Programming Paradigms

Data Abstraction and Object-Orientation (Part 4)

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Overview

- Encapsulation and Information Hiding
- Inheritance
- Initialization and Finalization
- Dynamic Method Binding ←
- Mix-in and Multiple Inheritance

Static vs. Dynamic Method Binding

- **Given: Subclass that defines a method already defined in the superclass**
- **How to decide which method gets called?**
  - Based on type of variable
  - Based on type of object the variable refers to

Example

```
class person { ... }
class student : public person { ... }
class professor : public person { ... }

void person::print_mailing_label() { ... }
void student::print_mailing_label() { ... }
void professor::print_mailing_label() { ... }

student s;
professor p;

person *x = &s;
person *y = &p;

s.print_mailing_label();
p.print_mailing_label();

x->print_mailing_label();
y->print_mailing_label();
```

Example

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class person { ... }
class student : public person { ... }
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x->print_mailing_label();
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```

Subclasses also define method `print_mailing_label`

Example

```
class person { ... }
class student : public person { ... }
class professor : public person { ... }

void person::print_mailing_label() { ... }
void student::print_mailing_label() { ... }
void professor::print_mailing_label() { ... }

student s;
professor p;
```

Variables of subtypes

```
person *x = &s;
person *y = &p;
```

Variables of supertype

```
s.print_mailing_label();
p.print_mailing_label();

x->print_mailing_label();
y->print_mailing_label();
```

Example

```
class person { ... }
class student : public person { ... }
class professor : public person { ... }

void person::print_mailing_label() { ... }
void student::print_mailing_label() { ... }
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```

Methods of subclasses called

Example

```
class person { ... }
class student : public person { ... }
class professor : public person { ... }

void person::print_mailing_label() { ... }
void student::print_mailing_label() { ... }
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x->print_mailing_label();
y->print_mailing_label();
```

← **Which methods to call here?**

Static Method Binding

- **Answer 1: Bind methods based on type of variable**
  - Can be statically resolved (i.e., at compile time)
  - Will call `print_mailing_label` of `person` because `x` and `y` are pointers to `person`

Dynamic Method Binding

- **Answer 2: Bind methods based on type of object the variable refers to**
  - In general, cannot be resolved compile time, but only at runtime
  - Will call `print_mailing_label` of `student` for `x` because `x` points to a `student` project (and likewise for `y` and `professor`)

Pros and Cons

Static method binding

- No performance penalty because resolved at compile-time
- But: Subclass cannot control its own state

Dynamic method binding

- Subclass can control its state
- But: Performance penalty of runtime method dispatch

Example (C++)

```
class text_file {
  char *name;
  // file pointer
  long position;
  public:
  void seek(long offset) {
    // (...)
  }
};

class read_ahead_text_file : public text_file {
  char *upcoming_chars;
  public:
  void seek(long offset) {
     // redefinition
  }
}
```

Example (C++)

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class text_file {
  char *name;
  // file pointer
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  public:
  void seek(long offset) {
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  public:
  void seek(long offset) {
     // redefinition
  }
}
```

