

Constructor/Destructor

- Constructor as conversion operator
- How to define operators
- Initialization list
- Destructors / array destruction
- Cloning
- Delegated constructor
- Using constructor
- Universal constructor
- Construction and exceptions

Constructor/Destructor

- In OO languages constructors to initialize objects
- Other style: using factory objects
- Constructors are also
 - Conversion operators
 - Create temporaries
- Destructors are to free resources
 - Resource: much more than memory
 - e.g. unlock, fclose, ...

A constructor quiz

```
#include <iostream>

struct foo {
    foo() = default;
    int a;
};

struct bar {
    bar();
    int b;
};

bar::bar() = default;

int main() {
    foo a{};
    bar b{};
    std::cout << a.a << ' ' << b.b;
}
```

Default-, value- and zero-initialization

```
T global;    // zero-initialization,
             // then default-initialization

void foo() {
    T i;      // default-initialization
    T j{};    // value-initialization (C++11)
    T k = T(); // value-initialization
    T l = T{}; // value-initialization (C++11)
    T m();    // function-declaration
    new T;    // default-initialization
    new T();  // value-initialization
    new T{};  // value-initialization (C++11)
}

struct A { T t; A():t() {} }; // t is value-initialized
struct B { T t; B():t{} {} }; // t is value-initialized(C++11)
struct C { T t; C()      {} }; // t is default-initialized
```

Default-, value- and zero-initialization

- Default initialization
 - If T is a class: default constructor is called
 - If an array, each element is default initialized
 - Otherwise: no initialization, results indeterminate value
- Value initialization
 - If T is a class: default initialized
 - (after zero initialized if T's default constructor is not user defined / deleted)
 - If an array, each element is value initialized
 - Otherwise: zero initialized
- Zero initialization
 - Applied to static and thread local variables before any other initialization
 - If T scalar (number, pointer, enum) set to 0
 - If Z is a class, all subobjects are zero initialized

User provided constructors

```
struct foo {
    foo() = default; // foo() is not user provided
};

struct bar {
    bar(); // bar() is user provided
};
bar::bar() = default; // bar() is user provided

//ill-formed, const with no user-provided constructor
const int my_int;

//well-formed, has a user-provided constructor
const std::string my_string;

//ill-formed, const no user-provided constructor
const foo my_foo;

//well-formed, has a user-provided constructor
const bar my_bar;
```

A constructor quiz: answers

```
#include <iostream>

struct foo {
    foo() = default; // foo() is not user provided
    int a;
};

struct bar {
    bar(); // bar() is user provided
    int b;
};

bar::bar() = default; // bar() is user provided

int main() {
    foo a{};
    bar b{};
    std::cout << a.a << ' ' << b.b;
}
```

A constructor quiz: answers

```
#include <iostream>

struct foo {
    foo() = default; // foo() is not user provided
    int a;
};

struct bar {
    bar(); // bar() is user provided
    int b;
};

bar::bar() = default; // bar() is user provided

int main() {
    foo a{}; // zero initialized then value initialized
    bar b{}; // value initialized
    std::cout << a.a << ' ' << b.b;
}
```


A constructor quiz: answers

```
#include <iostream>

struct foo {
    foo() = default; // foo() is not user provided
    int a;
};

struct bar {
    bar(); // bar() is user provided
    int b;
};

bar::bar() = default; // bar() is user provided

int main() {
    foo a{}; // zero initialized then value initialized
    bar b{}; // value initialized
    std::cout << a.a << ' ' << b.b; // 0
}
```

A constructor quiz: answers

```
#include <iostream>

struct foo {
    foo() = default; // foo() is not user provided
    int a;
};

struct bar {
    bar(); // bar() is user provided
    int b;
};

bar::bar() = default; // bar() is user provided

int main() {
    foo a{}; // zero initialized then value initialized
    bar b{}; // value initialized
    std::cout << a.a << ' ' << b.b; // 0 undefined
}
```

Quote from the standard

N4140 (essentially C++14) [dcl.fct.def.default]/5:

Explicitly-defaulted functions and implicitly-declared functions are collectively called defaulted functions, and the implementation shall provide implicit definitions for them (12.1 12.4, 12.8), which might mean defining them as deleted. A function is user-provided if it is user-declared and not explicitly defaulted or deleted on its first declaration. A user-provided explicitly-defaulted function (i.e., explicitly defaulted after its first declaration) is defined at the point where it is explicitly defaulted; if such a function is implicitly defined as deleted, the program is ill-formed.

