Object-Orientation

CSCI 3136

Principles of Programming Languages

Faculty of Computer Science

Dalhousie University

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Reading: Chapter 9

What is a Object-Oriented Programming?

Elements of object-oriented programming:

- Data items to be manipulated are ***objects***.
- Objects are members of ***classes***, that is, classes are types.
- Objects store data in ***fields*** and behaviour in ***methods*** specified by their classes.

Main characteristics of most object-oriented programming systems:

- ***Encapsulation*** by hiding internals of an object from the user of the object.
- Customization of behaviour through ***inheritance***.
- Polymorphism through ***dynamic method binding***.

Advantages of Object-Oriented Programming

It ***reduces conceptual load***:

- It reduces the amount of detail the programmer must think about at the same time.

It provides ***fault and change containment***:

- It limits the portion of a program that needs to be looked at when debugging.
- It limits the portion of a program that needs to be changed when changing the behaviour of an object without changing its interface.

It provides ***independence of program components*** and thus ***facilitates code reuse***.

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Note: Most of these are consequences of encapsulation and thus apply also to programming using modules.

Some Object-Oriented Languages

- SIMULA 67
- Smalltalk 72
- C++, 80s
- Modula-3, late 80s
- CLOS, 88
- Eiffel, 92
- Oberon, 90s (last version 95)
- Java, 95
- Ada 95

Class Example in C++

Header

```
class list_node {

  list_node *prev, *next, *head;

public:

  int val;

  list_node();
  ~list_node();

  list_node *predecessor();
  list_node *successor();
  bool singleton();
  void insert_before(list_node *new_node);
  void remove();
};
```

Implementation

```
void list_node::insert_before(list_node *new_node) {
  if (!new_node->singleton())
    throw new list_err("inserting more than a single node");
  prev->next     = new_node;
  new_node->prev = prev;
  new_node->next = this;
  prev           = new_node;
  new_node->head_node = head_node;
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Private fields

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Private fields: `list_node *prev, *next, *head;`

Public field: `int val;`

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Private fields

Public field

Constructor

Implementation

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Private fields

Public field

Constructor

Destructor

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Public field: `int val;`

Constructor: `list_node();`

Destructor: `~list_node();`

Public methods: `predecessor`, `successor`, `singleton`, `insert_before`, `remove`

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```

- `list_node *prev, *next, *head;` — Private fields
- `int val;` — Public field
- `list_node();` — Constructor
- `~list_node();` — Destructor
- `predecessor`, `successor`, `singleton`, `insert_before`, `remove` — Public methods

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`list_node::insert_before` — Method definition outside class needs to be qualified.

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}
```

Method definition outside class needs to be qualified. (`list_node::insert_before`)

Reference to current object (`this`)

Inheritance

Using inheritance we can define a new ***derived*** or ***child class*** based on an existing ***parent class*** or ***superclass***.

The derived class

- Inherits all fields and methods of the superclass,
- Can define additional fields and methods, and
- Can override existing fields and methods.

Purpose: Extend or specialize the behaviour of the superclass.

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This allows us to define a ***class hierarchy***.

- If only single inheritance is allowed, the hierarchy is a tree.
- If multiple inheritance is allowed, the hierarchy is a lattice.

Syntax of Inheritance

C++

```
class push_button : public widget { ... }
```

Java

```
public class push_button extends widget { ... }
```

Ada

```
type push_button is new widget with ...
```

Syntax of Inheritance

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public class push_button extends widget { ... }
```

Ada

```
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```

Bad example in the textbook (C++)

```
class queue : public list { ... }
```

Why is this a bad example?

Overriding Methods of a Base Class

To replace a method of a base class, redefine it in the derived class:

```
class widget {
  ...
  void paint();
  ...
};

class push_button : public widget {
  ...
  void paint();
  ...
};
```

Overriding Methods of a Base Class

To replace a method of a base class, redefine it in the derived class:

```
class widget {
  ...
  void paint();
  ...
};

class push_button : public widget {
  ...
  void paint();
  ...
};
```

Methods of the base class are still accessible in the derived class:

- Using scope resolution (`::`) in C++
- Using the `super` keyword in Java or Smalltalk
- Using explicit renaming in Eiffel

Syntax of Accessing Members of the Base Class

C++:	`widget::paint()`
Java:	`super.paint()`
C#:	`base.paint()`
Smalltalk:	`super paint.`
Objective C:	`[super paint]`
Eiffel:	`class queue inherit list` `  rename remove as old_remove`

Encapsulation

Using modules:

- Define an ***opaque*** module type, a type whose definition is not exported by the module.
- Export subroutines to manipulate objects of the type. The implementation of these subroutines is not visible to the module's user.

