EDAF30 – Programming in C++

7. Error handling

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2019

Outline

1. Error handling
   - Exceptions
   - Catching exceptions
   - Throwing exceptions
   - Exceptions and resource management
   - Specification of exceptions
   - Static assert
   - assert
2. type casts
3. more on const

Error handling
Three levels of error handling

1. Direcly handle the error locally and continue execution
2. Categorize and pass error to another module that is expected to handle it
3. Identify the error, give an error message, and crash the program *("fail-fast", e.g.,* `assert`*)*

Level 2: exceptions (or return values)

Throwing exceptions

Example: checking arguments in the `Vector` class

```
Vector::Vector(int size) {
  if(size < 0) throw length_error("negative size");
  elem = new double[size];
  sz = size;
}

int& Vector::operator[] (int i) {
  if (i<0 || i>=sz) throw out_of_range("Vector::operator[]");
  return elem[i];
}
```

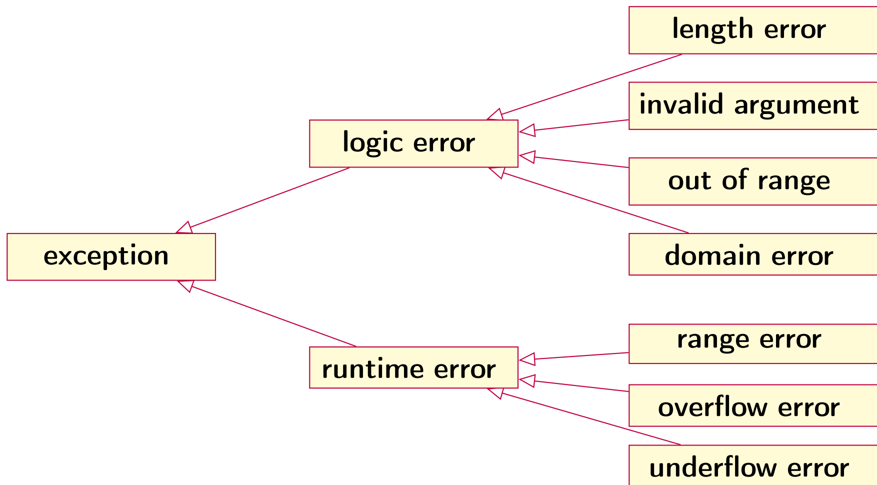
- *NB: to allow checking arguments, we use a* **`signed`** *integer type for values that should always be positive*
- `Vector` cannot reasonably handle the error locally, only the caller can know why it passed a certain argument
- `std::vector::`**`operator`**`[]` does no checks (`at()` does)

Exceptions

- Error handling is done with **`throw`** and **`catch`**. Like Java.
- *"stack unwinding"* until a matching **`catch`** is found.
- When an excepion is thrown, activation records are popped off the stack until a function containing a matching **`catch`** is found. (*"stack unwinding"*)
- If an exception is not caught, the program crashes. (by calling `std::terminate()`.)
- Standard classes for exceptions: `#include <stdexcept>`

The exception classes of the standard library

Class hierarchy for classes in `<stdexcept>`



Error handling
Catching exceptions

```
try {
        // Code that may throw
}
catch (some_exception&) {
        // Code handling some_exception
}
catch (another_exception&) {
        // Code handling another_exception
}
catch (...) {
        // default/generic exception handling
}
```

The first **catch** clause with a matching type is selected.
⇒ Catch derived classes before the base class.

... is valid C++, matches anything

Catching exceptions

Example:

```
try {
        cout << "Enter a number: ";
        int i;
        if (cin >> i) {
            int r = f(i);
            cout << "Result: " << r << endl;
        }
}
catch(std::overflow_error&) {
        cout << "Overflow error\n");
}
catch(std::exception& e) {
        cout << typeid(e).name() << ": " << e.what() << endl;
}
```

Catching exceptions

Example:

```
try {
        cout << "Enter a number: ";
        int i;
        if (cin >> i) {
            int r = f(i);
            cout << "Result: " << r << endl;
        }
}
catch(std::overflow_error&) {
        cout << "Overflow error\n");
}
catch(std::exception& e) {
        cout << typeid(e).name() << ": " << e.what() << endl;
}
```

predefined function in the class exception

Catching exceptions
... and rethrowing

```
try{
  do_something();
}
catch {std::ength_error& le) {
  // handle length error
}
catch {std::out_of_range&) {
  // handle out_of_range
}
catch (...) {
  throw;    // defult: pass on
}
```

