Compilers and Formal Languages

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The Goal of this Course

Write a compiler

Today a lexer.

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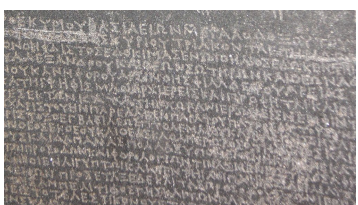

lexing $\Rightarrow$ recognising words (Stone of Rosetta)

Regular Expressions

In programming languages they are often used to recognise:

- operands, digits
- identifiers
- numbers (non-leading zeros)
- keywords
- comments

`http://www.regexper.com`

Lexing: Test Case

```
write "Fib";
read n;
minus1 := 0;
minus2 := 1;
while n > 0 do {
       temp := minus2;
       minus2 := minus1 + minus2;
       minus1 := temp;
       n := n - 1
};
write "Result";
write minus2
```

"if true then then 42 else +"

KEYWORD:
  if, then, else,
WHITESPACE:
  " ", \n,
IDENTIFIER:
  LETTER · (LETTER + DIGIT + _)*
NUM:
  (NONZERODIGIT · DIGIT*) + 0
OP:
  +, -, *, %, <, <=
COMMENT:
  /* · ∼(ALL* · (*/) · ALL*) · */

"if true then then 42 else +"

```
KEYWORD(if),
WHITESPACE,
IDENT(true),
WHITESPACE,
KEYWORD(then),
WHITESPACE,
KEYWORD(then),
WHITESPACE,
NUM(42),
WHITESPACE,
KEYWORD(else),
WHITESPACE,
OP(+)
```

"if true then then 42 else +"

```
KEYWORD(if),
IDENT(true),
KEYWORD(then),
KEYWORD(then),
NUM(42),
KEYWORD(else),
OP(+)
```

There is one small problem with the tokenizer. How should we tokenize…?

```
"x-3"
```

```
ID: …
OP:
  "+", "-"
NUM:
  (NONZERODIGIT · DIGIT*) + ''0''
NUMBER:
  NUM + ("-" · NUM)
```

The same problem with

$$(ab + a) \cdot (c + bc)$$

and the string abc.

The same problem with

$$(ab + a) \cdot (c + bc)$$

and the string *abc*.

Or, keywords are `if` etc and identifiers are letters followed by "letters + numbers + _"*

```
if      iffoo
```

POSIX: Two Rules

- Longest match rule ("maximal munch rule"): The longest initial substring matched by any regular expression is taken as the next token.

- Rule priority: For a particular longest initial substring, the first regular expression that can match determines the token.

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http://www.haskell.org/haskellwiki/Regex_Posix

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traditional lexers are fast, but hairy

Sulzmann & Lu Matcher

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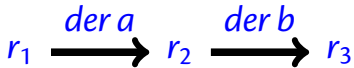

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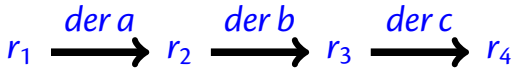

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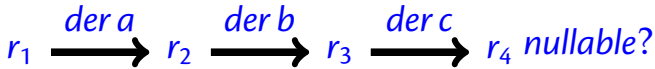
We want to match the string *abc* using r_1:



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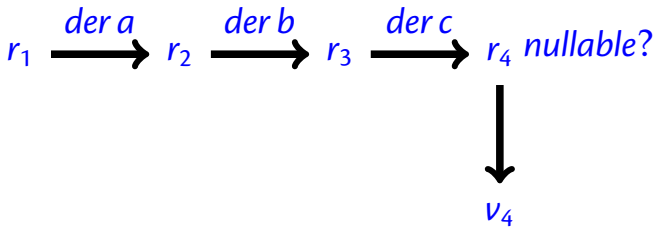

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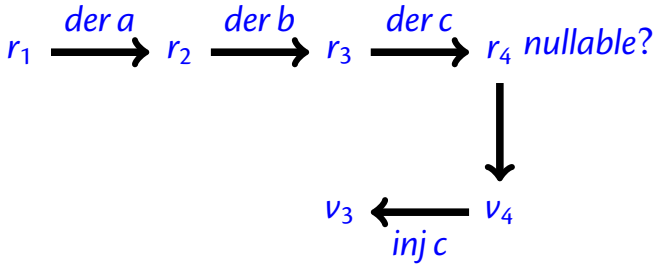

