TDD38/726G82 - Advanced programming in C++

Class design

Christoffer Holm

Department of Computer and information science

LINKÖPING UNIVERSITY

LINKÖPING UNIVERSITY

LINKÖPING
UNIVERSITY

References & const

const

```
int x { 5 };
int const y { 7 };
int const* v { &x };
int* const w { &x };

x = 7; // allowed
y = 5; // not allowed

v = &y; // allowed
w = &y; // not allowed

*v = 8; // not allowed
*w = 10; // allowed
```

References & const

`const`

- A variable declared `const` cannot be modified after initialization
- A pointer to a `const` object can be modified, but it cannot modify the underlying object
- A `const` pointer cannot change what they point to
- A non-`const` object can be converted to a `const` version, but **not** vice versa.

References & const

`const`

Rule of thumb: `const` applies to the left:

```
int const * const
```

References & const

`const`

Rule of thumb: `const` applies to the left:

```
int const * const
```

References & const

`const`

Rule of thumb: `const` applies to the left:

```
int const * const
```

References & const

`const`

... Except when it’s at the start:

```
const int
```

References & const

`const`

... Except when it’s at the start:

```
const int
```

References & const

Value categories & References

Given some type `T`, there are four different references;

- `T&`
- `T const&`
- `T&&`
- `T const&&`

References & const

Value categories & References

Given some type `T`, there are four different references;

- `T&`
  - Called *lvalue-reference*;
  - Used to alias existing object;
  - Can only bind to *lvalues*.
- `T const&`
- `T&&`
- `T const&&`

References & const

Value categories & References

Given some type `T`, there are four different references;

- `T&`
- `T const&`
    - Called *const lvalue-reference*;
    - Can bind to all `const` objects;
    - can bind to all non-`const` objects.
- `T&&`
- `T const&&`

References & const

Value categories & References

Given some type `T`, there are four different references;

- `T&`
- `T const&`
- `T&&`
  - Called *rvalue-reference*;
  - Used to extend the lifetime of temporary objects;
  - Binds to all rvalues turning them into xvalue.
- `T const&&`

References & const

Value categories & References

Given some type `T`, there are four different references;

- `T&`
- `T const&`
- `T&&`
- `T const&&`
  - Called *const rvalue-reference*;
  - Is a weaker version of *const lvalue-reference*;
  - can only bind to rvalues that are `const`.

References & const

What will happen? Why?

```
void fun(int const&) { cout << 1; }
void fun(int&)       { cout << 2; }
void fun(int&&)      { cout << 3; }

int main()
{
  int a;
  int const c{};
  fun(23);
  fun(a);
  fun(c);
}
```

LINKÖPING UNIVERSITY

Classes

The Anatomy of a Class Declaration

- Declared with either `class` or `struct`;
- Has *data members*;
- Has *member functions*;
- Each member has an *access level*.

Classes

The Anatomy of a Class Declaration

- Declared with either `class` or `struct`;

```
class My_Class
{
};
```

```
struct My_Struct
{
};
```

- Has *data members*;
- Has *member functions*;
- Each member has an *access level*.

Classes

The Anatomy of a Class Declaration

- Declared with either `class` or `struct`;
  - `class` and `struct` only have minor differences;
  - All members in a `class` are by default *private*;
  - All members in a `struct` are by default *public*;
  - Inheritance has respective access level.
- Has *data members*;
- Has *member functions*;
- Each member has an *access level*.

Classes

The Anatomy of a Class Declaration

- Declared with either `class` or `struct`;
- Has *data members*;

```
class Cls
{
  int number;
  std::string text;
};
```

- Has *member functions*;
- Each member has an *access level*.

Classes

The Anatomy of a Class Declaration

- Declared with either `class` or `struct`;
- Has *data members*;
- Has *member functions*;

```
class Cls
{
  void foo(int);
  void foo(double);
  void foo();
};
```

- Each member has an *access level*.

