CS250 - Discussion 1
Chisel + Scala Primer

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The Chisel Software Architecture

**Chisel**
(Hardware Construction Language)
Domain Specific Language

**Scala**
(General Functional / Object Oriented Language)

**Java / Java Runtime Environment (JRE)**
(General Object Oriented Language and Runtime)
Cross Platform, Heavily Documented, Large Standard Library

**SBT**
(Build Tool for Scala)
Build Tool, Package Manager
SCALA
Running Scala Interactively

- Scala provides a REPL (Read-Evaluate-Print Loop) interface
- Can be accessed using sbt
  - `> sbt console`
- Can use this to try out scala snippets ...
  - Or just as a cool calculator!
Semicolons & Ending Statements

• Semicolons are used in C type languages to denote the end of a statement
• Scala uses them for the same purpose
• Scala also infers line ends as the end of a statement
  – Except if the line ends in =, {, (, or an operator
• Semicolons can be used to separate statements in a single line

Valid Scala Syntax:

```scala
val a = 1 + 2    //preferred
val a = 1 + 2;
val a = 4; val b = 5; val c = a+b
val a = 1 + (2 + 3)
```

Information from *Programming Scala, 2nd Edition* by Dean Wampler and Alex Payne
Different Function Call Syntax

• Typical Java syntax is also typically valid scala syntax
• Methods with no arguments can omit ()
  – object.fun() is equivalent to object.fun
• Methods with no arguments can be called with a postfix syntax (no longer recommended as semicolons are optional)
  – object.fun() is equivalent to object fun
• Methods with one argument can be called with infix notation
  – object.oneArg(5) is equivalent to object oneArg 5
  – Infix notation should only be used for purely functional method (no side effects) or methods that take a function as a parameter
  – Should be used for high-order functions (map, foreach, ...)
val vs. var

- val defines a constant value
- var defines a variable
- vals are preferred in Scala
- Note that if val is a reference to an object, the underlying object may be modified but the reference cannot be changed

Information from *Scala for the Impatient* by Cay S. Horstmann

Why are vals preferred?

Functional Purity

• A pure function is one that has no side effects
• A function has a side effect when it relies on or changes some external state
• A pure functions will always yield the same return value with the same input data (arguments)
• Purely functional languages (Scala is not one) only allow pure functions
• You have been writing pure functions for a long time ... in math class!
  – \( f(x) = x^2 + 2x + 1 \) is a pure function!
• vars are mutable and represent state, vals are immutable
• Ideally, one would have some input and apply several functions to it
Defining Functions

• Functions:
  - def fctnName(a: Type, b: AnotherType): ReturnType = { function body ...}
  - def addInt(c: Int, d: Int) = c + d
  - The return type is optional, the argument types are mandatory
  - If recursion is used, return type is mandatory

• Procedures: Functions without a return value
  - def procedureName(a: Type, b: AnotherType) {procedure body ...}
  - def printMe(a: Int) {println("Val="+a)}

Information from Scala for the Impatient by Cay S. Horstmann
class vs. object

- Classes are very similar to Java classes
  - They define a sort of template from which objects can be instantiated.
  - They have member vals, vars, and functions (called methods when defined in a class)
  - When you have an object, you can call it’s class methods using the standard object.method() syntax

Information from *Scala for the Impatient* by Cay S. Horstmann
class vs. object

• The object keyword is used to describe *singleton objects*
  – A singleton object only has only *one* instance
  – You can think of it as defining a class and instantiating it only once

Information from *Scala for the Impatient* by Cay S. Horstmann
class vs. object

Companion Classes

• Why is there an object keyword?
• Java classes allow static methods and variables
  – Functions and fields that can be called without an object
    • Class.Function, Class.Field
  – They can serve many uses including helper functions, factories, and more
• Scala does *not* allow static methods to be declared in classes
• Instead, scala defines companion objects with the same name as the class.
• Static methods are placed in the companion object
• Because the companion object has the name name as the class, a call to Class.method is actually a call to the method in the companion object
The apply function

• The apply function is syntactic sugar to overload the () operator.

• You can define an apply method in classes that allow you to use object(arg) in your code

• You can define an apply function in the companion object typically to act as a factory (returns an object of the companion class).

Information from Scala for the Impatient by Cay S. Horstmann
The apply function

class MyClass (name: String, id: Int) {
    var myName = name
    var myId = id
    def printMe() {println(myName + " ID: " + myId)}
    def apply() = myId
    def apply(a: Int) {myId = a}
}

object MyClass {
    def apply(s: String) = new MyClass(s, 0)
}
val a = MyClass("bob")
a.printMe()
a(10)
a(10)
a.printMe()

Output:
  bob ID: 0
  bob ID: 10
When to use `new`?

