Parser Combinators

Before we continue ...

A Word from the Sponsor!

Don't Fear Monads

They are just a versatile abstraction, like `map` or `fold`.

```
class Monad m where
  return :: a -> m a
  (>>=)  :: m a -> (a -> m b) -> m b
```

Parsers

A *parser* is a function that

- converts *unstructured* data (e.g. `String`, array of `Byte`,...)
- into *structured* data (e.g. JSON object, Markdown, Video...)

```
type Parser = String -> StructuredObject
```

Every large software system contains a Parser

System	Parses
Shell Scripts	Command-line options
Browsers	HTML
Games	Level descriptors
Routers	Packets
Netflix	Video
Spotify	Audio, Playlists…

How to build Parsers?

Two standard methods

Regular Expressions

- Doesn't really scale beyond simple things
- No nesting, recursion

'#' '#' alpa+

(x+y)*z

Parser Generators

1. Specify *grammar* via rules

```
Expr : Var                { EVar $1        }
     | Num                { ENum $1        }
     | Expr Op Expr       { EBin $1 $2 $3 }
     | '(' Expr ')'       { $2             }
     ;
```

String → obj

2. Tools like `yacc` , `bison` , `antlr` , `happy`

- convert *grammar* into *executable function*

parser generator

Grammars Don't Compose!

If we have *two* kinds of structured objects `Thingy` and `Whatsit` .

```
Thingy : rule   { action }
;
```

```
Whatsit : rule  { action }
;
```

T_1 T_2 T_3 T_4

To parse *sequences* of `Thingy` and `Whatsit` we must *duplicate* the rules

```
Thingies : Thingy Thingies  { ... }
           EmptyThingy      { ... }
;

Whatsits : Whatsit Whatsits { ... }
           EmptyWhatsit     { ... }
;
```

No nice way to *reuse* the sub-parsers for `Whatsit` and `Thingy` :-(

(many thing)

many video

many title

A New Hope: Parsers as Functions

Lets think of parsers directly **as functions** that

- **Take** as input a `String`
- **Convert** a part of the input into a `StructuredObject`
- Return the **remainder** unconsumed to be parsed *later*

```
data Parser a = P (String -> (a, String))
```

`A Parser a`

- Converts a *prefix* of a `String`
- Into a *structured* object of type `a` and
- Returns the *suffix* `String` unchanged

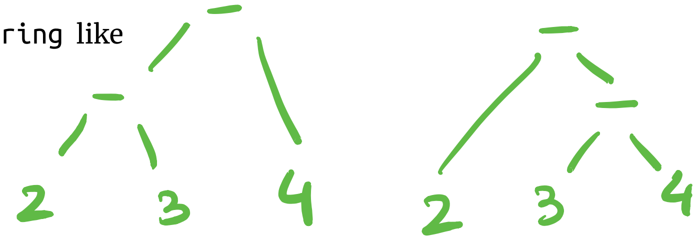
left assoc.

$e_1 \to (e_2 \to e_3)$

Parsers Can Produce Many Results

Sometimes we want to parse a `String` like

```
"2 - 3 - 4"
```



into a **list** of possible results

```
[(Minus (Minus 2 3) 4),   Minus 2 (Minus 3 4)]
```

So we generalize the `Parser` type to

```
data Parser a = P (String -> [(a, String)])
```

:-)

[]

EXERCISE

Given the definition

```
data Parser a = P (String -> [(a, String)])
```

Implement a function

```
runParser :: Parser a -> String -> [(a, String)]
runParser p s = ???
```

QUIZ

Given the definition

```
data Parser a = P (String -> [(a, String)])
```

Which of the following is a valid `Parser Char`

- that returns the **first** `Char` from a string (if one exists)

```haskell
-- A
oneChar = P (\cs -> head cs)

-- B
oneChar = P (\cs -> case cs of
                      []   -> [('', [])
                      c:cs -> (c, cs))

-- C
oneChar = P (\cs -> (head cs, tail cs))

-- D
oneChar = P (\cs -> [(head cs, tail cs)])

-- E
oneChar = P (\cs -> case cs of
                      [] -> []
                      cs -> [(head cs, tail cs)])
```

Lets Run Our First Parser!

```
>>> runParser oneChar "hey!"
[('h', "ey")]

>>> runParser oneChar "yippee"
[('y', "ippee")]

>>> runParser oneChar ""
[]
```

Failure to parse means result is an **empty** list!

