Programming Paradigms

Lecture 15:

Data Abstraction and Object-Orientation (Part 2)

Prof. Dr. Michael Pradel

Software Lab, University of Stuttgart

Winter 2019/2020

Wake-up Exercise

What does the following Java code print?

```
class WakeUp {
  {
    System.out.println("a");
  }
  WakeUp() {
    System.out.println("b");
  }
  static {
    System.out.println("c");
  }
}
// ...
WakeUp w = new WakeUp();
```

https://ilias3.uni-stuttgart.de/vote/0ZT9

Wake-up Exercise

What does the following Java code print?

```
class WakeUp {
  {
    System.out.println("a");
  }
  WakeUp() {
    System.out.println("b");
  }
  static {
    System.out.println("c");
  }
}
// ...
WakeUp w = new WakeUp();
```

Result: cab

https://ilias3.uni-stuttgart.de/vote/0ZT9

Wake-up Exercise

What does the following Java code print?

```
class WakeUp {
  {
    System.out.println("a");
  }
  WakeUp() {
    System.out.println("b");
  }
  static {
    System.out.println("c");
  }
}
// ...
WakeUp w = new WakeUp();
```

Static initializer: Executed when class loaded

Result: cab

https://ilias3.uni-stuttgart.de/vote/0ZT9

Wake-up Exercise

What does the following Java code print?

```
class WakeUp {
  {
    System.out.println("a");
  }
  WakeUp() {
    System.out.println("b");
  }
  static {
    System.out.println("c");
  }
}
// ...
WakeUp w = new WakeUp();
```

Instance initializer: Executed when class instantiated, just before the constructor

Result: cab

https://ilias3.uni-stuttgart.de/vote/0ZT9

Wake-up Exercise

What does the following Java code print?

```
class WakeUp {
  {
    System.out.println("a");
  }
  WakeUp() {
    System.out.println("b");
  }
  static {
    System.out.println("c");
  }
}
// ...
WakeUp w = new WakeUp();
```

Constructor: Executed last

Result: cab

https://ilias3.uni-stuttgart.de/vote/0ZT9

Overview

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

```
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();
```

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;

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

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

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

Variables of subtypes

Variables of supertype

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();
```

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() { ... }
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();
```

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++)

```
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
  }
}
```

- 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

Ada 95: Decide Per Reference

```
procedure print_mailing_label(r : person) is ...
procedure print_mailing_label(s : student) is ...
procedure print_mailing_label(p : professor) is ...

procedure print_label(r : person'Class) is
begin
  print_mailing_label(r);
  -- calls appropriate overloaded version,
  -- depending on type of r at runtime
end print_label
```

Ada 95: Decide Per Reference

```
procedure print_mailing_label(r : person) is ...
procedure print_mailing_label(s : student) is ...
procedure print_mailing_label(p : professor) is ...

procedure print_label(r : person'Class) is
begin
  print_mailing_label(r);
  -- calls appropriate overloaded version,
  -- depending on type of r at runtime
end print_label
```

