Laboratorio di Tecnologie dell'Informazione

Ing. Marco Bertini
marco.bertini@unifi.it
http://www.micc.unifi.it/bertini/
Exceptions
What are exceptions?

- Exceptions are a mechanism for handling an error during execution.
- A function can indicate that an error has occurred by throwing an exception.
- The code that deals with the exception is said to handle it.
Why use exceptions?

- Code where the error occurs and code to deal with the error can be separated.
- Exceptions can be used with constructors and other functions/operators which cannot return an error code.
- Properly implemented exceptions lead to better code.
How to use exceptions?

- **try**
  - Try executing some block of code
  - See if an error occurs

- **throw**
  - An error condition occurred
  - Throw an exception to report the failure

- **catch**
  - Handle an exception thrown in a try block
How exceptions work?

- Normal program control flow is halted
  - At the point where an exception is thrown
- The program call stack “unwinds”
  - Stack frame of each function in call chain “pops”
  - Variables in each popped frame are destroyed
  - Goes until an enclosing try/catch scope is reached
- Control passes to first matching catch block
  - Can handle the exception and continue from there
  - Can free some resources and re-throw exception
What’s right about exceptions

• Can’t be silently ignored: if there is no applicable catch block for an exception the program terminates

• Automatically propagate across scopes (due to stack unwinding)

• Handling is out of main control flow, the code that implements the algorithm is not polluted
Exceptions syntax
C++ exceptions syntax

- Use `try-catch` blocks to catch an exception

```c++
try {
    statement(s);
}
catch (ExceptionClass identifier) {
    statement(s);
}
catch (ExceptionClass identifier) {
    statement(s);
}
```

Place a statement(s) (function or method) that might throw an exception within a `try` block. A try block **must** be followed by one or more `catch` blocks.

Appropriate code to handle the exception.
C++ exception flow

- When a statement (function or method) in a try block causes an exception:
  - Rest of try block is ignored.
  - Control passes to catch block corresponding to the exception.
  - After a catch block executes, control passes to statement after last catch block associated with the try block.

```cpp
try {
    ...
    statement;
    ...
}
catch (ExceptionClass identifier) {
    statement(s);
}
statement(s);
```
• A more complex example of exception flow:

```cpp
void encodeChar(int i, string& str)
{
    ...
    str.replace(i, 1, 1, newChar);
}
```

Can throw the `out_of_range` exception.

```cpp
void encodeString(int numChar, string& str)
{
    for(int i=numChar-1; i>=0; i--)
        encodeChar(i, str);
}
```

```cpp
int main()
{
    string str1 = "NTU IM";
    encodeString(99, str1);
    return 0;
}
```

Abnormal program termination
Catching the exception

- Two examples on how to catch the exception:

```cpp
void encodeChar(int i, string& str)
{
    try
    {
        ...
        str.replace(i, 1, 1, newChar);
    } catch (out_of_range e) {
        cout << "No character at " << i << endl;
    }
}

void encodeString(int numChar, string& str)
{
    for(int i=numChar-1; i>=0; i--)
        encodeChar(i, str);
}

int main()
{
    string str1 = "NTU IM";
    encodeString(99, str1);
    return 0;
}
```

No character at 98
No character at 97
...
Catching the exception

• Two examples on how to catch the exception:

```c++
void encodeChar(int i, string& str)
{
    ...  
    str.replace(i, 1, 1, newChar);
}

void encodeString(int numChar, string& str)
{
    try
    {
        for(int i=numChar-1; i>=0; i--)
            encodeChar(i, str);
    } catch (out_of_range e) {
        cout << "Something wrong" << endl;
    }
}

int main()
{
    string str1 = "NTU IM";
    encodeString(99, str1);
    return 0;
}
```
Handlers

- A handler may re-throw the exception that was passed:
  - it forwards the exception
  - Use: throw; // no operand
  - after the local handler cleanup it will exit the current handler

- A handler may throw an exception of a different type
  - it translates the exception
Catching multiple exceptions

- The order of catch clauses is important:
  - Especially with inheritance-related exception classes
  - Put more specific catch blocks before more general ones
  - Put catch blocks for more derived exception classes before catch blocks for their respective base classes
- `catch(...)` catches any type
Catching multiple exceptions example

```cpp
try {
    // can throw exceptions
} catch (DerivedExc &d) {
    // Do something
} catch (BaseExc &d) {
    // Do something else
} catch (...) {
    // Catch everything else
}
```
Throwing exceptions

• When you detect an error within a method, you can throw an exception by using a throw statement.