More to read on initialization

[accu]

<https://accu.org/index.php/journals/2379#FN01>

[cppcore]

<https://github.com/isocpp/CppCoreGuidelines/blob/master/CppCoreGuidelines.md#Res-always>

[cppref1] value-initialization

http://en.cppreference.com/w/cpp/language/value_initialization

[cppref2] default-initialization

http://en.cppreference.com/w/cpp/language/default_initialization

[cppref3] zero-initialization

http://en.cppreference.com/w/cpp/language/zero_initialization

–

A simple date class

```
class date
{
public:
    // default constructor
    date();
    // constructor
    date( int y, int m=1, int d=1);
    // explicit constructor
    explicit date( const char *s);
    // ...
private:
    // ...
    int year;
    int month;
    int day;
};
```

Where to define operators

- Theory says: bind with class
 - Member operators
- Some operators can't be members
 - `std::ostream& operator<<(std::ostream&, const X&)`
- Sometimes members creates unwanted dependences
 - `std::getline(std::basic_istream&, std::basic_string&)`
- Sometime operators should be symmetric

Symmetry

```
#include "date.h"

int main()
{
    date today;    // current date from OS

    if ( today < date(2016) ) // works

    if ( today < 2016 )      // works

    if ( 2016 < today )      // not working
                            // if operator< is member
};
```

Operators

```
// date.h
class date
{
public:
    // ...
private:
    // ...
    int year;
    int month;
    int day;
};

    bool operator<( date d1, date d2);
inline bool operator==(date d1,date d2)    { ... }
inline bool operator!=( date d1, date d2) { ... }
inline bool operator<=( date d1, date d2) { ... }
inline bool operator>=( date d1, date d2) { ... }
inline bool operator>( date d1, date d2)  { ... }
```


Creation of subobjects

```
// date.h
class date
{
public:
    date( int y, int m, int d);
private:
    // ...
    int year;
    int month;
    int day;
};

date::date(int y, int m, int d) : day(d), month(m), year(y)
{ . . . }

// rearranged to declaration order:
date::date(int y, int m, int d) : year(y), month(m), day(d)
{ . . . }
```

Destructors

- Should be virtual?
 - When used in polymorphic way
 - When there is multiple inheritance

```
class Base
{
public:
    virtual ~Base();
};
class Der : public Base
{
public:
    virtual ~Der();
};
```

```
void f()
{
    Base *bp = new Der;
    // ...
    delete bp;
}
```

Arrays are not polymorphic!

```
struct Base
{
    Base() { cout << "Base" << " "; }
    virtual ~Base() { cout << "~Base" << endl; }
    int i;
};
struct Der : public Base
{
    Der() { cout << "Der" << endl; }
    virtual ~Der() { cout << "~Der" << " "; }
    int it[10]; // sizeof(Base) != sizeof(Der)
};
int main()
{
    Base *bp = new Der;
    Base *bq = new Der[5];

    delete bp;
    delete [] bq; // this causes runtime error
}
```

Cloning – “Virtual” constructors

- Constructors are not virtual
- But sometimes we need similar behavior

```
std::vector<Base*> source;  
std::vector<Base*> target;  
  
source.push_back(new Derived1());  
source.push_back(new Derived2());  
source.push_back(new Derived3());  
  
// should create new instances of the  
// corresponding Derived classes and  
// place them to target  
deep_copy( target, source);
```

Wrong approach

```
deep_copy( std::vector<Base*> &target,  
           const std::vector<Base*> &source)  
{  
    for(auto i = source.begin(); i!=source.end(); ++i)  
    {  
        target.push_back(new Base(**i)); // creates Base()  
    }  
}
```

Wrong approach 2

```
deep_copy( std::vector<Base*> &target,  
           const std::vector<Base*> &source)  
{  
    for(auto i = source.begin(); i!=source.end(); ++i)  
    {  
        if ( Derived1 *dp = dynamic_cast<Derived1*>(*i) )  
            target.push_back(new Derived1(*dp));  
        else if ( Derived2 *dp = dynamic_cast<Derived2*>(*i) )  
            target.push_back(new Derived2(*dp));  
        else if ( Derived3 *dp = dynamic_cast<Derived3*>(*i) )  
            target.push_back(new Derived3(*dp));  
    }  
}
```

