

# Comp 311

# Functional Programming

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# Announcements

- Homework 5:
  - Assigned today! (PDF description on Piazza)
  - This homework is unchanged from last year
  - Due the last day of class
  - You can use all of your remaining slip days on this
- Homework 6:
  - Optional (can replace a bad score on previous homework)
  - Due with Homework 5, or 12/8 (whichever is later)
- The final is December 8<sup>th</sup> in Duncan Hall 1064 at 2pm

# Some Additional Scala Features

# Scripting in Scala

- Scala is designed for building large-scale systems
- It also scales down to small scripts:
  - In a single file, we can place class definitions, function definitions, and even top-level expressions

# Scripting in Scala

- In a single file `hello.scala`, write:

```
println("Hello, scripting world!")
```

- From the command-line (in an environment where `scala` has been installed):

```
scala hello.scala
```

# Scripting in Scala

- Command-line arguments are available via a global array named `args`:

```
println("Hello, " + args(0) + "!")
```

# Scripting in Scala

- At the shell:

```
scala hello.scala Owls
```

- And the result is:

```
Hello, Owls!
```

# Scripting in Scala

- On Unix, you can run a Scala script directly from the shell by putting a *shebang* at the top of your script:

```
#!/usr/bin/env scala
```

```
println("hello")
```

- Then make the file executable (let's name the file `hello`):

```
chmod u+x hello
```



# Scala Applications

## The “Java” Way

- To compile a stand-alone Scala application, you can put the driver into a singleton object with a `main` method

# Scala Applications

- Any singleton object might contain a main method that takes an argument of type `Array[String]`:

```
package edu.rice.cs.comp311.lectures.lecture22
```

```
object ArgLengths {  
  def main(args: Array[String]): Unit = {  
    for (arg <- args)  
      println(arg + ": " + arg.length)  
  }  
}
```

# Scala Applications

## The “Scala” Way

- To compile a stand-alone Scala application, you can put the driver into a singleton object with the `App` trait
- All code in the body of the object (i.e., the “constructor” code) is run when the app is launched

# Scala Applications

- Any singleton object might contain a main method that takes an argument of type `Array[String]`:

```
package edu.rice.cs.comp311.lectures.lecture22
```

```
object ArgLengths extends App {  
  for (arg <- args) {  
    println(arg + ": " + arg.length)  
  }  
}
```

For loops (no *yeild* keyword) are only for side-effects.  
Just syntactic sugar for the *foreach* method.

# Scala Applications

- Any singleton object might contain a main method that takes an argument of type `Array[String]`:

```
package edu.rice.cs.comp311.lectures.lecture22
```

```
object ArgLengths extends App {  
  args foreach { arg =>  
    println(arg + ": " + arg.length)  
  }  
}
```

# Scala Applications

- Compile using `scalac` or `fsc`
  - `scalac` will recompile all referenced jars, files,...
  - Therefore, it can be slow
- `fsc` starts a process the first time it is run that memoizes compilation of referenced files

# Scala Applications

- Execute a compiled classfile using the `scala` command
- Include the full path name

```
scala edu.rice.cs.comp311.lectures.lecture22.ArgLengths
```

# Fields in Non-Case Classes

- constructor of a class is a function:
  - When it is called, the enclosing environment is extended and an object is returned, as defined by the body of the class



# Fields in Non-Case Classes

- A natural consequence:
  - The arguments to a constructor call are not directly accessible outside the object that is returned from the call
- To make a parameter accessible, define a field
- Case classes automatically define a field for every constructor parameter

# The Follow Code Will Not Pass Type Checking

```
class Rational(numerator: Int, denominator: Int) {  
  def +(that: Rational) =  
    new Rational(numerator * that.denominator +  
                 that.numerator * denominator,  
                 denominator * that.denominator)  
}
```

# Declaring the Fields Explicitly Fixes The Problem

```
class Rational(n: Int, d: Int) {  
  val numerator = n  
  val denominator = d  
  
  def +(that: Rational) =  
    new Rational(numerator * that.denominator +  
                 that.numerator * denominator,  
                 denominator * that.denominator)  
}
```

# Auxiliary Constructors

- Scala allows for multiple constructor declarations
- Additional constructors are defined as methods with name `this`
- The first action of an auxiliary constructor must be to invoke another constructor
- Only constructors defined earlier in the class definition are in scope

# Auxiliary Constructors

```
class Rational(n: Int, d: Int) {  
  val numerator = n  
  val denominator = d  
  
  def this(n: Int) = this(n, 1)  
  
  def +(that: Rational) =  
    new Rational(numerator * that.denominator +  
                 that.numerator * denominator,  
                 denominator * that.denominator)  
}
```



# Companion Objects

- A class can be given a *companion object*:
  - A singleton object definition with the same name
  - Must be defined in the same file as the class
  - The object and class share private members