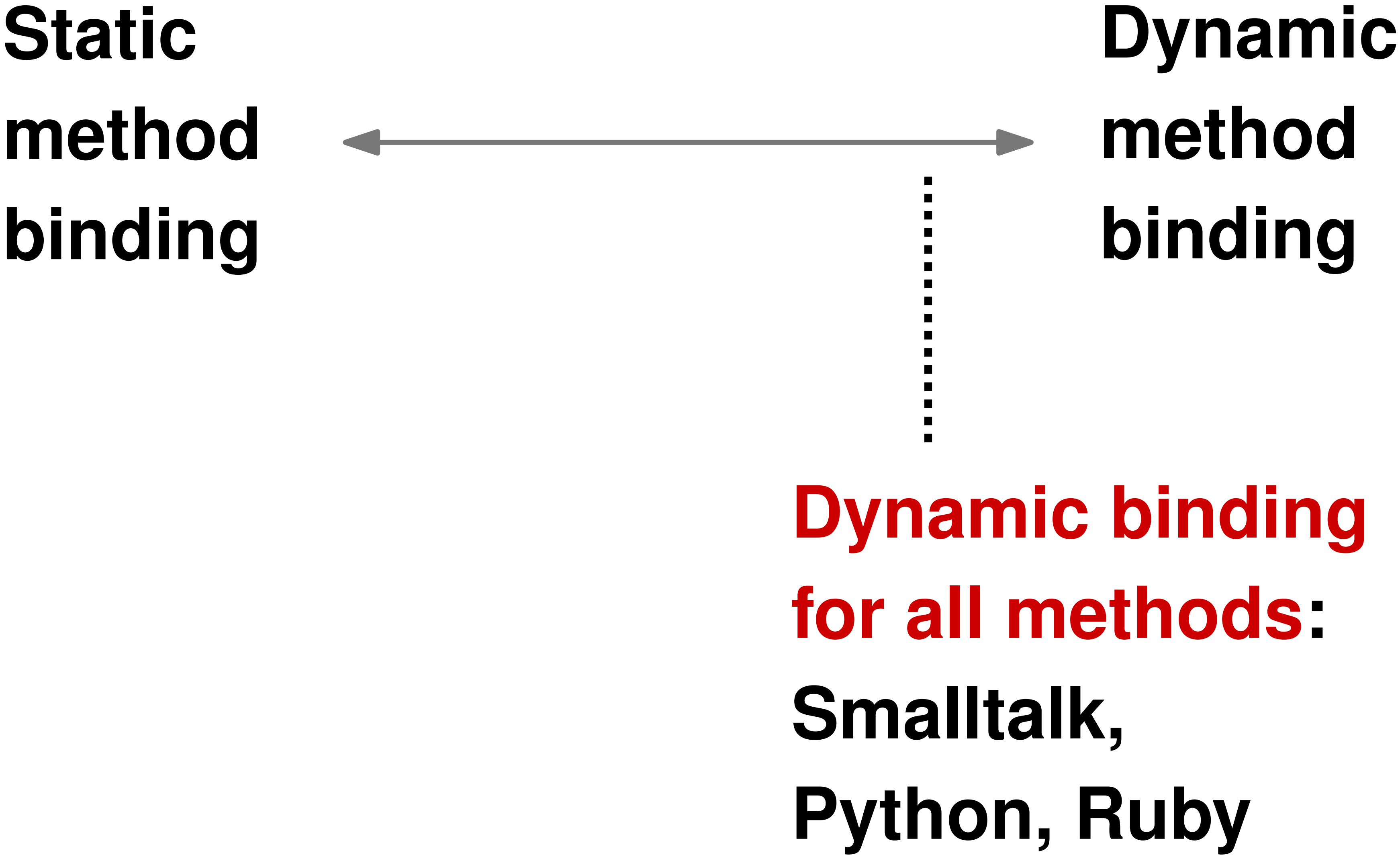
- Subclass needs to change `upcoming_chars` in `seek`
- But with static method binding, cannot guarantee that it gets called

