Parser Combinators

Before we continue …

A Word from the Sponsor!

```
Don't Fear Monads
```

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

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...)

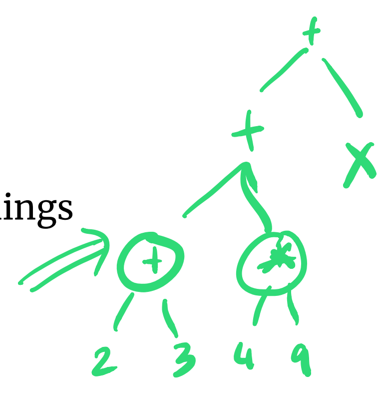
```
type Parser = String -> StructuredObject
```

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

Parser Generators

1. Specify *grammar* via rules

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

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

- convert *grammar* into *executable function*

Grammars Don't Compose!

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

```
Thingy : rule   { action }
;

Whatsit : rule  { action }
;
```

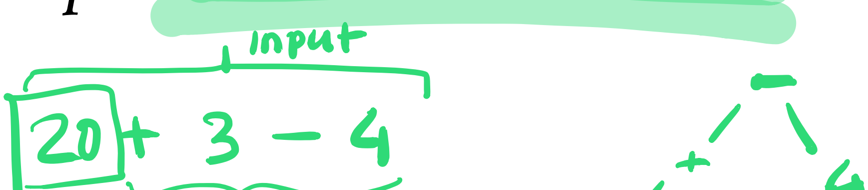
To parse *sequences* of `Thingy` and `Whatsit` we must *duplicate* the rules

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

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

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

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))
```

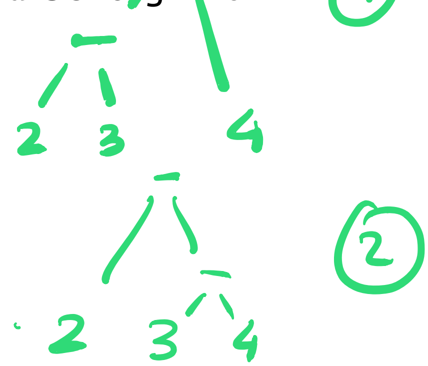
A `Parser a`

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

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)])
```

list of results

EXERCISE

Given the definition

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

Implement a function

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

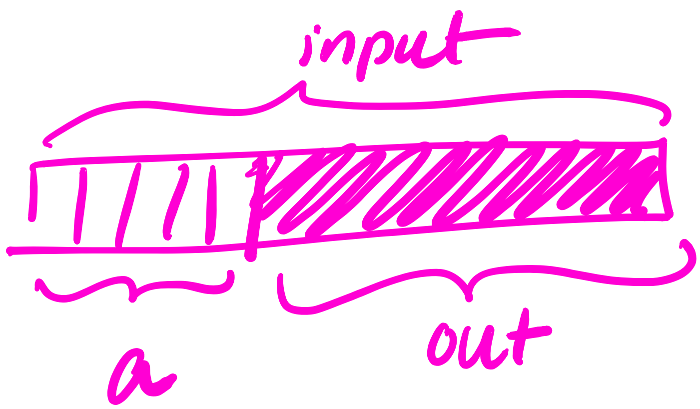
QUIZ

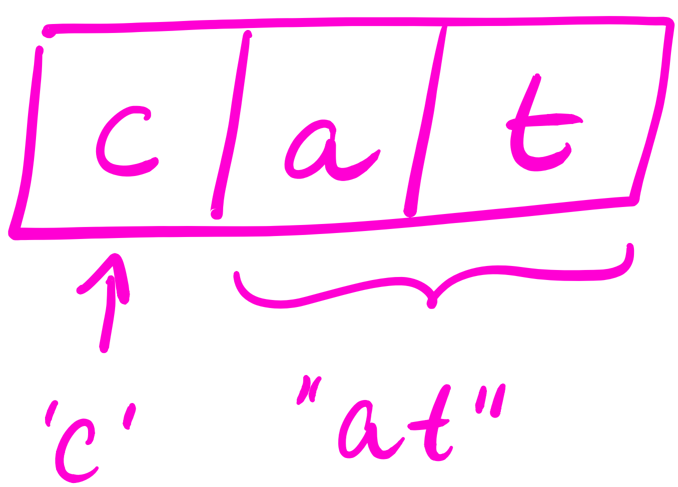
Given the definition

```
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)])
```

result rem.

