Parser Combinators

Chapter 9 of Pilquist/Chiusano/Bjarnason

What do we learn from Chapter 9?

- How to **use** a parser combinator library?
- Specify a simple language (JSON) **using** a grammar and regexes
- **Design** an internal DSL for expressing grammars in Scala
- Implement a Program Expression Grammar
- Separating **design** from implementations

The yellow skills are more advanced,
but the blue ones are more often used.

Key Concepts in Chapter 9

- Algebraic design, algebra (type, operators, and laws)
- Full abstraction of a type
- Type constructor
- Higher-kind, higher-kinded polymorphism
- Structure-preserving map (the structure preservation law)
- Internal DSL

All of these are well hidden in the chapter (some not named explicitly), so make sure you identify them after class.

Input data in JSON format

(this is an example in concrete syntax of JSON; basically a character string)

```
{
  "Company name" : "Microsoft",
  "Ticker" : "MSFT",

  "Active" : true,
  "Price"  : 30.66,
  "Shares outstanding" : 8.38e9,
  "Related companies" :
    [ "HPQ", "IBM", "YHOO", "DELL", "GOOG", ],
}
```

The Example in JSON's Abstract Syntax

(no longer a string, but a structured Scala object)

```scala
val json = JObject(Map(
  "Shares outstanding" -> JNumber(8.38E9),
  "Price" -> JNumber(30.66),
  "Company name" -> JString("Microsoft"),
  "Related companies" -> JArray(
     Vector(JString("HPQ"), JString("IBM"),
            JString("YHOO"), JString("DELL"),
            JString("GOOG"))),
  "Ticker" -> JString("MSFT"),
  "Active" -> JBool(true)))
```

Abstract Syntax for JSON

(the types of what we want to obtain from the input, using a parser)

```
enum JSON
  case JNull
  case JNumber(get: Double)
  case JString(get: String)
  case JBool(get: Boolean)
  case JArray(get: IndexedSeq[JSON])
  case JObject(get: Map[String, JSON])
```

Menti!

Agenda

1. Running Example: parsing JSON
2. Design patterns, concepts, and principles
3. Parsing JSON (review of the combinators)
4. Implementing a concrete parser
5. Parsing libraries in programming languages

Algebraic Design

- **Algebraic design**: *design your interface first, along with associated laws. Use the types and laws to refactor and evolve the interface*.
- We are using types heavily, **designing the API with types**, compiling and trying expressions.
- Since **laws are properties**, they are **tests** (property tests). This is a form of test-driven development (TDD), or test-first development.

Algebraic Design, Full Abstraction, Higher Kinds

(the API/Interface first; separation of design & Implementation)

These types are **abstracted fully**;
We work without deciding how
they are implemented.
We only typecheck & compile!

```
trait Parsers[ParseError, Parser[+_]]:
  def char(c: Char): Parser[Char]
  def string(c: String): Parser[String]

  extension [A](p: Parser[A])
    def run(input: String): Either[ParseError,A]
    def or(p2: Parser[A]): Parser[A]
    ...
```

This is a higher kind (a type that is polymorphic in type constructors not in types!)

This is a type (variable)

This is a type constructor (variable).
This particular variable must be instantiated with a covariant type constructor.

Menti x 3!

Algebraic Design

(laws, aka tests)

```
forAll { (c: Char) => char(c).run(c.toString) == Right(c) }

forAll { (s: String) => string(s).run(s) == Right(s) }

forAll { (s1: String, s2: String) =>
  val p = string(s1).or(string(s2))
  p.run(s1) == Right(s1) && p.run(s2) == Right(s2)
}

...
```

You can make such tests compile, before you have the implementation of parsers!

Map is structure preserving

Consider two new combinators:

```
extension [A](p: Parser[A])
  def many: Parser[List[A]]              // Kleene-star
  def map[B](f: A => B): Parser[B]
```

Example:

`char('a').many.map { _.size }` ← What does this parser produce (menti) ?

Law:

```
p.map(a => a) == p // for any parser p
```

This means that map is structure preserving

(it only changes values produced, so with identity there is no change at all).