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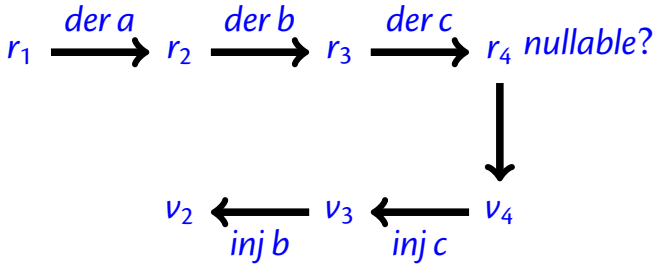

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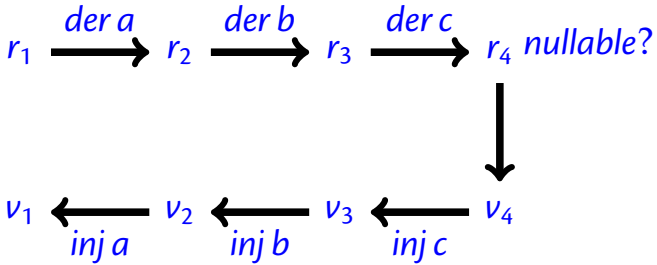

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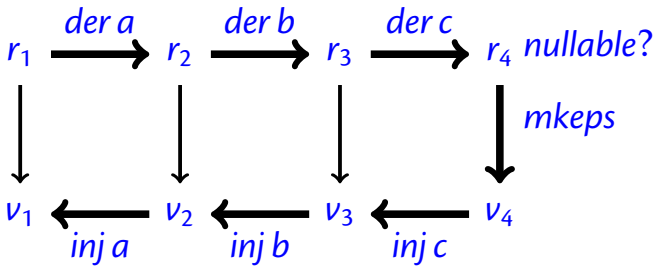


Regexes and Values

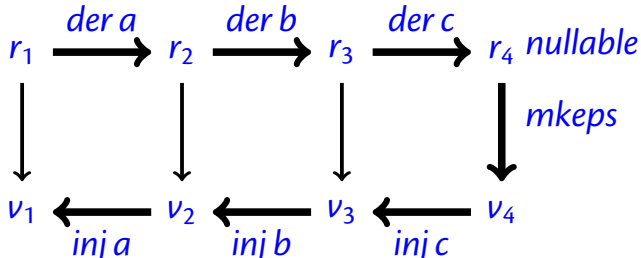
Regular expressions and their corresponding values:

$$
\begin{array}{rcl}
r & ::= & \mathbf{0} \\
 & | & \mathbf{1} \\
 & | & c \\
 & | & r_1 \cdot r_2 \\
 & | & r_1 + r_2 \\
 & | & r^* \\
 & | & \ldots
\end{array}
\qquad
\begin{array}{rcl}
v & ::= & \\
 & & \mathit{Empty} \\
 & | & \mathit{Char}(c) \\
 & | & \mathit{Seq}(v_1, v_2) \\
 & | & \mathit{Left}(v) \\
 & | & \mathit{Right}(v) \\
 & | & \mathit{Stars}\,[] \\
 & | & \mathit{Stars}\,[v_1, \ldots v_n] \\
 & | & \ldots
\end{array}
$$

```
abstract class Rexp
case object ZERO extends Rexp
case object ONE extends Rexp
case class CHAR(c: Char) extends Rexp
case class ALT(r1: Rexp, r2: Rexp) extends Rexp
case class SEQ(r1: Rexp, r2: Rexp) extends Rexp
case class STAR(r: Rexp) extends Rexp

abstract class Val
case object Empty extends Val
case class Chr(c: Char) extends Val
case class Sequ(v1: Val, v2: Val) extends Val
case class Left(v: Val) extends Val
case class Right(v: Val) extends Val
case class Stars(vs: List[Val]) extends Val
```

