

EDAF50 – C++ Programming

12. Recap.

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- 1 Classes and inheritance
 - Scope
 - Constructors and copying
 - const for objects and members
 - Object slicing
- 2 function objects and pointers
- 3 Rules of thumb
- 4 Advice

Inheritance and *scope*

- ▶ The *scope* of a derived class is *nested* inside the base class
 - ▶ Names in the base class are visible in derived classes
 - ▶ *if not hidden* by the same name in the derived class
- ▶ Use the *scope operator* `::` to access hidden names
- ▶ Name lookup happens at compile-time
 - ▶ *static type* of a pointer or reference determines which names are visible (like in Java)
 - ▶ Virtual functions must have the same parameter types in derived classes.

Function overloading and inheritance

No function overloading between levels in a class hierarchy

```
struct Base{
    virtual void f(int x) {cout << "Base::f(int): " << x << endl;}
};
struct Derived :Base{
    void f(double d) {cout << "Derived::f(double): " << d << endl;}
};

void example() {
    Base    b;
    b.f(2);      Base::f(int): 2
    b.f(2.5);   Base::f(int): 2 (as expected)
    Derived d;
    d.f(2);     Derived::f(double): 2
    d.f(2.5);   Derived::f(double): 2.5

    Base& dr = d;
    dr.f(2.5);  Base::f(int): 2
    dr.f(2);    Base::f(int): 2
}
```

Function overloading and inheritance

Make functions visible using using

```
struct Base{
    virtual void f(int x) {cout << "Base::f(int): " << x << endl;}
};
struct Derived :Base{
    using Base::f;
    void f(double d) {cout << "Derived::f(double): " << d << endl;}
};

void example() {
    Base b;
    b.f(2);      Base::f(int): 2
    b.f(2.5);   Base::f(int): 2

    Derived d;
    d.f(2);     Base::f(int): 2
    d.f(2.5);  Derived::f(double): 2.5
}
```

Constructors

Member initialization rules

```
class Vector {
public:
    Vector() =default;
    explicit Vector(int s) :size{s},elem{new T[size]} {}
    T* begin() {return elem.get();}
    T* end() {return begin()+size;}
    // functionality for growing...
private:
    std::unique_ptr<T[]> elem{nullptr};
    int size{0};
};
```

Error! size is uninitialized when used to create the array.

- ▶ If a member has both *default initializer* and a member initializer in the constructor, the constructor is used.
- ▶ `Vector() =default;` is necessary to make the compiler generate a default constructor.
- ▶ Members are initialized *in declaration order*. (Compiler warning if member initializers are in different order.)

Constructors

Special cases: zero or one argument

```
class KomplexTal {  
public:  
    KomplexTal():re{0},im{0} {}  
    KomplexTal(const KomplexTal& k) :re{k.re},im{k.im} {}  
    KomplexTal(double x):re{x},im{0} {}  
    //...  
private:  
    double re;  
    double im;  
};
```

default constructor

copy constructor

converting constructor

Constructors

Implicit conversion

```
struct Foo{
    Foo(int i) :x{i} {cout << "Foo(" << i << ")\n";}
    Foo(const Foo& f) :x(f.x) {cout << "Copying Foo(" << f.x << ")\n";}
    Foo& operator=(const Foo& f) {cout << "Foo = Foo(" << f.x << ")\n";
        x=f.x;
        return *this;
    }
    int x;
};
```

```
void example()
{
```

```
    int i=10;
```

```
    Foo f = i;    Foo(10) (an optimized away copy(move) construction)
```

```
    f = 20;      Foo(20)
                 Foo = Foo(20) (would move if operator=(Foo&&) defined)
```

```
    Foo g = f;   Copying Foo(20)
```

Constructors

Default constructor

Default constructor

- ▶ A constructor that can be called without arguments
 - ▶ May have parameters with default values
- ▶ Automatically defined if *no constructor is defined*
(in declaration: `=default`, cannot be called if `=delete`)
- ▶ If not defined, the type is *not default constructible*

