EDAF50 – C++ Programming

4. Classes

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Outline

User-defined types
Categories

- Concrete classes
- Abstract classes
- Class hierarchies

User-defined types
Concrete classes

A concrete type

- "behaves just like a built-in type"
- its representation is part of its definition,
  That allows us to
  - refer to objects directly (not just using pointers or references)
  - initialize objects directly and completely (with a *constructor*)
  - place objects
    - on the stack (i.e., local variables)
    - in other objects (i.e., member variables)
    - in statically allocated memory (e.g., global variables)
  - copy objects
    - assignment of a variable
    - copy-constructing an object
    - value parameter of a function

Constructors

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*

Default constructor with member initializer list.

```
class Bar {
public:
    Bar(int v=100, bool b=false) :value{v},flag{b} {}
private:
    int value;
    bool flag;
};
```

Default arguments

- If a constructor can be called without arguments, it is a default constructor.

```
class KomplextTal {
public:
    KomplextTal(float x=1):re(x),im(0) {}
    //...
};
```

gives the same default constructor as the explicit

```
    KomplextTal():re{1},im{0} {}
```

Constructors
Two ways of initializing members

With member initializer list in constructor

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

Members can have a *default initializer*, in C++11:

```
class Foo {
public:
    Foo() =default;
private:
    int value {0};
    bool flag {false};
};
```

- prefer default initializer to overloaded constructors or default arguments

Constructors
Initialization and assignment

It is (often) *possible* to write like in Java, but

- it is less efficient
- the members must be *assignable*

Java-style: assignment in constructor

```
class Foo {
public:
    Foo(const Bar& v) {
        value = v;  NB! assignment, not initialization
    }
private:
    Bar value; is default constructed before the body of the constructor
};
```

*An object is initialized **before** the body of the constructor is run*

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
Prefer default member initializers

Use default member initializers if class member variables have default values.

Default values through overloaded ctors: risk of inconsistency

```
class Simple {
public:
    Simple() :a(1), b(2), c(3) {}
    Simple(int aa, int bb, int cc=-1) :a(aa), b(bb), c(cc) {}
    Simple(int aa) :a(aa), b(0), c(0) {}
private:
    int a;
    int b;
    int c;
};
```

Use default member initializers if class member variables have default values.

With default initializers: consistent

```
class Simple {
public:
    Simple() =default;
    Simple(int aa, int bb, int cc) :a(aa), b(bb), c(cc) {}
    Simple(int aa) : a(aa) {}
private:
    int a {-1};
    int b {-1};
    int c {-1};
};
```

Constructors
Default constructor and parentheses

The default constructor *cannot be called with empty parentheses*.

```
Bar b1;
Bar b2{};
Bar be();   // wrong!  "most vexing parse"
Bar b3(25); // OK

Bar* bp1 = new Bar;
Bar* bp2 = new Bar{};
Bar* bp3 = new Bar(); //OK
```

NB! The compiler error will be at the *use* of `be` e.g.,

```
be.fun();
```

```
request for member 'fun' in 'be', which is of non-class type 'Bar()'
```

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 *(different meaning from Java)*

```
struct A { int x; };

int i; // i is initialized to 0 (global variable)
A a;   // a.x is initialized to  0 (global variable)

int main() {
    int j;           // j is uninitialized
    int k = int();   // k is initialized to 0
    int l{};         // l is initialized to 0

    A b;             // b.x is uninitialized
    A c = A();       // c.x is initialized to 0
    A d{};           // d.x is initialized to 0
}
```

- *always initialize variables*
- *always implement default constructor (or =**delete**)*

Constructors
Delegating constructors (C++11)

In C++11 a constructor can call another (like `this(...)` in Java).

```
struct Test{
    int val;

    Test(int v) :val{v} {}

    Test(int v, int scale) :Test(v*scale) {};     // delegation

    Test(int a, int b, int c) :Test(a+b+c) {};    // delegation
};
```

A delegating constructor call shall be *the only member-initializer.*
(A constructor initializes an object *completely*.)

The pointer `this`
Self reference

In a member function, there is an implicit *pointer* **`this`**, pointing to the object the function was called on. (cf. **`this`** in Java).