r_1: $a \cdot (b \cdot c)$
r_2: $\mathbf{1} \cdot (b \cdot c)$
r_3: $(\mathbf{0} \cdot (b \cdot c)) + (\mathbf{1} \cdot c)$
r_4: $(\mathbf{0} \cdot (b \cdot c)) + ((\mathbf{0} \cdot c) + \mathbf{1})$



r_1: $a \cdot (b \cdot c)$
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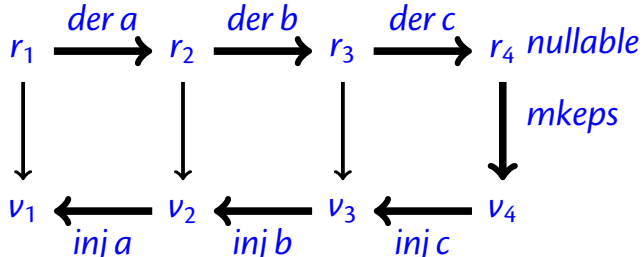


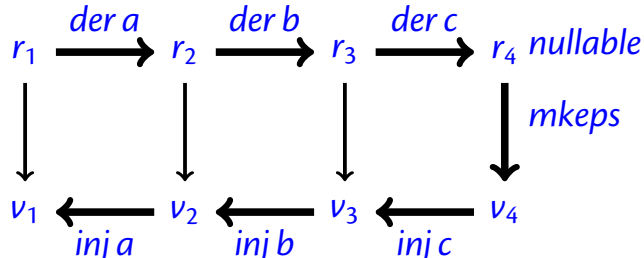
v_1: $Seq(Char(a), Seq(Char(b), Char(c)))$
v_2: $Seq(Empty, Seq(Char(b), Char(c)))$
v_3: $Right(Seq(Empty, Char(c)))$
v_4: $Right(Right(Empty))$

Flatten

Obtaining the string underlying a value:

$$
\begin{array}{lcl}
|Empty| & \stackrel{\text{def}}{=} & [] \\
|Char(c)| & \stackrel{\text{def}}{=} & [c] \\
|Left(v)| & \stackrel{\text{def}}{=} & |v| \\
|Right(v)| & \stackrel{\text{def}}{=} & |v| \\
|Seq(v_1, v_2)| & \stackrel{\text{def}}{=} & |v_1| \mathbin{@} |v_2| \\
|Stars\,[v_1, \ldots, v_n]| & \stackrel{\text{def}}{=} & |v_1| \mathbin{@} \ldots \mathbin{@} |v_n|
\end{array}
$$

r_1: $a \cdot (b \cdot c)$
r_2: $\mathbf{1} \cdot (b \cdot c)$
r_3: $(\mathbf{0} \cdot (b \cdot c)) + (\mathbf{1} \cdot c)$
r_4: $(\mathbf{0} \cdot (b \cdot c)) + ((\mathbf{0} \cdot c) + \mathbf{1})$



v_1: $Seq(Char(a), Seq(Char(b), Char(c)))$
v_2: $Seq(Empty, Seq(Char(b), Char(c)))$
v_3: $Right(Seq(Empty, Char(c)))$
v_4: $Right(Right(Empty))$

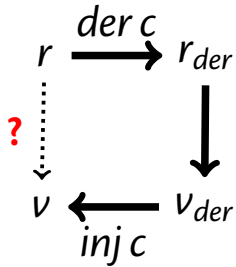
$|v_1|$: abc
$|v_2|$: bc
$|v_3|$: c
$|v_4|$: $[]$

Mkeps

Finding a (posix) value for recognising the empty string:

$$
\begin{array}{lcl}
mkeps\,(\mathbf{1}) & \stackrel{\text{def}}{=} & Empty \\
mkeps\,(r_1 + r_2) & \stackrel{\text{def}}{=} & \text{if } nullable(r_1) \\
 & & \text{then } Left(mkeps(r_1)) \\
 & & \text{else } Right(mkeps(r_2)) \\
mkeps\,(r_1 \cdot r_2) & \stackrel{\text{def}}{=} & Seq(mkeps(r_1), mkeps(r_2)) \\
mkeps\,(r^*) & \stackrel{\text{def}}{=} & Stars\,[]
\end{array}
$$