Support in Popular PLs

Static method binding

Dynamic method binding

Support in Popular PLs

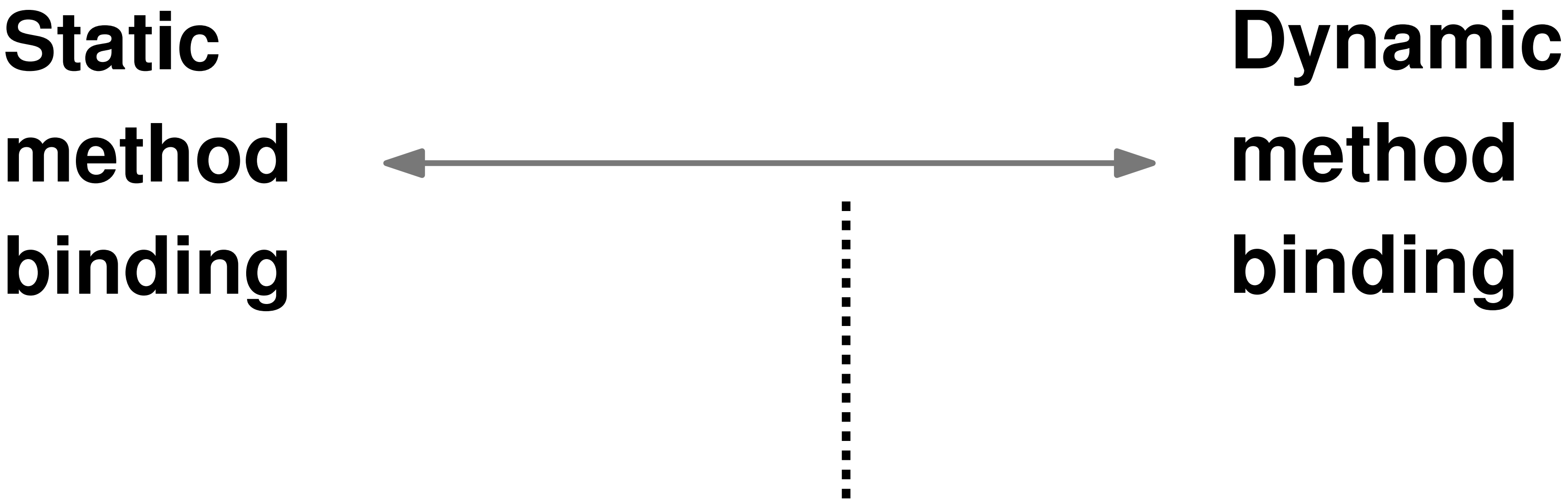


Static method binding

Dynamic method binding

Dynamic binding for all methods: Smalltalk, Python, Ruby

Support in Popular PLs



Static method binding

Dynamic method binding

Dynamic binding by default, but method or class can be marked as not overridable: Java, Eiffel

Support in Popular PLs

Static
method
binding

Dynamic
method
binding

Static binding by default,
but programmer can
specify dynamic binding

Java, Eiffel: Final/frozen Methods

- **Mark individual methods (or classes) as non-overridable**
  - Java: `final` keyword for methods and classes
  - Eiffel: `frozen` keyword for individual methods

C++, C#: Overriding vs. Redefining

Override method:
Dynamic binding

Redefine methods
with same name:
Static binding

- C++: Superclass must mark method as `virtual` to allow overriding
- C#: Subclass must mark method with `override` to override the superclass method

Demo

Virtual.cpp

Abstract Methods and Classes

- **Abstract method**
  - Implementation omitted
  - Subclass must provide it
- **Abstract class: Class with at least one abstract method**

Demo

Abstract.java

Abstract.cpp

Quiz: Method Binding

```
# Pseudo code
class A:
  void foo():
    ...
  void bar():
    ...

class B extends A:
  void bar():
    ...

A x = new B()
B y = x
x.bar() # call 1
y.bar() # call 2
```

What is called when

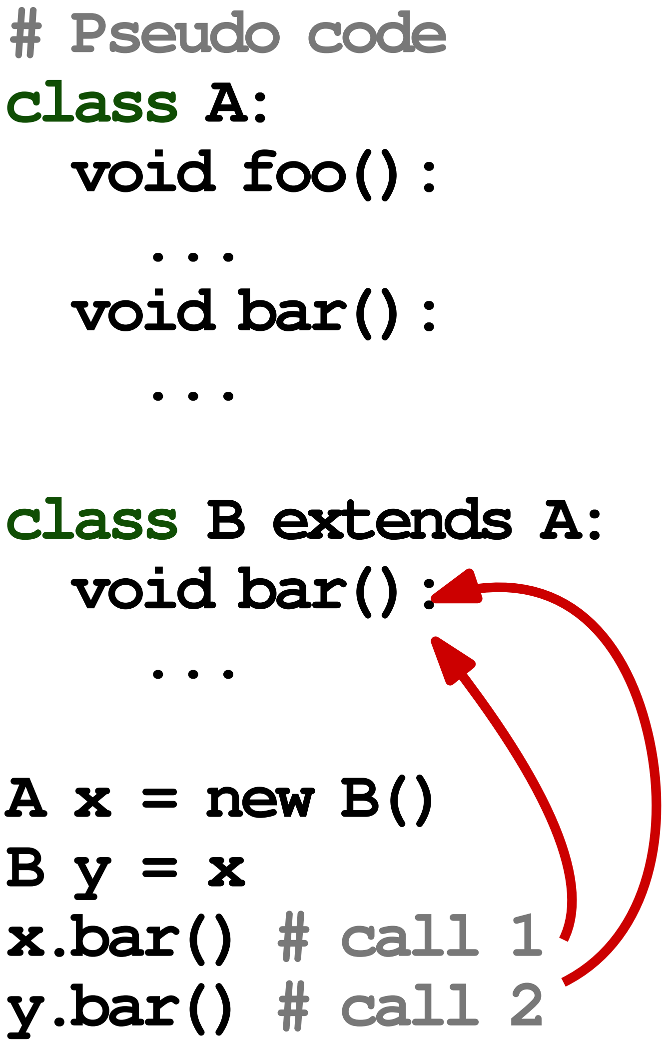
a) PL always uses dynamic method binding

