

Constructors/Destructors/Operators

- Constructor types
- 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 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, ...

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

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;
}
```

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 still user-provided

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

User provided constructors

```
struct foo {  
    foo() = default; // foo() is not user-provided  
};  
  
struct bar {  
    bar(); // bar() is user-provided  
};  
bar::bar() = default; // bar() is still user-provided  
  
//ill-formed, const with no user-provided constructor  
const int my_int;  
  
//well-formed, const but has a user-provided constructor  
const std::string my_string;  
  
//ill-formed, const with no user-provided constructor  
const foo my_foo;  
  
//well-formed, const but 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 still 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;
}
```

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

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, 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.

Some more initializations :)

```
int i;           // default
int i{};        // value
static int i;   // zero
static int i = constexpr_fun(); // constant

int i{1}, j(42); // direct
int i = 42, j = i; // copy
int i = {42};     // copy-list
int i{42};        // direct-list

int iarr[3] = {0, 1}; // aggregate iarr[2] == 0
int iarr[3] = {.1=2}; // aggregate
const int &ieref = 42; // reference

// static: zero- or const initialization
// dynamic: non static
// unordered: dynamic init. of class template static member
// ordered: dynamic init. Of other non-locals with static life
// implicit: default or value
```

<https://i.imgur.com/3wlxtI0.mp4>

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

value-initialization http://en.cppreference.com/w/cpp/language/value_initialization

[cppref2] default-initialization

default-initialization http://en.cppreference.com/w/cpp/language/default_initialization

[cppref3] zero-initialization

zero-initialization http://en.cppreference.com/w/cpp/language/zero_initialization

Constructor as conversion operator

```
class date { ... };
```

```
main()
```

```
{
```

```
    date exam{2019, 12, 15}; // constructor with 3 ints  
    date semester{2022,2}; // constructor with 2 ints
```

```
    if ( exam < date{2020} ) { ... } // 2020.1.1  
    else if ( exam < date{} ) { ... } // today
```

```
    date exam2{"2019.12.15"}; // constructor with string
```

```
}
```

- How many constructors should we define?

Constructor as conversion operator

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

Side note: Schwartz error

```
while ( cin >> i ) // 1st attempt: cin.operator int() Jerry Schwarz
```

```
std::istream& tempc = cin.operator>>(i);  
int tempi = tempc.operator int();  
while ( tempi )
```

```
while ( cin << i )
```

```
int tempi1 = cin.operator int();  
int tempi2 = tempi1 << i;  
while ( tempi2 )
```

`operator bool()` is not better: `bool` -> `int` promotion

Side note: safe bool conversion

```
while ( cin >> i ) // 2nd attempt: cin.operator void*() Jerry Schwarz

std::istream& tempc = cin.operator>>(i);
void* tempptr = tempc.operator void*();
while ( tempi ) // contextually converted to bool

while ( cin << i )

void* tempi1 = cin.operator void*(); // no operator<<(void*,int)
delete std::cin; // delete ( operator void*(std::cin) )

// C++11 solution: explicit specifier
explicit operator bool() const; // not to use in implicit conversion
// works in if, while, etc...

// C++20
explicit (expr) operator bool() const; // explicit if expr is true
```

How to define operators?

- $a + b$

`a.operator+(b)`

`operator+(a,b)`

- $a = b$, $a[b]$, $a(b_1, b_2, \dots)$, $a->$ only member

`a.operator= (b)`

`a.operator[] (b)`

`a.operator() (b1, b2, ...)`

`a.operator->()`

Where to define operators?

- Theory says: data and operations on it have strong binding
 - Member operators

- Some operators can't be members

```
std::ostream& operator<<(std::ostream&, const X&)
```

- Sometimes members creates unwanted dependencies

```
std::getline(std::basic_istream&, std::basic_string&)
```

- Sometime operators should be symmetric

Symmetry

```
class date
{
public:
    bool operator<(const date& rhs);
};

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

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

    if ( today < 2016 )       // works

};
```

Symmetry

```
class date
{
public:
    bool operator<(const date& rhs);
};

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

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

    if ( today < 2016 )       // works

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

Symmetry

```
class date
{
public:
};
bool operator<(const date& lhs, const date& rhs);

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

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

    if ( today < 2016 )       // works

    if ( 2016 < today )       // works
                                // if operator< is global
};
```