Using classes:

- ***Public*** methods are accessible to the class's user, ***private*** methods are not.
- Private methods are accessible to other objects of the same class.
- Effective use of inheritance requires more fine-grained control over visibility of methods than sufficient when using modules.

Visibility in C++

Three visibility levels:

- ***Private*** methods/fields are visible to members of objects of the same class and to friends.
- ***Protected*** methods/fields are visible to members of objects of the same class or derived classes and to friends.
- ***Public*** methods/fields are visible to the whole world.

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Friends:

- A class can declare other classes and functions to be its friends, thereby providing them with access to its private and protected members.

```
class X {
  int a;
  friend void f(int);
  friend class Y;
};
```

Altering Visibility in Derived Classes

Derived classes can restrict (but not increase) the visibility of its base class's members in objects of the derived class.

```
class A : public B { ... }
```

- All methods have the same visibility in the derived class as in the base class.

```
class A : protected B { ... }
```

- Public and protected members of the base class become protected in the derived class. Private members remain private.

```
class A : private B { ... }
```

- All members of the base class become private in the derived class.

Altering Visibility of Individual Members

```
class A {
  public:
    void a();
    void b();
  private:
    void c();
};

class B : private A {
  public:
    using A::a();
    using A::c();
};
```

Altering Visibility of Individual Members

```
class A {
  public:
    void a();
    void b();
  private:
    void c();
};

class B : private A {
  public:
    using A::a();
    using A::c();
};
```

- `a()` is public in B.
- `b()` is private in B.
- The second `using` statement is illegal because it would increase the visibility of a private member of `A`.

Visibility Rules in Other Languages

Eiffel

- Derived classes can both restrict and increase the visibility of members of base classes.

Java

- Similar to C++, with the following exceptions.
- Base classes are always public.
- Protected members are visible in derived classes ***and in the same package***.
- No notion of friends.

Python

- All class members are public.

Smalltalk, Objective C

- All methods are public.
- All fields are private.

Constructors

A ***constructor*** does not allocate the space for an object; it initializes ("constructs") the object in the allocated space.

Execution order of constructors:

- Constructor(s) of base class(es).
- Constructors of class members.
- Constructor of the class itself.

```
class A {
public:
  A() { cout << "A"; }
};

class B {
public:
  B() { cout << "B"; }
}

class C : A {
  B b;
public:
  C() { cout << "C"; }
};

int main() {
  C c;
}
```

This prints "ABC".

Constructor and Method Overloading (1)

```
class A {
  ...
public:
  A()      { ... }                // Constructor 1
  A(int x) { ... }                // Constructor 2

  void f(float x)       { ... }   // Method 1
  void f(int x)         { ... }   // Method 2
  void f(int x) const { ... }     // Method 3
};

int main() {
  A       x;    // Calls constructor 1
  const A y(5); // Calls constructor 2

  x.f(3.4);     // Calls method 1
  x.f(3);       // Calls method 2
  y.f(3);       // Calls method 3
  y.f(4.5);     // Error: non-const method applied to const object
}
```

Constructor and Method Overloading (2)

```
class A {
  ...
public:
  A()      { ... }

  void f(int x)   { ... }  // Method 1
  void f(int &x)  { ... }  // Method 2
};

int main() {
  A   x;
  int y = 3;

  x.f(y); // Error: cannot decide which method to call
}
```

Copy Constructors and Assignment

```
class A {
  int x;
public:
  A()            : x(0)              { cout << "C1"; }
  A(const A& a) : x(a.x)            { cout << "C2"; }
  const A& operator =(const A& a) { x = a.x; cout << "A"; }
};

int main() {
  A u;      // Prints "C1"
  A v(u);   // Prints "C2"
  A w = u; // Prints "C2"
  A x;      // Prints "C1"
  x = u;    // Prints "A"
}
```

Copy Constructors and Assignment

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int main() {
  A u;      // Prints "C1"
  A v(u);   // Prints "C2"
  A w = u; // Prints "C2"
  A x;      // Prints "C1"
  x = u;    // Prints "A"
}
```

A similar analysis applies to

```
class A {
  int x;
public:
  A() : x(1) {}
};
```

vs

```
class A {
  int x;
public:
  A() { x = 1; }
};
```

Static vs Dynamic Method Binding (1)

In languages with a reference model of variables or when using pointers in C++, we can use an object of a derived class where an object of the base class is expected.

Assume the derived class overrides a method of the base class.

When accessing an object of the derived class through a variable whose type is the base class, which method should we call?