• The remaining code within the function does not execute.

• Syntax: `throw ExceptionClass(stringArgument);`

void myMethod(int x) throw(MyException)
{
    if (...)
        throw MyException(“MyException: ...”);
    ...
} // end myMethod
• The exception is propagated back to the point where the function was called.

```java
try {
    ...
    myMethod(int x);
    ...
} catch (ExceptionClass identifier) {
    statement(s);
}
```
Specifying exceptions

- Functions that throw an exception have a throw clause, to restrict the exceptions that a function can throw.
  - Allow stronger type checking enforced by the compiler
  - By default, a function can throw anything it wants
- A throw clause in a function’s signature
  - Limits what can be thrown
  - A promise to calling function
- A throw clause with no types
  - Says nothing will be thrown
- Can list multiple types, comma separated
Specifying exceptions examples

// can throw anything
void Foo::bar();

// promises not to throw
void Foo::bar() throw();

// promises to only throw int
void Foo::bar() throw(int);

// throws only char or int
void Foo::bar() throw(char,int);
Destructors and exceptions
Destructors and exceptions

- Prevent exceptions from leaving destructors: premature program termination or undefined behaviour can result from destructors emitting exceptions

- during the stack unwinding resulting from the processing of the exception are called the destructors of local objects, and one may trigger another exception
How to behave: example

class DBConnection {
    public:
        //...
        // return a DBConnection object
        static DBConnection create();
        void close(); // close connection and
                       // throws exception if
                       // closing fails
};

// class to manage DBConnection
class DBConnMgr {
    public:
        //...
        DBConnMgr(DBConnection dbc);
        ~DBConnMgr() {
            db.close(); // we’re sure it
                        // gets closed
        }
        private:
            DBConnection db;
};

// client code
{
    DBConnMgr dbc( DBConnection::create() );
    //... use DBConnection through DBConnMgr interface
} // DBConnMgr obj is automatically destroyed, calling the close
How to behave: example

```cpp
class DBConnection {
public:
    //...

    // return a DBConnection object
    static DBConnection create();

    void close(); // close connection and
      // throws exception if
      // closing fails

};

// class to manage DBConnection
class DBConnMgr {
public:
    //...
    DBConnMgr(DBConnection dbc);
    ~DBConnMgr() {
        db.close(); // we’re sure it
      // gets closed
    }

private:
    DBConnection db;
};

// client code
{
    DBConnMgr dbc( DBConnection::create() );
    //... use DBConnection through DBConnMgr interface
} // DBConnMgr obj is automatically destroyed, calling the close
```

If close() throws the destructor propagates the exception
(Not so good) solutions

• Terminate the program:

```cpp
dBConnMgr::~DBConnMgr() {
    try{ db.close(); } // log failure and...
    catch (...) {
        std::abort();
    }
}
```

• Swallow the exception:

```cpp
dBConnMgr::~DBConnMgr() {
    try{ db.close(); } // just log the error
    catch (...) {
```

(Not so good) solutions

- **Terminate the program:**

  ```cpp
  DBConnMgr::~DBConnMgr() {
    try{ db.close(); }
    catch (...) {
      // log failure and...
      std::abort();
    }
  }
  ```

- **Swallow the exception:**

  ```cpp
  DBConnMgr::~DBConnMgr() {
    try{ db.close(); }
    catch (...) {
      // just log the error
    }
  }
  ```

With this solution we’re just hiding the problem
A better strategy

// class to manage DBConnection
class DBConnMgr {
public:
    //...
    DBConnMgr(DBConnection dbc);
    void close() {
        db.close();
        closed = true;
    }
    ~DBConnMgr() { // we’re sure it gets closed
        if( !closed ) {
            try {
                db.close();
            } catch (...) {
                // log and... terminate or swallow
            }
        }
    }

private:
    DBConnection db;
    bool closed;
};
A better strategy

// class to manage DBConnection
class DBConnMgr {
public:
    //...
    DBConnMgr(DBConnection dbc);
    void close() {
        db.close();
        closed = true;
    }
    ~DBConnMgr() { // we’re sure it gets closed
        if( !closed ) {
            try {
                db.close();
            } catch (...) {
                // log and... terminate or swallow
            }
        }
    }

private:
    DBConnection db;
    bool closed;
};