Inline functions

```
// 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 ) { ... }
```

Operators in C++20

```
#include <compare>
```

```
class date
```

```
{
```

```
public:
```

```
    // ...
```

```
    bool operator==(const Date& d) const = default;           // memberwise
```

```
    std::strong_ordering operator<=>( const Date& d) const;    // "spaceship"
```

```
private:
```

```
    // ...
```

```
    int year;
```

```
    int month;
```

```
    int day;
```

```
};
```

```
std::strong_ordering Date::operator<=>( const Date& d) const
```

```
{
```

```
    if (auto c = year_ <=> d.year_; c != 0 ) return c;
```

```
    if (auto c = month_ <=> d.month_; c != 0 ) return c;
```

```
    return day_ <=> d.day_;
```

```
}
```

```
// generated: bool Date::operator!=( const Date& d ) { return ! (*this == d); }
```

```
// generated: bool Date::operator<(const Date& d) { return (*this<=>d) < 0; }
```

```
// generated: bool Date::operator<=(const Date& d) { return (*this<=>d) <= 0; }
```

```
// etc...
```

Operators in C++20

```
#include <compare>
```

```
class date
```

```
{
```

```
public:
```

```
    // ...
```

```
    // bool operator==(const Date& d) const = default;
```

```
    std::strong_ordering operator<=>( const Date& d) const = default; // lexicogr
```

```
private:
```

```
    // ...
```

```
    int year;
```

```
    int month;
```

```
    int day;
```

```
};
```

```
std::strong_ordering Date::operator<=>( const Date& d) const
```

```
{
```

```
    if (auto c = year_ <=> d.year_; c != 0 ) return c;
```

```
    if (auto c = month_ <=> d.month_; c != 0 ) return c;
```

```
    return day_ <=> d.day_;
```

```
}
```

```
// generated: bool Date::operator==(const Date& d) { return (*this<=>d) == 0; }
```

```
// generated: bool Date::operator!=( const Date& d ) { return ! (*this == d); }
```

```
// generated: bool Date::operator<(const Date& d) { return (*this<=>d) < 0; }
```

```
// generated: bool Date::operator<=(const Date& d) { return (*this<=>d) <= 0; }
```

```
// etc...
```

Three way comparision

- Spaceship operator

$(a <=> b) < 0$ if $a < b$
 $(a <=> b) > 0$ if $a > b$
 $(a <=> b) == 0$ if $a == b$

- Return type

<code>std::strong_ordering</code>	equal, less, greater	$a == b \Rightarrow f(a) == f(b)$
<code>std::weak_ordering</code>	equivalent, less, greater	
<code>std::partial_ordering</code>	equivalent, less, greater, unordered	$1.f <=> \text{NaN}$

- Reversing operators

$a == 10$ $a.operator==(10)$
 $10 == a$ $a.operator==(10)$ assume symmetry

$a <=> 10$ $a.operator<=>(10)$
 $10 <=> a$ $a.operator<=>(10)$ assume symmetry

Three way comparision

- Spaceship operator

$(a <=> b) < 0$ if $a < b$
 $(a <=> b) > 0$ if $a > b$
 $(a <=> b) == 0$ if $a == b$

- Return type

<code>std::strong_ordering</code>	equal, less, greater	$a == b \Rightarrow f(a) == f(b)$
<code>std::weak_ordering</code>	equivalent, less, greater	
<code>std::partial_ordering</code>	equivalent, less, greater, unordered	$1.f <=> \text{NaN}$

- Reversing operators

<code>a == 10</code>	<code>a.operator==(10)</code>
<code>10 == a</code>	<code>a.operator==(10)</code> assume symmetry
<code>a <=> 10</code>	<code>a.operator<=>(10)</code>
<code>10 <=> a</code>	<code>a.operator<=>(10)</code> assume symmetry
<code>10 <=> a</code>	<code>0 <=> a.operator<=>(10)</code> assume symmetry