b) PL always uses static method binding

c) PL always uses static method binding unless overriding method marked with `override`

Please vote via Ilias.

Quiz: Method Binding



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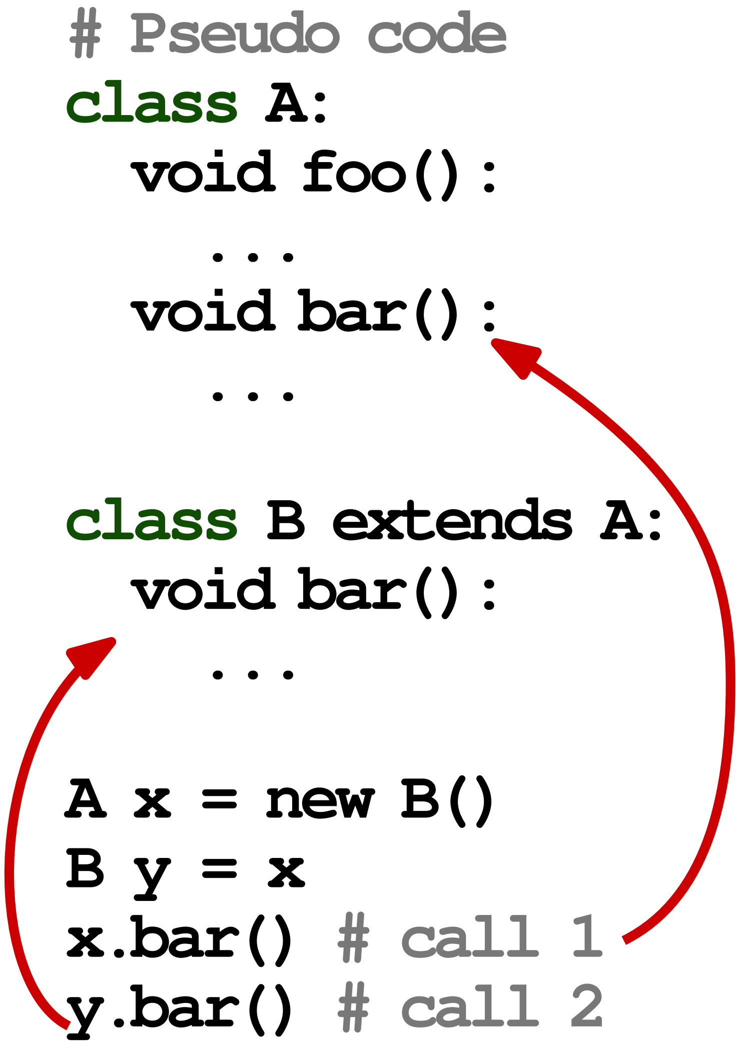
Quiz: Method Binding