Inject



Inject

Injecting ("Adding") a character to a value

$$
\begin{array}{ll}
inj\ (c)\ c\ (Empty) & \stackrel{\text{def}}{=} Char\ c \\
inj\ (r_1 + r_2)\ c\ (Left(v)) & \stackrel{\text{def}}{=} Left(inj\ r_1\ c\ v) \\
inj\ (r_1 + r_2)\ c\ (Right(v)) & \stackrel{\text{def}}{=} Right(inj\ r_2\ c\ v) \\
inj\ (r_1 \cdot r_2)\ c\ (Seq(v_1, v_2)) & \stackrel{\text{def}}{=} Seq(inj\ r_1\ c\ v_1, v_2) \\
inj\ (r_1 \cdot r_2)\ c\ (Left(Seq(v_1, v_2))) & \stackrel{\text{def}}{=} Seq(inj\ r_1\ c\ v_1, v_2) \\
inj\ (r_1 \cdot r_2)\ c\ (Right(v)) & \stackrel{\text{def}}{=} Seq(mkeps(r_1), inj\ r_2\ c\ v) \\
inj\ (r^*)\ c\ (Seq(v, Stars\ vs)) & \stackrel{\text{def}}{=} Stars\ (inj\ r\ c\ v\ ::\ vs)
\end{array}
$$

inj: 1st arg $\mapsto$ a rexp; 2nd arg $\mapsto$ a character; 3rd arg $\mapsto$ a value
result $\mapsto$ a value

$$inj\,(c)\,c\,(Empty) \stackrel{\text{def}}{=} Char\,c$$

$$inj\ (r_1 + r_2)\ c\ (Left(v)) \stackrel{\text{def}}{=} Left(inj\ r_1\ c\ v)$$
$$inj\ (r_1 + r_2)\ c\ (Right(v)) \stackrel{\text{def}}{=} Right(inj\ r_2\ c\ v)$$

$$
\begin{array}{ll}
\mathit{inj}\ (r_1 \cdot r_2)\ c\ (\mathit{Seq}(v_1, v_2)) & \stackrel{\text{def}}{=} \mathit{Seq}(\mathit{inj}\ r_1\ c\ v_1, v_2) \\
\mathit{inj}\ (r_1 \cdot r_2)\ c\ (\mathit{Left}(\mathit{Seq}(v_1, v_2))) & \stackrel{\text{def}}{=} \mathit{Seq}(\mathit{inj}\ r_1\ c\ v_1, v_2) \\
\mathit{inj}\ (r_1 \cdot r_2)\ c\ (\mathit{Right}(v)) & \stackrel{\text{def}}{=} \mathit{Seq}(\mathit{mkeps}(r_1), \mathit{inj}\ r_2\ c\ v)
\end{array}
$$

$$
\mathit{der}\ c\ (r_1 \cdot r_2) \stackrel{\text{def}}{=} \textbf{if}\ \mathit{nullable}(r_1)\ \textbf{then}\ (\mathit{der}\ c\ r_1) \cdot r_2 + \mathit{der}\ c\ r_2\ \textbf{else}\ (\mathit{der}\ c\ r_1) \cdot r_2
$$

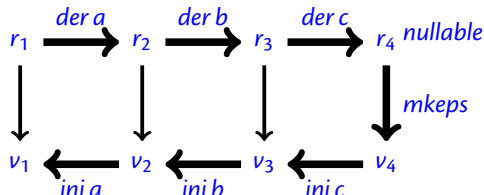
$$inj\,(r^*)\,c\,(Seq(v, Stars\,vs)) \stackrel{\text{def}}{=} Stars\,(inj\,r\,c\,v\ ::\ vs)$$

Lexing

$$lex\ r\ [] \stackrel{\text{def}}{=} \text{if } nullable(r) \text{ then } mkeps(r) \text{ else } error$$

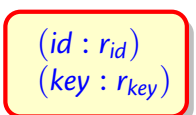
$$lex\ r\ a :: s \stackrel{\text{def}}{=} inj\ r\ a\ lex(der(a, r), s)$$

lex: returns a value



Records

- new regex: $(x : r)$ new value: $Rec(x, v)$



Records

- new regex: $(x : r)$ new value: $Rec(x, v)$
- $nullable(x : r) \stackrel{\text{def}}{=} nullable(r)$
- $der\, c\, (x : r) \stackrel{\text{def}}{=} der\, c\, r$
- $mkeps(x : r) \stackrel{\text{def}}{=} Rec(x, mkeps(r))$
- $inj\, (x : r)\, c\, v \stackrel{\text{def}}{=} Rec(x, inj\, r\, c\, v)$