Classes

The Anatomy of a Class Declaration

- Declared with either `class` or `struct`;
- Has *data members*;
- Has *member functions*;
- Each member has an *access level*.

```
class Cls
{
public:
  void foo(int);
private:
  int number;
};
```

Classes

Class Scope

- Each class defines its own *scope*;
- All members belong to said scope;
- The name of the members can be access with the *scope resolution operator* `::`

Classes

Class Scope

```
// class declaration
class Cls;

// class definition
class Cls
{
public:
  // member function declaration
  void foo();
};

// member function definition
void Cls::foo() { cout << "foo" << endl; }
```

Classes

The Object Model

- Each class in C++ defines a type;
- Values/expressions with this type are called *objects*;
- Creating an object of a class type is called *instantiation*.

Classes

The Object Model

```
class Cls
{
public:
  void set(int n) {
    num = n;
  }
  int get() {
    return num;
  }
private:
  int num;
};
```

```
int main()
{
  Cls o1;
  Cls o2;

  o1.set(1);
  o2.set(2);

  cout << o1.get() << ' '
       << o2.get()
       << endl;
}
```

Classes

The Object Model

```
class Cls
{
public:
  void set(int n) {
    this->num = n;
  }
  int get() {
    return this->num;
  }
private:
  int num;
};
```

```
int main()
{
  Cls o1;
  Cls o2;

  o1.set(1);
  o2.set(2);

  cout << o1.get() << ' '
       << o2.get()
       << endl;
}
```

Classes

Mental Model

```
// What we write
class Cls
{
public:
  void set(int n);
private:
  int num;
};
int main()
{
  Cls obj;
  obj.set(5);
}
```

Classes

Mental Model

```
// What we write
class Cls
{
public:
  void set(int n);
private:
  int num;
};
int main()
{
  Cls obj;
  obj.set(5);
}
```

```
// What we "think"
struct Cls
{
  int num;
};
void set(Cls* this,
         int n);

int main()
{
  Cls obj;
  set(&obj, 5);
}
```

Classes

Constant Member Functions

```
class Cls
{
public:
  void fun() const;
private:
  int data;
};
void Cls::fun() const
{
  // not allowed
  data = 5;
}
```

Classes

Constant Member Functions & Mental Model

```
// What we write
class Cls
{
public:
  void fun() const;
private:
  int data;
};
void Cls::fun() const
{
  // not allowed
  data = 5;
}
```

```
// What we "think"
struct Cls
{
  int data;
};



void fun(Cls const* this)
{
  // not allowed
  this->data = 5;
}
```

Classes

Ref-qualifiers

```
class Cls
{
public:
  void fun() &;
  void fun() &&;
  void fun() const&;
};
```

- indicate what type of object `this` is;
- pointers can only point to glvalues;
- mental model breaks down.

Classes

Ref-qualifiers

```
class Cls
{
public:
  void fun() &;
  void fun() &&;
  void fun() const&;
};
```

```
struct Cls
{

};
void fun(Cls& this);
void fun(Cls&& this);
void fun(Cls const& this);
```

Classes

Ref-qualifiers

```
class Cls
{
public:
  void fun() &;
  void fun() &&;
  void fun() const&;
};
```

```
Cls c1{};
c1.fun();

Cls{}.fun();

Cls const c2{};
c2.fun();
```

LINKÖPING UNIVERSITY

Lifetime Management

Constructors

```
class Cls
{
public:
  Cls(int a) : val1{a}, val3{2}
  {
    // can execute code here as well
  }
private:
  int val1;
  int val2 {2+3};
  int val3 {4};
};
```

Lifetime Management

Constructors

- The constructor is called whenever we create an object
- Initialization of data members happen *before* we actually execute the body of the constructor
- This is done in the *member-initializer-list* (See the things after : but before the body of the constructor)
- All data members that are initialized *must* be initialized in-order

Lifetime Management

Constructors

```
int main()
{
  Cls obj1{5};
  Cls obj2(5);
  Cls* ptr{new Cls{5}}; // heap allocation
  Cls{5}; // prvalue
}
```

Lifetime Management

Constructors

- Avoid initializing members in the body of the constructor;
- `const`-members *must* be initialized in the *member-initializer-list*;
- Initializing in the body is an *assignment*.

