

# EDAF30 – Programming in C++

## *12. Recap.*

Sven Gestegård Robertz  
*Computer Science, LTH*

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# Outline

- 1 Classes and inheritance
  - Scope
  - const for objects and members
- 2 Rules of thumb
- 3 Syntax
- 4 More about polymorphic types
- 5 Object slicing example
- 6 Namespaces and ADL

# 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)
```



### 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

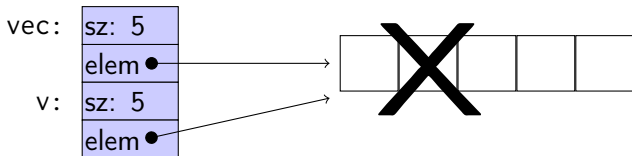
## Copy constructor

- ▶ 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**



# 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: RAI and *rule of three (five)*
- ▶ be careful with type casts. Use *named casts*

## use *range for*

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

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

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

## *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.



# Rules of thumb for function parameters

## “reasonable defaults”

	cheap to copy	moderately cheap to copy	expensive to copy
In	f(X)	f(const X&)	
Out	X f()		f(X&)
In/Out	f(X&)		

# Declarations and parentheses

- ▶ Parentheses matter in declarations of pointers to arrays and functions
  - ▶ `int *a[10]` declares `a` as an array of `int*`
  - ▶ `int (*a)[10]` declares `a` as a pointer to `int[10]`
  - ▶ `int (&a)[10]` declares `a` as a reference to `int[10]`
  - ▶ `int (*f)(int)` declares `f` as a pointer to function  $int \rightarrow int$
- ▶ BUT may be used anywhere

```
struct Foo;

Foo test;
Foo(f);           // Foo f;

int x;
int(y);           // int y;
int(z){17};       // int z{17};
int(q){}:         // int q{};
```

## Example: A class hierarchy

```
class Animal{
public:
    void speak() const { cout << get_sound() << endl;}
    virtual string get_sound() const =0;
    virtual ~Animal() =default;
};

class Dog :public Animal{
public:
    string get_sound() const override {return "Woof!";}
};
class Cat :public Animal{
public:
    string get_sound() const override {return "Meow!";}
};
class Bird :public Animal{
public:
    string get_sound() const override {return "Tweet!";}
};
class Cow :public Animal{
public:
    string get_sound() const override {return "Moo!";}
};
```

# Example

## Use (not polymorphic)

```
int main()
{
    Dog d;
    Cat c;
    Bird b;
    Cow w;

    d.speak();      Woof!
    c.speak();      Meow!
    b.speak();      Tweet!
    w.speak();      Moo!
}
```

# Example

## Call by reference

```
void test_polymorph(const Animal& a)
{
    a.speak();
}

int main()
{
    Dog d;
    Cat c;
    Bird b;
    Cow w;

    test_polymorph(d);           Woof!
    test_polymorph(c);           Meow!
    test_polymorph(b);           Tweet!
    test_polymorph(w);           Moo!
}
```

# Example

## Container with polymorph objects

```
int main()
{
    Dog d;
    Cat c;
    Bird b;
    Cow w;

    std::vector<Animal> zoo{d,c,b,w};

    for(auto x : zoo){
        x.speak();
    }
}
```

error: cannot allocate an object of abstract type 'Animal'

# Example

## Must use container of pointers

```
int main()
{
    Dog d;
    Cat c;
    Bird b;
    Cow w;

    std::vector<Animal*> zoo{&d,&c,&b,&w};

    for(auto x : zoo){
        x->speak();      Woof!
    };                  Meow!
                       Tweet!
    }                   Moo!
```

# 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
}
```

- ▶ Limit visibility of names
  - ▶ expressing which functions/classes/objects belong together
  - ▶ reduce risk of name clashes
  - ▶ cf. package in Java
- ▶ Accessing names in namespaces:
  - ▶ qualified name (with scope operator): `std::cout`
  - ▶ **using** declaration: `using std::cout;`
    - ▶ brings in a single name into the current scope
  - ▶ **using** directive: `using namespace std;`
    - ▶ brings in all names in namespace `std` into the current scope
    - ▶ avoid in general, or use in limited scope
  - ▶ never write **using**-directives in header files
    - ▶ introduces names in user code
- ▶ Namespaces *can be extended*
  - ▶ Except (with some exceptions) `std` ( $\Rightarrow$  undefined behaviour)

## namespace Example

### declarations (.h)

```
namespace foo {  
    void test();  
}
```

```
namespace bar {  
    void test();  
}
```

```
int main()  
{  
    foo::test();  
    bar::test();  
    using namespace foo;  
    test();  
}
```

```
foo::test()  
bar::test()  
foo::test()
```

### definitions (.cc)

```
using std::cout;  
using std::endl;
```

```
namespace foo {  
    void test()  
    {  
        cout << "foo::test()\n";  
    }  
}
```

```
void bar::test()  
{  
    cout << "bar::test()\n";  
}
```

## ▶ Unnamed namespaces

- ▶ local to a particular file (also if **#included**)
- ▶ is used to hide names (cf. **static** in C)
- ▶ names clash with global names

```
namespace foo {  
    void test()  
    {  
        cout << "foo::test()\n";  
    }  
}  
namespace {  
    void test()  
    {  
        cout << "::test()\n";  
    }  
}
```

```
int main()  
{  
    test();  
    foo::test();  
    ::test();  
}  
  
::test()  
foo::test()  
::test()
```

## ▶ Alternative names for namespaces (*namespace aliases*):

```
namespace my_name=a_really_long_and_weird_namespace_name;
```

# Argument Dependent Lookup (ADL)

Name lookup is done in *enclosing scopes*, but...

```
namespace test{
    struct Foo{
        Foo(int v) :x{v} {}
        int x;
    };
    std::ostream& operator<<(std::ostream& o, const Foo& f) {
        return o << "Foo(" << f.x << ")";
    }
} // namespace test

int main()
{
    test::Foo f(17);
    std::cout << f << '\n';
}
```

- ▶ The function `operator<<(ostream&, const Foo&)` is not visible in `main()`.
- ▶ Through ADL it is found in the namespace of its argument (`test`).

# Argument Dependent Lookup (ADL)

```
namespace test{
    struct Foo;
    std::ostream& operator<<(std::ostream& o, const Foo& f);
    using std::cout;
    void print(const Foo& f)
    {
        cout << f << '\n';
    }
    void print(int i)
    {
        cout << i << '\n';
    }
} // namespace test

int main()
{
    test::Foo f(17);

    print(f);
    print(17);
    test::print(17);
}
```

- ▶ The functions `test::operator<<()` and `test::print(const Foo&)` are found through ADL.
- ▶ The function `test::print(int)` is not found.
- ▶ unless `using test::print`.