Constructors

Copy constructor

- ▶ Is called when initializing an object
- ▶ Is *not called* on assignment
- ▶ Can be defined, otherwise a standard copy constructor is generated (=default, =delete)
- ▶ default copy constructor
 - ▶ Is automatically generated if not defined in the code
 - ▶ exception: if there are members that cannot be copied
 - ▶ *shallow copy* of each member

Classes

Default copy construction: shallow copy

```
void f(Vector v);
```

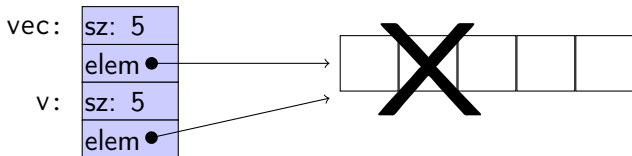
```
void test()
```

```
{
```

```
    Vector vec(5);
```

```
    f(vec); // call by value -> copy
```

```
}
```



- ▶ The parameter `v` is default copy constructed: the value of each member variable is copied
- ▶ When `f()` returns, the destructor of `v` is executed: `(delete[] elem;)`
- ▶ The array pointed to *by both copies* is deleted. Disaster!

“Rule of three”

Canonical construction idiom

If a class implements any of these:

- ❶ Destructor
- ❷ Copy constructor
- ❸ Copy assignment operator

it (quite probably) should implement (or `=delete`) *all three*.

If one of the automatically generated does not fit, the other ones probably won't either.

“Rule of three five”

Canonical construction idiom, from C++11

If a class implements any of these:

- ❶ Destructor
- ❷ Copy constructor
- ❸ Copy assignment operator
- ❹ *Move* constructor
- ❺ *Move* assignment operator

it (quite probably) should implement (or `=delete`) *all five*.

and possibly an overloaded swap function.

Constant objects

- ▶ **const** means “I promise not to change this”
- ▶ Objects (variables) can be declared **const**
 - ▶ “I promise not to change the variable”
- ▶ References can be declared **const**
 - ▶ “I promise not to change the referenced object”
 - ▶ a **const&** can refer to a non-**const** object
 - ▶ common for function parameters
- ▶ Member functions can be declared **const**
 - ▶ “I promise that the function does not change the object”
 - ▶ A **const** member function *may not call non-const member functions*
 - ▶ Functions can be overloaded on **const**

Operator overloading

Operator overloading syntax:

```
return_type operator⊗ (parameters...)
```

for an operator ⊗ e.g. == or +

For classes, two possibilities:

- ▶ as a member function
 - ▶ *if the order of operands is suitable*
E.g., ostream& **operator**<<(ostream&, **const** T&)
cannot be a member of T
- ▶ as a *free* function
 - ▶ if the public interface is enough, *or*
 - ▶ if the function is declared **friend**

Conversion operators

Exempel: Counter

Conversion to int

```
struct Counter {
    Counter(int c=0) :cnt{c} {};
    Counter& inc()      {++cnt; return *this;}
    Counter inc() const {return Counter(cnt+1);}
    int get() const {return cnt;}
    operator int() const {return cnt;}
private:
    int cnt{0};
};
```

Note: **operator** T().

- ▶ no return type in declaration (must obviously be T)
- ▶ can be declared **explicit**

Constructors

Member initialization rules

```
class Bar {
public:
    Bar() =default;
    Bar(int v, bool b) :value{v},flag{b} {}
private:
    int value {0};
    bool flag {true};
};
```

- ▶ If a member has both *default initializer* and a member initializer in the constructor, the constructor is used.
- ▶ Members are initialized *in declaration order*. (Compiler warning if member initializers are in different order.)
- ▶ `Bar() =default;` is necessary to make the compiler generate a default constructor (as another constructor is defined)