Lifetime Management

Destructors

```
class Cls
{
public:
  Cls(int x = 0) : data{new int{x}} { }
  ~Cls()
  {
    delete data;
  }
private:
  int* data;
};
```

Lifetime Management

Destructors

```
Cls global{0}; // static storage
void fun()
{
  static Cls other{1}; // static storage
  Cls cls{2};
}
int main()
{
  Cls c{3};
  fun();
  c.~Cls(); // don't do this
}
```

Lifetime Management

Destructors

- Objects that have *static storage* are destroyed at the end of the program.
- Global variables are created at the start of the program,
- Static variables in functions are constructed the first time that function is called and will persist between all future calls.

Lifetime Management

Destructors

- Even though destructors can be called explicitly it should be avoided:
- Once the lifetime ends the destructor will be called automatically by the compiler;
- Meaning, if you have called it yourself before that point the destructor will be called twice which will (in most cases) cause issues.

Lifetime Management

Special Member Functions

```
class Cls
{
public:
  Cls(); // default constructor
  Cls(Cls const&); // copy constructor
  Cls(Cls&&); // move constructor

  ~Cls(); // destructor

  Cls& operator=(Cls const&); // copy assignment
  Cls& operator=(Cls&&); // move assignment
};
```

Lifetime Management

Special Member Functions

The compiler can generate these functions, unless:

- a constructor declared; no default constructor
- copy operations declared; no move operations
- move operations declared; no copy operations

Lifetime Management

Special Member Functions

The compiler can generate these functions, unless:

- a constructor declared; no default constructor
- copy operations declared; no move operations
- move operations declared; no copy operations
- Possible to bypass these rules with `=default` and `=delete`.

Lifetime Management

Rule of N

- rule of three
- rule of five
- rule of zero

Lifetime Management

Rule of N

- rule of three
  - Before C++11 (Note this concept is not valid in C++11 or later);
  - If a class require a destructor or copy operation;
  - it should (probably) implement the destructor, copy constructor and copy assignment.
- rule of five
- rule of zero

Lifetime Management

Rule of N

- rule of three
- rule of five
  - C++11 and onwards;
  - If a class requires a destructor, copy or move operations;
  - it should implement a destructor, copy operations and move operations.
- rule of zero

Lifetime Management

Rule of N

- rule of three
- rule of five
- rule of zero
  - If all resources used in the class take care of their own data;
  - the class should *not* have to implement any destructor, copy or move operations.

Lifetime Management

Special Member Functions

```
class Cls
{
public:
  Cls(int);                 // remove default ctor
  Cls() = default;          // generate it anyway
  Cls(Cls const&) = delete;// remove copy ctor
  Cls(Cls&&) = default;     // generate move ctor
};
```

Lifetime Management

Special Member Functions

```
Cls identity(Cls obj)
{
  return obj;
}
int main()
{
  Cls obj1{};
  Cls obj2 = Cls{};
  obj1 = identity(obj1);
  obj1 = obj2;
}
```

Lifetime Management

Special Member Functions

```
Cls identity(Cls obj)
{
  return obj;
}
int main()
{
  Cls obj1{};
  Cls obj2 = Cls{};
  obj1 = identity(obj1);
  obj1 = obj2;
}
```

Lifetime Management

Special Member Functions

```
Cls identity(Cls obj)
{
  return obj;
}
int main()
{
  Cls obj1{};
  Cls obj2 = Cls{};
  obj1 = identity(obj1);
  obj1 = obj2;
}
```

Lifetime Management

Special Member Functions

```
Cls identity(Cls obj)
{
  return obj;
}
int main()
{
  Cls obj1{};
  Cls obj2 = Cls{};
  obj1 = identity(obj1);
  obj1 = obj2;
}
```