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Parsing Combinators: TOKENS for JSON

(We build a parser combinator language in which we can specify the translation)

```
val QUOTED: Parser[String] =
  regex(""""([^"]*)"""".r)
    .map { _.dropRight(1).substring(1) }

val DOUBLE: Parser[Double] =
  regex("""(\+|-)?[0-9]+(\.[0-9]+((e|E)(-|\+)?[0-9]+)?)?""".r)
    .map { _.toDouble }

val ws: Parser[Unit] =
  regex("""\s+""".r).map { _ => () }
```

Parsing JSON start symbol

```
lazy val json : Parser[JSON] =
  ws.? |* { jstring | jobject | jarray |
   jnull | jnumber | jbool }
```

- **|** is choice, delegates to ‘or’
- **?** means optional, also known as ‘opt’
- ***|** is sequencing & drop the right side when building AST
  (’ x *| y ’ is a syntactic sugar for ’ (x ** y).map { _._1 } ’
  (’ x |* y ’ is a syntactic sugar for ’ (x ** y).map { _._2 } ’
- Laziness allows recursive rules (like in EBNF)

Turn terminals into AST leaves

```
val jnull: Parser[JSON] =
  string("null") |* ws.? |* succeed(JNull)

val jbool: Parser[JBool] =
  (string("true") |* ws.? |* succeed(JBool(true ))) |
  (string("false")|* ws.? |* succeed(JBool(false)))

val jstring: Parser[JString] =
  { QUOTED *| ws.? }.map { JString(_) }

val jnumber: Parser[JNumber] =
  { DOUBLE *| ws.? }.map { JNumber(_) }
```

Parse complex values

[simplified to fit on a slide]

```
lazy val jarray: Parser[JArray] =
  { char('[') |* ws.?
    |* (json *| char(',') |* ws.? ).*
    *| "]" *| ws.? }.map { l => JArray(l.toVector) }

lazy val field: Parser[(String, JSON)] =
  QUOTED *| ws.? *| char(':') *| ws.? ** json *| char(',') *| ws.?

lazy val jobject: Parser[JObject] =
  { char('{') |* ws.? |* field.* *| char('}') *| ws.? }
    .map { l => JObject(l.toMap) }
```

Parser Combinators

(AKA PEGs = Program Expression Grammars)

- Good for ad hoc jobs, parsing when regexes does not suffice
- Very lightweight as a dependency, no change to build process
- More expressive than generator-based tools (Turing complete)
- In standard libraries of many modern languages
- Error reporting weaker during parsing (but fpinscala does a good job)
- Usually slower than generated parsers (and use more memory), unless implemented at compile time (but parboiled2!)
- Typically no support for debugging grammars

Internal Domain Specific Languages

(Parser Combinators are one example)

- Parser Combinators are a language (loosely similar to EBNF)
- Slogan: internal DSL is syntactic sugar of host language
- No external tools, pure Scala (or another host), no magic involved

Let's analyze an expression

```
QUOTED *| char(':') ** json *| char(',')  // parser producing a field
```

earlier:

```
QUOTED : Parser[String]                   // parser producing a String
```

but

```
extension (p: Parser[A]) def *|(p2: Parser[Any]): Parser[A]
```

so

```
ext1(p=QUOTED).*| (char(':')): Parser[String]
```

and also we have (an alias for `product`)

```
extension (p: Parser[A]) def **[B](p2: Parser[B]): Parser[(A, B)]
```