```
class person {
public:
  void print_mailing_label();
};

class student : public person {
public:
  void print_mailing_label();
};

class professor : public person {
public:
  void print_mailing_label();
};

int main() {
  student   s;
  professor p;
  person    *x = &s, *y = &p;

  // professor::print_mailing_label
  p.print_mailing_label();
  // student::print_mailing_label
  s.print_mailing_label();
  // ???
  x->print_mailing_label();
  y->print_mailing_label();
}
```

Static vs Dynamic Method Binding (2)

Static method binding:

- The method invoked is determined by the type of the variable through which the object is accessed.
- Languages with static method binding: Simula, C++, Ada 95

Dynamic method binding:

- The method invoked is determined by the type of the accessed object.
- Languages with dynamic method binding: Smalltalk, Modula 3, Java, Eiffel

Which is more efficient: static or dynamic method binding?

Which is more natural?

Static and Dynamic Method Binding in C++

Given C++'s focus on efficiency, its default is static method binding.

Dynamic method binding is available by declaring the method to be ***virtual***.

```
class A {
public:
  void f();
  virtual void g();
};

class B : public A {
public:
  void f();
  void g();
};

int main() {
  B  b;
  A *a = &b;

  b.f();  // B::f
  b.g();  // B::g
  a->f(); // A::f
  a->g(); // B::g
}
```

Abstract Classes

An ***abstract method*** is a method that is required to be defined only in derived classes.

C++

```
class person {
  ...
  virtual void print_mailing_label() = 0;
  ...
};
```

Java

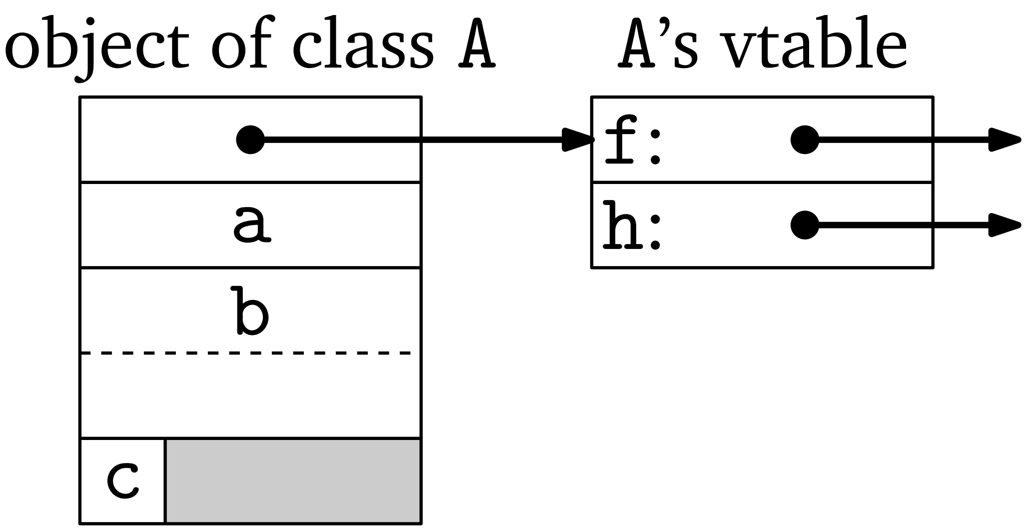
```
class person {
  ...
  abstract void print_mailing_label();
  ...
};
```

An ***abstract*** class has at least one abstract method and thus cannot be instantiated.

If all methods are abstract, then all the class does is define an interface.

Implementation of Virtual Methods