Throwing exceptions

Creating own exceptions as subclasses

```
#include<stdexcept>

class communication_error : public runtime_error {
public:
        communication_error(const string& mess = "")
                : runtime_error(mess) {}
};
```

Throwing

```
throw communication_error("Checksum error");
```

Throwing exceptions

Creating custom exceptions

```
struct MyOwnException{
  MyOwnException(const std::string& msg, int val)
            : m{msg},v{val} {}
    std::string m;
    int v;
};
```

Using custom exceptions

```
void f() {
    throw MyOwnException("An error occurred", 17);
}

void test1() {
    try{
        f();
    } catch(MyOwnException &e) {
        cout << "Exception: " << e.m << " - " << e.v << endl;
    }
}
```

Catching exceptions

Resource mangement: destructors and "*stack unwinding*"

```
struct Foo {
  int x;
  Foo(int ix) :x{ix} {
    cout << "Foo("<<x<<")\n";}
  ~Foo() {
    cout << "~Foo("<<x<<")\n";}
};

void test(int i)
{
  Foo f(i);
  if(i == 0) {
    throw std::out_of_range("noll?");
  } else {
    Foo g(100+i);
    test(i-1);
    cout << "after call to test("
         << i-1 << ")\n";
  }
}
```

```
int main() {
 Foo f(42);
 try{
   Foo g(17);
   test(2);
 } catch(std::exception& e) {
    cout<<e.what()<< endl; }
}
```

```
Foo(42)
Foo(17)
Foo(2)
Foo(102)
Foo(1)
Foo(101)
Foo(0)
~Foo(0)
~Foo(101)
~Foo(1)
~Foo(102)
~Foo(2)
~Foo(17)
noll?
~Foo(42)
```

Catching exceptions

Resource mangement: destructors and “*stack unwinding*”

```
struct Foo {
  int x;
  Foo(int ix) :x{ix} {
    cout << "Foo("<<x<<")\n";}
  ~Foo() {
    cout << "~Foo("<<x<<")\n";}
};

void test(int i)
{
  Foo f(i);
  if(i == 0) {
    throw std::out_of_range("noll?");
  } else {
    Foo g(100+i);
    test(i-1);
    cout << "after call to test("
         << i-1 << ")\n";
  }
}
```

```
int main() {
 Foo f(42);
 try{
   Foo g(17);
   test(2);
 } catch(std::exception& e) {
    cout<<e.what()<< endl; }
}
```

```
Foo(42)
Foo(17)
Foo(2)
Foo(102)
Foo(1)
Foo(101)
Foo(0)
~Foo(0)
~Foo(101)
~Foo(1)
~Foo(102)
~Foo(2)
~Foo(17)
noll?
~Foo(42)
```

Catching exceptions

Resource mangement: destructors and "*stack unwinding*"

```
struct Foo {
  int x;
  Foo(int ix) :x{ix} {
    cout << "Foo("<<x<<")\n";}
  ~Foo() {
    cout << "~Foo("<<x<<")\n";}
};

void test(int i)
{
  Foo f(i);
  if(i == 0) {
    throw std::out_of_range("noll?");
  } else {
    Foo g(100+i);
    test(i-1);
    cout << "after call to test("
         << i-1 << ")\n";
  }
}
```

```
int main() {
 Foo f(42);
  try{
    Foo g(17);
    test(2);
  } catch(std::exception& e) {
     cout<<e.what()<< endl; }
}
```

```
Foo(42)
Foo(17)
Foo(2)
Foo(102)
Foo(1)
Foo(101)
Foo(0)
~Foo(0)
~Foo(101)
~Foo(1)
~Foo(102)
~Foo(2)
~Foo(17)
noll?
~Foo(42)
```

Catching exceptions

Resource mangement: destructors and "*stack unwinding*"

```
struct Foo {
  int x;
  Foo(int ix) :x{ix} {
    cout << "Foo("<<x<<")\n";}
  ~Foo() {
    cout << "~Foo("<<x<<")\n";}
};

void test(int i)
{
  Foo f(i);
  if(i == 0) {
    throw std::out_of_range("noll?");
  } else {
    Foo g(100+i);
    test(i-1);
    cout << "after call to test("
         << i-1 << ")\n";
  }
}
```

```
int main() {
 Foo f(42);
 try{
   Foo g(17);
   test(2);
 } catch(std::exception& e) {
    cout<<e.what()<< endl; }
}
```

```
Foo(42)
Foo(17)
Foo(2)
Foo(102)
Foo(1)
Foo(101)
Foo(0)
~Foo(0)
~Foo(101)
~Foo(1)
~Foo(102)
~Foo(2)
~Foo(17)
noll?
~Foo(42)
```

