Computer Programming with Scala
Week 2: Dealing with Complexity (OOP)

Martin Quinson

November 2015

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
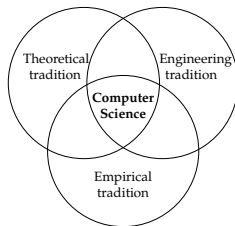- Computational Sciences: simulation as third pilar (with observation & theory)

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The Historical Heritages of Computer Science
- Maths: proves necessary facts
- Natural Sciences: tests contingent facts
- Engineering: solves problems

Theoretical tradition · Engineering tradition · **Computer Science** · Empirical tradition

Programming Complex Systems is at the core of the discipline
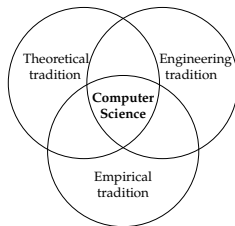(That's the topic of this course :)

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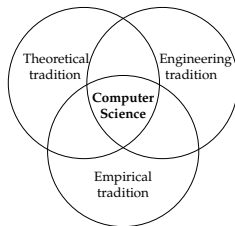Scala: Nice little language, that turns out to be a multi-paradigm beauty (beast?)

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This week: How to cope with complexity in programs?

What is the Right Solution for my Problem?

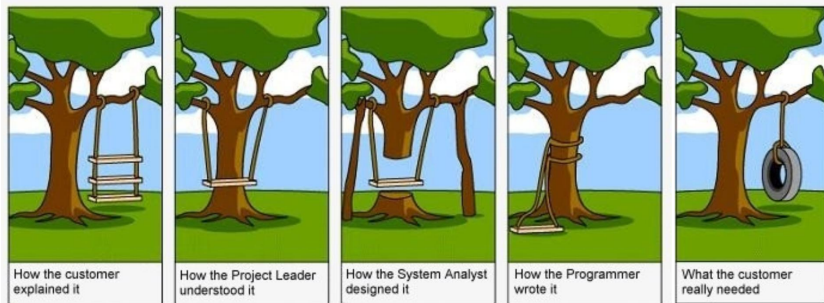- The Correct one: provides the right answer
- The Efficient one: fast, use little memory, but also: fast write
- The Simple one: KISS! (acronym for *keep it simple, silly*)

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*)

Real Problems ain't easy

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

| How the customer explained it | How the Project Leader understood it | How the System Analyst designed it | How the Programmer wrote it | What the customer really needed |

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 ☹

Dealing with Complexity: Reductionism

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Composite Structure: Software System composed of manageable pieces
- 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
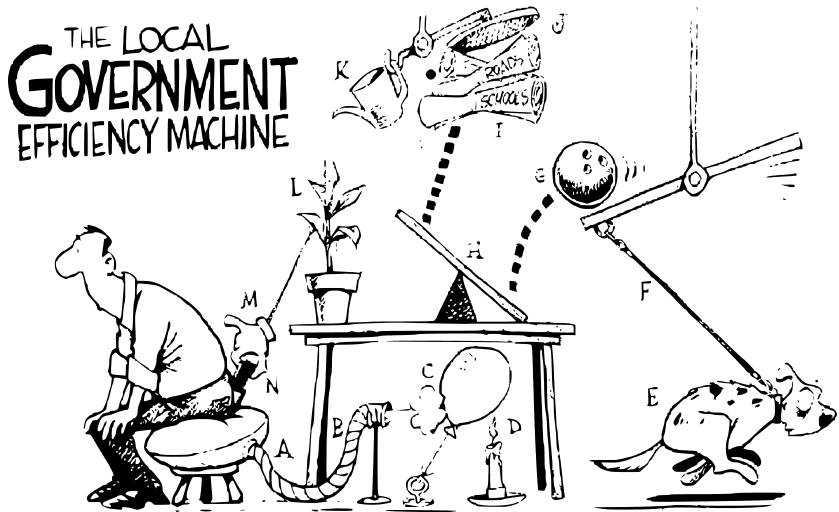
- Utterly complex interactions to reach the point
- No definitive rule to avoid bad designs. Only bad smells.

