

Applicative Regular Expressions w/ the Free Alternative

Justin Le <https://blog.jle.im>

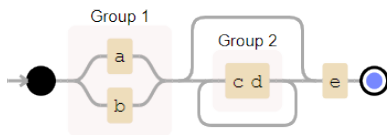
Composed 2019, June 24

Preface

Slide available at <https://mstksg.github.io/talks/composeconf-2019/free-alternative.md>.

Regular Expressions

$(a|b)(cd)^*e$

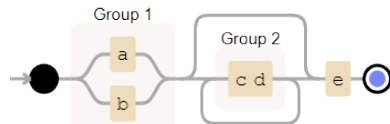


Regular Expressions

$(a|b)(cd)^*e$

Matches:

- ▶ ae
- ▶ acdcdcdde
- ▶ bcde

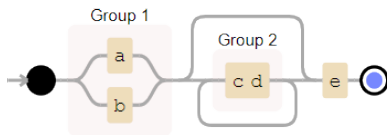


Doesn't match:

- ▶ acdcd
- ▶ abcde
- ▶ bce

Captures

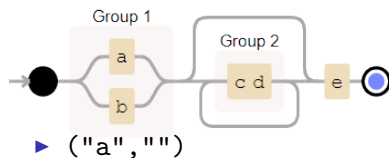
$(a|b)(cd)^*e$



Captures

$(a|b)(cd)^*e$

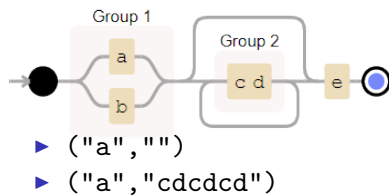
- ▶ $ae \rightarrow$
- ▶ $acdcdcde \rightarrow$
- ▶ $bcde \rightarrow$



Captures

$(a|b)(cd)^*e$

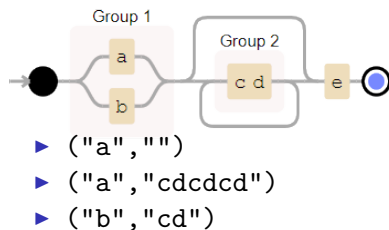
- ▶ $ae \rightarrow$
- ▶ $acdcdcde \rightarrow$
- ▶ $bcde \rightarrow$



Captures

$(a|b)(cd)^*e$

- ▶ $ae \rightarrow$
- ▶ $acdcdcde \rightarrow$
- ▶ $bcde \rightarrow$



Applicative Regular Expressions

“Type-indexed” regular expressions.

```
type Regexp a  
  -- ^ type of "result"
```

Applicative Regular Expressions

“Type-indexed” regular expressions.

```
type Regexp a
    -- ^ type of "result"

char    :: Char    -> RegExp Char
string  :: String  -> RegExp String
```

Applicative Regular Expressions

“Type-indexed” regular expressions.

```
type Regexp a
    -- ^ type of "result"

char    :: Char    -> RegExp Char
string  :: String  -> RegExp String

runRegexp :: RegExp a -> String -> Maybe a
```

Applicative Regular Expressions

```
char    :: Char      -> RegExp Char
string  :: String    -> RegExp String
(<|>)   :: RegExp a -> RegExp a -> RegExp a
many    :: RegExp a -> RegExp [a]
```

```
myRegex :: RegExp (Char, [String])
myRegex = (,) <$> (char 'a' <|> char 'b')
              <*> many (string "cd")
              <*> char 'e'
```

Applicative Regular Expressions

```
char    :: Char      -> RegExp Char
string  :: String    -> RegExp String
(<|>)   :: RegExp a -> RegExp a -> RegExp a
many    :: RegExp a -> RegExp [a]
```

```
myRegex :: RegExp (Char, [String])
myRegex = (,) <$> (char 'a' <|> char 'b')
              <*> many (string "cd")
              <*> char 'e'
```

```
runRegex myRegex :: String -> Maybe (Char, [String])
```