```
class A {
  int    a;
  double b;
  char   c;
public:
  virtual void f();
  int g();
  virtual int h();
  double k();
};
```



The ***virtual method table*** or ***vtable*** is an array of addresses of the virtual methods of the object.

Overhead: Two extra memory accesses.

Implementation of Single Inheritance

Record of derived class

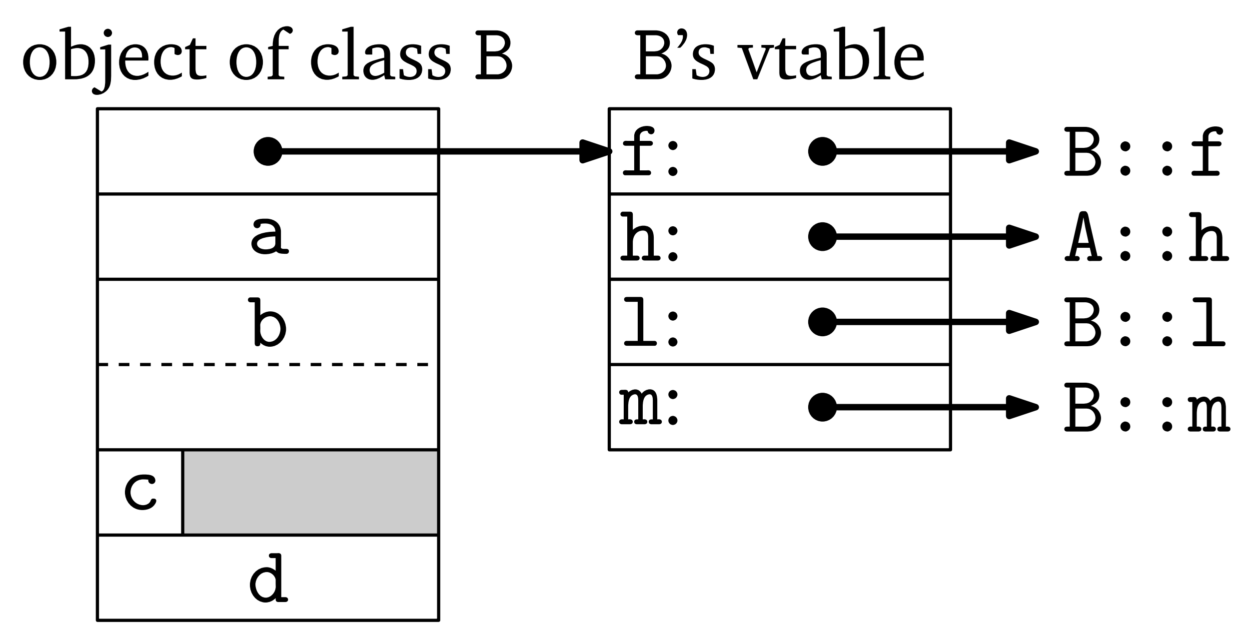
- Append extra data members to the record of the base class.
- Provides trivial access to these members through pointers whose type is the base class.

```
class A {
  int    a;
  double b;
  char   c;
public:
  virtual void f();
  int g();
  virtual int h();
  double k();
};
```

```
class B : public A {
  int d;
public:
  void f();
  virtual double l();
  virtual double *m();
};
```

Vtable of derived class

- Copy vtable of base class.
- Replace entries of overridden virtual methods.
- Append entries of virtual methods declared in derived class.



Inheritance and Type Checks

```
class A { ... };
class B : public A { ... };

A a;
B b;
A *x;
B *y;

x = &b; // ok; references through q will use prefixes of b's
        // data space and vtable

y = &a; // static semantic error; a lacks the additional data and vtable
        // entries of an object of class B

y = x;  // error, but q actually does point to an instance of B
```

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y = x;  // error, but q actually does point to an instance of B
```

Is there a way to resolve the second error? It is not actually an error, but as it is, the compiler cannot tell.

Dynamic Cast

C++

- `y = dynamic_cast<B*>(x);`
- Permits the assignment if `x` points to an object of class `B` or a derived class. Returns a null pointer otherwise.

Dynamic Cast

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Java

- Same semantics but with C-style cast syntax:

  `y = (B) x;`

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Implementation: Include in each vtable the address of a run-time type descriptor.

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- Same semantics but with C-style cast syntax:

  `y = (B) x;`

Implementation: Include in each vtable the address of a run-time type descriptor.

Note: C++ also supports C-style casts without type checks. This is more efficient but less safe.

Type Casting in C++

`dynamic_cast<T*> p`

- Converts to type `T*` if the object pointed to by `p` is of class `T` or of a derived class. Returns a null pointer otherwise.
- Possible only for classes derived from polymorphic base classes and only when run-time type information (RTTI) is enabled.

`static_cast<T*> p` and `reinterpret_cast<T*> p`

- Perform conversions between unrelated types.
- `static_cast` performs some minimal type checking, while `reinterpret_cast` makes a bit-for-bit copy.

`const_cast<T*> p`

- Does not perform any type conversion other than removing the `const`-ness of a pointer.

Multiple Inheritance

Multiple inheritance allows a derived class to have multiple baseclasses:

```
class A : public B, public C { ... }
```

Implementation issues

- How to access objects of `A` through a baseclass pointer.
- How to allow overriding of methods of different base classes.
- ...

Semantic issues

- If a method `m` is defined in more than one base class, which method is invoked by `a.m()`, where `a` is of class `A`?
- If `B` and `C` are derived classes of a common base class `D`, does `A` have two or only one copy of each data member of `D`?
- ...