Computer Programming with Scala

Week 2: Dealing with Complexity (OOP)

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November 2015

école normale supérieure rennes

Remember Last Week

Computer Science and Informatics

- **Science of Abstraction:** building hierarchies of symbols and concepts
  Programming computers: surface activity, but the easiest to practice with
- Computational Sciences: simulation as third pilar (with observation & theory)

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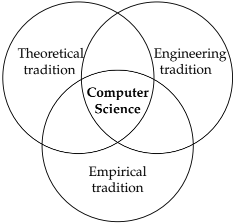
The Historical Heritages of Computer Science

- Maths: proves necessary facts
- Natural Sciences: tests contingent facts
- Engineering: solves problems



Programming Complex Systems is at the core of the discipline

(That's the topic of this course :)

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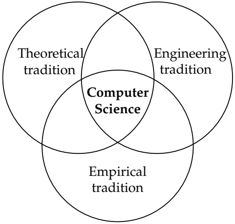

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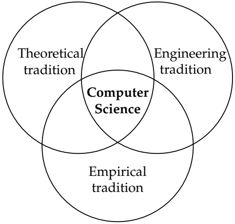

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This week: How to cope with complexity in programs?

What is the Right Solution for my Problem?

- The Correct one: provides the right answer
- The Efficient one: fast, use little memory, but also: fast write
- The Simple one: KISS! (acronym for *keep it simple, silly*)

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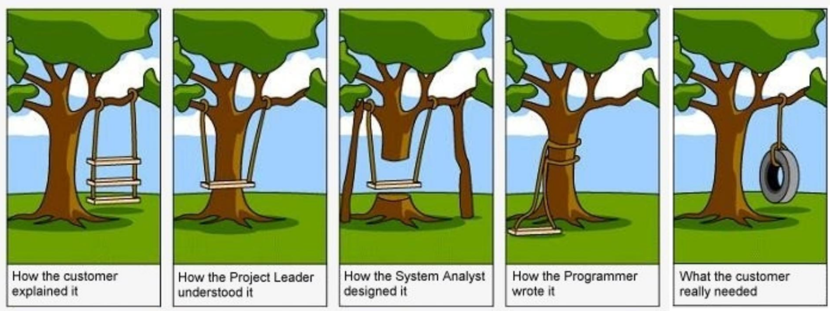
Real Problems ain't easy

- They are complex: composed of several interacting entities
- They are dynamic: the specification evolves with the understanding



Turning the obvious into the useful is a living definition of the word *frustration*.

Alan J. Perlis

Dealing with Complexity: Reductionism

Divide each difficulty into as many parts as is feasible and necessary to resolve it.

– René Descartes (1596-1650)

Composite Structure: Software System composed of manageable pieces

- The smaller the component, the simpler it is ☺
- The more parts, the more possible interactions ☹

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- The smaller the component, the simpler it is ☺
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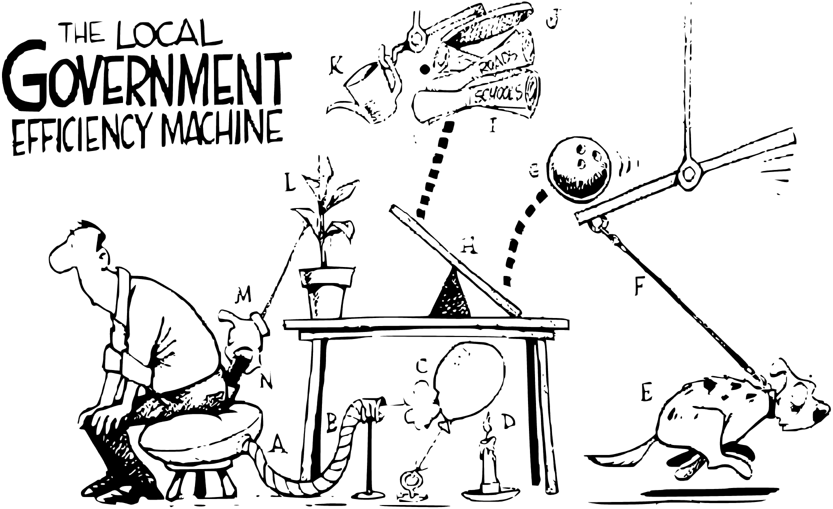
The Complexity Balance is important!