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
```

oneChar :: Parser Char

What must the type of `foo` be?

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

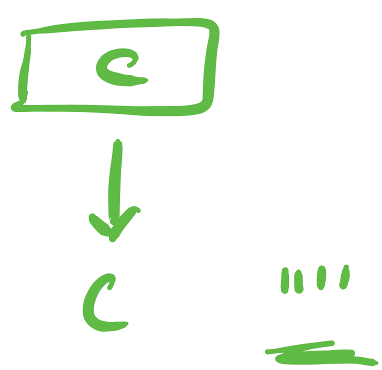
Lets implement the above as `pairP`

```
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"
```

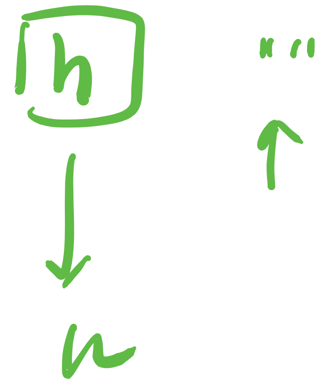
A. `[((h,h), "")]`

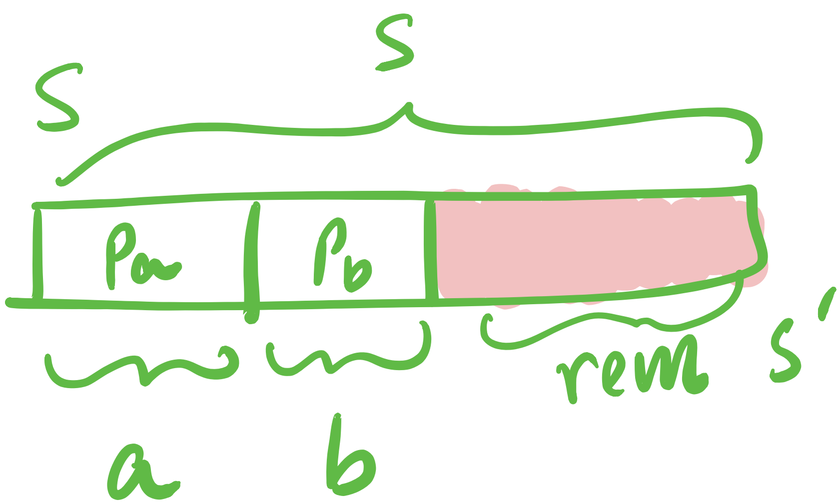
B. `[(h, "")]`

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
```

return ST x = STC (\s -> (s, x))
old new

QUIZ

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

```
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

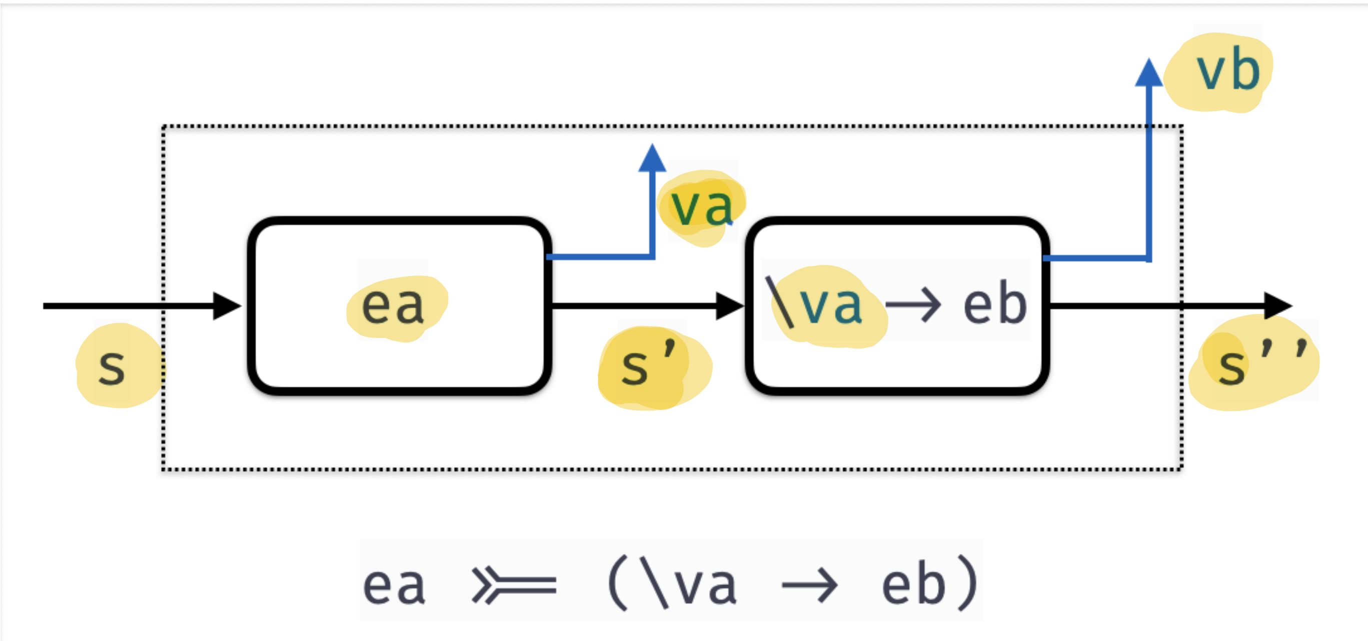
Next, lets implement `bindP`

- 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!*

Parser Combinators

Lets write lots of *high-level* operators to **combine** parsers!

Here's a cleaned up `pairP`