$(id : r_{id})$
$(key : r_{key})$

Records

- new regex: $(x : r)$ new value: $Rec(x, v)$
- $nullable(x : r) \stackrel{\text{def}}{=} nullable(r)$
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- $inj\, (x : r)\, c\, v \stackrel{\text{def}}{=} Rec(x, inj\, r\, c\, v)$

for extracting subpatterns $(z : ((x : ab) + (y : ba))$

$(id : r_{id})$
$(key : r_{key})$

- A regular expression for email addresses

$$\begin{array}{l}(\text{name: } [a\text{-}z0\text{-}9\_\,.\!-]^+)\cdot@\cdot\\ \quad(\text{domain: } [a\text{-}z0\text{-}9\,\!-]^+)\cdot.\cdot\\ \quad\quad(\text{top\_level: } [a\text{-}z\,.]^{\{2,6\}})\end{array}$$

`christian.urban@kcl.ac.uk`

- the result environment:

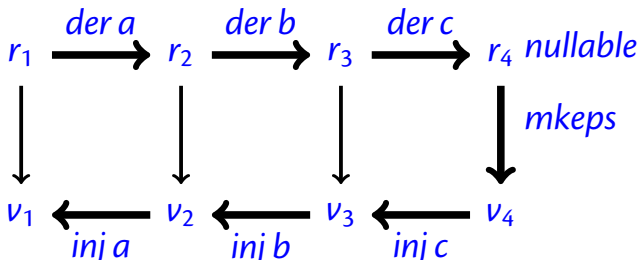
$$[(\mathit{name} : \texttt{christian.urban}),\ (\mathit{domain} : \texttt{kcl}),\ (\mathit{top\_level} : \texttt{ac.uk})]$$

While Tokens

$$\texttt{WHILE\_REGS} \stackrel{\text{def}}{=} (((\texttt{"k"} : \texttt{KEYWORD}) + (\texttt{"i"} : \texttt{ID}) + (\texttt{"o"} : \texttt{OP}) + (\texttt{"n"} : \texttt{NUM}) + (\texttt{"s"} : \texttt{SEMI}) + (\texttt{"p"} : (\texttt{LPAREN} + \texttt{RPAREN})) + (\texttt{"b"} : (\texttt{BEGIN} + \texttt{END})) + (\texttt{"w"} : \texttt{WHITESPACE}))^*$$

Simplification

- If we simplify after the derivative, then we are building the value for the simplified regular expression, but **not** for the original regular expression.



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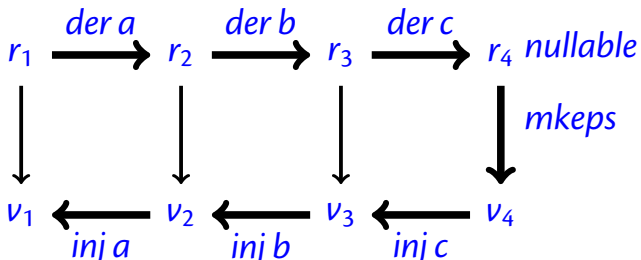

$$(\mathbf{0} \cdot (b \cdot c)) + ((\mathbf{0} \cdot c) + \mathbf{1}) \mapsto \mathbf{1}$$

Normally we would have

$$(\mathbf{0} \cdot (b \cdot c)) + ((\mathbf{0} \cdot c) + \mathbf{1})$$

and answer how this regular expression matches the empty string with the value

$$\mathit{Right}(\mathit{Right}(\mathit{Empty}))$$

But now we simplify this to $\mathbf{1}$ and would produce Empty (see *mkeps*).

