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)

Self-Reference

Inside an object definition, the this keyword refers to the object being defined.

This provides another form of recursion:

```scala
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 `Obj` that extends a trait `Tr` is automatically a subtype (`Obj <: Tr`).
- Likewise, a class `Cl` that extends a trait `Tr` is a subtype of `Tr` (`Cl <: Tr`).
- A class (or object) `Sub` that extends another class `Super` is a subtype of `Super` (`Sub <: 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.

```
class A { private[A] var 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 ~ 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.

```
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.
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" }
scala> val b: A = new B
scala> b.foo()
scala> val c: A = new C
scala> c.foo()
```

// error
Type tests and coercions

- Given $x: A$, Java/Scala allow us to test whether its run-time type is actually subclass $B$
  
  scala> b.isInstanceOf[B]

- and to coerce such a reference to $y: B$
  
  scala> val b2: B = b.asInstanceOf[B]

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

  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

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

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

  class E { class F { var 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