
    catch (ExceptionA& e) {
        cout << "catch ExceptionA&" << endl;
    }
    catch (std::exception& e) {
        cout << "catch std::exception&" << endl;
    }

    return 0;
}
```

Quiz 2

- Go to https://www.slido.com/
- Join #**csd-ys**
- Click "Polls"

- Submit your answer in the following format:
  - **Student ID: Your answer**
  - **e.g. 2022123456: 4)**

- Note that your quiz answer must be submitted **in the above format** to receive a quiz score!

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

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

To catch each exception types in a hierarchy:

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

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.
  - else, 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 divide(int a, int b) {
    if( b == 0 ) {
        throw ExceptionA();     // "catch std::exception&"
        //throw ExceptionB();     // "catch ExceptionB&"
    }
    return (a/b);
}

int main () {
    int x=2, y=0;
    double z;
    try {
        try{
            z = divide(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 **outer catch blocks**.

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

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

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

Stack Unwinding

- A *function call stack* is composed of *stack frames*.

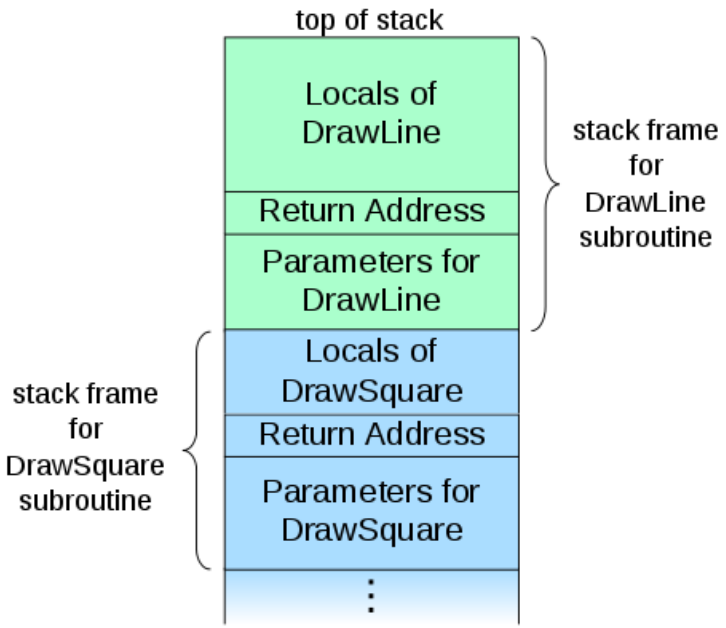
```
void DrawSquare(Point topleft, Point
bottomright)
{
    Point bottomleft = ...;
    DrawLine(topleft, bottomleft);
    ...
}