Constructors

Special cases: zero or one argument

```
class KomplexTal {  
public:  
    KomplexTal():re{0},im{0} {}  
    KomplexTal(const KomplexTal& k) :re{k.re},im{k.im} {}  
    KomplexTal(double x):re{x},im{0} {}  
    //...  
private:  
    double re;  
    double im;  
};
```

default constructor

copy constructor

converting constructor

Constructors

Implicit conversion

```
struct Foo{
    Foo(int i) :x{i} {cout << "Foo(" << i << ")\n";}
    Foo(const Foo& f) :x(f.x) {cout << "Copying Foo(" << f.x << ")\n";}
    Foo& operator=(const Foo& f) {cout << "Foo = Foo(" << f.x << ")\n";
        x=f.x;
        return *this;
    }
    int x;
};
```

```
void example()
{
```

```
    int i=10;
```

```
    Foo f = i;      Foo(10) (conversion + optimized away copy/move)
```

```
    f = 20;        Foo(20)
                  Foo = Foo(20) (would move if operator=(Foo&&) defined)
```

```
    Foo g = f;     Copying Foo(20)
```

Conversion operators

Exempel: Counter

Conversion to int

```
struct Counter {
    Counter(int c=0) :cnt{c} {};
    Counter& inc()      {++cnt; return *this;}
    Counter inc() const {return Counter(cnt+1);}
    int get() const {return cnt;}
    operator int() const {return cnt;}
private:
    int cnt{0};
};
```

Note: **operator** T().

- ▶ no return type in declaration (must obviously be T)
- ▶ can be declared **explicit**

Example

A class hierarchy

```
struct Foo{
    virtual void print() const {cout << "Foo" << endl;}
};

struct Bar :Foo{
    void print() const override {cout << "Bar" << endl;}
};

struct Qux :Bar{
    void print() const override {cout << "Qux" << endl;}
};
```

Polymorph class example, *object slicing*

What is printed?

```
void print1(const Foo* f)
{
    f->print();
}
void print2(const Foo& f)
{
    f.print();
}
void print3(Foo f)
{
    f.print();
}
```

```
void test()
{
    Foo* a = new Bar;
    Bar& b = *new Qux;
    Bar c = *new Qux;

    print1(a); Bar
    print1(&b); Qux
    print1(&c); Bar

    print2(*a); Bar
    print2(b); Qux
    print2(c); Bar

    print3(*a); Foo
    print3(b); Foo
    print3(c); Foo
}
```

Function pointers

Pointers can also point to functions

```
int add(int x, int y) {
    return x+y;
}

int sub(int a, int b) {
    return a-b;
}

int main() {
    int (*pf)(int, int);

    pf = add;
    cout << "add: " << pf(3,4) << endl;

    pf = sub;
    cout << "sub: " << pf(3,4) << endl;
}
```

Function pointers as arguments to functions

```
double eval(int (*f)(int,int), int m, int n)
{
    return f(m, n);
}

int add(int x, int y)
{
    return x + y;
}
int sub(int a, int b)
{
    return a - b;
}
int main ()
{
    cout << eval(add, 3, 4) << endl;
    cout << eval(sub, 3, 4) << endl;
}
```

Function objects

the `std::function` type (in `<functional>`)

`std::function<return_type(args...)>` is a type that can wrap anything you can invoke as a function (with *type erasure*.)

Example

```
int eval(std::function<int(int,int)> f, int x, int y){
    return f(x,y);
}
```

`eval` can be called with anything callable (*int, int*) \rightarrow *int*:
a function pointer, functor, or lambda expression:

```
int add(int, int);

cout << eval(add,10,20) << endl;
cout << eval(std::multiplies<int>{},10,20) << endl;
cout << eval([](int a, int b){return a+10*b;},10,20) << endl;
```

Function objects

the `std::function` type (in `<functional>`)

Example: a vector of functions

```
std::vector<std::function<int(int,int)>> fs;

fs.emplace_back(add);
fs.emplace_back(std::multiplies<int>{});
fs.emplace_back([](int a, int b){return a+10*b;});

for(const auto& f: fs){
    cout << eval(f,10,20) << '\n';
}
```

Function objects

partial application: `std::bind` (in `<functional>`)

