15. C++ advanced (IV): Exceptions

Some operations that can fail

- Opening files for reading and writing

```
std::ifstream input("myfile.txt");
```

- Parsing

```
int value = std::stoi("12-8");
```

- Memory allocation

```
std::vector<double> data(ManyMillions);
```

- Invalid data

```
int a = b/x; // what if x is zero?
```


Possibilities of Error Handling

- None (inacceptable)
- Global error variable (flags)
- Functions returning Error Codes
- Objects that keep error status
- Exceptions

Global error variables

- Common in older C-Code
- Concurrency is a problem.
- Error handling at good will. Requires extreme discipline, documentation and litters the code with seemingly unrelated checks.

Functions Returning Error Codes

- Every call to a function yields a result.
- Typical for large APIs (e.g. OS level). Often combined with global error code.[19]
- Caller can check the return value of a function in order to check the correct execution.

[19] Global error code thread-safety provided via thread-local storage.

Functions Returning Error Codes

Example

```
#include <errno.h>
...

pf = fopen ("notexisting.txt", "r+");
if (pf == NULL) {
  fprintf(stderr, "Error opening file: %s\n", strerror( errno ));
}
else { // ...
  fclose (pf);
}
```


Error state Stored in Object

- Error state of an object stored internally in the object.

Example

```
int i;
std::cin >> i;
if (std::cin.good()){// success, continue
        ...
}
```


Exceptions

- Exceptions break the normal control flow
- Exceptions can be thrown (throw) and catched (catch)
- Exceptions can become effective accross function boundaries.

Example: throw exception

```
class MyException{};

void f(int i){
  if (i==0) throw MyException();
  f(i-1);
}

int main()
{
  f(4);
  return 0;
}
```

```
terminate called after throwing an instance of 'MyException'
Aborted
```

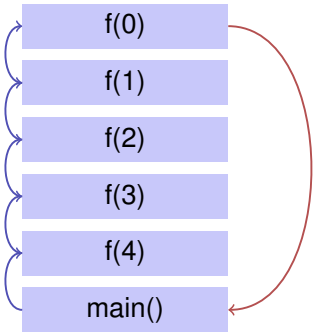

Example: catch exception

```
class MyException{};

void f(int i){
  if (i==0) throw MyException();
  f(i-1);
}

int main(){
  try{
    f(4);
  }
  catch (MyException e){
      std::cout << "exception caught\n";
  }
}
```

```
exception caught
```



Resources get closed

```
class MyException{};
struct SomeResource{
    ~SomeResource(){std::cout << "closed resource\n";}
};
void f(int i){
  if (i==0) throw MyException();
  SomeResource x;
  f(i-1);
}
int main(){
  try{f(5);}
  catch (MyException e){
      std::cout << "exception caught\n";
  }
}
```

```
closed resource
closed resource
closed resource
closed resource
closed resource
exception caught
```


When Exceptions?

Exceptions are used for *error handling* exclusively.

- Use `throw` only in order to identify an error that violates the post-condition of a function or that makes the continued execution of the code impossible in an other way.
- Use `catch` only when it is clear how to handle the error (potentially re-throwing the exception)
- Do *not* use `throw` in order to show a programming error or a violation of invariants, use `assert` instead.
- Do *not* use exceptions in order to change the control flow. Throw is *not* a better return.

Why Exceptions?

This:

```
int ret = f();
if (ret == 0) {
  // ...
} else {
  // ...code that handles the error...
}
```

may look better than this on a first sight:

```
try {
  f();
  // ...
} catch (std::exception& e) {
  // ...code that handles the error...
}
```


Why exceptions?

Truth is that toy examples do not necessarily hit the point.

Using return-codes for error handling either pollutes the code with checks or the error handling is not done right in the first place.

That's why

Example 1: Expression evaluation (expression parser from Introduction to programming), cf.
`http://codeboard.io/projects/46131`

Input: `1 + (3 * 6 / (/ 7 ))`
Error is deap in the recursion hierarchy. How to produce a meaningful error message (and continue execution)? Would have to pass error code over recursion steps.

Second Example

Value type with guarantee: values in range provided.

```
template <typename T, T min, T max>
class Range{
public:
  Range(){}
  Range (const T& v) : value (v) {
    if (value < min) throw Underflow ();
    if (value > max) throw Overflow ();
  }
  operator const T& () const {return value;}
private:
  T value;
};
```

Error handling in the constructor.

Types of Exceptions, Hierarchical

```
class RangeException {};
class Overflow : public RangeException {};
class Underflow : public RangeException {};
class DivisionByZero: public RangeException {};
class FormatError: public RangeException {};
```


Operators

```
template <typename T, T min, T max>
Range<T, min, max> operator/ (const Range<T, min, max>& a,
                              const Range<T, min, max>& b){
  if (b == 0) throw DivisionByZero();
  return T (a) * T(b);
}

template <typename T, T min, T max>
std::istream& operator >> (std::istream& is, Range<T, min, max>& a){
  T value;
  if (!(is >> value)) throw FormatError();
  a = value;
  return is;
}
```

Error handling in the operator.

Error handling (central)

```
Range<int,-10,10> a,b,c;
try{
  std::cin >> a;
  std::cin >> b;
  std::cin >> c;
  a = a / b + 4 * (b - c);
  std::cout << a;
}
catch(FormatError& e){ std::cout << "Format error\n"; }
catch(Underflow& e){ std::cout << "Underflow\n"; }
catch(Overflow& e){ std::cout << "Overflow\n"; }
catch(DivisionByZero& e){ std::cout << "Divison By Zero\n"; }
```