# Companion Objects and Factory Methods

- Companion objects are well-suited for defining factory methods:

```
object Rational {  
  def apply(n: Int, d: Int) =  
    if (d != 0) new Rational(n, d)  
    else throw new Error("Given a zero denominator")  
}
```



# Private Primary Constructors

- Primary constructors can be hidden by prefixing them with the keyword `private`:

```
class Rational private(n: Int, d: Int) {  
  val numerator = n  
  val denominator = d  
  
  def this(n: Int) = this(n, 1)  
  
  def +(that: Rational) =  
    new Rational(numerator * that.denominator +  
                 that.numerator * denominator,  
                 denominator * that.denominator)  
}
```

# Private Constructors and Companion Objects

```
> Rational(1,1)           // ok
> Rational(1,0)           // error
> new Rational(1,2)       // error
> new Rational(2)         // ok
```

# Extractors

# Extractors

- It is possible to control how an object will interact with pattern matching through the use of *extractors*
- Extractors are objects that define an `unapply` method, which takes an object and returns an option of one or more elements

# Extractors

```
object Rational {  
  def apply(n: Int, d: Int) = {  
    if (d != 0) new Rational(n, d)  
    else throw new Error("Given a zero denominator")  
  }  
  
  def unapply(q: Rational): Option[(Int, Int)] = {  
    Some((q.numerator, q.denominator))  
  }  
}
```

# Extractors

- An unapply method is called in a pattern by prefixing the name of the extractor object followed by a tuple of expected elements
- If the unapply method returns `Some((x1,...xN))` and the arity of the tuple `(x1,...xN)` matches the number of bound variables in the pattern, we have a match

# Extractors

```
class Rational private(n: Int, d: Int) {  
  val numerator = n  
  val denominator = d  
  
  def +(that: Rational) = {  
    that match {  
      case Rational(n2, d2) =>  
        Rational(n * d2 + n2 * d,  
                d * d2)  
    }  
  }  
}
```

# Case Classes Revisited

- We are now in a position to better explain what a case class definition is given implicitly:
  - Immutable fields for every parameter
  - Structural `equals` and `hashCode` methods
  - A structural `toString` method
  - A companion object with `apply` and `unapply` methods
  - A `copy` method with parameters for each constructor parameter, defaulted to the field values of the receiver



# Extractors vs Case Classes

- Explicit extractors are more verbose than using case classes
- However, they have advantages of their own:
  - separates implementation from pattern matching
  - can deconstruct objects outside of their class definitions
  - can perform more sophisticated deconstruction
    - e.g. regular expression matching on strings

# Extractors vs Case Classes

- Case classes also have many advantages:
  - Conciseness
  - Performance: Scala compiler optimizes patterns with case classes aggressively

# Combinator Parsing

# Combinator Parsing

- Sometimes there are situations in which we need to process expressions in a small ad-hoc language
  - Configuration files for your program
  - An input language to your program such as search queries

# Combinator Parsing

- Options:
  - Roll your parser
    - Requires significant expertise and time
  - Use a parser generator (ANTLR)
    - Many advantages but also requires learning and wiring up a new tool into your program

# Combinator Parsing

- Another option:
  - Define an *internal domain-specific language*
  - Consists of a library of *parser combinators*:
    - Scala functions and operators that serve as the building blocks for parsers

# Combinator Parsing

- Each combinator corresponds to one *production* of a context-free grammar

# Arithmetic Expressions

`expr ::= term {"+" term | "-" term}.`  
`term ::= factor {"*" factor | "/" factor}.`  
`factor ::= floatingPointNumber | "(" expr ")".`



# Arithmetic Expressions

expr ::= term { "+" term | "-" term } .  
term ::= factor { "\*" factor | "/" factor } .  
factor ::= floatingPointNumber | "(" expr ")" .

*Denotes definition of a production*

# Arithmetic Expressions

`expr ::= term {"+" term | "-" term}.`  
`term ::= factor {"*" factor | "/" factor}.`  
`factor ::= floatingPointNumber | "(" expr ")"`.

*Denotes alternatives*



# Arithmetic Expressions

expr ::= term {"+" term | "-" term}.  
term ::= factor {"\*" factor | "/" factor}.  
factor ::= floatingPointNumber | "(" expr ")".

*Denotes zero or more repetitions*

# Arithmetic Expressions

expr ::= term {"+" term | "-" term}.  
term ::= factor {"\*" factor | "/" factor}.  
factor ::= floatingPointNumber | "(" expr ")".