Good Composite Systems?

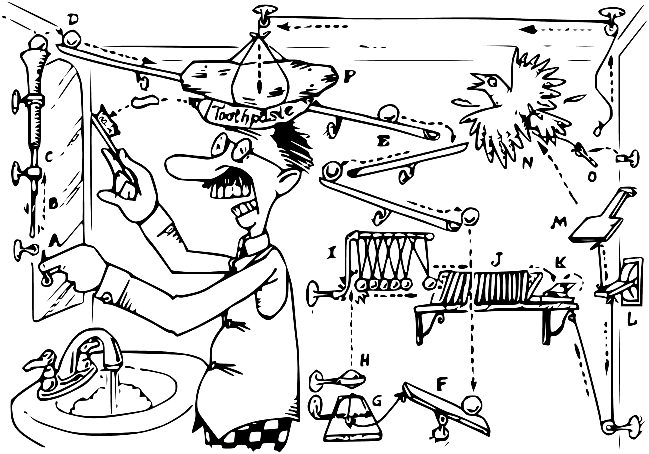
- Each component has a carefully specified function
- Components are easily integrated together
- Example: Audio speakers easily connected to the amplifier

Bad Composite Systems: Rube Goldberg Machines



- Utterly complex interactions to reach the point
- No definitive rule to avoid bad designs. Only bad smells.

The Rube Goldberg's Toothpaste Dispenser

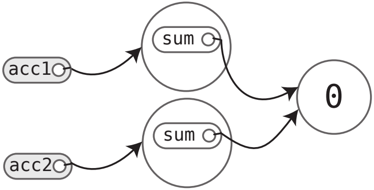


- Such **over engineered** solutions should obviously remain jokes
- Right level of abstraction: focus on relevant properties
- Right composition: focus on relevant components, that are easily integrated

First OOP Principle: Object Encapsulation

- Group things that go together. Example: (x,y) of the point
- Give meaning to raw data. Example: an accumulator is (more than) an integer

```scala
class Checksum {
  var sum = 0
}
val acc1 = new Checksum
val acc2 = new Checksum
```



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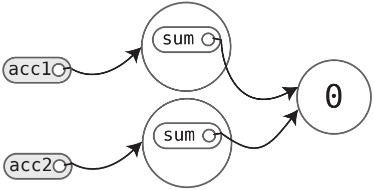
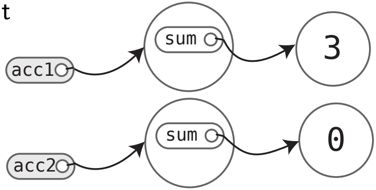


- You can change the value of the content

```
acc1.sum = 3
```



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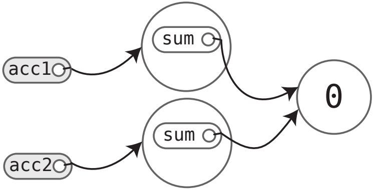

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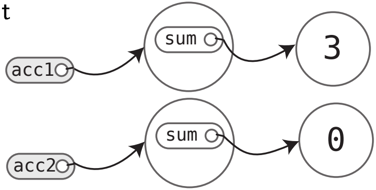

- You still cannot change the `val`ue itself

```
scala> acc1 = new Checksum
<console>:12: error: reassignment to val
```

More OOP Syntax

First version

```
class Checksum {
  var sum = 0
  def add(b: Int): Unit = {
    sum += b
  }
  def checksum(): Int = {
    return ~ (sum & 0xFF) + 1
  }
}
```

- Each Checksum object:
  1 variable + 2 methods

```
scala> val acc = new Checksum
scala> acc.add(346634554)
scala> println(acc.checksum)
-58
```

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Even better version: hide your data

```
class Checksum {
  private var sum = 0
  def add(b: Int): Unit = sum += b
  def checksum(): Int = ~(sum & 0xFF) + 1
}
```

The private keyword hides class content from the outer world

```
scala> acc.sum = 3
<console>:13: error: variable sum in class Checksum cannot be accessed in Checksum
```