Rectification

rectification functions:

$$
\begin{array}{lcll}
r \cdot \mathbf{0} & \mapsto & \mathbf{0} & \\
\mathbf{0} \cdot r & \mapsto & \mathbf{0} & \\
r \cdot \mathbf{1} & \mapsto & r & \lambda f_1\, f_2\, v.\, Seq(f_1\, v, f_2\, Empty) \\
\mathbf{1} \cdot r & \mapsto & r & \lambda f_1\, f_2\, v.\, Seq(f_1\, Empty, f_2\, v) \\
r + \mathbf{0} & \mapsto & r & \lambda f_1\, f_2\, v.\, Left(f_1\, v) \\
\mathbf{0} + r & \mapsto & r & \lambda f_1\, f_2\, v.\, Right(f_2\, v) \\
r + r & \mapsto & r & \lambda f_1\, f_2\, v.\, Left(f_1\, v)
\end{array}
$$

Rectification

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r \cdot \mathbf{0} & \mapsto & \mathbf{0} & \\
\mathbf{0} \cdot r & \mapsto & \mathbf{0} & \\
r \cdot \mathbf{1} & \mapsto & r & \lambda f_1\, f_2\, v.\, Seq(f_1\, v, f_2\, Empty) \\
\mathbf{1} \cdot r & \mapsto & r & \lambda f_1\, f_2\, v.\, Seq(f_1\, Empty, f_2\, v) \\
r + \mathbf{0} & \mapsto & r & \lambda f_1\, f_2\, v.\, Left(f_1\, v) \\
\mathbf{0} + r & \mapsto & r & \lambda f_1\, f_2\, v.\, Right(f_2\, v) \\
r + r & \mapsto & r & \lambda f_1\, f_2\, v.\, Left(f_1\, v)
\end{array}
$$

old *simp* returns a rexp;
new *simp* returns a rexp and a rectification function.

Rectification $\_ + \_$

$simp(r)$:

case $r = r_1 + r_2$

let $(r_{1s}, f_{1s}) = simp(r_1)$

$(r_{2s}, f_{2s}) = simp(r_2)$

case $r_{1s} = \mathbf{0}$: return $(r_{2s}, \lambda v.\, Right(f_{2s}(v)))$

case $r_{2s} = \mathbf{0}$: return $(r_{1s}, \lambda v.\, Left(f_{1s}(v)))$

case $r_{1s} = r_{2s}$: return $(r_{1s}, \lambda v.\, Left(f_{1s}(v)))$

otherwise: return $(r_{1s} + r_{2s}, f_{alt}(f_{1s}, f_{2s}))$

$f_{alt}(f_1, f_2) \stackrel{\text{def}}{=}$

$\lambda v.$ case $v = Left(v')$: return $Left(f_1(v'))$

case $v = Right(v')$: return $Right(f_2(v'))$

```
def simp(r: Rexp): (Rexp, Val => Val) = r match {
  case ALT(r1, r2) => {
    val (r1s, f1s) = simp(r1)
    val (r2s, f2s) = simp(r2)
    (r1s, r2s) match {
      case (ZERO, _) => (r2s, F_RIGHT(f2s))
      case (_, ZERO) => (r1s, F_LEFT(f1s))
      case _ =>
         if (r1s == r2s) (r1s, F_LEFT(f1s))
         else (ALT (r1s, r2s), F_ALT(f1s, f2s))
    }
  }
  ...
}
def F_RIGHT(f: Val => Val) = (v:Val) => Right(f(v))
def F_LEFT(f: Val => Val) = (v:Val) => Left(f(v))
def F_ALT(f1: Val => Val, f2: Val => Val) =
  (v:Val) => v match {
    case Right(v) => Right(f2(v))
    case Left(v) => Left(f1(v)) }
```

Rectification $\_ \cdot \_$

$simp(r)$:...