*Square brackets [ ] denote optional occurrences (not used here).*

# Example Arithmetic Expression

$$2 * 3 + 4 * 5 - 6$$

# A Formal Grammar for Arithmetic Expressions in BNF

```
expr ::= term {"+" term | "-" term}.  
term ::= factor {"*" factor | "/" factor}.  
factor ::= floatingPointNumber | "(" expr ")".
```

*Denotes one or more repetitions*

# Example Arithmetic Expression

2 \* 3 + 4 \* 5 - 6

*factors*

A diagram illustrating the concept of factors in an arithmetic expression. The expression "2 \* 3 + 4 \* 5 - 6" is shown in black text. Below it, the word "factors" is written in a red, italicized font. Five red arrows originate from the word "factors" and point upwards to the numbers 2, 3, 4, 5, and 6 in the expression, highlighting them as the factors of the multiplication operations.

# Arithmetic Expressions

expr ::= term { "+" term | "-" term } .  
term ::= factor { "\*" factor | "/" factor } .  
factor ::= floatingPointNumber | "(" expr ")" .

*Denotes one or more repetitions*



# Example Arithmetic Expression

$$2 * 3 + 4 * 5 - 6$$
The diagram shows the arithmetic expression  $2 * 3 + 4 * 5 - 6$ . Three red boxes are drawn around the terms: the first box contains  $2 * 3$ , the second box contains  $4 * 5$ , and the third box contains  $6$ . Three red arrows originate from a single point below the word 'terms' and point upwards to the bottom center of each of the three boxes.

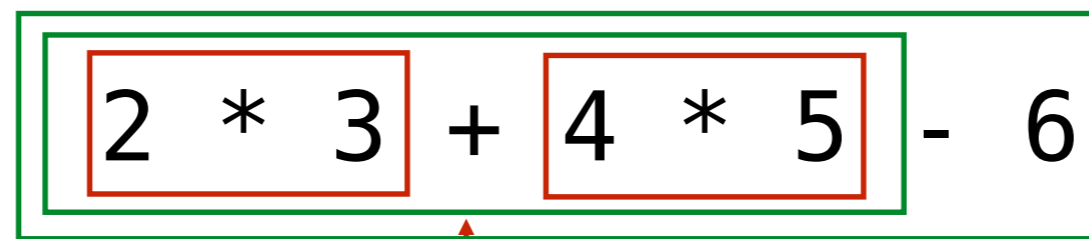
*terms*

# Arithmetic Expressions

expr ::= term { "+" term | "-" term } .  
term ::= factor { "\*" factor | "/" factor } .  
factor ::= floatingPointNumber | "(" expr ")" .

*Denotes one or more repetitions*

# Example Arithmetic Expression



*expressions*

# This Grammar Encodes Operator Precedence

- Expressions contain terms
- Terms contain factors
- Factors only contain expressions if they are enclosed in parentheses

# Encoding a Grammar Using Scala Parser Combinators

```
import scala.util.parsing.combinator._

class Arith extends JavaTokenParsers {
  def expr: Parser[Any] = term~rep("+~term | "-~term)
  def term: Parser[Any] = factor~rep("*~factor | "/"~factor)
  def factor: Parser[Any] = floatingPointNumber | "("~expr~")"
}
```

# Encoding a Grammar Using Scala Parser Combinators

```
import scala.util.parsing.combinator._  
  
class Arith extends JavaTokenParsers {  
  def expr: Parser[Any] = term~rep("+~term | "-~term)  
  def term: Parser[Any] = factor~rep("*~factor | "/"~factor)  
  def factor: Parser[Any] = floatingPointNumber | "("~expr~")"  
}
```



*A parser for floating point numbers inherited from  
JavaTokenParsers.*

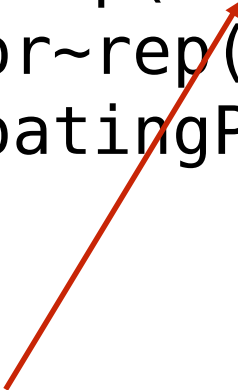
# Encoding a Grammar Using Scala Parser Combinators

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  def factor: Parser[Any] = floatingPointNumber | "("~expr~")"  
}
```

*A combinator that takes two parsers and returns a new parser that first applies the left parser to its input, then its right to whatever remains.*

# Encoding a Grammar Using Scala Parser Combinators

```
import scala.util.parsing.combinator._  
  
class Arith extends JavaTokenParsers {  
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  def term: Parser[Any] = factor~rep("*~factor | "/"~factor)  
  def factor: Parser[Any] = floatingPointNumber | "("~expr~")"  
}
```

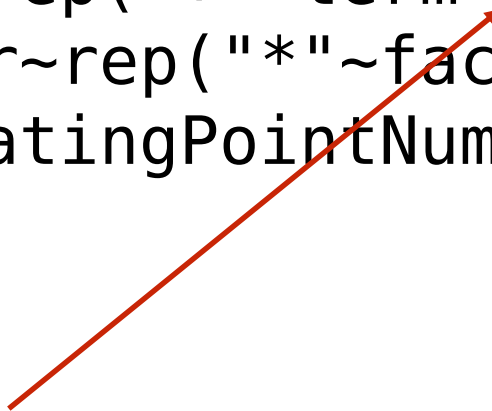


*This combinator is overloaded so that string arguments  
are converted to simple parsers that match the string.*



# Encoding a Grammar Using Scala Parser Combinators