"Class-wide type" of `person`, i.e., `person` itself and all its subtypes

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`

https://ilias3.uni-stuttgart.de/vote/0ZT9

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`

https://ilias3.uni-stuttgart.de/vote/0ZT9

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`

https://ilias3.uni-stuttgart.de/vote/0ZT9

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`

https://ilias3.uni-stuttgart.de/vote/0ZT9

Method Lookup

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

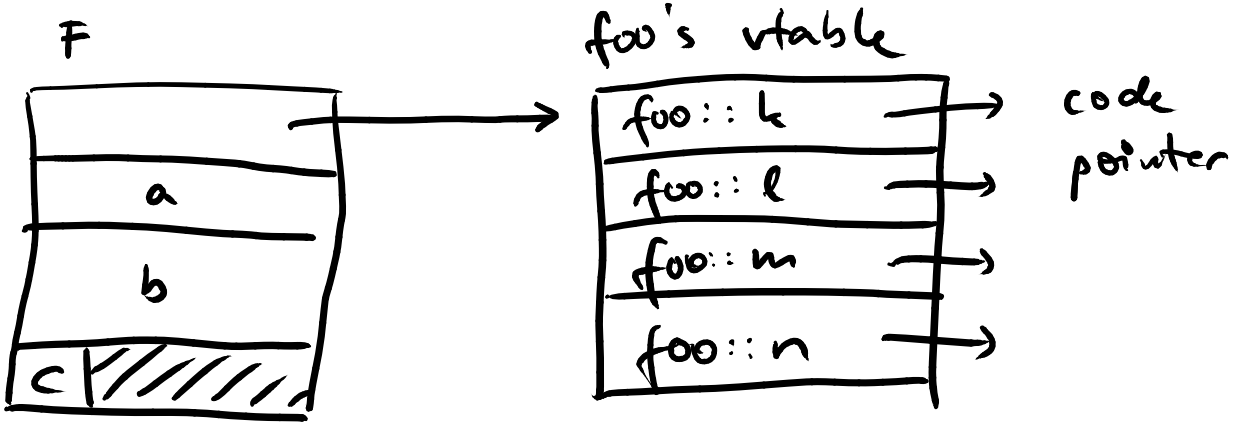
- Most common implementation:

  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 foo::m)

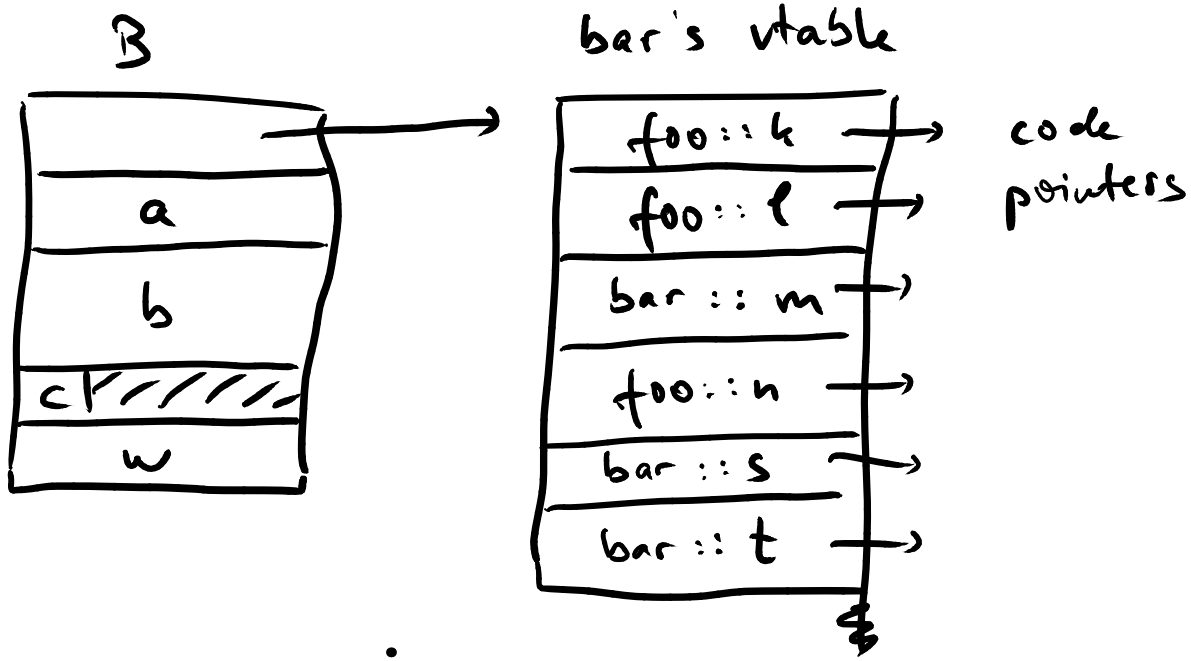
```
r1 := F
r2 := *r1          // vtable address
r2 := *(r2 + (3-1) x 4)   // assuming sizeof(address) == 4 bytes
call *r2
```