Partial ordering

```
#include <optional>
#include <compare>
```

<https://brevzin.github.io/c++/2019/07/28/comparisons-cpp20/>

```
struct IntNan {
    std::optional<int> val = std::nullopt;

    bool operator==(IntNan const& rhs) const {
        if (!val || !rhs.val) {
            return false;
        }
        return *val == *rhs.val;
    }
    std::partial_ordering operator<=>(IntNan const& rhs) const {
        if (!val || !rhs.val) {
            // we can express the unordered state as a first class value
            return std::partial_ordering::unordered;
        }
        // int <=> int returns strong_ordering, convertible to partial_ordering
        return *val <=> *rhs.val;
    }
};

// (IntNan{2} <=> IntNan{4}) < 0 ) // true
// (IntNan{2} <=> IntNan{}) == std::partial_ordering::unordered // true
// IntNaN{2} <= IntNan{} // false
```

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)
{ . . . }
```

Creation of subobjects C++11

```
class Simple
{
public:
    Simple( ) { cout << a << b << s << '\n'; }

private:
    int a{1};
    int b{2};
    std::string s{"string"};
};

int main()
{
    Simple obj;           // ?
    return 0;
}
```

Creation of subobjects C++11

- `class Simple`

```
{  
public:  
    Simple( ) { cout << a << b << s << '\n'; }  
  
private:  
    int a{1};  
    int b{2};  
    std::string s{"string"};  
};  
  
int main()  
{  
    Simple obj;           // 12string  
    return 0;  
}
```

Creation of subobjects C++11

```
class Simple
{
public:
    Simple( ) { cout << a << b << s << '\n'; }
    Simple(int aa, int bb) : a(aa), b(bb)
        { cout << a << b << s << '\n'; }
private:
    int a{1};
    int b{2};
    std::string s{"string"};
};

int main()
{
    Simple obj{5, 6};    // ?
    return 0;
}
```

Creation of subobjects C++11

```
class Simple
{
public:
    Simple( ) { cout << a << b << s << '\n'; }
    Simple(int aa, int bb) : a(aa), b(bb)
        { cout << a << b << s << '\n'; }
private:
    int a{1};
    int b{2};
    std::string s{"string"};
};

int main()
{
    Simple obj{5,6};    // 56string
    return 0;
}
```

Creation of subobjects C++11

```
class Simple
{
public:
    Simple( ) { cout << a << b << s << '\n'; }
    Simple(int aa, int bb) : a(b), b(bb)
        { cout << a << b << s << '\n'; }
private:
    int a{1};
    int b{2};
    std::string s{"string"};
};

int main()
{
    Simple obj{5, 6};    // ?
    return 0;
}
```

Creation of subobjects C++11

```
class Simple
{
public:
    Simple( ) { cout << a << b << s << '\n'; }
    Simple(int aa, int bb) : a(b), b(bb)
        { cout << a << b << s << '\n'; }
private:
    int a{1};
    int b{2};
    std::string s{"string"};
};

int main()
{
    Simple obj{5,6};    // 06string a is undefined!
    return 0;
}
```

Destructors

- Should be virtual?
 - If used in polymorphic way
 - If 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];
};
int main()
{
    Base *bp = new Der;
    Base *bq = new Der[5];

    delete bp; // fine: virtual destructor called
    delete [] bq;
}
```

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];
};
int main()
{
    Base *bp = new Der;
    Base *bq = new Der[5];

    delete bp; // fine: virtual destructor called
    delete [] bq; // this line causes runtime error
}
```

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; // fine: virtual destructor called
    delete [] bq; // this line causes runtime error
}
```

Cloning – “Virtual” constructors

- Constructors are not virtual
- But sometimes we need “virtual” 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 or move!
{
    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
```

# Virtual assignment operator?

```
#include <iostream>
```

```
• struct Base
{
 virtual Base&
 operator=(const Base& rhs) { /* ... */ }

 int a;
};

• struct Derived : public Base
{
 virtual Derived&
 operator=(const Base& rhs) override
 { /* ... */ }

 implicit Derived& operator=(const
Derived& rhs) = default;

 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
virtual Base::operator=
d1 == 3,4
```

# Virtual assignment operator?

```
#include <iostream>
```

```
• struct Base
{
 virtual Base&
 operator=(const Base& rhs) { /* ... */ }

 int a;
};

• struct Derived : public Base
{
 virtual Derived&
 operator=(const Base& rhs) override
 { /* ... */ }

 Derived& operator=(const Derived& rhs)
 {
 std::cout<<"'implicit'"
 " Derived::operator=\n";
 }

 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
'implicit' Derived::operator=
virtual Base::operator=
d1 == 3,4
```

# Virtual assignment operator?