Some OOP Vocabulary

```
class Checksum {
  private var sum = 0
  def add(b: Int): Unit = sum += b
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- `sum`: field or member
- `add`: procedure (does not return a value)
- `checksum`: method (returns a value)

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- The whole is a method call
- `346634554`: method parameter (or explicit parameter)
- `acc`: method call receiver (or implicit parameter)

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- Public Interface: what you can do from outside
- Class: type of object of acc
- Instance: one of the Checksums' object

Don't mix Class vs. Instance

- It's *Concept* vs. *Object*
- e.g.: *Car model* vs. *actual car* or to *Human being* vs. *an individual*

Reducing the Syntaxic Sugar further

- Scala allows to omit the . and the ()

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- This is particularly cool if you define a method called +

```
class Checksum {
  private var sum = 0
  def +(b: Int): Unit = sum += b
  def checksum(): Int = ~(sum & 0xFF) + 1
}
val acc = new Checksum
acc + 346634554    // nice, isn't it?
```

Singletons: When you need only one instance

```
object checksum {
  private var sum = 0
  def +(b: Int): Unit = sum += b
  def checksum(): Int = ~(sum & 0xFF) + 1
}

checksum + 346634554
```

- You can directly use checksum as an instance of the class
- You cannot create several instances

Functional Objects: objects with no mutable state

- `sum` is a variable, so `Checksums` may change without notice
- Side effects $\leadsto$ harder to reason about the object (particularly if multi-threaded)

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class Rational(n: Int, d: Int) {
  println("Created "+ n +"/"+ d)
}
```

```
scala> new Rational(1, 2)
Created 1/2
res0: Rational = Rational@424c0bc4
```

- Problem: `Rational@424c0bc4` is neither nice looking nor informative

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class Rational(n: Int, d: Int) {
  override def toString() = n+"/"+d
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- Notice the `override` keyword, because `toString()` is redefined

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Checking preconditions

```
scala> new Rational(5, 0)
res0: Rational = 5/0
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  - We want to forbid this

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scala> new Rational(5, 0)
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```
class Rational(n: Int, d: Int) {
  require(d != 0)
  override def toString() = n+"/"+d
}
```

- `new Rational(5,0)` will now fail with an `IllegalArgumentException`

Adding methods to the `Rational` class

```
class Rational(n: Int, d: Int) {
  require(d != 0)
  override def toString() = n+"/"+d
  def *(that: Rational): Rational =
    new Rational(
      n * that.n, d * that.d)
}
```

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Compilation error

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error: value d is not a member of Rational
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- Indeed, d is not a field of Rational (that's a constructor parameter)

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Second try

```scala
class Rational(n: Int, d: Int) {
  require(d != 0)
  val num: Int = n
  val den: Int = d
  override def toString() = num+"/"+den
  def *(that: Rational): Rational =
    new Rational(
      this.num * that.num,
      this.den * that.den
    )
}
```

```
scala> val oneHalf = new Rational(1, 2)
oneHalf: Rational = 1/2

scala> val twoThirds = new Rational(2,3)
twoThirds: Rational = 2/3

scala> oneHalf * twoThirds
res0: Rational = 2/6
```

- Much better looking.
- (`val`s don't need to be private)
- (`this`: current object; that: param)

More flesh to the `Rational` class

Auxiliary Constructors

```
scala> val five = new Rational(5)
five: Rational = 5/1
```

```
class Rational(n: Int, d: Int) {
  require(d != 0)
  val num: Int = n
  val den: Int = d
  // auxiliary constructor
  def this(n: Int) = this(n, 1)

  override def toString() = num+"/"+den
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}
```

```
scala> val five = new Rational(5)
five: Rational = 5/1
```

Private Fields and Methods

```
class Rational(n: Int, d: Int) {
  require(d != 0)
  private val g = gcd(n.abs,d.abs)
  val num: Int = n / g
  val den: Int = d / g
  ...
  private def gcd(a: Int, b: Int): Int =
    if (b == 0) a else gcd(b, a % b)
}
```

```
scala> new Rational(66,42)
res0: Rational = 11/7
```

Mixing Rationals and Integers

```
scala> val x = new Rational(2/3)
x: Rational = 2/3

scala> x * 2
res0: Rational = 4/3
```