```
import scala.util.parsing.combinator._  
  
class Arith extends JavaTokenParsers {  
  def expr: Parser[Any] = term~rep("+~term | "-~term)  
  def term: Parser[Any] = factor~rep("*~factor | "/"~factor)  
  def factor: Parser[Any] = floatingPointNumber | "("~expr~")"  
}
```



*A combinator that takes two parsers and returns a new parser that first applies the left parser to its input, and returns the result, unless the left parser fails (then it applies the right parser).*

# Encoding a Grammar Using Scala Parser Combinators

```
import scala.util.parsing.combinator._  
  
class Arith extends JavaTokenParsers {  
  def expr: Parser[Any] = term~rep("+~term | "-~term)  
  def term: Parser[Any] = factor~rep("*~factor | "/"~factor)  
  def factor: Parser[Any] = floatingPointNumber | "("~expr~")"  
}
```



*A combinator that takes a parser and repeatedly applies it to the input as many times as possible.*

# To Convert a Grammar to a Definition with Parser Combinators

- Every production becomes a method
- The result of each method is `Parser[Any]`
- Insert the explicit operator `~` between two consecutive symbols of a production
- Represent repetition with calls to the function `rep` instead of `{ }`
- Represent repetitions with a separator with calls to the function `repsep`
- Represent optional occurrences with `opt` instead of `[ ]`

# Exercising Our Parser

```
object ParseExpr extends Arith {  
  def main(args: Array[String]) = {  
    println("input: " + args(0))  
    println(parseAll(expr, args(0)))  
  }  
}
```

# An Example Parse of Grammatical Input

```
scala edu.rice.cs.comp311.lectures.lecture22.ParseExpr 2*3+4*5-6
```

```
input: 2*3+4*5-6
```

```
[1.10] parsed: ((2~List((*~3)))~List((+~(4~List((*~5))))), (-~(6~List()))))
```

# An Example Parse of Ungrammatical Input

```
scala edu.rice.cs.comp311.lectures.lecture22.ParseExpr 2*3+4*5-6)  
-bash: syntax error near unexpected token `)'
```

# What is Returned from a Parser

- Parsers built from strings return the string (if it matches)
- `~` combinator returns both results
  - as elements of a case class named `~`
  - (with a `toString` that places the `~` infix)
- `|` combinator returns the result of whichever succeeds
- `rep` operator returns a list of its results
- `opt` operator returns an `Option` of its result

# Transforming the Output of a Parser

- The  $\wedge\wedge$  combinator transforms the result of a parser:
  - Let  $P$  be a parser that returns a result of type  $R$
  - Let  $f$  be a function that takes an argument of type  $R$

$P \wedge \wedge f$

- Returns a parser that applies  $P$ , takes the result and applies  $f$  to it



# Transforming the Output of a Parser

```
floatingPointNumber ^^ (_.toDouble)
```

# Transforming the Output of a Parser

`"true" ^^ (x => true)`

# Parsing JSON

- Many processes need to exchange complex data with other processes (often over a network)
- We need a portable way to represent the structure of data so that processes can conveniently send data amongst themselves
- One popular alternative is JSON
  - the Javascript Object Notation

# Parsing JSON

- A JSON object is a sequence of members separated by commas and enclosed in braces
- Each member is a string/value pair, separated by a colon
- A JSON array is a sequence of values separated by commas and enclosed in square brackets

# JSON Example

```
{
  "address book" : {
    "name" : "Eva Luate",
    "address" : {
      "street" : "6100 Main St"
      "city" : "Houston TX",
      "zip" : 77005
    },
    "phone numbers": [
      "555 555-5555",
      "555 555-6666"
    ]
  }
}
```

# A Simple JSON Parser

```
class JSON extends JavaTokenParsers {  
  def value: Parser[Any] = {  
    obj | arr | stringLiteral |  
      floatingPointNumber | "null" | "true" | "false"  
  }  
  def obj: Parser[Any] = "{"~repsep(member, ",")~"}"  
  def arr: Parser[Any] = "["~repsep(value, ",")~"]"  
  def member: Parser[Any] = stringLiteral~":"~value  
}
```

# Mapping JSON to Scala

- We would like to parse JSON objects into Scala objects as follows:
  - A JSON object is represented as a `Map[String, Any]`
  - A JSON array is represented as a `List[Any]`
  - A JSON string is represented as a `String`
  - A JSON numeric literal is represented as a `Double`
  - The values `true`, `false`, `null` are represented as corresponding Scala values