```
#include <iostream>
```

```
• struct Base
{
 virtual Base&
 operator=(const Base& rhs) { /* ... */ }

 int a;
};

• struct Derived : public Base
{
 /* implicit */ Derived& operator=(const
Derived& rhs)
 {
 static_cast<Base&>(*this) =
 static_cast<Base&>(rhs);
 b = rhs.b;
 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";
}
```

[http://library.ijs.si/Stacks/Proceedings/InformationSociety/2018/IS2018\\_Volume\\_G%20-%20CSS.pdf](http://library.ijs.si/Stacks/Proceedings/InformationSociety/2018/IS2018_Volume_G%20-%20CSS.pdf)

(Szalay, Porkoláb - *Visualising Compiler-generated Special Member Functions of C++ Types*; page 55)

# 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
};
```

# 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 = boost::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{boost::lexical_cast<int>(s)} { }
 // ...
};
```

# Injected 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)
 // ...
};
```

# Injected 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;
 Der(char c) : Base(c) { std::cout << "Der(char) " << c << std::endl; }
 Der(double d) : Base(d) { std::cout << "Der(double) " << d << std::endl; }

 using Base::f;
 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
```

# Injected constructors: strong types

```
#include <iostream>
```

```
struct Date
```

```
{
 int year, month, day; // no constructor: aggregate type
};
```

```
struct BornDate : Date { }; // still aggregate type
```

```
struct DeathDate : Date { }; // still aggregate type
```

```
void print(BornDate born, DeathDate death);
```

```
int main()
```

```
{
 const BornDate born = { 1823, 1, 1 }; // aggregate initialization
 const DeathDate death = { 1849, 7, 31 }; // aggregate initialization

 print(born, death);
 // print(death, born); // compile error
}
```

# 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} }
};
```

```
auto x1 = 5; // deduced type is int
auto x2(5); // deduced type is int
auto x3{ 5 }; // deduced type is int since C++17
auto x4{ 5, 6 }; // error since C++17
auto x5 = { 5 }; // std::initializer_list<int>
```

```
enum class E;
E e { 42 }; // ok, since C++17
```

# Class template argument deduction

- Possible traps

```
#include <iostream>
#include <vector>

int main()
{
 std::vector v1{1,2};
 std::vector v2(v1.begin(), v1.end());
 std::vector v3{v1.begin(), v1.end()};

 std::cout << v1[0] << v2[0] << '\n'; //<< v3[0] << '\n';
 return 0;
}
```

# Class template argument deduction

- Possible traps

```
#include <iostream>
#include <vector>
```

```
int main()
{
 std::vector v1{1,2};
 std::vector v2(v1.begin(), v1.end());
 std::vector v3{v1.begin(), v1.end()};

 std::cout << v1[0] << v2[0] << v3[0] << '\n';
 return 0;
}
```

```
ctad1.cpp:11:31: error: invalid operands to binary expression ('std::basic_ostream<char,
std::char_traits<char> >::__ostream_type' (aka 'basic_ostream<char,
std::char_traits<char> >') and
'__gnu_cxx::__alloc_traits<std::allocator<__gnu_cxx::__normal_iterator<int *,
std::vector<int, std::allocator<int> > >, __gnu_cxx::__normal_iterator<int *,
std::vector<int, std::allocator<int> > >>::value_type' (aka
'__gnu_cxx::__normal_iterator<int *, std::vector<int, std::allocator<int> > >'))
 std::cout << v1[0] << v2[0] << v3[0] << '\n';
```

# Class template argument deduction

- Possible traps

```
#include <iostream>
#include <vector>

int main()
{
 std::vector v1{1,2};
 std::vector v2(v1.begin(), v1.end());
 std::vector v3{v1.begin(), v1.end()};

 std::cout << v1[0] << v2[0] << '\n'; //<< v3[0] << '\n';
 return 0;
}

// vector<T>::vector<T>(std::initializer_list<T>);
// <Iter> vector<T>::vector<T>(Iter b, Iter e);
// T := Iter::value_type
```