Catching exceptions
Resource mangement: destructors and “*stack unwinding*”

```
struct Foo {
  int x;
  Foo(int ix) :x{ix} {
    cout << "Foo("<<x<<")\n";}
  ~Foo() {
    cout << "~Foo("<<x<<")\n";}
};

void test(int i)
{
  Foo f(i);
  if(i == 0) {
    throw std::out_of_range("noll?");
  } else {
    Foo g(100+i);
    test(i-1);
    cout << "after call to test("
         << i-1 << ")\n";
  }
}
```

```
int main() {
 Foo f(42);
 try{
   Foo g(17);
   test(2);
 } catch(std::exception& e) {
    cout<<e.what()<< endl; }
}
```

```
Foo(42)
Foo(17)
Foo(2)
Foo(102)
Foo(1)
Foo(101)
Foo(0)
~Foo(0)
~Foo(101)
~Foo(1)
~Foo(102)
~Foo(2)
~Foo(17)
noll?
~Foo(42)
```

Catching exceptions
Resource mangement: destructors and "*stack unwinding*"

```
struct Foo {
  int x;
  Foo(int ix) :x{ix} {
    cout << "Foo("<<x<<")\n";}
  ~Foo() {
    cout << "~Foo("<<x<<")\n";}
};

void test(int i)
{
  Foo f(i);
  if(i == 0) {
    throw std::out_of_range("noll?");
  } else {
    Foo g(100+i);
    test(i-1);
    cout << "after call to test("
         << i-1 << ")\n";
  }
}
```

```
int main() {
 Foo f(42);
 try{
   Foo g(17);
   test(2);
 } catch(std::exception& e) {
    cout<<e.what()<< endl; }
}
```

```
Foo(42)
Foo(17)
Foo(2)
Foo(102)
Foo(1)
Foo(101)
Foo(0)
~Foo(0)
~Foo(101)
~Foo(1)
~Foo(102)
~Foo(2)
~Foo(17)
noll?
~Foo(42)
```

Catching exceptions

Resource mangement: destructors and "*stack unwinding*"

```
struct Foo {
  int x;
  Foo(int ix) :x{ix} {
    cout << "Foo("<<x<<")\n";}
  ~Foo() {
    cout << "~Foo("<<x<<")\n";}
};

void test(int i)
{
  Foo f(i);
  if(i == 0) {
    throw std::out_of_range("noll?");
  } else {
    Foo g(100+i);
    test(i-1);
    cout << "after call to test("
         << i-1 << ")\n";
  }
}
```

```
int main() {
 Foo f(42);
 try{
   Foo g(17);
   test(2);
 } catch(std::exception& e) {
    cout<<e.what()<< endl; }
}
```

```
Foo(42)
Foo(17)
Foo(2)
Foo(102)
Foo(1)
Foo(101)
Foo(0)
~Foo(0)
~Foo(101)
~Foo(1)
~Foo(102)
~Foo(2)
~Foo(17)
noll?
~Foo(42)
```

Specifying exceptions in C++11

The keyword **noexcept** specifies if a function may throw or not.
No specification is equal to **noexcept**(**false**).

In the function declaration

```
struct Foo {
    void f();
    void g() noexcept;
};
```

and in the function definition

```
#include<stdexcept>
void Foo::f() {
    throw std::runtime_error("f failed");
}
void Foo::g() noexcept{
    throw std::runtime_error("g lied and failed");
}
```

Exception specification
Example usage

```
#include<typeinfo> // for typeid

void test_noexcept()
{
    Foo f;

    try {
        f.f();
    }catch(std::exception &e) {
        cout << typeid(e).name() << ": " << e.what() << endl;
    }
    try {
        f.g();
    }catch(std::exception &e) {
        cout << typeid(e).name() << ": " << e.what() << endl;
    }
    cout << "done\n";
}
```

```
St13runtime_error: f failed
```

```
terminate called after throwing an instance of 'std::runtime_error'
  what():  g lied and  failed
```

Exception specification
older C++, do not use

Older C++ had "exception lists" for a function: the types of exceptions that may be generated by the function are specifid with the keyword **throw**.