case $r = r_1 \cdot r_2$

let $(r_{1s}, f_{1s}) = simp(r_1)$

$(r_{2s}, f_{2s}) = simp(r_2)$

case $r_{1s} = \mathbf{0}$: return $(\mathbf{0}, f_{error})$

case $r_{2s} = \mathbf{0}$: return $(\mathbf{0}, f_{error})$

case $r_{1s} = \mathbf{1}$: return $(r_{2s}, \lambda v.\, Seq(f_{1s}(Empty), f_{2s}(v)))$

case $r_{2s} = \mathbf{1}$: return $(r_{1s}, \lambda v.\, Seq(f_{1s}(v), f_{2s}(Empty)))$

otherwise: return $(r_{1s} \cdot r_{2s}, f_{seq}(f_{1s}, f_{2s}))$

$f_{seq}(f_1, f_2) \stackrel{\text{def}}{=}$

$\lambda v.$ case $v = Seq(v_1, v_2)$: return $Seq(f_1(v_1), f_2(v_2))$

```
def simp(r: Rexp): (Rexp, Val => Val) = r match {
  case SEQ(r1, r2) => {
    val (r1s, f1s) = simp(r1)
    val (r2s, f2s) = simp(r2)
    (r1s, r2s) match {
      case (ZERO, _) => (ZERO, F_ERROR)
      case (_, ZERO) => (ZERO, F_ERROR)
      case (ONE, _) => (r2s, F_SEQ_Empty1(f1s, f2s))
      case (_, ONE) => (r1s, F_SEQ_Empty2(f1s, f2s))
      case _ => (SEQ(r1s,r2s), F_SEQ(f1s, f2s))
    }
  }
  ...}
def F_SEQ_Empty1(f1: Val => Val, f2: Val => Val) =
  (v:Val) => Sequ(f1(Empty), f2(v))
def F_SEQ_Empty2(f1: Val => Val, f2: Val => Val) =
  (v:Val) => Sequ(f1(v), f2(Empty))
def F_SEQ(f1: Val => Val, f2: Val => Val) =
  (v:Val) => v match {
    case Sequ(v1, v2) => Sequ(f1(v1), f2(v2)) }
```

Rectification Example

$$(b \cdot c) + (\mathbf{0} + \mathbf{1}) \mapsto (b \cdot c) + \mathbf{1}$$

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$$\begin{aligned} f_{s1} &= \lambda v.v \\ f_{s2} &= \lambda v.Right(v) \end{aligned}$$

Rectification Example

$$\underline{(b \cdot c) + (\mathbf{0} + \mathbf{1})} \mapsto (b \cdot c) + \mathbf{1}$$

$$\begin{array}{lcl} f_{s1} & = & \lambda v.v \\ f_{s2} & = & \lambda v.Right(v) \end{array}$$

$$f_{alt}(f_{s1}, f_{s2}) \stackrel{\text{def}}{=}$$
$$\lambda v.\ \text{case}\ v = Left(v'):\ \ \text{return}\ Left(f_{s1}(v'))$$
$$\text{case}\ v = Right(v'):\ \text{return}\ Right(f_{s2}(v'))$$

Rectification Example

$$\underline{(b \cdot c) + (\mathbf{0} + \mathbf{1})} \mapsto (b \cdot c) + \mathbf{1}$$

$$\begin{array}{lcl} f_{s1} & = & \lambda v.v \\ f_{s2} & = & \lambda v.Right(v) \end{array}$$

$$\begin{array}{ll} \lambda v. & \text{case } v = Left(v'): \quad \text{return } Left(v') \\ & \text{case } v = Right(v'): \text{return } Right(Right(v')) \end{array}$$

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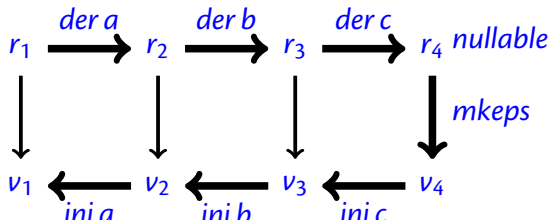
mkeps simplified case: $Right(Empty)$
rectified case: $Right(Right(Empty))$

Lexing with Simplification

$$lex\ r\ [] \stackrel{\text{def}}{=} \text{if } nullable(r) \text{ then } mkeps(r) \text{ else } error$$

$$lex\ r\ c :: s \stackrel{\text{def}}{=} \text{let } (r', frect) = simp(der(c, r))$$
$$inj\ r\ c\ (frect(lex(r', s)))$$