EXERCISE

Your turn: Write a parser to grab **first two chars**

```
twoChar :: Parser (Char, Char)
twoChar = P (\cs -> ???)
```

When you are done, we should get

```
>>> runParser twoChar "hey!"
[(('h', 'e'), "y!")]

>>> runParser twoChar "h"
[]
```

QUIZ

Ok, so recall

```
twoChar :: Parser (Char, Char)
twoChar  = P (\cs -> case cs of
                      c1:c2:cs' -> [((c1, c2), cs')]
                      _         -> [])
```

Suppose we had some `foo` such that `twoChar'` was equivalent to `twoChar`

```
twoChar' :: Parser (Char, Char)
twoChar' = foo oneChar oneChar
```

What must the type of `foo` be?

Parser Char → Parser Char → Parser (Char, Char)

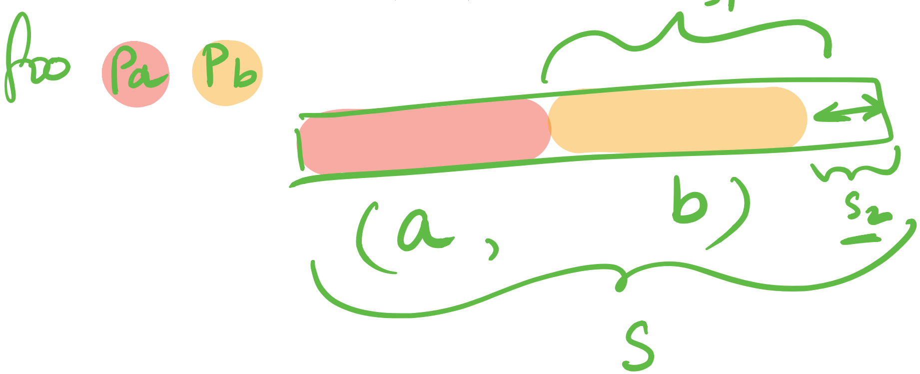
A. `Parser (Char, Char)`

B. `Parser Char -> Parser (Char, Char)`

C. `Parser a -> Parser a -> Parser (a, a)`

D. `Parser a -> Parser b -> Parser (a, b)`

E. `Parser a -> Parser (a, a)`



EXERCISE: A `forEach` *Loop*

Lets write a function

```
forEach :: [a] -> (a -> [b]) -> [b]
forEach xs f = ???
```

such that we get the following behavior

```
>>> forEach [] (\i -> [i, i + 1])
[]

>>> forEach [10,20,30] (\i -> [show i, show (i+1)])
["10", "11", "20", "21", "30", "31"]
```

QUIZ

What does `quiz` evaluate to?

```
quiz = forEach [10, 20, 30] (\i ->
         forEach [0, 1, 2] (\j ->
           [i + j]
         )
       )
```

A. `[10,20,30,0,1,2]`

B. `[10,0,20,1,30,2]`

C. `[[10,11,12], [20,21,22] [30,31,32]]`

D. `[10,11,12,20,21,22,30,31,32]`

E. `[32]`

A `pairP` *Combinator*

Lets implement the above as `pairP`

```
forEach :: [a] -> (a -> [b]) -> [b]
forEach xs f = concatMap f xs

pairP :: Parser a -> Parser b -> Parser (a, b)
pairP aP bP = P (\s -> forEach (runParser aP s) (\(a, s') ->
                         forEach (runParser bP s') (\(b, s'') ->
                           ((a, b), s'')
                       )
                )
```

Now we can write

```
twoChar = pairP oneChar oneChar
```

QUIZ

What does `quiz` evaluate to?

```
twoChar = pairP oneChar oneChar

quiz    = runParser twoChar "h"
```

A. `[((h ,h ), "")]`

B. `[(h , "")]`

C. `[("", "")]`

D. `[]`

E. Run-time exception

Does the `Parser a` type remind you of something?

Lets implement the above as `pairP`

```
data Parser a = P (String -> [(a, String)])

data ST s a   = S (s -> (a, s))
```

`Parser` is a Monad!

Like a state transformer, `Parser` is a monad!
(http://homepages.inf.ed.ac.uk/wadler/papers/marktoberdorf/baastad.pdf)

We need to implement two functions

```
returnP :: a -> Parser a

bindP   :: Parser a -> (a -> Parser b) -> Parser b
```

QUIZ

Which of the following is a valid implementation of `returnP`

```haskell
data Parser a = P (String -> [(a, String)])

returnP   :: a -> Parser a

returnP a = P (\s -> [])          -- A

returnP a = P (\s -> [(a, s)])    -- B

returnP a = P (\s -> (a, s))      -- C

returnP a = P (\s -> [(a, "")])   -- D

returnP a = P (\s -> [(s, a)])    -- E
```

HINT: `return a` should just

- "produce" the parse result `a` and
- leave the string unconsumed.

