Elements of Programming Languages
Lecture 10: Objects and Classes

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Overview

- Last time: “programming in the large”
  - Programs, packages/namespaces, importing
  - Modules and interfaces
  - Mostly: using Scala for examples

- Today: the elephant in the room:
  - Objects and Classes
  - A taste of “advanced” OOP constructs: inner classes, anonymous objects and mixins
  - Illustrate using examples in Scala, and some comparisons with Java
Objects

- **An object** is a module with some additional properties:
  - **Encapsulation**: Access to an object’s components can be limited to the object itself (or to a subset of objects)
  - **Self-reference**: An object is a value and its methods can refer to the object’s fields and methods (via an implicit parameter, often called `this` or `self`)
  - **Inheritance**: An object can inherit behavior from another “parent” object

- Objects/inheritance are tied to classes in some (but not all) OO languages
- In Scala, the `object` keyword creates a *singleton object* (“class with only one instance”)
- (in Java, objects can only be created as instances of classes)
Inside an object definition, the `this` keyword refers to the object being defined.

This provides another form of recursion:

```java
object Fact {
    def fact (n: Int): Int = {
        if (n == 0) {1} else {n * this.fact(n-1)}
    }
}
```

Moreover, as we’ll see, the recursion is open: the method that is called by `this.foo(x)` depends on what `this` is at run time.
Encapsulation and Scope

- An object can place restrictions on the scope of its members.
- Typically used to prevent external interference with ‘internal state’ of object.
- For example: Java, C++, C# all support:
  - private keyword: “only visible to this object”
  - public keyword: “visible to all”
- Java: package scope (default): visible only to other components in the same package.
- Scala: private[X] allows qualified scope: “private to (class/object/trait/package) X”
- Python, Javascript: don’t have (enforced) private scope (relies on programmer goodwill).
Classes

- A class is an interface with some additional properties:
  - **Instantiation**: classes can describe how to construct associated objects (instances of the class)
  - **Inheritance**: classes may inherit from zero or more parent classes as well as implement zero or more interfaces
  - **Abstraction**: Classes may be abstract, that is, may name but not define some fields or methods
  - **Dynamic dispatch**: The choice of which method is called is determined by the run-time type of a class instance, not the static type available at the call

- Not all object-oriented languages have classes!
  - Smalltalk, JavaScript are well-known exceptions
  - Such languages nevertheless often use prototypes, or commonly-used objects that play a similar role to classes
Constructing instances

- Classes typically define special functions that create new instances, called *constructors*
  - In C++/Java, constructors are defined explicitly and separately from the initialized data
  - In Scala, there is usually one “default” constructor whose parameters are in scope in the whole class body
    - (additional constructors can be defined as needed)
- Constructors called with the `new` keyword

```scala
class C(x: Int, y: String) {
  val i = x
  val s = y
  def this(x: Int) = this(x,"default")
}
scala> val c1 = new C(1,"abc")
scala> val c2 = new C(1)
```
Inheritance

- An object can *inherit* from another.
- This means: the parent object, and its components, become “part of” the child object
  - accessible using `super` keyword
  - (though some components may not be directly accessible)
- In Java (and Scala), a class extends exactly one superclass (`Object`, if not otherwise specified)
- In C++, a class can have *multiple* superclasses
- Non-class-based languages, such as JavaScript and Smalltalk, support inheritance directly on objects via *extension*
Subtyping

- As (briefly) mentioned last week, an object $\text{Obj}$ that extends a trait $\text{Tr}$ is automatically a subtype ($\text{Obj} <: \text{Tr}$)
- Likewise, a class $\text{Cl}$ that extends a trait $\text{Tr}$ is a subtype of $\text{Tr}$ ($\text{Cl} <: \text{Tr}$)
- A class (or object) $\text{Sub}$ that extends another class $\text{Super}$ is a subtype of $\text{Super}$ ($\text{Sub} <: \text{Super}$)
- However, subtyping and inheritance are distinct features:
  - As we’ve already seen, subtyping can exist without inheritance
  - moreover, subtyping is about types, whereas inheritance is about behavior (code)
Inheritance and encapsulation

- Inheritance complicates the picture for encapsulation somewhat.

- private keyword prevents access from outside the class (including any subclasses).