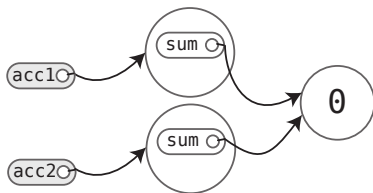# The Rube Goldberg's Toothpaste Dispenser
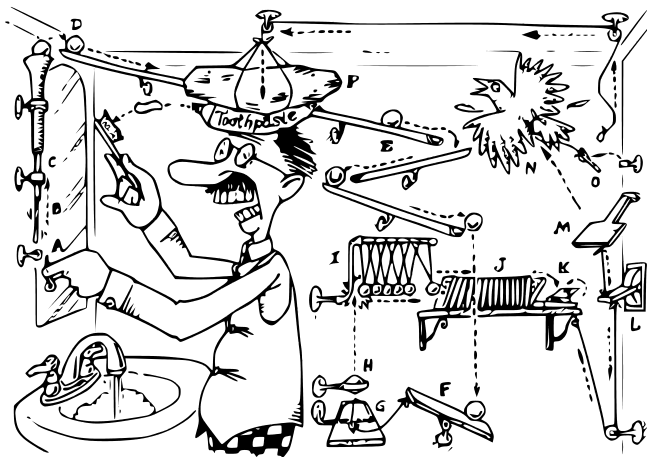
- Such **over engineered** solutions should obviously remain jokes
- Right level of abstraction: focus on relevant properties
- Right composition: focus on relevant components, that are easily integrated

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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acc1.sum = 3
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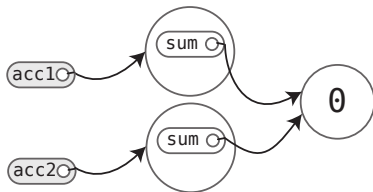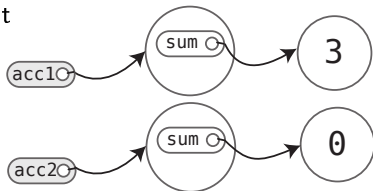- Give meaning to raw data. Example: an accumulator is (more than) an integer

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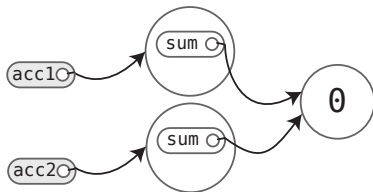

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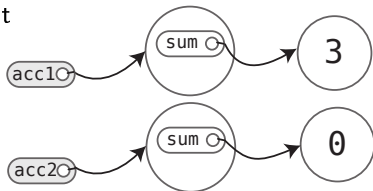
```scala
acc1.sum = 3
```


- You still cannot change the value itself

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

More OOP Syntax

First version

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

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Even better version: hide your data

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

Some OOP Vocabulary

```scala
class Checksum {
  private var sum = 0
  def add(b: Int): Unit = sum += b
  def checksum(): Int = ~(sum & 0xFF) + 1
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- ▶ sum: field or member
- ▶ add: procedure (does not return a value)
- ▶ checksum: method (returns a value)

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acc.add(346634554)
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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 ()

  `acc.add(346634554)`   becomes   `acc add 346634554`

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

```scala
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

```scala
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

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- Side effects ⤳ harder to reason about the object (particularly if multi-threaded)

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

```scala
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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Redefining the toString() method

```scala
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
scala> new Rational(5, 0)
res0: Rational = 5/0
```

- ▶ We want to forbid this

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Checking preconditions

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

```
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

```scala
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

`error: value d is not a member of Rational`

▶ 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
    )
}
```

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  (that's a constructor parameter)

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

```scala
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
  def *(that: Rational): Rational =
    new Rational(this.num * that.num,
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}
```

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

Private Fields and Methods

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

Mixing Rationals and Integers

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

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