Lifetime Management

Special Member Functions

```
Cls identity(Cls obj)
{
  return obj;
}
int main()
{
  Cls obj1{};
  Cls obj2 = Cls{};
  obj1 = identity(obj1);
  obj1 = obj2;
}
```

Copy ctor

Lifetime Management

Special Member Functions

```
Cls identity(Cls obj)
{
  return obj;
}
int main()
{
  Cls obj1{};
  Cls obj2 = Cls{};
  obj1 = identity(obj1);
  obj1 = obj2;
}
```

Copy ctor

Lifetime Management

Special Member Functions

```
Cls identity(Cls obj)
{
  return obj;
}
int main()
{
  Cls obj1{};
  Cls obj2 = Cls{};
  obj1 = identity(obj1);
  obj1 = obj2;
}
```

Move ctor

Copy ctor

Lifetime Management

Special Member Functions

```
Cls identity(Cls obj)
{
  return obj;
}
int main()
{
  Cls obj1{};
  Cls obj2 = Cls{};
  obj1 = identity(obj1);
  obj1 = obj2;
}
```

Copy ctor

Move ctor

Move assign

Lifetime Management

Special Member Functions

```
Cls identity(Cls obj)
{
  return obj;
}
int main()
{
  Cls obj1{};
  Cls obj2 = Cls{};
  obj1 = identity(obj1);
  obj1 = obj2;
}
```

Copy ctor

Move ctor

Move assign

Lifetime Management

Special Member Functions

```
Cls identity(Cls obj)
{
  return obj;
}
int main()
{
  Cls obj1{};
  Cls obj2 = Cls{};
  obj1 = identity(obj1);
  obj1 = obj2;
}
```

Copy ctor

Move ctor

Move assign

Lifetime Management

Special Member Functions

```
Cls identity(Cls obj)
{
  return obj;
}
int main()
{
  Cls obj1{};
  Cls obj2 = Cls{};
  obj1 = identity(obj1);
  obj1 = obj2;
}
```

Lifetime Management

Special Member Functions

```
Cls identity(Cls obj)
{
  return obj;
}
int main()
{
  Cls obj1{};
  Cls obj2 = Cls{};
  obj1 = identity(obj1);
  obj1 = obj2;
}  Copy assign
```

Lifetime Management

Special Member Functions

```
Cls identity(Cls obj)
{
  return obj;
}
int main()
{
  Cls obj1{};
  Cls obj2 = Cls{};
  obj1 = identity(obj1);
  obj1 = obj2;
}
```

Lifetime Management

Special Member Functions

```
Cls identity(Cls obj)
{
  return obj;
}
int main()
{
  Cls obj1{};
  Cls obj2 = Cls{};
  obj1 = identity(obj1);
  obj1 = obj2;
}
```

Lifetime Management

Special Member Functions

```
Cls identity(Cls obj)
{
  return obj;
}
int main()
{
  Cls obj1{};
  Cls obj2 = Cls{};
  obj1 = identity(obj1);
  obj1 = obj2;
}
```

Lifetime Management

Special Member Functions

```
Cls identity(Cls obj)
{
  return obj;
}
int main()
{
  Cls obj1{};
  Cls obj2 = Cls{};
  obj1 = identity(obj1);
  obj1 = obj2;
}
```

Lifetime Management

As if rule

- The compiler is allowed to modify the code however it want;
- As long as the *observable behaviour* is exactly the same.

Lifetime Management

As if rule

- The compiler is allowed to modify the code however it want;
- As long as the *observable behaviour* is exactly the same.
- *Copy elision* is an exception to the *as if rule*;
- it allows the compiler to remove calls to copy or move constructors.

Lifetime Management

Copy elision

```
int main()
{
    Cls t1{};
    Cls t2{t1};
    Cls t3{Cls{}};
}
```

Lifetime Management

What will happen? Why?

```
struct Cls
{
  Cls() = default;
  Cls(Cls const&) { cout << "C"; }
  Cls(Cls&&) { cout << "M"; }
  ~Cls() = default;
};

Cls ident(Cls c)
{
  return c;
}

int main()
{
  Cls c1{Cls{}};
  Cls c2{ident(c1)};
  Cls c3{c2};
}
```

LINKÖPING UNIVERSITY

Operator Overloading

Operators

- Most operators can be overloaded;
- the exceptions are `. .* :: ?:`

Operator Overloading

Binary operators

- Given any binary operator `@`;
- `x@y` becomes `x.operator@(y)` or `operator@(x,y)`.