Bind

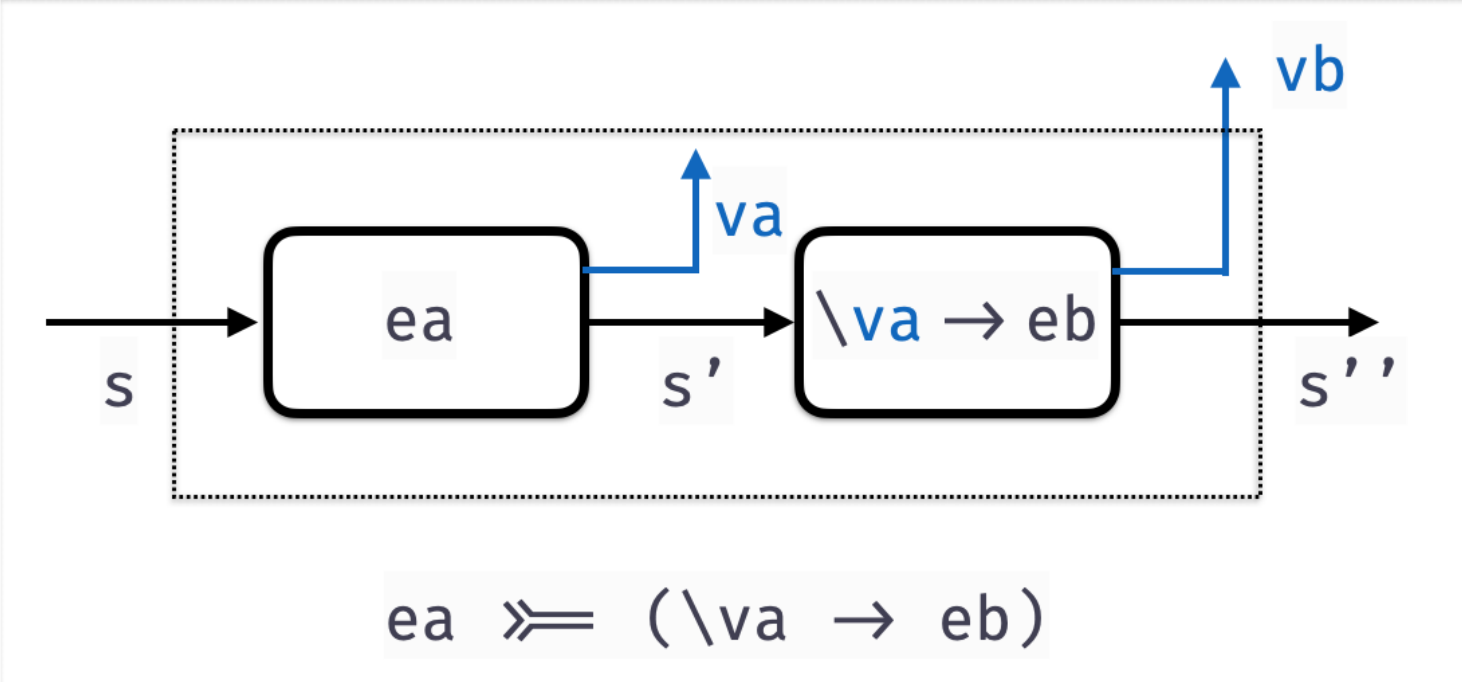
Next, lets implement `bindP`

- we almost saw it as `pairP`

```
bindP :: Parser a -> (a -> Parser b) -> Parser b
bindP aP fbP = P (\s ->
  forEach (runParser aP s) (\(a, s') ->
    forEach (runParser (fbP a) s') (\(b, s'') ->
      [(b, s'')]
    )
  )
)
```

The function

- Builds the `a` values out of `aP` (using `runParser`)
- Builds the `b` values by calling `fbP a` on the *remainder* string `s'`
- Returns `b` values and the remainder string `s''`



The `Parser` *Monad*

We can now make `Parser` an instance of `Monad`

```
instance Monad Parser where
  (>>=)  = bindP
  return = returnP
```

And now, let the *wild rumpus start!*