Example of exception list:

```
int f(int) throw(typ1, typ2, typ3) {
        //...
        throw typ1("Error of type 1 occurred");
        //...
        throw typ2("Error of type 2 occurred");
        //...
        throw typ3("Error of type 3 occurred");
}
```

No list	$\Rightarrow$	Any type of exception may be thrown
Empty list (**throw()**)	$\Rightarrow$	No exceptions may be thrown

Rules of thumb for exceptions

- Consider error handling early in the design process
- Use specific exception types, not built-in types.
  (do not `throw 17;`, `throw false;` , etc.)
- "Throw by value, catch by reference"
- If a function should not throw, declare `noexcept`.
- Specify *invariants* for your types
  - The constructor establishes the invariant, or throws.
  - Member functions can rely on the invariant.
  - Member functions must not break the invariant.
  - Example: `Vector`
    - the size `sz` is a positive number
    - the array `elem` points to has size `sz`
    - if the allocation of the array fails `std::bad_alloc` is thrown

If something can be checked at compile-time, use `static_assert`.

Static assert

If something can be checked at compile-time, use `static_assert`.

```
static_assert ( bool_constexpr , message )         (since C++11)
    message can be omitted.                        (since C++17)

constexpr int some_param = 10;

int foo(int x)
{
    static_assert(some_param > 100, "");
    return 2*x;
}

int main()
{
    int x = foo(5);

    std::cout << "x is " << x << std::endl;
    return 0;
}
```

```
error: static assertion failed:
    static_assert(some_param > 100, "");
```

Static assert
Type traits

The standard library provides (meta)functions to query properties of types.

```
#include <type_traits>

template <class T>
T foo(const T& t)
{
  static_assert(std::is_copy_constructible<T>::value &&
                std::is_copy_assignable<T>::value,
                "foo requires copying");

    ... // the code of the function
}
```

assert
in <cassert>

A C standard macro for *fail fast* (at run-time).

```
void assert(some expression);
```

Prints an error message and calls `std::abort()`
if the value of the expression is **`false`**.

Example

```
#include <cassert>

std::vector<int> create_vector(int i)
{
    assert(i>=0);

    return std::vector<int>(i);
}
```

Typically only used during development.
If `NDEBUG` is defined, it generates no code.

Type casts
Implicit conversions

Automatic conversions

- Expressions of the type $x \odot y$, for some binary operator $\odot$
  E.g.: **`double + int ==> double`**
  `float + long + char ==> float`
- Assignments and initialization: The value of the right-hand-side is converted to the type of the left-hand-side
- Conversion of an argument to the type of the (formal) parameter
- Expresions in `if` statements, etc. $\Rightarrow$ **`bool`**
- built-in array $\Rightarrow$ pointer (*array decay*)
- `0` $\Rightarrow$ `nullptr` (empty pointer in C++11, previously the constant `NULL` was defined)

type casts
Explicit, named type casts (C++-11)

- **static_cast**<new_type> (expr)
  - convert between compatible types (*does not do range check*)
  - "the inverse of a *standard* implicit conversion" (mostly)
- **reinterpret_cast**<new_type> (expr)
  - no safety net, same as C-style cast
- **const_cast**<new_type> (expr) - add or remove **const**
- **dynamic_cast**<new_type> (expr) - use for pointers to objects in class hierarchies. Uses *run-time type info*, like `instanceof` in Java.

Example

```
char c;               // 1 byte
int *p = (int*) &c;   // pointer to int: 4 bytes

*p = 5; // undefined behaviour, stack corruption

int *q = static_cast<int*> (&c); // compiler error
```

Type casting
Explicit type casts, C style

Syntax in C and in C++, like in Java

`(type) expression` , e.g. `(float) 10`

- Greater risk of mistakes - use named casts
  - makes the code clearer, e.g., **`const_cast`** can only change **`const`**
  - easy to search for: casts are among the first to look for when debugging
- Warning in GCC: `-Wold-style-casts`
- Common in older code

Alternative syntax in C++

```
type(expression)
```

`type` must be *a single word*,

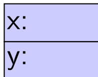
`int *(...)` eller i.e., `unsigned long(...)` is not OK.

Type casts
Warning example

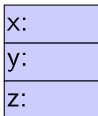
```
struct Point{
    int x;
    int y;
};

struct Point3d {
    int x;
    int y;
    int z;
};
```

Point:



Point3d:



Data types and variables

- some concepts:
  - a *type* defines the set of possible values and operations (for an *object*)
  - an *object* is a place in memory that holds a *value*
  - a *value* is a sequence of bits interpreted according to a *type*.