so

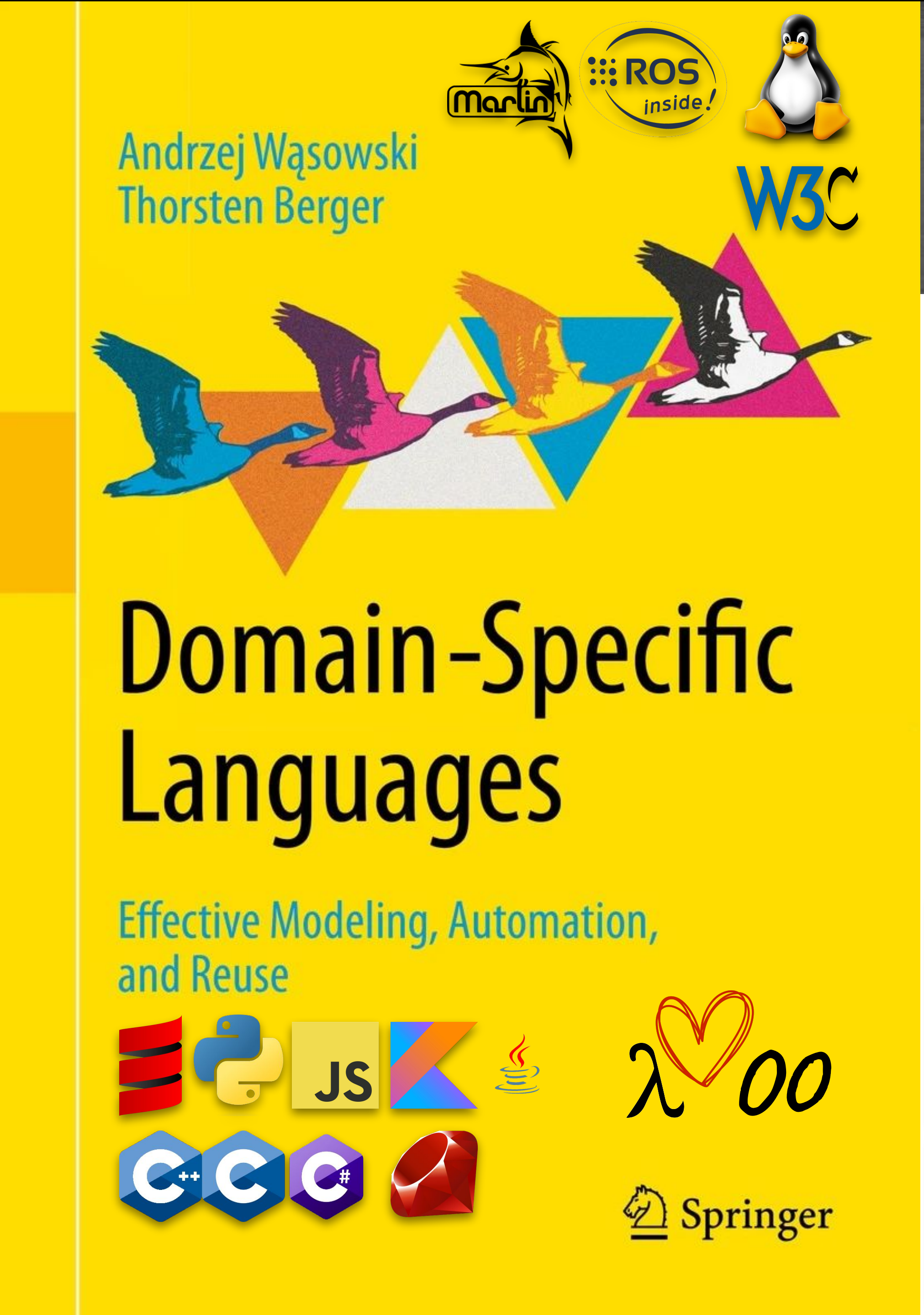
```
ext2(p=ext1(p=QUOTED).*|char(':')).product(json): Parser[(String,JSON)]
```

and the extension with *| already used above gives:

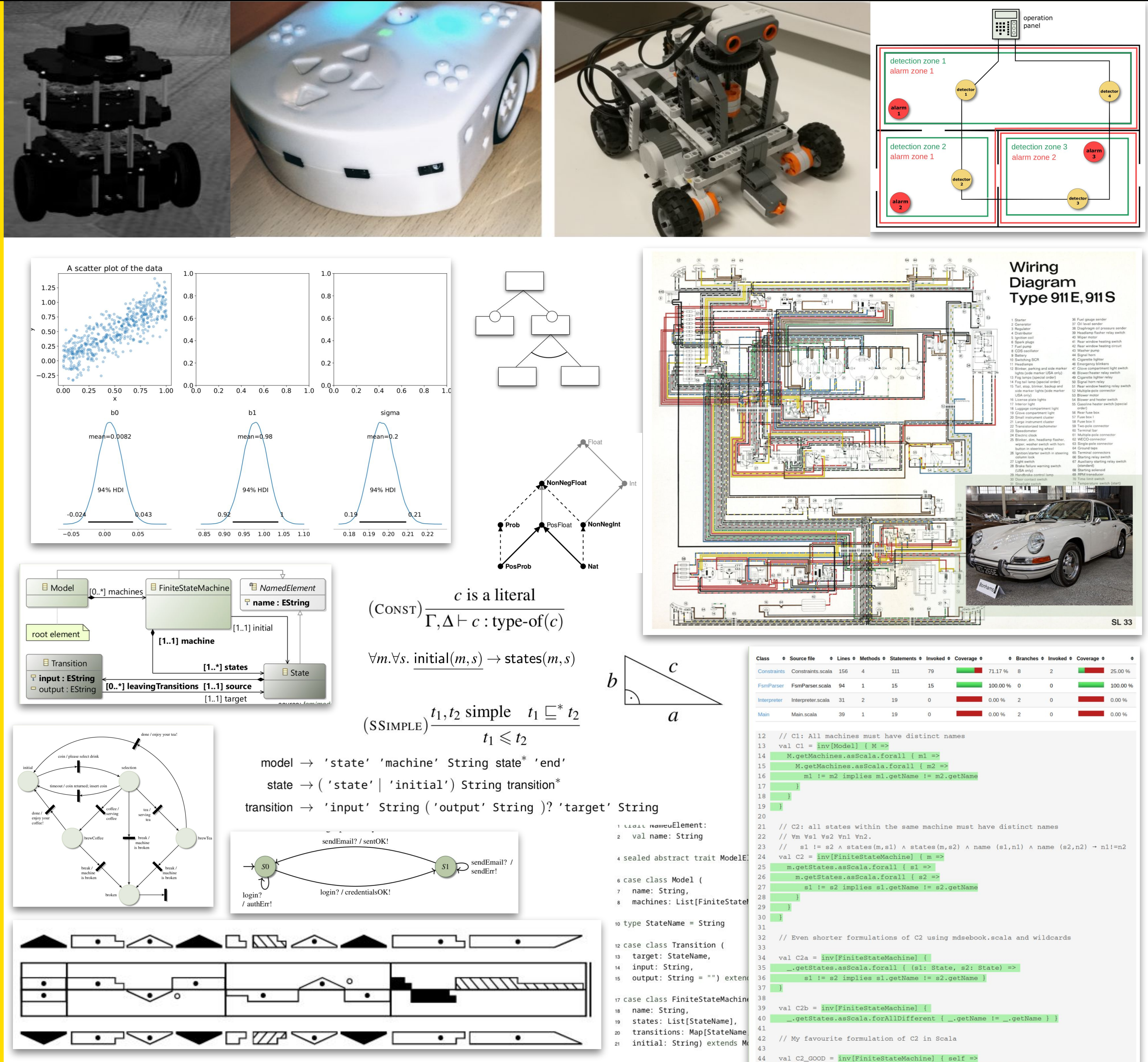
```
ext1(p=ext2(p=ext1(p=QUOTED).*|char(':')).product(json)).*|(char('.'))
  : Parser[(String,JSON)]
```

What did we use to build this DSL

- Polymorphic types (that check syntax of our programs), for instance:
  `extension [A] (p: Parser[A]) *| : Parser[B] => Parser[A]`
- Function values: `type Parser[+A] = ParseState => Result[A]`
- We could've used automatic conversions (from string, char, regex)
- Calls to unary methods without period (infix ops are methods of ParserOps)
- `string(":") ** json` is really `string(":").**(json)`
  (which delegates to the right extension)
- Math symbols as names, eg: ?,|,*|,*|,*, etc
  (btw. Scala allows unicode identifiers, used in scalaz/cats internal DSLs)
- No parentheses on nullary methods
  `ws.?` translates to `ws.?()` (which delegates to `ws.opt`)
- Used Scala's parentheses, braces, etc as elements of our DSL