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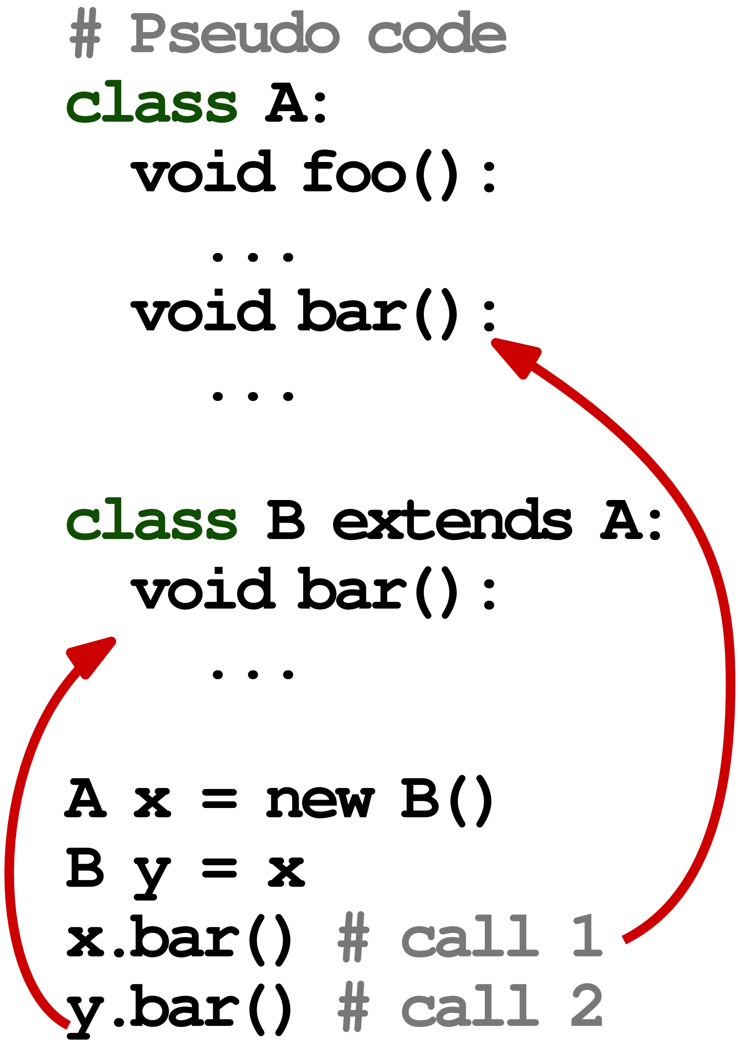

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# Pseudo code
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  void foo():
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What is called when

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Method Lookup

With dynamic method binding, how does the program find the right method to call?

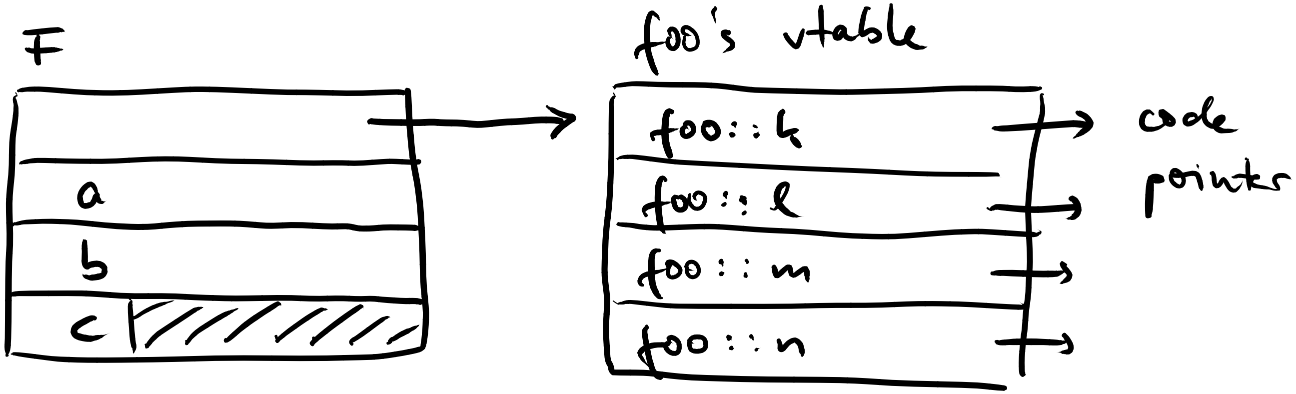
- Most common implementation:

  Virtual method table (“vtable”)
- Every object points to table with its methods
- Table is shared among all instances of a class

```
class foo {
    int a;
    double d;
    char c;

    public:
    virtual void k() {..}
    virtual int l() {..}
    virtual void m() {..}
    virtual double n() {...}

} F;
```



Compiler-generated code for dynamic method binding for F.m():

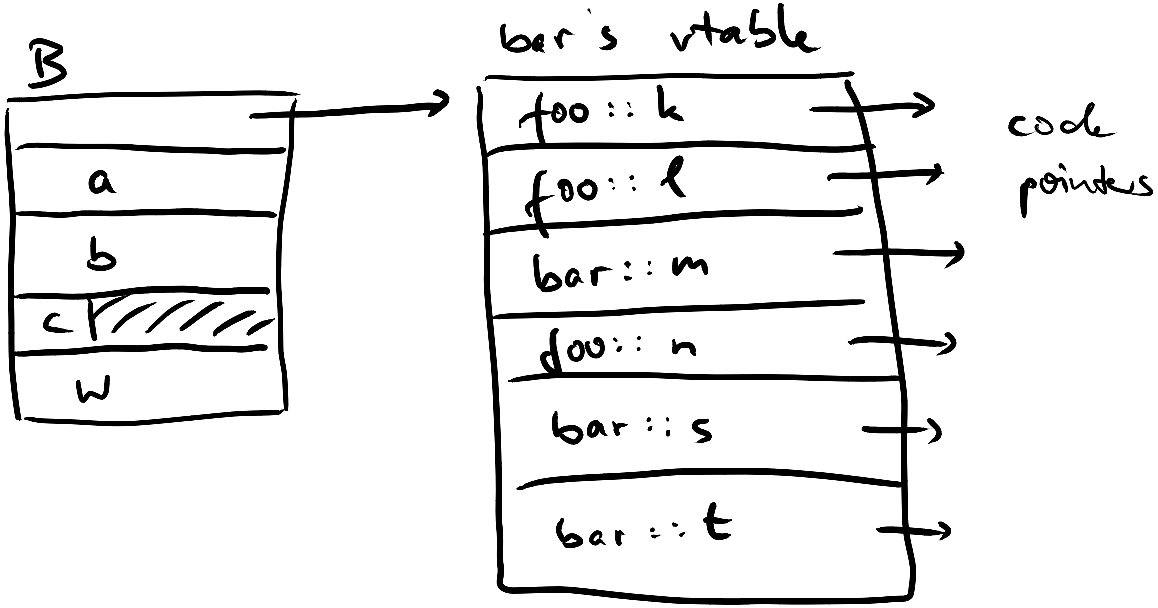
```
r1 := F
r2 := *r1 // vtable address
r2 := *(r2 + (3-1)*4) // assuming sizeof(address) is 4 bytes
call *r2
```

Implementation of Inheritance

- **Representation of subclass instance, including its vtable: Fully compatible with superclass**
  - Can use subclass instance like a superclass instance without additional code

```
class bar: public foo {
      int w;

      public:
      void m()  {..}
      virtual double s() {..}
      virtual char * t() {..}
} B;
```



Implementation of Inheritance (2)

```
class foo { ... }
class bar : public foo { ... }

foo F;
bar B;

foo *q;
bar *s;

q = &B;

s = &F;
```

Implementation of Inheritance (2)

```
class foo { ... }
class bar : public foo { ... }

foo F;
bar B;

foo *q;
bar *s;

q = &B;

s = &F;
```

Okay: References through `q` will use prefixes of `B`'s data space and vtable

Implementation of Inheritance (2)

```
class foo { ... }
class bar : public foo { ... }

foo F;
bar B;

foo *q;
bar *s;

q = &B;

s = &F;
```

Static semantic error: `F` lacks the additional data and vtable entries of a `bar` object