- typical use: **`return *this`** for operations returning a reference to the object itself

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 state of the object”
  - *technically: implicit declaration* `const T* const this;`

Constant objects
Example

const references and const functions

```
class Point{
public:
    Point(int xi, int yi) :x{xi},y{yi}{}
    int get_x() const {return x;}
    int get_y() const {return y;}
    void set_x(int xi) {x = xi;}
    void set_y(int yi) {y = yi;}
private:
    int x;
    int y;
};
void example(Point& p, const Point& o) {
    p.set_y(10);
    cout << "p: "<< p.get_x() << "," << p.get_y() << endl;

    o.set_y(10);
    cout << "o: "<< o.get_x() << "," << o.get_y() << endl;
}
passing 'const Point' as 'this' argument discards qualifiers
```

Constant objects
Example

Note **const** in the declaration (and definition!) of the member function **operator[](int) const**: ("**const** *is part of the name*")

```
class Vector {
public:
    //...
    double operator[](int i) const;      // function declaration
    //...
private:
    double* elem;
    //...
};


double Vector::operator[](int i) const    // function definition
{
    return elem[i];
}
```

Constant objects
Example: **const** overloading

The functions **operator**[](**int**) and **operator**[](**int**) **const** *are different functions*.

Example

```
class Vector {
    double& operator[](int i)       {return elem[i];}
    double  operator[](int i) const {return elem[i];}
private:
    double* elem;
    //...
};
```

- If **operator**[] is called on a
  - non-**const** object, a *reference* is returned
  - **const** object, a *copy* is returned
- The assignment `v[2] = 10;` only works on a non-const `v`.

A concrete type

- "behaves just like a built-in type"
- the representation is part if the definition,
  That allows us to
  - refer to objects directly (not just using pointers or references)
  - initialize objects directly and completely (with a *constructor*)
  - place objects
    - on the stack (i.e., in local variables)
    - in other objects
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  - copy objects
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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`)

```
void function(Bar); // by-value parameter

Bar b1(10,false};

Bar b2{b1};          // the copy constructor is called
Bar b3(b2);          // the copy constructor is called
Bar b4 = b2;         // the copy constructor is called

function(b2);        // the copy constructor is called
```

Copy Constructors
default

- Declaration:

```
class C {
public:
    C(const C&) =default;
};
```

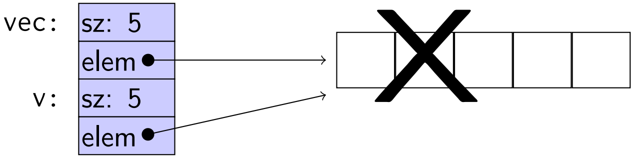
- default copy constructor
  - Is automatically generated if not defined in the code
    - exception: if there are members that cannot be copied
  - *shallow copy* of each member
    - Works for members variables with built-in types,
    - or *classes that behave like built-in types* (RAII-types)
    - *Does not work* for classes which manage resources “manually” (More on this later)

```
class Vector{
public:
    Vector(int s) :elem{new double[s]}, sz{s} {}
    ~Vector() {delete[] elem;}
    double& operator[](int i) {return elem[i];}
    int size() {return sz;}
private:
    double* elem;
    int sz;
};
```

No copy constructor defined ⇒ default generated.

Classes
Default copy construction: shallow copy

```
void f(Vector v);

void test()
{
    Vector vec(5);
    f(vec); // call by value -> copy
    // ... other uses of vec
}
```



- 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!

Constructors
Special cases: zero or one parameter

Copy Constructor

- Has a **const** & as parameter: `Bar::Bar(const Bar& b);`

Converting constructor

- A constructor with one parameter defines an *implicit type conversion* from the type of the parameter

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

default constructor copy constructor converting constructor

Converting constructor
Warning - implicit conversion

```
class Vector{
public:
    Vector(int s);    // create Vector with size s
    ...
    int size() const; // return size of Vector
    ...
};

void example_vector()
{
    Vector v = 7;

    std::cout << "v.size(): " << v.size() << std::endl;

}
```

```
v.size(): 7
```

In `std::vector` the corresponding constructor is declared

```
    explicit vector( size_type count );
```