- `new` will call the constructor
- `val a = MyClass("bob")` calls the apply function in the companion object
- `val b = new MyClass("bob", 10)` calls the constructor

Information from *Scala for the Impatient* by Cay S. Horstmann
Control Statements and Loops

• If/else
  – Like Java
    
    ```scala
    if (n<len) {
        //do something
    } else if (n==len) {
        //do something
    } else {
        //do something
    }
    ```

• While
  – Also like Java
    
    ```scala
    while (n<len){
        //do something
    }
    ```

Information from *Scala for the Impatient* by Cay S. Horstmann
Control Statements and Loops

• For
  – Not like Java
    ```scala
    for (i <- 0 until len){
      //do something
    }
    ```

    – Also supports special syntax for nested loops
    ```scala
    for (i <- 0 to len1; j <- 0 until len2){
      //do something
    }
    ```

Information from *Scala for the Impatient* by Cay S. Horstmann
Control Statements and Loops

• For
  – Well ... actually like Java but the for each variant
  – Can loop over elements in collection (using an iterator)
  – In the previous for loops, 0 until len creates a Range that can be iterated over.

```scala
val a = Seq(1, 2, 3, 4, 5)
for (i <- a){
  //i takes the value of each
  //element in the sequence a
  println(i)
}
```

Information from *Learning Scala* by Jason Swartz
Ranges

- Ranges are used in several parts of scala
  - Especially in for loops
- Ranges are sequences of numbers that
  - Start at one number (inclusive)
  - End at another number (inclusive or exclusive)
  - By some increment

- `val a = 0 to 5`
  - `a = (0, 1, 2, 3, 4, 5)`
- `val b = 0 until 5`
  - `b = (0, 1, 2, 3, 4)`
- `val c = 0 to 4 by 2`
  - `c = (0, 2, 4)`
- `val d = 1.5 to 3.0 by 0.5`
  - `d = (1.5, 2.0, 2.5, 3.0)`

Information from *Programming Scala, 2nd Edition* by Dean Wampler and Alex Payne
Matching

• Like a C switch statement but much more powerful
• Can match on values, types, Boolean expressions, and more!
• A bit advanced for this course but good to know if you come across it
• Related to partial functions

```scala
val a = Seq(8, 6, 7, 5, 3, 0, 9)
for( i <- a ){
  val rtn = i match {
    case _ if i > 5 => "over"
    case 5     => "five"
    case _     => "under"
  }
  println(rtn)
}
```

Information from *Programming Scala, 2nd Edition* by Dean Wampler and Alex Payne
Tuples

- Tuples are simply ordered collections of data.
- The values cannot be iterated over.
- Data in tuples do not need to have the same type.
- Data from tuples can be extracted using a special syntax where the index starts from 1.
- The relation operator \(-\rightarrow\) is syntactic sugar for making 2-tuples and is targeted at key-value pairs.

```
val stuff = (3, 5.6, "hello")
stuff: (Int, Double, String) = (3,5.6,hello)
println(stuff._1)
3
println(stuff._2)
5.6
println(stuff._3)
hello
```

```
val keyValPair = "name" -> "Oski"
keyValPair: (String, String) = (name,Oski)
```
Functions as “First Class Citizens”

• You have seen that you can assign a number to a val or var
  – `val a = 5`

• You can also assign a function to a val or var!
  – `val a = scala.math.abs _`
  – `a(-5)`
  – 5
  – The space, underscore specifies that you want to assign the `function` to `a` and not the value returned

• Functions can actually be passed around, just like numeric values!

Information from *Scala Cookbook* by Alvin Alexander
High Order Functions

- **High Order Functions** either:
  - take a function as an argument
  - return a function
- **Why functions can be passed!**

```scala
def highOrder(a: Int, b: Int, c:Int, fun:(Int,Int) => Int) = {
  val tmp1 = fun(a, b)
  val tmp2 = fun(b, c)
  fun(tmp1, tmp2)
}
highOrder: (a: Int, b: Int, c: Int, fun: (Int, Int) => Int)Int
```

```scala
def addInt(a:Int, b:Int) = a + b
addInt: (a: Int, b: Int)Int
```

```scala
val result = highOrder(2, 5, 7, addInt)
result: Int = 19
```

Information from *Becoming Functional* by Joshua Backfield
*Scala Cookbook* by Alvin Alexander
Anonymous Functions

- It seems silly to define a function like `addInt` if we only pass it to high order functions.
- What we would like is to define the function we want inside the function call.
- We can do this with anonymous functions!
- Anonymous functions are sometimes called lambda functions, closures, or function literals.
- There is a subtle difference between lambda functions and closures.

```scala
def highOrder(a: Int, b: Int, c: Int, fun: (Int, Int) => Int) = {
  val tmp1 = fun(a, b)
  val tmp2 = fun(b, c)
  fun(tmp1, tmp2)
}
val result = highOrder(2, 5, 7, (a, b) => a + b)
result: Int = 19
```

Types are not needed since the inference engine infers the types of `a` and `b` from `highOrder`.