`std::bind()` : create a new function object by “partial application” of a function (object)

Example

```
std::vector<int> v = {1,3,2,4,3,5,4,6,5,7,6,8,3,9};  
std::vector<int> w;
```

```
using std::placeholders::_1;  
auto gt5 = std::bind(std::greater<int>(), _1, 5);
```

```
std::copy_if(v.begin(), v.end(), std::back_inserter(w), gt5);
```

or using namespace `std::placeholders`;

An alternative is to simply use a lambda:

```
auto gt5 = [](int x) {return x > 5;};
```

Function objects

Member function wrapper: `std::mem_fn` (in `<functional>`)

`std::mem_fn()` : create a new function object that is callable as a free function, with a reference to the object as the first argument.

Example

```
struct Foo{
    void print() const;
    void test(int i) const;
    Foo(int i=0) :x(i) {}
    int x;
};
int main() {
    std::vector<Foo> v{1,2,3,4,5,6,7,8,9,10};

    std::for_each(begin(v), end(v), std::mem_fn(&Foo::print));

    auto test = std::mem_fn(&Foo::test);
    const Foo& foo = *v.rbegin();
    test(foo, 123);
}
```

An alternative is to simply use a lambda:

```
auto test = [](const Foo& f, int x) {f.test(x);};
```

rules of thumb, “defaults”

- ▶ Iteration, *range for*
- ▶ *return value optimization*
- ▶ call by value or reference?
- ▶ reference or pointer parameters? (without transfer of ownership)
- ▶ default constructor and initialization
- ▶ resource management: RAll and *rule of three (five)*
- ▶ be careful with type casts. Use *named casts*

use *range for*

```
for(auto e : collection) { or (const) reference
    // ...
}
```

Works on any type T that has

- ▶ member functions `T::begin()` and `T::end()`, or
- ▶ free functions `begin(T)` and `end(T)`
- ▶ with proper **const** overloads

Use *range for* for iteration over *an entire* collection:

- ▶ safer and more obvious code
- ▶ no risk of accidentally assigning
 - ▶ the iterator
 - ▶ the loop variable
- ▶ no pointer arithmetic

return value optimization (RVO)

The compiler may optimize away copies of an object when returning a value from a function.

- ▶ *return by value* often efficient, also for larger objects
- ▶ RVO allowed *even if the copy constructor or the destructor has side effects*
- ▶ avoid such side effects to make code portable

Rules of thumb for function parameters

parameters and return values, “reasonable defaults”

- ▶ *return by value* if not *very expensive* to copy
- ▶ pass by reference if not *very cheap* to copy
(*Don't force the compiler to make copies.*)
 - ▶ input parameters: **const** T&
 - ▶ in/out or output parameters: T&

parameters: reference or pointer?

- ▶ required parameter: pass reference
- ▶ optional parameter: pass pointer (can be nullptr)

```
void f(widget& w)
{
    use(w); //required parameter
}
```

```
void g(widget* w)
{
    if(w) use(w); //optional parameter
}
```

Default constructor and initialization

- ▶ (automatically generated) default constructor (**=default**) does not always initialize members
 - ▶ *global variables* are initialized to 0 (or corresponding)
 - ▶ *local variables* are not initialized

```
struct Foo { int x; };

int a;    // a is initialized to 0
Foo b;    // b.x is initialized to 0

int main() {
    int c;           // c is not initialized
    int d = int();  // d is initialized to 0

    Foo e;           // e.x is not initialized
    Foo f = Foo();   // f.x is initialized to 0
    Foo g{};         // g.x is initialized to 0
}
```

- ▶ *always initialize variables (with value or empty {})*
- ▶ *always implement default constructor (or =delete)*

RAII: Resource acquisition is initialization

- ▶ Allocate resources for an object in the constructor
- ▶ Release resources in the destructor
- ▶ Simpler resource management, no naked **new** and **delete**
- ▶ Exception safety: destructors are run when an object goes out of scope
- ▶ *Resource-handle*
 - ▶ The object itself is small
 - ▶ Pointer to larger data on the heap
 - ▶ Example, our Vector class: pointer + size
 - ▶ Utilize move semantics
- ▶ `unique_ptr` is a *handle* to a specific object. Use *if you need an owning pointer*, e.g., for polymorph types.
- ▶ Prefer specific *resource handles* to smart pointers.