```scala
class Rational(n: Int, d: Int) {
  ...
  def *(that: Rational): Rational =
    new Rational(this.num * that.num,
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  def *(that: Int): Rational =
    new Rational(this * that.num, this.den)
}
```

Mixing Rationals and Integers

First try

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}
```

```scala
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>
 (x: Short)Int <and>
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cannot be applied to (Rational)
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Indeed, no method
 *(x: Rational)
in class Int

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Indeed, no method
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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
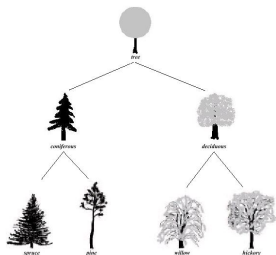
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Abstraction in programming
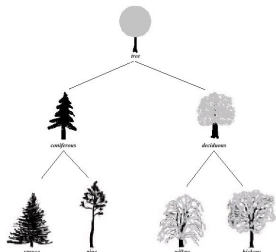
- Think about what your components should do before
- Abstract their **interface** before coding
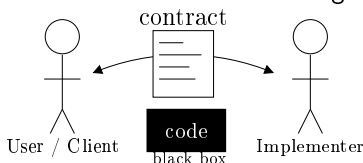
- Show your interface, hide your implementation

Good Property: Cohesion

<p align="center" style="color:red">A class = A concept</p>

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

Coupling

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Representing the coupling with boxes

High coupling
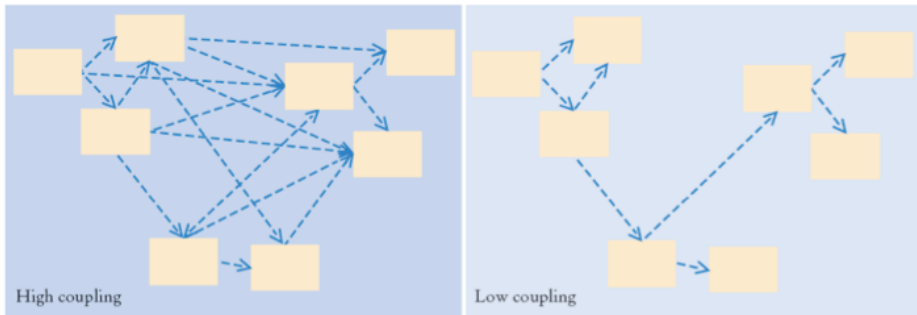
Low coupling

- 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

Vehicle
maker: String
start(): Unit

- You can build other "components" for other classes

Vehicle
maker: String
start(): Unit

Tire
diameter: Float
inflate(): Unit

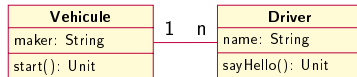| **Driver** |
|---|
| name: String |
| sayHello(): Unit |

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

- To combine them, you can either go for association or inheritance
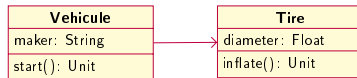
Class Association and Inheritance

Reciprocal Association

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

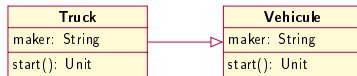| Vehicle		1 n	Driver	
maker: String			name: String	
start(): Unit			sayHello(): Unit	

Unidirectional Association

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

Vehicle		Tire	
maker: String		diameter: Float	
start(): Unit		inflate(): Unit	

Class inheritance

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

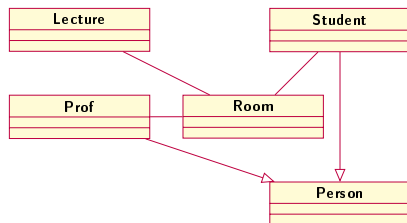| Truck		Vehicle	
maker: String		maker: String	
start(): Unit		start(): Unit	

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

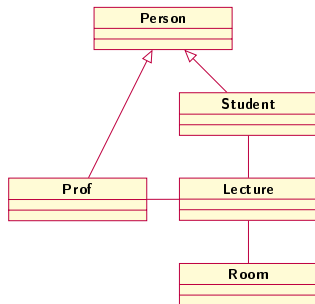# Quizz: Which Design is Preferable?
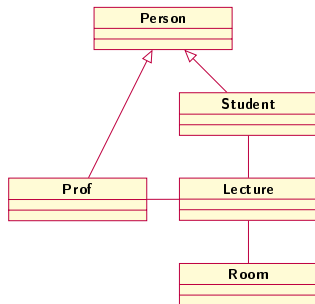
(A)

(B)

Quizz: Which Design is Preferable?

(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
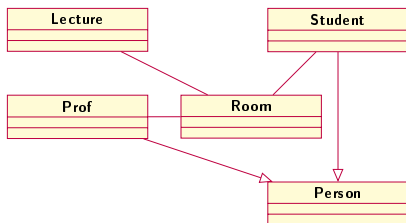
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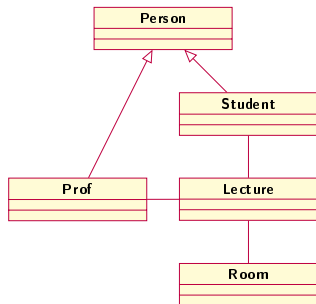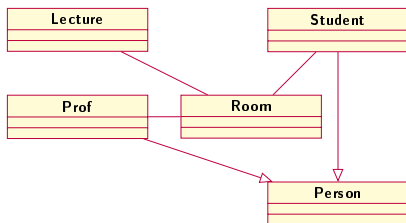

(A)   (B)

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

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

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

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

Association and Inheritance in Scala

Association

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

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