- protected keyword means “visible to instances of this object and its subclasses”

- Scala: Both private and protected can be qualified with a scope [X] where X is a package, class or object.

```scala
class A { private[A] val a = 1
          protected[A] val b = 2 }
class B extends A {
  def foo() = a + b
} // "a" not found
```
Cross-instance sharing

- Classes in Java can have *static* fields/members that are shared across all instances.
- Static methods can access *private* fields and methods.
- *static* is also allowed in interfaces (but only as of Java 8).
- Class with only static members $\sim$ module.
- C++: *friend* keyword allows sharing between classes on a case-by-case basis.
Companion Objects

- Scala has no static keyword
- Scala instead uses *companion objects*
  - Companion = object with the same name as the class and defined in the same scope
  - Companions can access each others’ private components

```scala
object Count { private var x = 1 }
class Count { def incr() = {Count.x = Count.x+1} }
```

- Note: This can only be done in compiled code, not interactively
- (More precisely, in interactive code the object and class need to be defined at the same time)
Multiple inheritance and the *diamond problem*

- As noted, C++ allows *multiple inheritance*.
- Suppose we did this (in Scala terms):

```scala
class Win(val x: Int, val y: Int)
class TextWin(...) extends Win
class GraphicsWin(...) extends Win
class TextGraphicsWin(...) extends TextWin and GraphicsWin
```

- In C++, this means there are two copies of `Win` inside `TextGraphicsWin`.
- They can easily become out of sync, causing problems.
- Multiple inheritance is also difficult to implement (efficiently); many languages now avoid it.
Abstraction

- A class may leave some components undefined
  - Such classes must be marked abstract in Java, C++, and Scala
  - To instantiate an abstract class, must provide definitions for the methods (e.g. in a subclass)
- Abstract classes can define common behavior to be inherited by subclasses
- In Scala, abstract classes can also have unknown type components
  - (optionally with subtype constraints)

```scala
abstract class ConstantVal {
  type T <: AnyVal
  val c: T
}
// a constant of any value type
```
Dynamic dispatch

- An abstract method can be implemented in different ways by different subclasses
- When an abstract method is called on an instance, the corresponding implementation is determined by the *run-time type* of the instance.
- (necessarily in this case, since the abstract class provides no implementation)

```scala
abstract class A { def foo(): String}
class B extends A { def foo() = "B"}
class C extends A { def foo() = "C" }  
scala> val b:A = new B
scala> val c:A = new C
scala> (b.foo(), c.foo())
```
Overriding

- An inherited method that is already defined by a superclass can be *overridden* in a subclass.
- This means that the subclass’s version is called on that subclass’s instances using dynamic dispatch.
- In Java, `@Override` annotation is optional, checked documentation that a method overrides an inherited method.
- In Scala, must use `override` keyword to clarify intention to override a method.

```scala
class A { def foo() = "A" }
class B extends A { override def foo() = "B" }  // correct
scala> val b: A = new B
scala> b.foo()

class C extends A { def foo() = "C" }  // error
```
Type tests and coercions

- Given \( x: A \), Java/Scala allow us to test whether its run-time type is actually subclass \( B \)

  ```scala
  scala> b.isInstanceOf[B]
  ...#
  ```

- and to coerce such a reference to \( y: B \)

  ```scala
  scala> val b2: B = b.asInstanceOf[B]
  ...#
  ```

- Warning: these features can be used to violate type abstraction!

  ```scala
  def weird[A](x: A) = if (x.isInstanceOf[Int]) {
    (x.asInstanceOf[Int]+1).asInstanceOf[A]
  } else {x}
  ```
Advanced constructs

- So far, we’ve covered the “basic” OOP model (circa Java 1.0).
- Modern languages extend this in several ways.
- We can define a class/object inside another class:
  - As a member of the enclosing class (tied to a specific instance)
  - or as a static member (shared across all instances)
  - As a local definition inside a method
  - As an anonymous local definition
- Some languages also support *mixins* (e.g. Scala traits)
- Scala supports similar, somewhat more uniform composition of classes, objects, and traits.
Classes/objects as members

- In Scala, classes and objects (and traits) can be nested arbitrarily.

```scala
class A { object B { val x = 1 } }
scala> val a = new A

object C { class D { val x = 1 } }
scala> val d = new C.D

class E { class F { val x = 1 } }
scala> val e = new E
scala> val f = new e.F
```
Summary

- Today
  - Objects, encapsulation, self-reference
  - Classes, inheritance, abstraction, dynamic dispatch

- This is only the tip of a very large iceberg...
  - there are almost as many “object-oriented” programming models as languages
  - the design space, and “right” formalisms, are still active areas of research

- Next time:
  - Inner classes, anonymous objects, mixins, parameterized types
  - Combining object-oriented and functional programming