Applicative Regular Expressions

```
runRegex myRegex "ae"
```

```
Just ('a', [])
```

```
runRegex myRegex "acdcdcde"
```

```
Just ('a', ["cd","cd","cd"])
```

```
runRegex myRegex "bcde"
```

```
Just ('b', ["cd"])
```

```
runRegex myRegex "acdcd"
```

```
Nothing
```

Applicative Regular Expressions

```
myRegex2 :: RegExp (Bool, Int)
myRegex2 = (,) <$> ((False <$ char 'a') <|> (True <$ char
    <*> fmap length (many (string "cd")))
    <*> char 'e')
```

Applicative Regular Expressions

```
myRegexp2 :: RegExp (Bool, Int)
myRegexp2 = (,) <$> ((False <$ char 'a') <|> (True <$ char
    <*> fmap length (many (string "cd")))
    <*> char 'e')
```

```
runRegexp myRegexp2 "ae"
Just (False, 0)
```

```
runRegexp myRegexp2 "acdcdcde"
Just (False, 3)
```

```
runRegexp myRegexp2 "bcde"
Just (True, 1)
```


What's so Regular?

What's so Regular?

Regular Language Base Members

1. Empty set: Always fails to match
2. Empty string: Always succeeds, consumes nothing
3. Literal: Matches and consumes a given char

What's so Regular?

Regular Language Base Members

1. Empty set: Always fails to match
2. Empty string: Always succeeds, consumes nothing
3. Literal: Matches and consumes a given char

Regular Language Operations

1. Concatenation: RS , sequence one after the other
2. Alternation: $R|S$, one or the other
3. Kleene Star: R^* , the repetition of R

An Alternative Perspective

An Alternative Perspective

```
class Functor f => Applicative f where
  -- / Always succeed, consuming nothing
  pure  :: a -> f a
  -- / Concatenation
  (<*>) :: f (a -> b) -> f a -> f b
```

An Alternative Perspective

```
class Functor f => Applicative f where
  -- / Always succeed, consuming nothing
  pure  :: a -> f a
  -- / Concatenation
  (<*>) :: f (a -> b) -> f a -> f b

class Applicative f => Alternative f where
  -- / Always fails to match
  empty :: f a
  -- / Alternation
  (<|>) :: f a -> f a -> f a
  -- / Reptition
  many  :: f a -> f [a]
```

An Alternative Perspective

1. Empty set: `empty`

An Alternative Perspective

1. Empty set: `empty`
2. Empty string: `pure x`

An Alternative Perspective

1. Empty set: `empty`
2. Empty string: `pure x`
3. Literal: `???`

An Alternative Perspective

1. Empty set: `empty`
2. Empty string: `pure x`
3. Literal: `???`
4. Concatenation: `<*>`

An Alternative Perspective

1. Empty set: `empty`
2. Empty string: `pure x`
3. Literal: `???`
4. Concatenation: `<*>`
5. Alternation: `<|>`

An Alternative Perspective

1. Empty set: `empty`
2. Empty string: `pure x`
3. Literal: `???`
4. Concatenation: `<*>`
5. Alternation: `<|>`
6. Repetition: `many`

Functor combinator-style

- ▶ Define a primitive type

```
type Prim a
```

Functor combinator-style

- ▶ Define a primitive type

```
type Prim a
```

- ▶ Add the structure you need

Functor combinator-style

- ▶ Define a primitive type

```
type Prim a
```

- ▶ Add the structure you need
 - ▶ If this structure is from a typeclass, use the free structure of that typeclass

Easy as 1, 2, 3

```
data Prim a = Prim Char a
    deriving Functor

data Alt :: (Type -> Type) -> (Type -> Type)
    -- ^ take a Functor
    -- ^ return a Functor

type RegExp = Alt Prim

liftAlt :: Prim a -> Alt Prim

char :: Char -> RegExp Char
char c = liftAlt (Prim c c)
```


Unlimited Power

```
empty :: RegExp a
pure  :: a -> RegExp a
char  :: Char -> RegExp Char
(<*>) :: RegExp (a -> b) -> RegExp a -> RegExp b
(<|>) :: RegExp a -> RegExp a -> RegExp a
many  :: RegExp a -> RegExp [a]
```