void DrawLine(Point p1, Point p2)
{
    ...
    Do something...
    ...
}

void main()
{
    DrawSquare(Point(0,0), Point(100,100));
    return 0;
}
```

If this is the next statement to be executed, the call stack will look like this: →

function call stack:



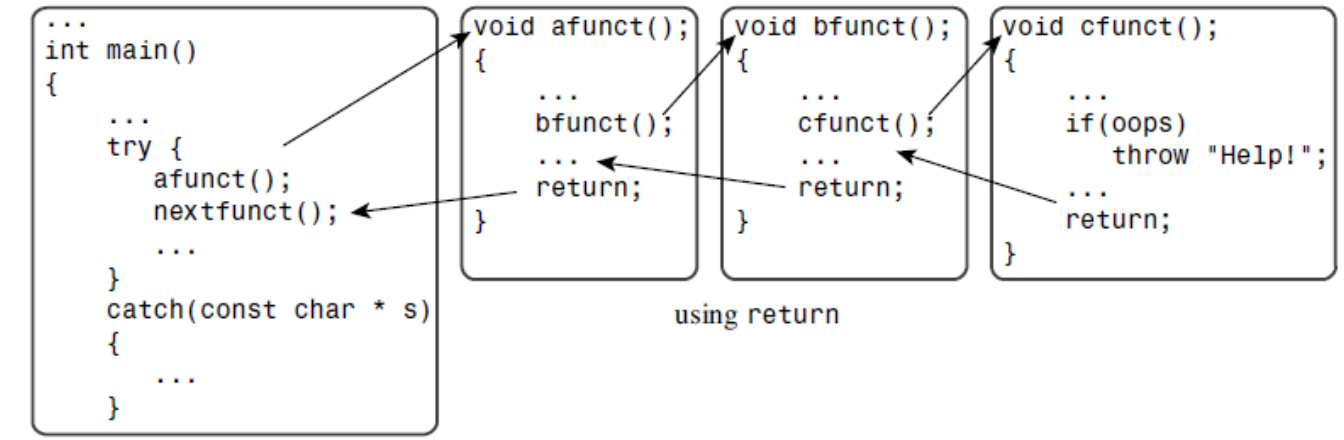
Stack Unwinding

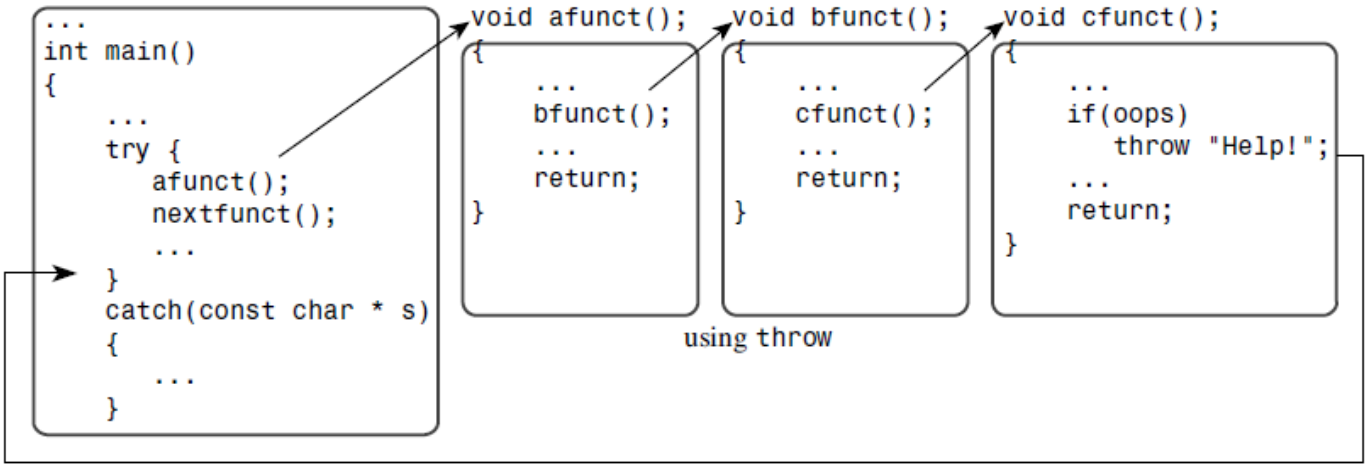
- Popping one or more *stack frames* off the *function call stack* is called *stack unwinding*.

- Exception handling involves *stack unwinding* if an exception is not handled in the same function.
  - When an exception occurs, the function call stack is linearly searched for the exception handler, and all the stack frames before the function with exception handler are removed from the function call stack.
  - **All objects in the removed stack frames is destroyed by calling destructors** (for class objects)

Stack Unwinding

- return vs. throw





Stack Unwinding: Example

- 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.

Stack Unwinding: 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

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\n";
  }
}
```

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

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

Output:

terminate called after throwing an instance of 'std::string'

Uncaught Exceptions: Example

- An ellipsis handler catches all uncaught exceptions

```
void ThrowsException() {
  throw string("Exception!");
}
void CallsOne() {
  ThrowsException();
}
void CallsTwo() {
  try {
    CallsOne();
  } catch (const char* e) {
    cout << "Caught in CallsTwo\n";
  }
}
```

```
int main() {
  try {
    try {
      CallsTwo();
    }
    catch (const char* e) {
      cout << "Caught an exception in main\n";
    }
  catch(...) { cout << "An ellipsis handler catches all
uncaught exceptions" << endl; }
  return 0;
}
```

Output:

An ellipsis handler catches all uncaught exceptions

Course Wrap-up

Topics we covered...

- 1 - Course Intro
  - 1 - Lab1 - Environment Setting,1 - Lab2 - G++, Make, GDB
- 2 - Review of C Pointer, Const and Structure
- 3 - Differences Between C and C++
- 4 - Dynamic Memory Allocation, References
- 5 - Compilation and Linkage, CMD Args
- 6 - Class
- 7 - Standard Template Library (STL)
- 8 - Inheritance, Const & Class
- 9 - Polymorphism 1
- 10 - Polymorphism 2
- 11 – Copy Constructor, Operator Overloading
- 12 - Template
- 13 - Exception Handling

Ending the class...

- We covered a large amount of complex C ++ content.
- I applaud your effort for all this hard work.
- Perhaps the programming language you will encounter will be easier to learn. Now, you can be proud of yourself.
- I recommend you ...
  - further study modern C++ on your own and
  - work on larger projects with your own topics, that use 3rd-party libraries in more diverse environments.
- I hope you will continue to **enjoy** programming.

Thanks for being a great class!