Cloning

```
class Base
{
public:
    virtual Base* clone() const = 0;
};

class Derived : public Base
{
public:
    virtual Derived* clone() const { return new Derived(*this); }
};

deep_copy( std::vector<Base*> &target, const std::vector<Base*> &source)
{
    for(auto i = source.begin(); i!=source.end(); ++i)
    {
        target.push_back((*i)->clone()); // inserts Derived()
    }
}
```

Assignment operator

```
class MyClass
{
public:
    MyClass& operator=(const MyClass& rhs);
    // ...
private:
    std::vector<int> v;
    // resources...
};

MyClass& MyClass::operator=(const MyClass& rhs)
{
    if ( &rhs != this )
    {
        // release old resources
        // allocate new resources
        // copy resources from rhs to new
        v = rhs.v;    // release+allocate+copy
    }
    return *this;
}
```


Assignment operator

```
class MyClass
{
public:
    MyClass& operator=(const MyClass& rhs);
    // ...
private:
    std::vector<int> v;
    // resources...
};

MyClass& MyClass::operator=(const MyClass& rhs)
{
    if ( &rhs != this )
    {
        MyClass temp(rhs); // allocate+copy
        v.swap(temp.v);    // do not throw
    }                       // release old resource
    return *this;
}
```

Assignment operator

```
class MyClass
{
public:
    MyClass& operator=(const MyClass& rhs);
    // ...
private:
    std::vector<int> v;
    // resources...
};

MyClass& MyClass::operator=(MyClass rhs) // allocate+copy
{
    if ( &rhs != this )
    {
        MyClass temp(rhs);
        v.swap(rhs.v); // do not throw
    } // release old resource
    return *this;
}
```

Virtual assignment operator?

```
#include <iostream>

struct Base
{
    virtual Base&
    operator=(const Base& rhs)
    {
        std::cout<<"Base::operator="<<'\\n';
        a = rhs.a;
        return *this;
    }
    int a;
};

struct Derived : public Base
{
    virtual Derived&
    operator=(const Base& rhs) override
    {
        std::cout<<"Derived::operator="<<'\\n';
        a = 42;
        b = 43;
        return *this;
    }
    int b;
};
```

```
int main()
{
    Derived d1;
    Derived d2;
    d1.a = 1; d1.b = 2;
    d2.a = 3; d2.b = 4;

    std::cout<<" d1 == "<<d1.a
                <<" , "<<d1.b<<'\\n';
    std::cout<<" d2 == "<<d2.a
                <<" , "<<d2.b<<'\\n';

    d1 = d2;
    std::cout<<" d1 == "<<d1.a
                <<" , "<<d1.b<<'\\n';
}
```

Virtual assignment operator?

```
#include <iostream>

struct Base
{
    virtual Base&
    operator=(const Base& rhs)
    {
        std::cout<<"Base::operator="<<'\\n';
        a = rhs.a;
        return *this;
    }
    int a;
};

struct Derived : public Base
{
    virtual Derived&
    operator=(const Base& rhs) override
    {
        std::cout<<"Derived::operator="<<'\\n';
        a = 42;
        b = 43;
        return *this;
    }
    int b;
};
```

```
int main()
{
    Derived d1;
    Derived d2;
    d1.a = 1; d1.b = 2;
    d2.a = 3; d2.b = 4;

    std::cout<<" d1 == "<<d1.a
                <<" , "<<d1.b<<'\\n';
    std::cout<<" d2 == "<<d2.a
                <<" , "<<d2.b<<'\\n';

    d1 = d2;
    std::cout<<" d1 == "<<d1.a
                <<" , "<<d1.b<<'\\n';
}
```

```
$ ./a.out
d1 == 1,2
d2 == 3,4
Base::operator=
d1 == 3,4
```

Delegated constructors C++11

```
// C++98
class X
{
    int a;
    validate(int x) { if (0<x && x<=max) a=x; else throw bad_X(x); }
public:
    X(int x) { validate(x); }
    X() { validate(42); }
    X(string s) { int x = lexical_cast<int>(s); validate(x); }
    // ...
};
```

```
// C++11
class X
{
    int a;
public:
    X(int x) { if (0<x && x<=max) a=x; else throw bad_X(x); }
    X() : X{42} { }
    X(string s) : X{lexical_cast<int>(s)} { }
    // ...
};
```