```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
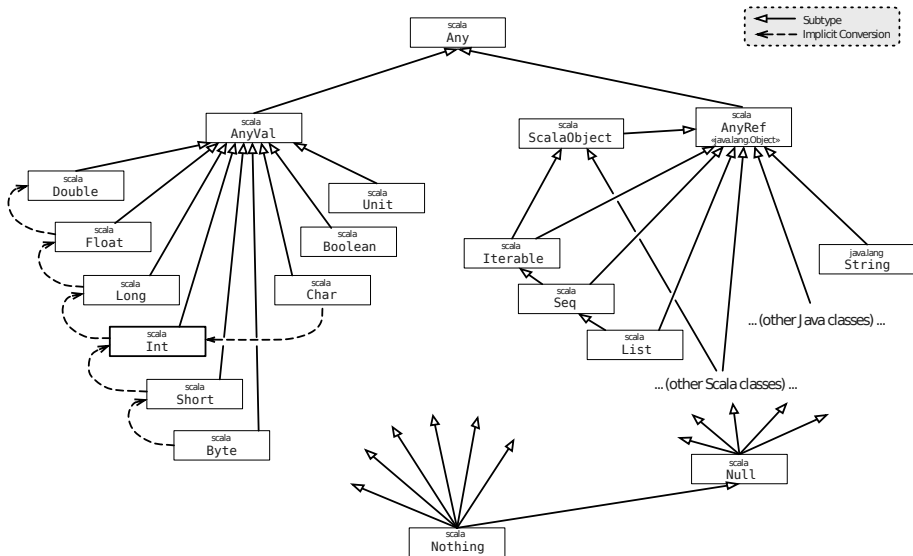
Polymorphism: Factorizing Complexity

Overriding content

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

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

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

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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

```scala
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?

(c) wikipedia

Multiple Inheritance

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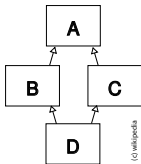   - Which to call between `B.fun` & `C.fun` ? If both, order? `A.fun` called twice?

(c) wikipedia
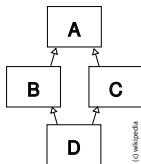
Simple Solution: don't do that.

- 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

```scala
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 }
}
```

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

```scala
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
```

Scala Traits: Mixing Orthogonal Concerns

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

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

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

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

```scala
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
```
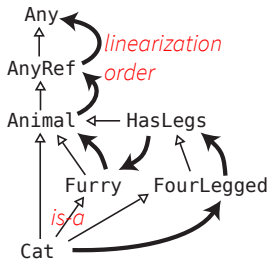

Linearization

- ▶ Strictly 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`

Exceptions

Purpose: Mechanism to deal with unexpected failures, eg system errors
- Thrown exception fly up in the call stack until it gets catched

Throwing an exception
- Exceptions are object, with a large hierarchy of [causes]
- You can (and should) create your own Exceptions, too

```scala
throw new IllegalArgumentException
```

Catching an exception

```scala
try {
  val f = new FileReader("input.txt")
  // Use that file
} catch {
  case ex: FileNotFoundException => // Handle
  case ex: IOException => // Handle I/O pb
} finaly {
  file.close() // Do that in any case
}
// Stuff
```

- Execution flow gets changed
- Breaks in the try block at first exception
- Branches to catch case (or out)
- Always runs the finally block
- Only catch the exceptions that you can deal with

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

<div align="center">

No holy war needed: Scala has both :)

</div>

"*A cat catches a bird and eats it*"

How would you design/organize/split this code?

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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()
```

"*A cat catches a bird and eats it*"

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val cat = new Cat
val bird = new Bird
cat.catch(bird)
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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Object-Oriented concepts are meant to help

- 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