Information from *Becoming Functional* by Joshua Backfield
*Scala Cookbook* by Alvin Alexander
Anonymous Functions

- There is even more syntactic sugar for anonymous functions!
- Underscores can be used “as positionally matched arguments”

```scala
def highOrder(a: Int, b: Int, c: Int, fun: (Int, Int) => Int) = {
  val tmp1 = fun(a, b)
  val tmp2 = fun(b, c)
  fun(tmp1, tmp2)
}

val result = highOrder(2, 5, 7, _+_)
result: Int = 19
```

The Underscore

• The underscore `_` is the wildcard character in Scala

• It is used in several contexts
  – Import statements to import all sub packages
  – In match statements to act as a placeholder
  – In assigning a function to a `val`
  – Anonymous functions to act as a placeholder
Useful High Order Functions

These functions take a Sequence or List and perform some operation

• Map
  – Applies a function to each element in a list and returns the resulting transform in a list

• Filter
  – Generates a new list with elements of the original list that fit some filter condition

• foldLeft, foldRight
  – A reduce operation where a list is traversed either from the left or from the right. In each step, a function is preformed on the list element and the result of the last fold operation, returning a single value.
  – Results in a single value at the end of evaluation

Information from *Programming Scala, 2nd Edition* by Dean Wampler and Alex Payne
zip, zipWithIndex and unzip

- Sometimes, you want to pair up values in two lists. You can do this with zip
  
  ```scala
  val list1 = Seq(1, 2, 3, 4)
  val list2 = Seq(5, 6, 7, 8)
  val zipped = list1 zip list2
  zipped: Seq[(Int, Int)] = List((1,5), (2,6), (3,7), (4,8))
  ```

- Unzip splits a list of tuples into a tuple of lists
  
  ```scala
  val unzipped = zipped.unzip
  unzipped: (Seq[Int], Seq[Int]) = (List(1, 2, 3, 4), List(5, 6, 7, 8))
  ```

- zipWithIndex zips each value with its index in the list
  
  ```scala
  scala> val list1WInd = list1.zipWithIndex
  list1WInd: Seq[(Int, Int)] = List((1,0), (2,1), (3,2), (4,3))
  ```

Information from *Scala Cookbook* by Alvin Alexander
Why val and not var?

• Like scala, chisel prefers using vals when possible

• Given that chisel is constructing a circuit, chisel constructs often represent physical things like nets, registers, ...

• It can be easier to reason about the circuit when constructs are assigned a unique, constant name (within a scope).
What is going on with :=?

• Since we like to use vals when declaring chisel constructs, how do we make circuit assignments?
• Scala won’t let you use =
• := is a special operator defined by chisel to represent circuit connections (similar to assignment in Verilog)
  – It defines which chisel constructs should be connected and in which cases
  – The when block will put in multiplexers as appropriate
• Data about connections is used by chisel to build a graph representation of the circuit
Scala vs. Chisel Types

• Scala and Chisel have different types
• This is because chisel needs information that Scala does not
  – Bit width information
• Unfortunately, the type inference system that Scala uses does not work as well with Chisel types.
  – Type promotion is not necessarily automatic (an artifact of Chisel’s implementation
• You may need to cast between Scala and Chisel types
• You may need to cast between Chisel types

val a = UInt(1, width=8)
a.toBits  //converts to bits
val b = 5
val c = Uint(b, width = 8)  //cast from Int to UInt
  //(actually construct obj)
Errors and Chisel

• Because Chisel is built on Scala and Scala is Built on Java, you can get 3 kinds of error messages
  – Scala compiler errors: Type mismatches, syntax, ...
  – Chisel checks: Illegal chisel but legal scala
  – Java Stack Trace: Underlying implementation crashed
Exercise in Debugging

• Problem: Types
  – Chisel Type
  – “Compile Time” Error
• Solution
  – Explicitly Cast to Chisel Type

```
val index = Reg(init = UInt(0, width = log2Up(n)))
val memVal = UInt(width = w)
val done = !io.en && (memVal == io.data) || (index == UInt(n-1))
// ...
when (io.en) {
  index := UInt(0)
} .elseif (done == Bool(false)) {
  index := index + 1
}
```
Decoupled

- The Decoupled interface is a ready/valid interface
- The producer drives the *bits* (data) and *valid* lines
- The receiver drives the *ready* line
- The producer raises the *valid* line when data is on the *bits* line
- The receiver raises the *ready* line when they are ready to receive data
- If *ready* and *valid* are both high, a *transaction* occurred (sometime called *fire*)
  - The receiver has to read in bits during the cycle that both ready and valid are high
  - The producer is allowed to put a new value on the bits line in the next cycle
  - If valid is still high in the next cycle, it is assumed that there is a new value

```scala
class DecoupledIO[+T <: Data](gen: T) extends Bundle{
  val ready = Bool(INPUT)
  val valid = Bool(OUTPUT)
  val bits = gen.cloneType.asOutput
  //...
}
```

Diagram:
- **Producer**
  - Ready
  - Valid
- **Consumer**
  - Bits
How do I find out about Chisel’s Implementation

- Github provides good search capability
- Search for “class Bits” or “object Bits” for example
- Access at https://github.com/ucb-bar/chisel/
- You also have a copy of the chisel repo for lab1