Use constructors C++11

```
class Base
{
public:
    void f(double);    // overloaded member function
    void f(int);      // overloaded member function

    Base(double);     // overloaded constructors
    Base(int);        // overloaded constructors
    // ...
};

class Derived : public Base
{
public:
    using Base::f;    // lift Base's f into Derived scope - works in C++98
    void f(char);    // provide a new f
    void f(int);     // prefer this f to Base::f(int)

    using Base::Base; // lift Base constructors Derived scope - C++11 only
    Derived(char);    // provide a new constructor
    Derived(int);     // prefer this constructor to Base::Base(int)
    // ...
};
```

Use constructors C++11

```
#include <iostream>

struct Base
{
    Base(int i)      { std::cout << "Base(int) " << i << std::endl; }
    Base(double d)  { std::cout << "Base(double) " << d << std::endl; }
    void f(int i)   { std::cout << "Base::f(int) " << i << std::endl; }
    void f(double d) { std::cout << "Base::f(double) " << d << std::endl; }
};

struct Der : Base
{
    using Base::Base;
    using Base::f;
    Der(char c) : Base(c)    { std::cout << "Der(char) " << c << std::endl; }
    Der(double d) : Base(d)  { std::cout << "Der(double) " << d << std::endl; }
    void f(char c) { std::cout << "Der::f(char) " << c << std::endl; }
};

int main()
{
    Der x1('x'), x2(1), x3(3.14);
    x1.f('x');
    x1.f(1);
    x1.f(3.14);
}
```

```
Base(int) 120
Der(char) x
Base(int) 1
Base(double) 3.14
Der(double) 3.14
Der::f(char) x
Base::f(int) 1
Base::f(double) 3.14
```

Uniform (braced) initialization C++11

```
double t[] = { 1, 2, 3.456, 99.99 };  
vector<double> v = { 1, 2, 3.456, 99.99 };
```

```
int x1(0);    //  
int x2 = 0;   // same as x2(0)  
int x3{0};    // C++11, but do not narrowing  
int x4 = {0}; // C++11, usually the same as x3{0}
```

```
std::atomic<int> a1{0}; // ok  
std::atomic<int> a2(0); // ok  
std::atomic<int> a3 = 0; // syntax error! Non-copyable
```

```
class X  
{  
private:  
    int x{0}; // ok, C++11  
    int y = 0; // ok, C++11  
    int z(0); // syntax error!  
};
```

```
C c2; // Ok  
C c1(); // Most vexing parse  
C c3{}; // Ok
```


Initializer list

```
vector<double> v = { 1, 2, 3.456, 99.99 };
```

```
list<pair<string,string>> languages = {  
    {"Nygaard", "Simula"},  
    {"Richards", "BCPL"},  
    {"Ritchie", "C"}  
};
```

```
map<vector<string>,vector<int>> years = {  
    { {"Maurice", "Vincent", "Wilkes"}, {1913, 1945, 1951, 1967, 2000} },  
    { {"Martin", "Ritchards"}, {1982, 2003, 2007} },  
    { {"David", "John", "Wheeler"}, {1927, 1947, 1951, 2004} }  
};
```

BUT!

```
auto x1 = 5;        // deduced type is int  
auto x2(5);        // deduced type is int  
auto x3{ 5 };      // deduced type is std::initializer_list (will fixed)  
auto x4 = { 5 };   // deduced type is std::initializer_list
```

Default and deleted constructors C++11

```
class X
{
private:
    X(const X&);           // pre-C++11
    X& operator=(const X&); // pre-C++11
};
```

```
class X : private boost::noncopyable
{
    // ...
};
```

```
class X
{
    X(const X&) = delete;           // C++11
    X& operator=(const X&) = delete; // C++11
};
```

```
class X
{
    X(const X&) = default;           // C++11
    X& operator=(const X&) = default; // C++11
};
```

Constructors and exceptions

```
class C
{
public:
    C(int i, int j)
    try
        : x(i), z(j)    // x(i) or z(j) may throw exception
    { }
    catch( ... )
    {
        // we get here if either x(i) or z(j) throws exception
        // if x(i) throws, then z uninitialized
        // if z(j) throws, then ~X::X() has already executed

        // what to do here ??
    }
private:
    X x;
    Z z;
};
```

Constructors and exceptions

```
class C
{
public:
    C(int i, int j)
        try
            : x(i), z(j)    // x(i) or z(j) may throw exception
        { }
        catch( ... )
        {
            // do something
            if ( ... )
                throw OtherException();
            // otherwise
            // constructor will re-throw original exception
        }
private:
    X x;
    Z z;
};
```