Client code should use this method...
A better strategy

// class to manage DBConnection
class DBConnMgr {
public:
    //...
    DBConnMgr(DBConnection dbc);
    void close() {
        db.close();
        closed = true;
    }
    ~DBConnMgr() { // we’re sure it gets closed
        if( !closed ) {
            try {
                db.close();
            } catch (...) {
                // log and... terminate or swallow
            }
        }
    }
private:
    DBConnection db;
    bool closed;
};

Client code should use this method...
...but if it doesn’t there’s the destructor
Defining exceptions classes

Syntax and example
Defining exceptions classes

- C++ Standard Library supplies a number of exception classes.
  
  - E.g., exception, out_of_range, ... etc.

- You may also want to define your own exception class.

- Should inherit from those pre-defined exception classes for a standardized exception working interface.

- Syntax:
  ```
  #include <exception>
  using namespace std;
  ```
Defining exceptions classes example

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

class MyException : public exception
{
public:
    MyException(const string & Message = "")
        : exception(Message.c_str()) {}
} // end class

throw MyException("more detailed information");

try
{
    ...
}
catch (MyException e)
{
    cout << e.what();
}
```
A full example

• An ADT List implementation using exceptions:
  • out-of-bound list index.
  • attempt to insert into a full list.
Define two exception classes

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

class ListIndexOutOfRangeException : public out_of_range {
public:
    ListIndexOutOfRangeException(const string& message = "")
        : out_of_range(message.c_str()) {}
}; // end ListException

class ListException : public logic_error {
public:
    ListException(const string & message = "")
        : logic_error(message.c_str()) {}
}; // end ListException
```
Declare the throw

```cpp
#include "MyListExceptions.h"

class List
{
public:

    void insert(int index, const ListItemType& newItem)
    throw(ListIndexOutOfRangeException,
         ListException);

}  // end List
```
void List::insert(int index, const ListItemType& newItem)
    throw(ListIndexOutOfRangeException, ListException) {
    if (size >= MAX_LIST)
        throw ListException("ListException: List full on insert");
    if (index >= 1 && index <= size+1)   {
        for (int pos = size; pos >= index; --pos)
            items[translate(pos+1)] = items[translate(pos)];
        // insert new item
        items[translate(index)] = newItem;
        ++size;  // increase the size of the list by one
    } else  // index out of range
        throw ListIndexOutOfRangeException(
            "ListIndexOutOfRangeException: Bad index on insert");
}  // end insert
Good Programming Style with C++ Exceptions

• Don’t use exceptions for normal program flow
  • Only use where normal flow isn’t possible
• Don’t let exceptions leave main or constructors
  • Violates “normal” initialization and termination
• Always throw some type
  • So the exception can be caught
• Use exception specifications widely
  • Helps caller know possible exceptions to catch
Exception-safe functions

- Exception-safe functions offer one of three guarantees:
  - **basic guarantee**: if an exception is thrown, everything in the program remains in a valid state
  - **strong guarantee**: if an exception is thrown, the state of the program is unchanged. The call to the function is atomic
  - **nothrow guarantee**: promise to never throw exception: they always do what they promise. All operations on built-in types are nothrow.
Exception-safe code

• When an exception is thrown, exception safe functions:

  • leak no resource (e.g. new-ed objects, handles, etc.)

  • don’t allow data structures to become corrupted (e.g. a pointer that had to point to a new object was left pointing to nowhere)
Credits

• These slides are (heavily) based on the material of:
  • Dr. Walter E. Brown, Fermi Lab
  • Dr. Chien Chin Chen, National Taiwan University
  • Dr. Jochen Lang, University of Ottawa
  • Fred Kuhns, Washington University
  • Scott Meyers, “Effective C++, 3rd ed.”