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class Rational(n: Int, d: Int) {
  ...
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}
```

```
scala> 2 * x
error: overloaded method value * with alternatives:
 (x: Double)Double <and>
 (x: Float)Float <and>
 (x: Long)Long <and>
 (x: Int)Int <and>
 (x: Char)Int <and>
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cannot be applied to (Rational)
```

Indeed, no method
*(x: Rational)
in class Int

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Second try

```
implicit def intToRational(x: Int) = new Rational(x)
```

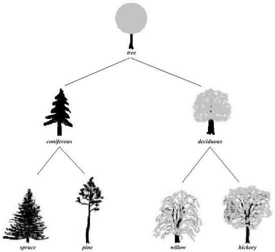
```
scala> 2 * x
res0: Rational = 4/3
```

- Removes much of the Caml sugar (!), at the price of implicit actions (F34R)

Designing a good OOP Composition

Abstraction

- Dealing with components and interactions without worrying about details
  Not "vague" or "imprecise", but focused on few relevant properties
- Eliminate the irrelevant and amplify the essential
- Capture commonality between different things



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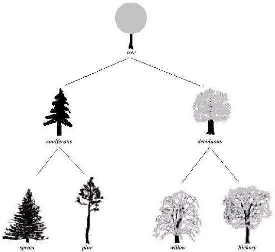
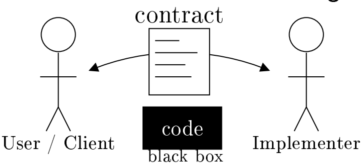


Abstraction in programming

- Think about what your components should do before
- Abstract their **interface** before coding



- Show your interface, hide your implementation

Good Property: Cohesion

A class = A concept

- Good cohesion if all parts of Public Interface are related to the concept
- Counter-example:

```
class CashRegister {
  def enterPayment(dollars:Int, quarters:Int, dimes:Int,
                   nickels:Int, pennies:Int):Unit = ...
  val NICKEL_VALUE = 0.05
  val DIME_VALUE = 0.1
  val QUARTER_VALUE = 0.25
}
```

- There is two concepts: `CashRegister` and `Coin`s
- There must be (at least) two classes

Coupling

- A class *depends* on another if it utilizes it
  - CashRegister depends on Coin, Coin does not depend on CashRegister
- Low Coupling (few inter-class dependencies) better than Tight Coupling
  - Thinking of components in isolation is easier

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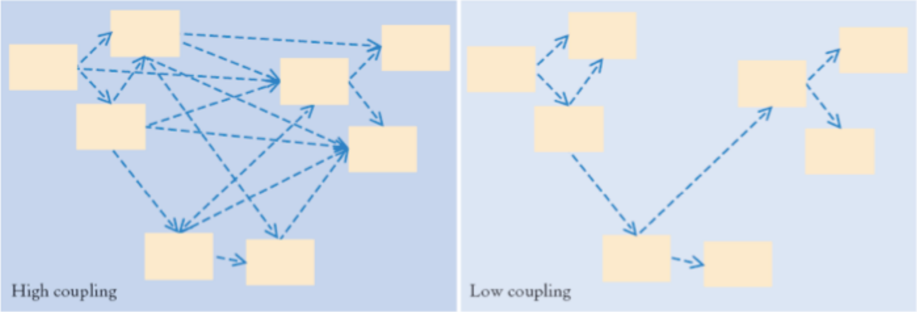
Representing the coupling with boxes



- Cycles in coupling diagrams would have a **bad smell**
- UML is the standard way of doing it (but don't get too picky!)

Beyond Encapsulation

- A class or object can be seen as a "component" with values and operations

Vehicule
maker: String
start(): Unit

- You can build other "components" for other classes

Vehicule
maker: String
start(): Unit

Tire
diameter: Float
inflate(): Unit

Driver
name: String
sayHello(): Unit

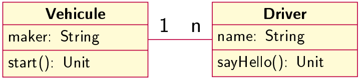
Truck
axleCount: Int
harness(t: Tow): Unit

- To combine them, you can either go for association or inheritance

Class Association and Inheritance

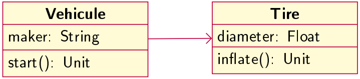
Reciprocal Association

- A "have some" B
- B also "have some" A
- You can specify the amount of A it has (but rarely need to)



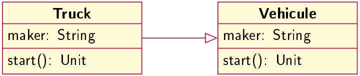
Unidirectional Association

- A "have some" B
- but B don't have any A



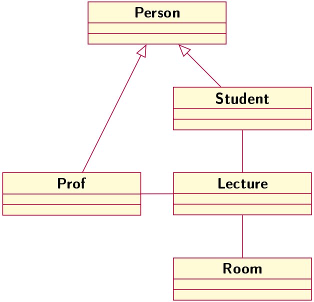
Class inheritance

- A "is a" B
- (B cannot "be a" A, or A=B)

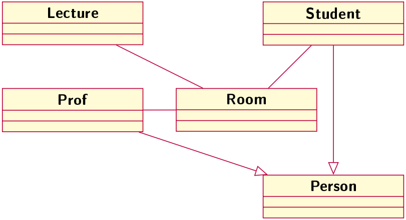


Don't worry if you forget the arrow shape: I always do too

Quizz: Which Design is Preferable?



(A)



(B)

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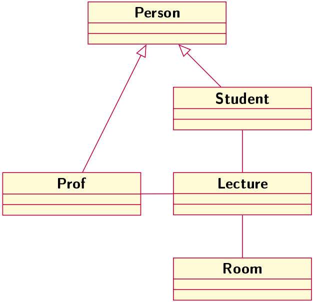
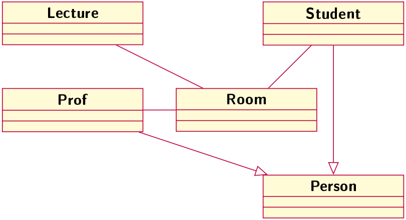


(A)



(B)

- Theory (n) coherent set of concepts allowing to speak of something
- These boxes quickly get boring, but notation helps thinking about large systems

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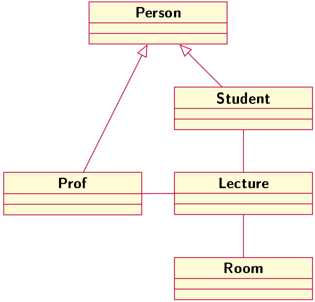

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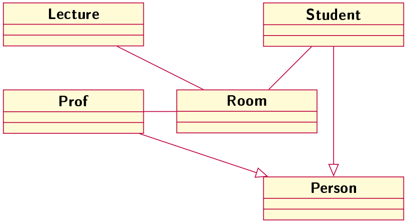

(B)

- Theory (n) coherent set of concepts allowing to speak of something
- These boxes quickly get boring, but notation helps thinking about large systems

So? What is a *Good Design?*

- Much of personal taste involved, even if we framed a bit the idea
- But how would you define a *Good Proof?*

Association and Inheritance in Scala

Association

- A "has a" B simply means that B is a field of A

```
class A {
  val x: Set[B]
}
```

```
class B {
  ...
}
```

Association and Inheritance in Scala

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```scala
class A {
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}
```

```scala
class B {
  ...
}
```

Inheritance

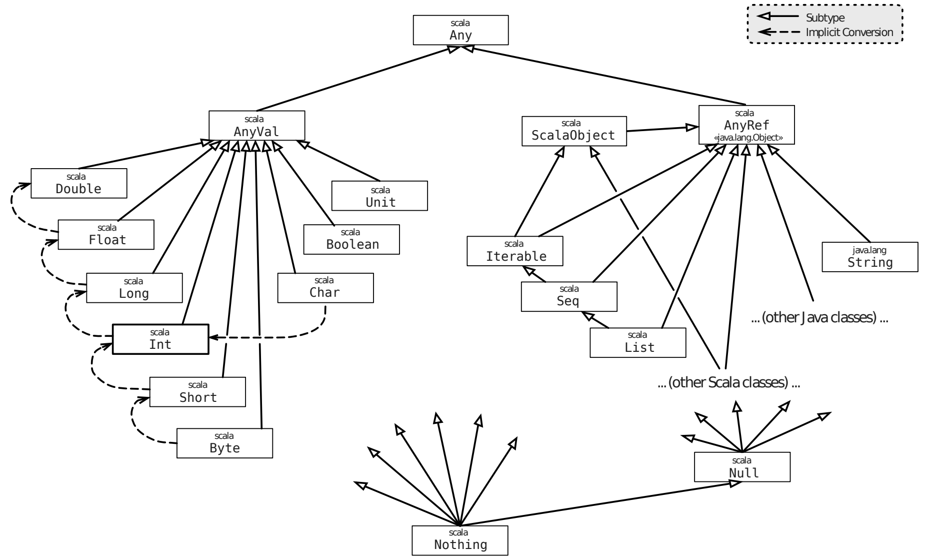
- B "is a" A means that B extends A

```scala
class A {
  ...
}
```

```scala
class B extends A {
  ...
}
```