Unlimited Power

```
empty :: RegExp a
pure  :: a -> RegExp a
char  :: Char -> RegExp Char
(<*>) :: RegExp (a -> b) -> RegExp a -> RegExp b
(<|>) :: RegExp a -> RegExp a -> RegExp a
many  :: RegExp a -> RegExp [a]

string :: String -> RegExp String
string = traverse char

digit :: RegExp Int
digit = asum [ intToDigit i <$ char i | i <- [0..9] ]
```

Parsing

Options:

1. *Interpret* into an `Alternative` instance, “offloading” the logic

Parsing

Options:

1. *Interpret* into an `Alternative` instance, “offloading” the logic
2. Direct pattern match on structure constructors (Haskell 101)

What is freeness?

What is freeness?

```
type FreeMonoid = []
```

```
injectFM :: a -> FreeMonoid a
```

```
runFM    :: Monoid m => (a -> m) -> (FreeMonoid a -> m)
```

What is freeness?

```
type FreeMonoid = []
```

```
injectFM :: a -> FreeMonoid a
```

```
runFM     :: Monoid m => (a -> m) -> (FreeMonoid a -> m)
```

```
(:[])     :: a -> [a]
```

```
foldMap   :: Monoid m => (a -> m) -> ([a] -> m)
```

What is freeness?

```
myMon :: FreeMonoid Int  
myMon = [1] <> [2] <> [3] <> [4]
```


What is freeness?

```
myMon :: FreeMonoid Int
myMon = [1] <> [2] <> [3] <> [4]

foldMap Sum myMon
Sum 10
```

What is freeness?

```
myMon :: FreeMonoid Int  
myMon = [1] <> [2] <> [3] <> [4]
```

```
foldMap Sum myMon  
Sum 10
```

```
foldMap Product myMon  
Product 24
```

What is freeness?

```
myMon :: FreeMonoid Int
myMon = [1] <> [2] <> [3] <> [4]

foldMap Sum myMon
Sum 10

foldMap Product myMon
Product 24

foldMap Max myMon
Max 4
```

What is freeness?

```
type Alt a
```

```
liftAlt :: f a -> Alt f a
```

```
runAlt  :: Alternative g
```

```
    => (forall b. f a -> g a)
```

```
    -> (Alt f a -> g a)
```

Hijacking StateT

StateT [Char] Maybe

- ▶ Prim a can be interpreted as *consumption*
- ▶ <*> sequences consumption
- ▶ <|> is backtracking

Hijacking StateT

```
processPrim :: Prim a -> StateT String Maybe a
processPrim (Prim c x) = do
    d:ds <- get           -- ^ match on stream
    guard (c == d)        -- ^ fail unless match
    put ds                -- ^ update stream
    return x              -- ^ return result value

matchPrefix :: Regexp a -> String -> Maybe a
matchPrefix re = evalStateT (runAlt processPrim re)
```

This works?

This works?

Yes!

```
matchPrefix myRegexp2 "ae"  
Just (False, 0)
```

```
matchPrefix myRegexp2 "acdcdcde"  
Just (False, 3)
```

```
matchPrefix myRegexp2 "bcde"  
Just (True, 1)
```


What just happened?

What just happened?

```
data Prim a = Prim Char a
  deriving Functor
```

```
type RegExp = Alt Prim
```

```
matchPrefix :: RegExp a -> String -> Maybe a
matchPrefix re = evalStateT (runAlt processPrim re)
  where
    processPrim (Prim c x) = do
      d:ds <- get
      guard (c == d)
      put ds
      pure x
```

What just happened?

1. Offload Alternative functionality to StateT: empty, <*>, pure, empty, many.

What just happened?

1. Offload Alternative functionality to StateT: `empty`, `<*>`, `pure`, `empty`, `many`.
2. Provide Prim-processing functionality with `processPrim`: `liftAlt`.

What do we gain?

1. Interpretation-invariant structure

What do we gain?