Smart pointers: `unique_ptr`

Example

```
struct Foo {
    int i;
    Foo(int ii=0) :i{ii} { std::cout << "Foo(" << i <<")\n"; }
    ~Foo() { std::cout << "~Foo("<<i<<")\n"; }
};
void test_move_unique_ptr()
{
    std::unique_ptr<Foo> p1(new Foo(1));
    {
        std::unique_ptr<Foo> p2(new Foo(2));
        std::unique_ptr<Foo> p3(new Foo(3));
        // p1 = p2; // error! cannot copy unique_ptr
        std::cout << "Assigning pointer\n";           Foo(1)
        p1 = std::move(p2);                            Foo(2)
        std::cout << "Leaving inner block...\n";      Foo(3)
    }                                                  Assigning pointer
    std::cout << "Leaving program...\n";             ~Foo(1)
}                                                    Leaving inner block...
}                                                    ~Foo(3)
                                                    Leaving program...
                                                    ~Foo(2)
```

Foo(2) survives the inner block
as `p1` takes over ownership.

Resource management

- ▶ Resource management: RAII and *rule of three (five)*
- ▶ Avoid “naked” **new** and **delete**
- ▶ Use constructors to establish *invariants*
 - ▶ throw exception on failure

for polymorph classes

- ▶ Copying often leads to disaster.
- ▶ **=delete**
 - ▶ Copy/Move-constructor
 - ▶ Copy/Move-assignment
- ▶ If copying is needed, implement a virtual `clone()` function

classes

- ▶ only create member functions for things that require access to *the representation*
- ▶ as default, make constructors with one parameter **explicit**
- ▶ only make functions **virtual** if you want polymorphism

polymorph classes

- ▶ access through reference or pointer
- ▶ A class with virtual functions must have a *virtual destructor*.
- ▶ use **override** for readability and to get help from the compiler in finding mistakes
- ▶ use **dynamic_cast** to navigate a class hierarchy

safer code

- ▶ initialize all variables
- ▶ use exceptions instead of returning error codes
- ▶ use *named casts* (if you must cast)
- ▶ only use **union** as an implementation technique inside a class
- ▶ avoid pointer arithmetics, except
 - ▶ for trivial array traversal (e.g., ++p)
 - ▶ for getting iterators into built-in arrays (e.g., a+4)
 - ▶ in very specialized code (e.g., memory management)

use compiler warnings (consult your compiler manual)

```
-Wall -Wextra -Werror -pedantic -pedantic-errors  
-Wold-style-cast -Wnon-virtual-dtor -Wconversion -Wshadow  
-Wtype-limits -Wtautological-compare -Wduplicated-cond
```

The compiler manual gives a comprehensive list of dangerous constructs.

The standard library

- ▶ use the standard library when possible
 - ▶ standard containers
 - ▶ standard algorithms
- ▶ prefer `std::string` to C-style strings (`char[]`)
- ▶ prefer containers (e.g., `std::vector<T>`) to built-in arrays (`T[]`)
- ▶ consider standard algorithms instead of hand-written loops

Often both

- ▶ safer and
- ▶ more efficient

than custom code

The standard containers

- ▶ use `std::vector` by default
- ▶ use `std::forward_list` for sequences that are usually empty
- ▶ be careful with iterator invalidation
- ▶ use `at()` instead of `[]` to get bounds checking
- ▶ use *range for* for simple traversal
- ▶ initialization: use `()` for sizes/iterators and `{}` for list of values
- ▶ use `emplace_back` instead of `push_back` of a temporary
- ▶ use member functions (not algorithms) for `std::map` and `std::set`

Write code that is correct and easily understandable

Good luck on the exam

Questions?