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

Overview

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

Motivation

- **Designing an inheritance tree with exactly one parent class: Difficult in practice**
- **Examples**
  - `Cat` may be both `Animal` and `Pet`
  - `Widget` in database maybe `Sortable`, `Graphable`, and `Storable`

Mix-in Inheritance

- **Mix-in: Class-like abstraction that provides methods to be used in other classes without inheriting from the mix-in**
- **A class can mix in multiple mix-ins**
- **Example:**
  - Combine mix-ins `Animal` and `Pet` into `Cat`

Support in Popular PLs

Many variants of the mix-in idea

- Java: Interfaces are a lightweight version of mix-ins
  - Since Java 8: Default implementations of interface methods
- Scala: “Traits”
- Ruby: `include` modules into a class

Overview

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

True Multiple Inheritance

- Sometimes, want to expand multiple classes
- Allowed in some PLs, e.g., C++, Python, OCaml
- Example (C++):

```
class student : public person, public system_user {
  ...
}
```

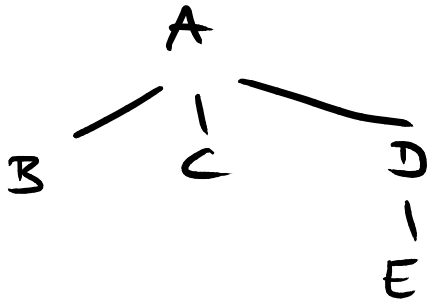
True Multiple Inheritance

- Sometimes, want to expand multiple classes
- Allowed in some PLs, e.g., C++, Python, OCaml
- Example (C++):

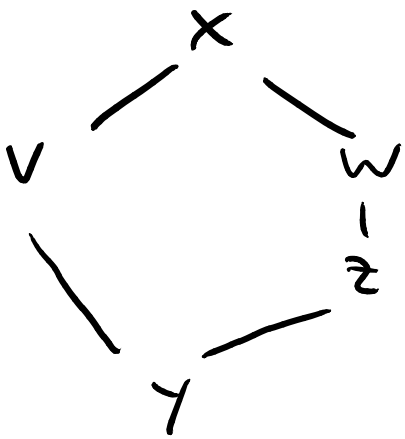
```
class student : public person, public system_user {
  ...
}
```

Gets all fields and methods of both superclasses

- Single inheritance : Class hierarchy is a tree



- Multiple inheritance: No longer a tree, but a directed, acyclic graph (DAG)



→ "diamond problem" : multiple paths to same superclass (here: $Y \to X$)

Semantic Issues

- What if two parent classes provide a method with the same name?
- What if two parent classes are both derived from a common "grandparent"? Does the "grandchild" have one or two copies of the grandparent's fields?
- How to represent objects in memory? Can each parent be a prefix of the child?

Semantic Issues

- What if two parent classes provide a method with the same name?
- What if two parent classes are both derived from a common "grandparent"? Does the "grandchild" have one or two copies of the grandparent's fields?
- How to represent objects in memory? Can each parent be a prefix of the child?

Answers depend on the PL and go beyond this lecture

Quiz: Data Abstraction

Which of the following is true?

- Static and dynamic method binding are the same in statically typed PLs.
- vtables store the fields of an object.
- A class can build upon multiple mix-ins.
- In Java, a class can directly extend multiple classes.

https://ilias3.uni-stuttgart.de/vote/0ZT9

Quiz: Data Abstraction

Which of the following is true?

- ~~Static and dynamic method binding are the same in statically typed PLs.~~
- ~~vtables store the fields of an object.~~
- A class can build upon multiple mix-ins.
- ~~In Java, a class can directly extend multiple classes.~~

https://ilias3.uni-stuttgart.de/vote/0ZT9

Overview

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