1. Interpretation-invariant structure
2. Actually meaningful types

What do we gain

StateT String Maybe is **not** a regular expression type.

```
notARegexp :: StateT String Maybe ()
```

```
notARegexp = put "hello"           -- no regular expression
```

What do we gain

StateT String Maybe is **not** a regular expression type.

```
notARegexp :: StateT String Maybe ()
```

```
notARegexp = put "hello"           -- no regular expression
```

Alt Prim **is** a regular expression type

Direct matching

```
newtype Alt f a = Alt { alternatives :: [AltF f a] }  
  
data AltF f a = forall r. Ap (f r) (Alt f (r -> a))  
               |  
               Pure a
```

Direct matching

```
newtype Alt f a = Alt { alternatives :: [AltF f a] }
```

```
data AltF f a = forall r. Ap (f r) (Alt f (r -> a))  
              |  
              Pure a
```

```
-- / Chain of </>s
```

```
newtype Alt f a
```

```
    = Choice (AltF f a) (Alt f a) -- ^ c  
    | Empty -- ^ n
```

```
-- / Chain of <*>s
```

```
data AltF f a
```

```
    = forall r. Ap (f r) (Alt f (r -> a)) -- ^ c  
    | Pure a -- ^ n
```

Direct Matching

```
matchAlts :: RegExp a -> String -> Maybe a
matchAlts (Alt res) xs = asum [ matchChain re xs | re <- res ]
```

Direct Matching

```
matchAlts :: RegExp a -> String -> Maybe a
matchAlts (Alt res) xs = asum [ matchChain re xs | re <- res ]

matchChain :: AltF Prim a -> String -> Maybe a
matchChain (Ap (Prim c x) next) cs = _
matchChain (Pure x)                cs = _
```

One game of Tetris later...

```
matchChain :: AltF Prim a -> String -> Maybe a
matchChain (Ap (Prim c x) next) cs = case cs of
    [] -> Nothing
    d:ds | c == d -> matchAlts (($ x) <$> next) ds
          | otherwise -> Nothing
matchChain (Pure x) _ = Just x
```

This works?

This works?

Yes!

```
matchChain myRegexp2 "ae"  
Just (False, 0)
```

```
matchChain myRegexp2 "acdcdcde"  
Just (False, 3)
```

```
matchChain myRegexp2 "bcde"  
Just (True, 1)
```

What do we gain?

- ▶ First-class program rewriting, Haskell 101-style

What do we gain?

- ▶ First-class program rewriting, Haskell 101-style
- ▶ **Normalizing** representation

What do we gain?

- ▶ First-class program rewriting, Haskell 101-style
- ▶ **Normalizing** representation
 - ▶ Equivalence in meaning = equivalence in structure

What do we gain?

- ▶ First-class program rewriting, Haskell 101-style
- ▶ **Normalizing** representation
 - ▶ Equivalence in meaning = equivalence in structure

What do we gain?

- ▶ First-class program rewriting, Haskell 101-style
- ▶ **Normalizing** representation
 - ▶ Equivalence in meaning = equivalence in structure

```
-- / Not regularizing
data RegExp a = Empty
              | Pure a
              | Prim Char a
              | forall r. Seq (RegExp a) (RegExp (r -> a))
              | Union (RegExp a) (RegExp a)
              | Many (RegExp a)

-- a/(b/c) /= (a/b)/c
```

Free your mind

Is this you?

“My problem is modeled by some (commonly occurring) structure over some primitive base.”

- ▶ Use a “functor combinator”!

Free your mind

Is this you?

“My problem is modeled by some (commonly occurring) structure over some primitive base.”

- ▶ Use a “functor combinator”!
- ▶ If your structure comes from a typeclass, use a free structure!

Further Reading

- ▶ Blog post:
<https://blog.jle.im/entry/free-applicative-regexp.html>
- ▶ Functor Combinatorpedia:
<https://blog.jle.im/entry/functor-combinatorpedia.html>
- ▶ Slides: <https://mstksg.github.io/talks/composeconf-2019/free-alternative.md>