Operator Overloading

Binary operators

- Given any binary operator `@`;
- `x@y` becomes `x.operator@(y)` or `operator@(x,y)`.
- Example:

```
struct Cls
{
  Cls operator+(Cls b);
};
int main()
{
  Cls a, b;
  Cls c{a+b};
}
```

Operator Overloading

Binary operators

- Given any binary operator `@`;
- `x@y` becomes `x.operator@(y)` or `operator@(x,y)`.
- Example:

```
struct Cls
{
  Cls operator+(Cls b);
};
int main()
{
  Cls a, b;
  Cls c{a.operator+(b)};
}
```

Operator Overloading

Binary operators

- Given any binary operator `@`;
- `x@y` becomes `x.operator@(y)` or `operator@(x,y)`.
- Example:

```
struct Cls
{
};
Cls operator+(Cls a, Cls b);
int main()
{
  Cls a, b;
  Cls c{a+b};
}
```

Operator Overloading

Binary operators

- Given any binary operator `@`;
- `x@y` becomes `x.operator@(y)` or `operator@(x,y)`.
- Example:

```
struct Cls
{
};
Cls operator+(Cls a, Cls b);
int main()
{
  Cls a, b;
  Cls c{operator+(a, b)};
}
```

Operator Overloading

Rule of thumb

- **Do I need this operator?**
- **What is the operators behaviour?**

Operator Overloading

Rule of thumb

- **Do I need this operator?**
  The operator should make sense. If there is any ambiguity then don’t make an operator overload.
- **What is the operators behaviour?**

Operator Overloading

Rule of thumb

- **Do I need this operator?**
  The operator should make sense. If there is any ambiguity then don’t make an operator overload.
- **What is the operators behaviour?**
  Should be similar to the built in types. The behaviour should be as predictable as possible.

Operator Overloading

Type conversions

```
class Cls
{
public:
  Cls(int i) : i{i} { }
  operator int() const
  {
    return i;
  }
private:
  int i;
};
```

Operator Overloading

Type conversions

- A constructor that can take **one** argument is called a *type converting constructor*;
- these constructors can be used by the compiler to perform conversions.
- The special operator `Cls::operator TYPE()` is called whenever the class `Cls` is converted to `TYPE`;
- the compiler is allowed to use this operator to perform implicit type conversions;
- but can also be explicitly called through casting.

Operator Overloading

Explicit keyword

```
class Cls
{
public:
  explicit Cls(int i) : i{i} { }
  explicit operator int() const
  {
    return i;
  }
private:
  int i;
};
```

Operator Overloading

Explicit keyword

- Declaring type converting constructors or operators as `explicit` means;
- the compiler is **not** allowed to use these functions for implicit type conversion;
- with the exception of `operator bool` which can be used for *contextual conversion*.

Operator Overloading

Contextual Conversion

```
struct Cls
{
  explicit operator bool() const { return flag; }
  bool flag{};
};
int main()
{
  Cls c{};
  if (c)
  {
    // ...
  }
}
```

LINKÖPING UNIVERSITY

Aggregates

What is an Aggregate?

An *aggregate* denotes a simple kind of data type with the following properties;

- An *array*- or *class type*;
- no user-provided constructors;
- no private or static data members;
- no virtual functions;
- no private base classes.

Aggregates

Basic Aggregate

```
struct Person
{
  string name{"unknown"};
  int age{};
};

int main()
{
  Person bob{"Bob", 37};
  Person robin{"Robin"};
  Person unknown{};
  Person sara{.name = "Sara", .age = 29};// C++20
}
```

www.liu.se

LINKÖPING
UNIVERSITY