```haskell
pairP :: Parser a -> Parser b -> Parser (a, b)
pairP aP bP = do
  a <- aP
  b <- bP
  return (a, b)
```

Failures are the Pillars of Success!

Surprisingly useful, always *fails*

- i.e. returns `[]` no successful parses

```haskell
failP :: Parser a
failP = P (\_ -> [])
```

QUIZ

failP = P(_ -> [])

Consider the parser

```
satP :: (Char -> Bool) -> Parser Char
satP p = do
  c <- oneChar
  if p c then return c else failP
```

What is the value of

```
quiz1 = runParser (satP (\c -> c == 'h')) "hellow"
quiz2 = runParser (satP (\c -> c == 'h')) "yellow"
```

	quiz1	quiz2
A	[]	[]
B	[('h', "ellow")]	[('y', "ellow")]
C	[('h', "ellow")]	[]
D	[]	[('y', "ellow")]

Parsing Alphabets and Numerics

We can now use `satP` to write

```
-- parse ONLY the Char c
char :: Parser Char
char c = satP (\c' -> c == c')

-- parse ANY ALPHABET
alphaCharP :: Parser Char
alphaCharP = satP isAlpha

-- parse ANY NUMERIC DIGIT
digitChar :: Parser Char
digitChar = satP isDigit
```

QUIZ

We can parse a single `Int` digit

```
digitInt :: Parser Int
digitInt = do
  c <- digitChar      -- parse the Char c
  return (read [c])   -- convert Char to Int
```

What is the result of

```
quiz1 = runParser digitInt "92"
quiz2 = runParser digitInt "cat"
```

	quiz1	quiz2
A	`[]`	`[]`
B	`[('9', "2")]`	`[('c', "at")]`
C	`[(9, "2")]`	`[]`
D	`[]`	`[('c', "at")]`

EXERCISE

Write a function

```
strP :: String -> Parser String
strP s = -- parses EXACTLY the String s and nothing else
```

when you are done, we should get the following behavior

```
>>> dogeP = strP "doge"

>>> runParser dogeP "dogerel"
[("doge", "rel")]

>>> runParser dogeP "doggoneit"
[]
```

HW 02-WHILE
DUE FRI DEC 04

A Choice Combinator

Lets write a combinator `orElse p1 p2` such that

- returns the results of `p1`

or, else *if those are empty*

- returns the results of `p2`

```
:: Parser a -> Parser a -> Parser a
orElse p1 p2 = -- produce results of `p1` if non-empty
               -- OR-ELSE results of `p2`
```

e.g. `orElseP` lets us build a parser that produces an alphabet *OR* a numeric character

```
alphaNumChar :: Parser Char
alphaNumChar = alphaChar `orElse` digitChar
```

Which should produce

```
>>> runParser alphaNumChar "cat"
[('c', "at")]

>>> runParser alphaNumChar "2cat"
[('2', "cat")]