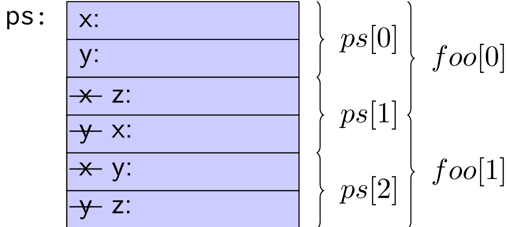
A typecast changes the ***value*** *of a particular memory location by changing how* ***it should be interpreted****.*

Type casts
Warning example

```
struct Point{
    int x;
    int y;
};

Point ps[3];

struct Point3d{
     int x;
     int y;
     int z;
};
Point3d* foo = (Point3d*) ps;
```



With *named casts*, this requires a **reinterpret_cast**<Point3d*>

With **static_cast**<Point3d*> the compiler gives the error
invalid **static_cast** from type 'Point[3] to type 'Point3d*'

special case: `void` pointer

A `void*` can point to an object of any type

In C
: a `void*` is implicitly converted to/from any pointer type.

In C++
: a `T*` is implicitly converted to `void*`. The other direction requires an explicit *type cast*.

`char[]`, `char*` och `const char*`
`const` is important for C-strings

A *string literal* (e.g., `"I am a string literal"`) is **const**.

- Can be stored in read-only memory
- **char*** `str1 = "Hello";` — *deprecated* in C++ – gives a warning
- **const char*** `str2 = "Hello";` — OK, the string is **const**
- **char** `str3[] = "Hello";` — `str3` can be modified

const and pointers

const modifies everything to the left (exception: if **const** is first, it modifies what is directly after)

Example

```
      int* ptr;
const int* ptrToConst;  //NB! (const int) *
int const* ptrToConst,  // equivalent, clearer?

int* const  constPtr;   // the pointer is constant

const int* const constPtrToConst; // Both pointer and object
int const* const constPtrToConst; // equivalent, clearer?
```

Be careful when reading:

```
char *strcpy(char *dest, const char *src);
```

(const char)*, not const (char*)

const and pointers
Example:

```
void Exempel( int* ptr,
              int const * ptrToConst,
              int* const constPtr,
              int const * const constPtrToConst )
{
    *ptr = 0;                       // OK: changes the value of the object
    ptr  = nullptr;                 // OK: changes the pointer

    *ptrToConst = 0;                // Error! cannot change the value
    ptrToConst  = nullptr;          // OK: changes the pointer

    *constPtr = 0;                  // OK: changes the value
    constPtr  = nullptr;            // Error! cannot change the pointer

    *constPtrToConst = 0;           // Error! cannot change the value
    constPtrToConst  = nullptr;     // Error! cannot change the pointer
}
```

Pointers

Pointers to constant and constant pointer

```
int k;               // int that can be modified
int const c = 100;// constant int
int const * pc;    // pointer to constant int
int *pi;             // pointer to modifiable int

pc = &c;    // OK
pc = &k;    // OK, but k cannot be changed through *pc
pi = &c;    // Error! pi may not point to a constant
*pc = 0;    // Error! pc is a pointer to const int

int* const cp = &k; // Constant pointer
cp = nullptr;         // Error! The pointer cannot be reseated
*cp = 123;            // OK! Changes k to 123
```

Type casts
Example: `const_cast`: avoid code duplication

```
class X {
public:
 //...

 const Z& getZ(size_t index) const {return foo?bar:baz;}
       Z& getZ(size_t index)       {return foo?bar:baz;}
};
```

assumption: the logic is the same. the only difference is the **const**ness of the returned reference.

problem: duplicated code for **const** / non-**const**-version of `getZ()`.

observation: if an object of type `X` is *not* **const** it is safe to

1. use `getZ(.)` **const** and
2. remove **const** from the return value.

Rule: Call the **const** version from the non-**const** function.

Type casts
Example: const_cast: avoid code duplication

```
class X {
public:
 //...

 const Z& getZ(size_t index) const {
   // really-really-really long access and checking code
 }

 Z& getZ(size_t index)
 {
   return const_cast<Z&>( static_cast<const X&>(*this).getZ(index));
 }

#if 0
 // A slightly less-ugly version: two lines, one cast
 Z& getZ(size_t index)
 {
   const X& constMe = *this;
   return const_cast<Z&>( constMe.getZ(index) );
 }
#endif
};
```

Suggested reading

References to sections in Lippman

Error handling, exceptions	(5.6, 18.1.1)
static assert	*not in Lippman*
assert	6.5.3

Next lecture

References to sections in Lippman

swap 13.3

Copying and moving objects 13.4, 13.6

(allocators) 12.2.2

(Classes, dynamic memory allocation) 13.5

Container Adapters 9.6

Pairs 11.2.3

Tuples 17.1