Andrzej Wąsowski
Thorsten Berger
Domain-Specific Languages
Effective Modeling, Automation, and Reuse
Springer



operation panel
detection zone 1
alarm zone 1
detection zone 2
alarm zone 1
detection zone 3
alarm zone 2
A scatter plot of the data
b0
b1
sigma
mean=0.0082
mean=0.98
mean=0.2
94% HDI
Wiring Diagram Type 911 E, 911 S
SL 33
Float
NonNegFloat
Int
Prob
PosFloat
NonNegInt
PosProb
Nat
Model
[0..*] machines
FiniteStateMachine
NamedElement
name : EString
root element
[1..1] initial
[1..1] machine
Transition
input : EString
output : EString
[1..*] states
State
[0..*] leavingTransitions
[1..1] source
[1..1] target
(Const) c is a literal / Γ,Δ ⊢ c : type-of(c)
∀m.∀s. initial(m,s) → states(m,s)
(SSimple) t1, t2 simple   t1 ⊑* t2 / t1 ⩽ t2
model → 'state' 'machine' String state* 'end'
state → ('state' | 'initial') String transition*
transition → 'input' String ('output' String)? 'target' String
sendEmail? / sentOK!
sendEmail? / sendErr!
login? / authErr!
login? / credentialsOK!
val name: String
sealed abstract trait ModelE
case class Model (
name: String,
type StateName = String
case class Transition (
target: StateName,
input: String,
case class FiniteStateMachin
name: String,
states: List[StateName],
// C1: All machines must have distinct names
// C2: all states within the same machine must have distinct names
// Even shorter formulations of C2 using mdsebook.scala and wildcards
// My favourite formulation of C2 in Scala

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Running the parser

- We need to implement a Parsers.run method

```
extension [A] (p: Parser[A])
  def run(input: String): Either[ParseError, A]
```

- Then we call a parser as follows

```
(string("abra") | string("cadabra")).run("abra")
```

```
(string("abra") | string("cada")).run("abra") == Right ("abra")
(string("abra") | string("cada")).run("Xbra") == Left
(ParseError(...))
```

Implementing a simple **run**

```scala
type Parser[+A] = Location => Result[A]

extension [A](p: Parser[A])
  def run (input: String): Either[ParseError, A] =
    p (Location(input, 0)) match
      case Success(a, n) => Right(a)
      case Failure(err, _) =>  Left(err)
```

Implementing a concrete parser

(simplified slightly for presentation, exercises use a more advanced represenation)

```
def string(s: String): Parser[String] = loc =>
  if loc.curr.startsWith(s) then
    Success(s, s.size)
  else
    val seen = loc.curr
          .substring (0, min(loc.curr.size, s.size))
    Failure(s"expected '$s' but seen '$seen'")
```

Implementing an operator/combinator

(slightly simplified for presentation, flatMap strikes back)

```
extension [A](p: Parser[A])
  def flatMap[B](f: A => Parser[B]): Parser[B] = loc =>
    p(loc) match
      case Success(a, n) => f(a)(loc.advanceBy(n))
      case e @ Failure(_, _) => e
```

Implementing an operator/combinator

(slightly simplified for presentation, a more complex variant used in the exercises)

```
extension [A](p: Parser[A])
  def or(p2: => Parser[A]): Parser[A] =
    loc => p(loc) match
      case Failure(_) => p2(loc)
      case r => r
```

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Parsing Libraries

Java	
Parser Generators	ANTLR, JavaCC, Rats!, APG, …
Parser Combinators	Parboiled, PetitParser
Scala	
Parser Generators	? (parboiled2)
Parser Combinators	Scala parser combinators (previously Scalalib), parboiled2 (technically also a generator), fastparse
JavaScript	
Parser Generators	ANTLR, Jison
Parser Combinators	Bennu, Parjs, and Parsimmon
C#	
Parser Generators	ANTLR, APG
Parser Combinators	Pidgin, superpower, parseq
C++	
Parser Generators	ANTLR, APG, boost meta-parse (?) , boost spirit (?)
Parser Combinators	Cpp-peglib, pcomb, boost meta-parse, boost spirit, Parser-Combinators

Conclusion

(what you need to get from this week)

- Algebraic design, algebra (type, operators, and laws)
- Full abstraction of a type
- Type constructor
- Higher-kind, higher-kinded polymorphism
- Structure-preserving map (the structure preservation law)
- Internal DSL, fluent interface
- … and parser combinators ☺