>>> runParser alphaNumChar "230"
[('2', "30")]
```

QUIZ

```
orElse :: Parser a -> Parser a -> Parser a
orElse p1 p2 = -- produce results of `p1` if non-empty
               -- OR-ELSE results of `p2`
```

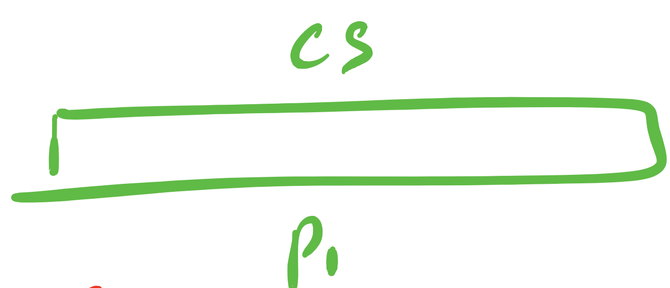
Which of the following implements `orElse` ?

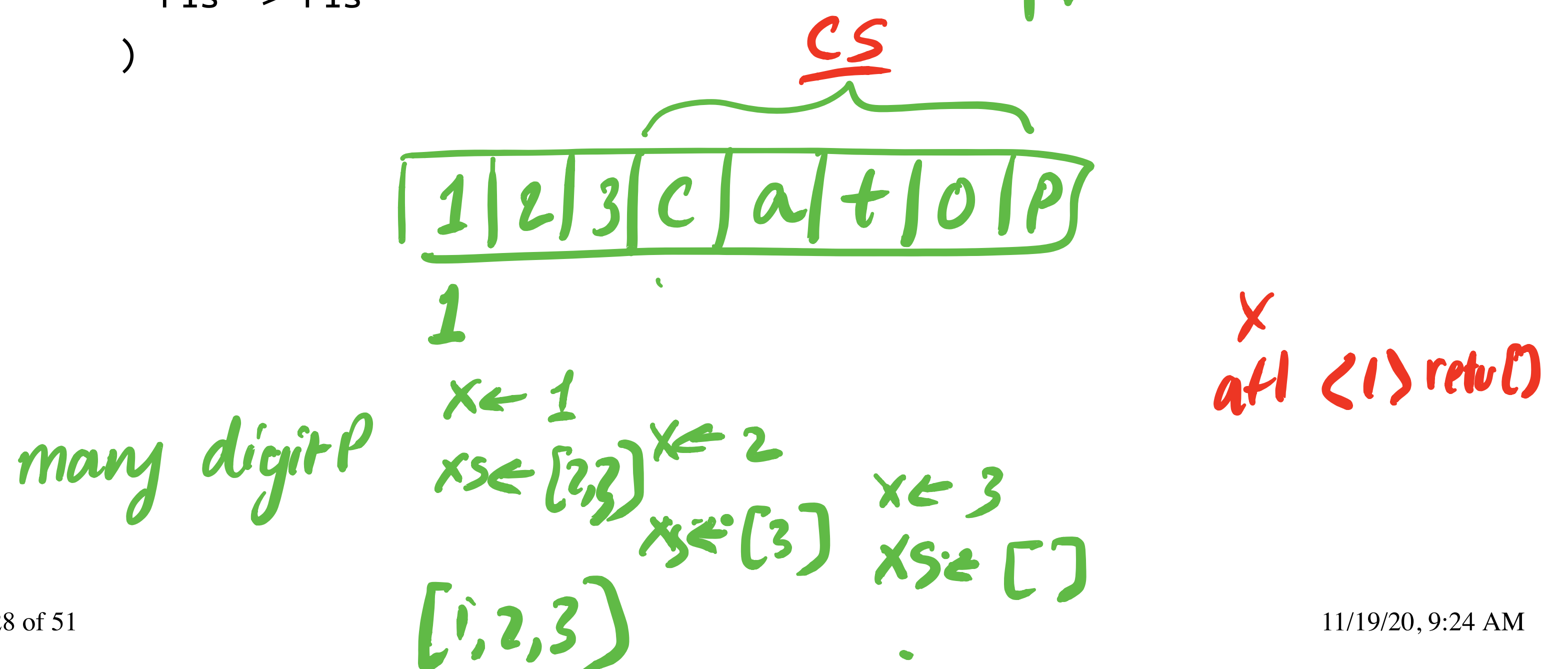
```haskell
-- a
orElse p1 p2 = do
  r1s <- p1
  r2s <- p2
  return (r1s ++ r2s)

-- b
orElse p1 p2 = do
  r1s <- p1
  case r1s of
    [] -> p2
    _  -> return r1s

-- c
orElse p1 p2 = P (\cs ->
  runParser p1 cs ++ runParser p2 cs
  )

-- d
orElse p1 p2 = P (\cs ->
  case runParser p1 cs of
    []  -> runParser p2 cs
    r1s -> r1s
  )
```





An "Operator" for `orElse`

It will be convenient to have a short "operator" for `orElse`

```
p1 <|> p2 = orElse p1 p2
```

A Simple Expression Parser

Now, lets write a *tiny* calculator!

```haskell
-- 1. First, parse the operator
intOp      :: Parser (Int -> Int -> Int)
intOp      = plus <|> minus <|> times <|> divide
  where
    plus   = do { _ <- char '+'; return (+) }
    minus  = do { _ <- char '-'; return (-) }
    times  = do { _ <- char '*'; return (*) }
    divide = do { _ <- char '/'; return div }

-- 2. Now parse the expression!
calc :: Parser Int
calc = do x  <- digitInt
          op <- intOp
          y  <- digitInt
          return (x `op` y)
```

When `calc` is run, it will both parse *and* calculate

```
>>> runParser calc "8/2"
[(4,"")]

>>> runParser calc "8+2cat"
[(10,"cat")]

>>> runParser calc "8/2cat"
[(4,"cat")]

>>> runParser calc "8-2cat"
[(6,"cat")]

>>> runParser calc "8*2cat"
[(16,"cat")]
```

The `calc0` parser implicitly forces *all operators* to be *right associative*

- doesn't matter for `+`, `*`
- but is incorrect for `-`

Does not respect precedence!

Simple Fix: Parentheses!

Lets write a combinator that parses something within `(...)`