- Methods and fields of A are also in B (`toString()` was already in `Rational`)
- That's a very powerful tool to factorize code and complexity

Scala Class Diagram



Polymorphism: Factorizing Complexity

Overriding content

- If B extends A, it can override (redefine) definitions of A

```
class A {
  def fun = println("I'm a A")
}
class B extends A {
  override def fun = println("I'm a B")
}
```

```
scala> val a = new A; a.fun
I'm a A
scala> val b = new B; b.fun
I'm a B
```

Polymorphism: Factorizing Complexity

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scala> val b = new B; b.fun
I'm a B
```

- The code selection depends on the static and dynamic types

Abstract class

- When a class is only there to factorize code but shouldn't be used directly

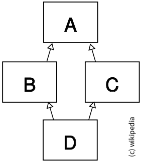
```
abstract class Ordered {
  def <(that:Ordered):Boolean
  def >(that:Ordered) =
          !(that < this)
}
```

- You cannot instanciate that class
- The class can contain *undefined def* further factorization opportunities
- Concrete sub-classes must implement them

Multiple Inheritance

Diamond Problem: Multiple Inheritance is not easy

- D inherits of B and C, which both inherit of A
- Both `B.fun` and `C.fun` override the same method `A.fun`
- `D.fun` is called.
    - Which to call between `B.fun` & `C.fun` ? If both, order? `A.fun` called twice?



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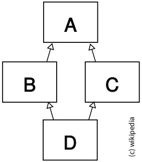

Simple Solution: don't do that.

- Scala and Java forbid multiple class inheritance
- Simpler, but missed factorizations opportunities

Safe multiple *is-a*: the Java interfaces

- Syntax: $\approx$ abstract classes without code any code (no diamond problem)
- Enables several implementations of the same interface
- In practice, abstract classes and interfaces are different:
  - abstract class to factorize code; interface = contract between implementer/user

Scala Traits: Mixing Orthogonal Concerns

- Interface providing concrete members / Abstract class with multiple inheritance
- Not exactly a class: cannot take constructor parameters

```
abstract class IntQueue {
  def get(): Int
  def put(x: Int)
}
class BasicIntQueue extends IntQueue {
  private val buf = new ArrayBuffer[Int]
  def get() = buf.remove(0)
  def put(x: Int) { buf += x }
}
```

```
trait Doubling extends IntQueue {
  abstract override def put(x: Int) {
    super.put(2 * x) }
}
```

```
scala> val queue = new BasicIntQueue
queue: BasicIntQueue = BasicIntQueue@2465
scala> queue.put(10)
scala> queue.put(20)
scala> queue.get()
res9: Int = 10
scala> queue.get()
res10: Int = 20
```

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res9: Int = 10
scala> queue.get()
res10: Int = 20
```

```
trait Doubling extends IntQueue {
  abstract override def put(x: Int) {
    super.put(2 * x) }
}
```

```
scala> class DQ extends
  BasicIntQueue with Doubling
scala> val q = new DQ; q.put(10); q.get()
res12: Int = 20
```

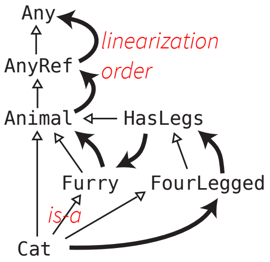
```
trait Filtering extends IntQueue {
  abstract override def put(x: Int) {
    if (x>=0) super.put(x) }
}
```

```
scala> class DFQ extends BasicIntQueue\
   with Doubling with Filtering
scala> val q=new DFQ;q.put(-1);q.put(10)
scala> q.get()
res12: Int = 20
```

