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# **Creative Software Design**

## **13 – Exception Handling**

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Fall 2022

# Final Exam (not changed)

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- Date & time: **Dec 13, 09:30 - 10:30 am**
- Place: **IT.BT 207**
- 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.
  
- Problem types: true/false, single choice, multiple choices, short answer, fill-in-blank, ...

# Today's Topics

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- 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

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- Exceptions are anomalous or *exceptional situations* requiring special processing – often changing the normal flow of program execution<sup>[wikipedia]</sup>

- 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 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?

- **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

```
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;  
    }  
}
```

# 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.  $y \neq 0$ ),
  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) {...}:**
  - Catches 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

# 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  
}
```

```
#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 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 (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 ( `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 #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 you must submit all quiz answers **in this format** to be counted as attendance.

```
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

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

# Nested Try Blocks

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- 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

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- 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*.

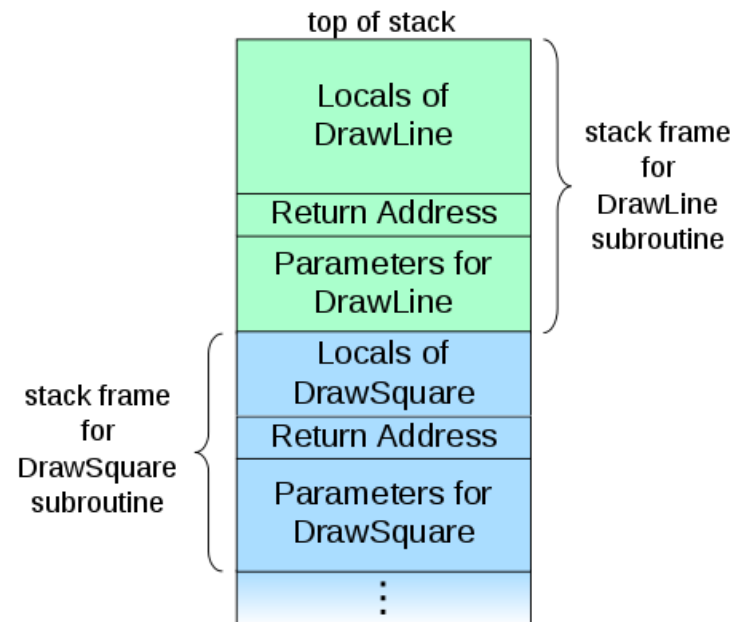
```
void DrawSquare(Point topleft, Point
bottomright)
{
    Point bottomleft = ...;
    DrawLine(topleft, bottomleft);
    ...
}

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:



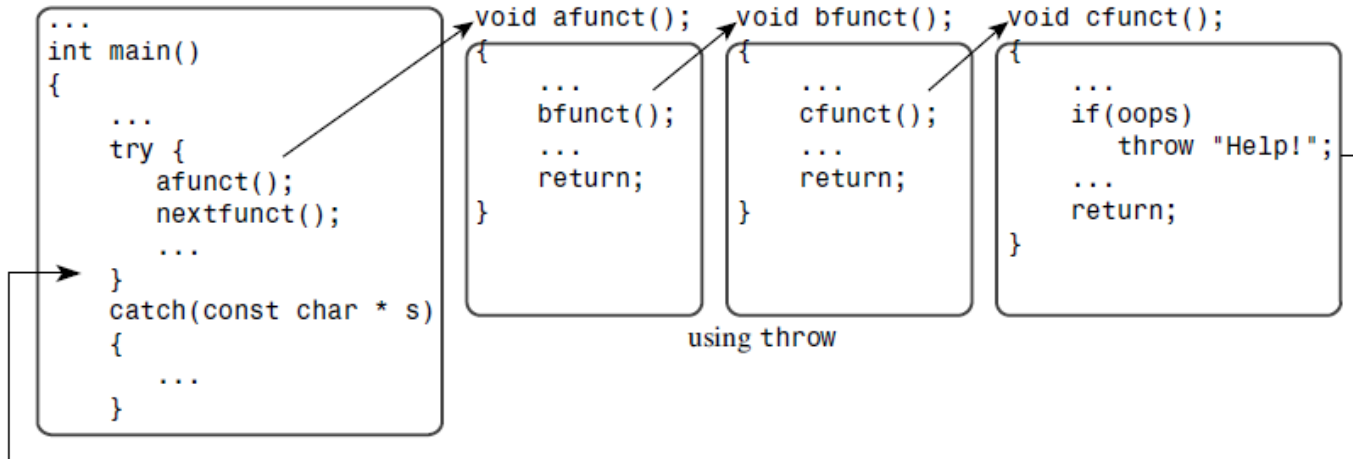
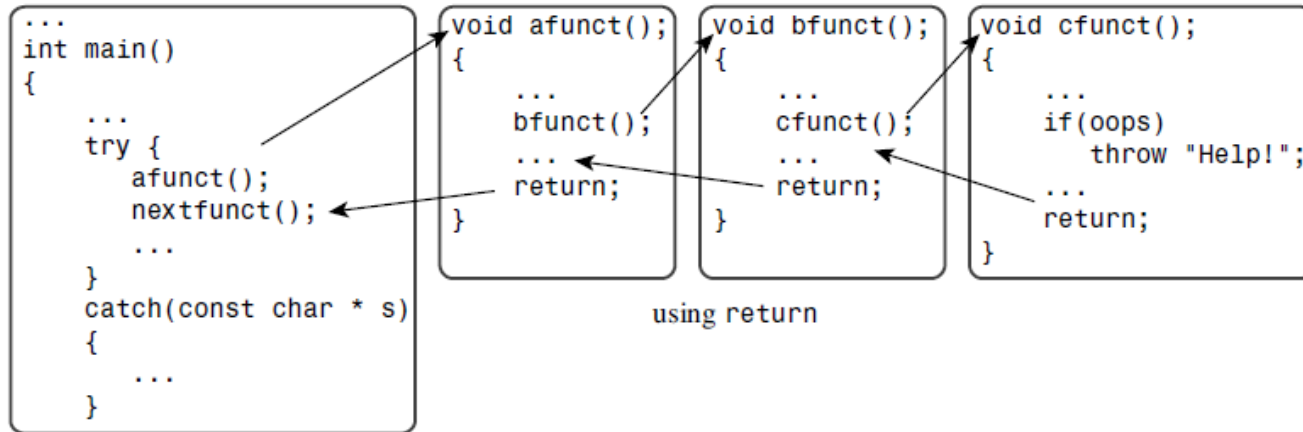
# Stack Unwinding

---

- 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...

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- 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 work on larger projects with your own topics, that use 3<sup>rd</sup>-party libraries in more diverse environments.
- I hope you will continue to **enjoy** programming.

**Thanks for  
being a great  
class!**