Converting constructor and **explicit**

explicit specifies that a constructor does not allow implicit type conversion.

```
struct A                        struct B
{                               {
  A(int);                         explicit B(int);
  // ...                          // ...
};                              };
```

```
A a1(2);       // OK          B b1(2);       // OK
A a2 = 1;      // OK          B b2 = 1;      // Error! [2]
A a3 = (A)1;   // OK          B b3 = (B)1;   // OK: explicit cast

a3 = 17;       // OK [1]      b3 = 17;       // Error! [3]
```

```
[1]: construct an A(17), and then copy
[2]: conversion from 'int' to non-scalar type 'B' requested
[3]: no match for 'operator=' (operand types are 'B' and 'int')
```

Copying objects
Difference between *construction* and *assignment*

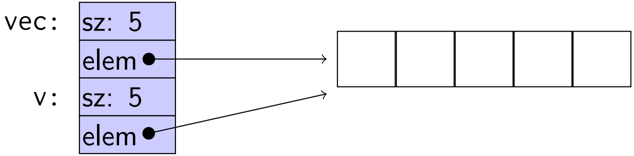
```
void function(Bar); // by-value parameter

Bar b1(10,false};

Bar b2{b1};          // the copy constructor is called
Bar b3(b2);          // the copy constructor is called
Bar b4 = b2;         // the copy constructor is called

function(b2);        // the copy constructor is called

b4 = b3;             // the copy constructor is not called
```

copy assignment – not construction

Copying objects
the *copy assignment* operator: `operator=`

The *copy assignment operator* is implicitly defined

- with the type `T& T::operator=(const T&)`
- if no `operator=` is declared for the type
- if all member variables can be copied
  - i.e., define a copy-assignment operator
- If all members are of built-in (and RAII) types the default variant works (same problems as with copy ctor).



- More on copy control when we discuss resource management

Preventing copying

- Declaration:

```
class C {
public:
    C(const C&) =delete;
    C& operator=(const C&) =delete;
};
```

- A class without copy constructor and copy assignment operator cannot be copied.
  - C++-98: declare private and don't define

friend

Functions or classes with access to all members in a class without being members themselves

Friend declaration in the class KomplextTal

```
class KomplextTal{
    //...
private:
    int re;
    int im;
    friend ostream& operator<<(ostream&, const KomplextTal&);
};
```

Definition outside the class KomplextTal

```
ostream& operator<<(ostream& o, const KomplextTal& c) {
    return o << c.re  << "+" c.im  << "i";
}
```

The free function **operator**<<(ostream&, **const** KomplextTal&) can access private members in KomplextTal.

`friend`

Functions or classes with *full access to all members* in a class without being members themselves

- Free functions,
- member functions of other classes, or
- entire classes can be friends.
- cf. `package` visibility in Java
- A friend declaration is not part of the class interface, and can be placed *anywhere in the class definition*.

Operator overloading

Most operators can be overloaded, except

```
sizeof   .   .*   ::     ?:
```

E.g., these operators can be overloaded

```
=
+ - * / %
^ & | ~
<< >>
&& || !
!= == < >
++ -- += *= .......
() []
```

. . . and the pointer and memory related

```
* -> ->*
&
new delete new[] delete[]
```

Operator overloading

Operator overloading syntax:

$$\texttt{return\_type}\ \textbf{operator}\otimes\ \texttt{(parameters...)}$$

for an operator $\otimes$ e.g. $==$ or $+$

For classes, two possibilities:

- as a member function
  - for binary operators, if the order of operands is suitable
    - a binary operator takes *one argument*
    - `*`**`this`** is the left operand,
    - the function argument is the right operand
- as a *free* function
  - if the public interface is enough, *or*
  - if the function is declared **`friend`**

Operator overloading
as member function and as free function

Example: declaration as member functions

```
class Komplex {
public:
    Komplex(float r, float i) : re(r), im(i) {}
    Komplex  operator+(const Komplex& rhs) const;
    Komplex  operator*(const Komplex& rhs) const;
    // ...
private:
    float re, im;
};
```

Example: declaration of `operator+` as `friend`

Declaration inside the class definition of `Komplex`:

```
friend Komplex operator+(const Komplex& l, const Komplex& r);
```

Note the number of parameters

Operator overloading

Defining **operator**+ in two ways:

- As member function (one parameter)

```
Komplex Komplex::operator+(const Komplex& rhs)const{
    return Komplex(re + rhs.re, im + rhs.im);
}
```

- As a free function (two parameters)

```
Komplex operator+(const Komplex& lhs, const Komplex& rhs){
    return Komplex(lhs.re + rhs.re, lhs.im + rhs.im);
}
```

NB! the **friend** *declaration is only in the class definition*

Operator overloading

Defining **operator+** in two ways:

- As member function

```
Komplex Komplex::operator+(const Komplex& rhs)const{
    return Komplex(re + rhs.re, im + rhs.im);
}
```

the right operand cannot be changed

the left operand cannot be changed

- As a free function

```
Komplex operator+(const Komplex& lhs, const Komplex& rhs){
    return Komplex(lhs.re + rhs.re, lhs.im + rhs.im);
}
```

*NB! the **friend** declaration is only in the class definition*

Operator overloading
Another implementation of +, using +=

Class definition

```
class Komplex {
public:
    Komplex& operator+=(const Komplex& z) {
        re += z.re;
        im += z.im;
        return *this;
    }
    // ...
};
```

Free function, does not need to be **friend**

```
Komplex operator+(Komplex a, const Komplex& b) {
    return a+=b;
}
```

NB! *call by value*: we want to return *a copy*.

Operator overloading

Example: inline **friend operator**<<

The definition (in the class definition)

```
#include <ostream>
using std::ostream;

class Komplex{
  friend ostream& operator<<(ostream& o, const Komplex& v) {
      o << v.re << '+' << v.im << 'i';
      return o;
  }
  //...
};
```

- *inline friend definition*: defines a free function in the same namespace as the class
- **operator**<< cannot be a member function (due to the order of operands it would have to be a member of std::ostream)

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**

Static members

static members: shared by all objects of the type (like Java)

- *declared* in the class definition
- *defined* outside class definition (if not **`const`**)
- can be **`public`** or **`private`** (or **`protected`**)

Function calls and results
Returning objects by value

- A function cannot return references to local variables
  - the object is destroyed at **`return`** – *dangling reference*
- How (in)efficient is it to return objects by value (a copy)?

return value optimization (RVO)

The compiler may optimize away copies of objects on **`return`** from functions

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

Rules of thumb for function parameters

- Return by value more often
- Do not over-use call-by-value

"reasonable defaults"

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

For results, if the cost of copying is

- small, or moderate ($< 1k$, contiguous): return by value (modern copilers do RVO: return value optimization)
- large : call by reference as *out parameter*
  - or maybe allocate with **new** and return pointer

Call by reference or by value?
Rules of thumb

For passing an object to a function when

- you may want *to change the value* of the object
  - reference: `void f(T&);` or
  - pointer: `void f(T*);`
- you *will not* change it, it is *large* (or impossible to copy)
  - constant reference: `void f(const T&);`
- otherwise, *call by value*
  - `void f(T);`

Call by reference or by value?
Rules of thumb

- How big is "large"?
  - more than a few *words*
- When to use out parameters?
  - prefer code that is obvious

    Example: two functions:

    ```
    void incr1(int& x)
    {
        ++x;
    }

    int incr2(int x)
    {
      return x + 1;
    }
    ```

    Use:

    ```
    int v = 0;
    ...

    incr1(v);
    ...

    v = incr2(v);
    ```

    Here it is much clearer that `v = incr2(v)` changes `v`

  - For multiple output values, consider returning a **`struct`**, a `std::pair` or a `std::tuple`

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
}
```

Suggested reading

References to sections in Lippman

Classes	2.6, 7.1.4, 7.1.5
Constructors	7.5–7.5.4
(Aggregate classes)	("C structs" without constructors) 7.5.5
Destructors	13.1.3
this and const	p 257–258
inline	6.5.2, p 273
friend	7.2.1
static members	7.6
Copying	13.1.1
Assignment	13.1.2
Operator overloading	14.1 – 14.3

Next lecture

References to sections in Lippman

Dynamic memory and smart pointers 12.1

Dynamically allocated arrays 12.2.1

Classes, resource management 13.1, 13.2

Type casts 4.11