- Evaluation Order ≈ traits further to the right take effect first

Traits and Diamond Problem

```scala
class Animal
trait Furry extends Animal
trait HasLegs extends Animal
trait FourLegged extends HasLegs
class Cat extends Animal with Furry with FourLegged
```



Linearization

- Strictily defined (but complex) order of traits and classes
- First found implementation wins – other method candidates are ignored
- super is not who you think, but it's for the best

Packages

Purpose: group together objects (reduce coupling)

Declaration Syntax

- Statement at beginning of file

```
package bobsrockets.navigation

class Navigator
```

- Several packages in the same file

```
package bobsrockets.navigation {
  class Navigator
}
```

- Nested packages

```
package bobsrocket {
  package navigation {
    class Navigator
    package tests {
      class NavigatorSuite
    }
  }
}
```

Usage Syntax: Imports

- Statement at beginning of file

```
import bobsrockets.navigation
import alicehost._
```

- Fully qualified names

```
val n = new bobsrocket.navigation.Navigator
```

- Flexible `import`: even within a function, or import methods as singletons
- Class files must be in right relative subdirectory: `bobsrocket/navigation/Navigator.class`

Dealing with Complexity

Some classical design principles

- Composition: split problem in simpler sub-problems and compose pieces
- Abstraction: forget about details and focus on important aspects

Object Oriented Programming

- Data are the central element
- Encapsulation: Divide complexity into manageable units
- Heritage: Factorize behavior between related units
- Polymorphism: Use a specialized unit instead of the expected one

Functional Programming

- Functions and behaviors are the central elements
- Usually produces programs that are easier to reason about
- Somehow harder to write when not used to

No holy war needed: Scala has both :)

"A cat catches a bird and eats it"

How would you design/organize/split this code?

"A cat catches a bird and eats it"

How would you design/organize/split this code?

As a OOP programmer

- There is two nouns: cat and bird
- Cat has two verbs associated: catch and eat

```
class Bird
class Cat {
   def catch(b: Bird): Unit = ...
   def eat(): Unit = ...
}
val cat = new Cat
val bird = new Bird
cat.catch(bird)
cat.eat()
```

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cat.eat()
```

As a FP programmer

- There is two verbs: catch and eat
- They are composed and apply to typed values

```
trait Cat
trait Bird
trait Catch
trait FullTummy
def catch(hunter: Cat, prey: Bird):
    Cat with Catch = ...
def eat(consumer: Cat with Catch):
    Cat with FullTummy = ...
val story = (catch _) andThen (eat _)
story(new Cat, new Bird)
```

Example and Code from *Scala in Depth*

OOP vs. FP

So, do you prefer nouns or verbs? Well, both.

Object-Oriented Programming	Functional Programming
Composition of objects (nouns)	Composition of functions (verbs)
Encapsulated stateful interaction	Deferred side effects
Iterative algorithms	Recursive algorithms and continuations
Imperative flow	Lazy evaluation
Explicit Memory Layout (HW-like)	Pattern matching

But they seem somehow incompatible . . . until Scala

- Scala is a convincing attempt to mix them
- Everything is an object (including functions)
- Best practices: prefer immutable values, even if mutables exist
- Large OOP systems were introducing FP in Java anyway (with ugly hacks)
  Now the language and compiler helps (but still that Frankenstein smell)

Conclusion

Computer Science is the Science of Abstraction

- But sorting the concepts require some technics
- Computer Scientists are engineers terraforming ideas and concepts :)

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- Encapsulation and abstraction to design objects; Association to compose them
- Inheritance to factorize objects; Abstract class to further factorize concepts
- Dynamic binding: complex problem (more to come in practical)
- Want more factorization while avoiding the Diamond Problem
  - Traits goes further than Java's interface without the C++ Diamond madness

Functional Programming: orthogonal approach

- Focuses on verbs instead of nouns
- Which is best suited depends on the problem (and programmer)

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Functional Programming: orthogonal approach

- Focuses on verbs instead of nouns
- Which is best suited depends on the problem (and programmer)

Scala gives you both OOP and FP

- Everything is an object (even functions), and you want to use immutable objects