# Initializer list

```
vector<double> v{ 1, 2, 3.456, 99.99 }; // constructor
v = { 4., 6. }; // operator=
f({ 4., 6., 7. }); // void f(std::vector<double>)
for (auto i : { 1, 2, 3, 4, 5 }) ... // range for
```

```
const T noname[N]; // underlying temporary array
// may allocated in read-only area
// each element is copy initialized
// but no narrowing conversion
// life-time extension due to initializer_list
```

```
class initializer_list<T> // lightweight proxy
{
public:
 // usual copy operations do shallow copy of initializer_list objects
 size_type size() const;
 constexpr const T* begin() const;
 constexpr const T* end() const;
private:
 T *begin;
 T *end; // or size_t n;
};
```

# 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;
};
```

# 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;
};
```

## Destructors must not throw!

# Complex initialization

```
void f(int param, bool flag)
{
 const int ci1 = 10 * param + 3;

 const int ci2 = flag ? 2 * param : 2 + param;

 const int ci3 = ? /* very complex initialization */

};
```

# Complex initialization

```
void f(int param, bool flag)
{
 const int ci1 = 10 * param + 3;

 const int ci2 = flag ? 2 * param : 2 + param;

 const int ci3 = f(param, flag, ci1, ...);
 /* very complex initialization */

};

int f(int param, bool flag /*, many extra params (by reference) */)
{
 int value;
 /* very complex initialization of value */
 return value;
}
```

# Complex initialization

```
void f(int param, bool flag)
{
 const int ci1 = 10 * param + 3;

 const int ci2 = flag ? 2 * param : 2 + param;

 const int ci3 = [&]{ /* access to the environment */

 int value;
 /* very complex initialization of value */
 return value;
 }(); /* immediately invoked function expression (IIFE) */
};
```

# std::launder

```
struct X { const int n; };
union U { X x; float f; };

void f()
{
 U u{{ 42 }}; // aggregate initialization, u.x.n == 42
 X *xp = new (&u.x) X { 99 }; // placement new

 std::cout << u.x.n << '\n'; // 42 ??
};
```

# std::launder

```
struct X { const int n; };
union U { X x; float f; };

void f()
{
 U u{{ 42 }}; // aggregate initialization, u.x.n == 42
 X *xp = new (&u.x) X { 99 }; // placement new

 std::cout << u.x.n << '\n'; // 42 ??
};
```

<https://timsong-cpp.github.io/cppwp/n4659/basic.life#8>

*If, after the lifetime of an object has ended and before the storage which the object occupied is reused or released, a new object is created at the storage location which the original object occupied, a pointer that pointed to the original object, a reference that referred to the original object, or the name of the original object will automatically refer to the new object and, once the lifetime of the new object has started, can be used to manipulate the new object, if:*

- (8.1) the storage for the new object exactly overlays the storage location which the original object occupied, and*
- (8.2) the new object is of the same type as the original object (ignoring the top-level cv-qualifiers), and*
- (8.3) the type of the original object is not const-qualified, and, if a class type, does not contain any non-static data member whose type is const-qualified or a reference type, and*
- (8.4) the original object was a most derived object of type T and the new object is a most derived object of type T (that is, they are not base class subobjects).*

# std::launder

```
struct X { const int n; };
union U { X x; float f; };

void f()
{
 U u{{ 42 }}; // aggregate initialization, u.x.n == 42
 X *xp = new (&u.x) X { 99 }; // placement new

 auto ptr = std::launder(&u.x.n); // optimization firewall
 std::cout << u.x.n << '\n'; // 99
};
```

<https://timsong-cpp.github.io/cppwp/n4659/basic.life#8>

*If, after the lifetime of an object has ended and before the storage which the object occupied is reused or released, a new object is created at the storage location which the original object occupied, a pointer that pointed to the original object, a reference that referred to the original object, or the name of the original object will automatically refer to the new object and, once the lifetime of the new object has started, can be used to manipulate the new object, if:*

- (8.1) the storage for the new object exactly overlays the storage location which the original object occupied, and*
- (8.2) the new object is of the same type as the original object (ignoring the top-level cv-qualifiers), and*
- (8.3) the type of the original object is not const-qualified, and, if a class type, does not contain any non-static data member whose type is const-qualified or a reference type, and*
- (8.4) the original object was a most derived object of type T and the new object is a most derived object of type T (that is, they are not base class subobjects).*