Environments

Obtaining the "recorded" parts of a value:

$$
\begin{array}{lcl}
env(Empty) & \stackrel{\text{def}}{=} & [] \\
env(Char(c)) & \stackrel{\text{def}}{=} & [] \\
env(Left(v)) & \stackrel{\text{def}}{=} & env(v) \\
env(Right(v)) & \stackrel{\text{def}}{=} & env(v) \\
env(Seq(v_1, v_2)) & \stackrel{\text{def}}{=} & env(v_1) \mathbin{@} env(v_2) \\
env(Stars\,[v_1, \ldots, v_n]) & \stackrel{\text{def}}{=} & env(v_1) \mathbin{@} \ldots \mathbin{@} env(v_n) \\
env(Rec(x : v)) & \stackrel{\text{def}}{=} & (x : |v|) :: env(v)
\end{array}
$$

While Tokens

$$\texttt{WHILE\_REGS} \stackrel{\text{def}}{=} (\texttt{("k" : KEYWORD)} + \texttt{("i" : ID)} + \texttt{("o" : OP)} + \texttt{("n" : NUM)} + \texttt{("s" : SEMI)} + \texttt{("p" : (LPAREN + RPAREN))} + \texttt{("b" : (BEGIN + END))} + \texttt{("w" : WHITESPACE)})^*$$

```
"if true then then 42 else +"
```

```
KEYWORD(if),
WHITESPACE,
IDENT(true),
WHITESPACE,
KEYWORD(then),
WHITESPACE,
KEYWORD(then),
WHITESPACE,
NUM(42),
WHITESPACE,
KEYWORD(else),
WHITESPACE,
OP(+)
```

```
"if true then then 42 else +"
```

```
KEYWORD(if),
IDENT(true),
KEYWORD(then),
KEYWORD(then),
NUM(42),
KEYWORD(else),
OP(+)
```

Lexer: Two Rules

- Longest match rule ("maximal munch rule"): The longest initial substring matched by any regular expression is taken as next token.
- Rule priority: For a particular longest initial substring, the first regular expression that can match determines the token.

Environments

Obtaining the "recorded" parts of a value:

$$
\begin{array}{lcl}
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\end{array}
$$

While Tokens

$$
\begin{aligned}
\texttt{WHILE\_REGS} \stackrel{\text{def}}{=} \big((&\texttt{"k"} : \texttt{KEYWORD}) + \\
(&\texttt{"i"} : \texttt{ID}) + \\
(&\texttt{"o"} : \texttt{OP}) + \\
(&\texttt{"n"} : \texttt{NUM}) + \\
(&\texttt{"s"} : \texttt{SEMI}) + \\
(&\texttt{"p"} : (\texttt{LPAREN} + \texttt{RPAREN})) + \\
(&\texttt{"b"} : (\texttt{BEGIN} + \texttt{END})) + \\
(&\texttt{"w"} : \texttt{WHITESPACE})\big)^*
\end{aligned}
$$

```
"if true then then 42 else +"
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```
KEYWORD(if),
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NUM(42),
WHITESPACE,
KEYWORD(else),
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OP(+)
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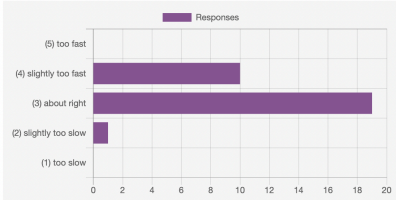
```

```
KEYWORD(if),
IDENT(true),
KEYWORD(then),
KEYWORD(then),
NUM(42),
KEYWORD(else),
OP(+)
```

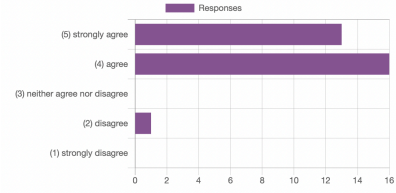
(AppropriatePace) ...teaches at a pace that is:



Show chart data

Average: 3.30

(ExplainsMaterialClearly) ...explains the material clearly



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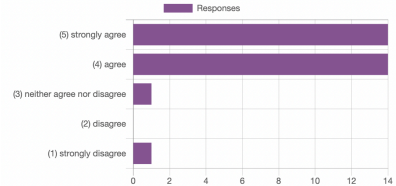
Average: 4.37

(contemporary) ..makes clear the contemporary relevance of the subject



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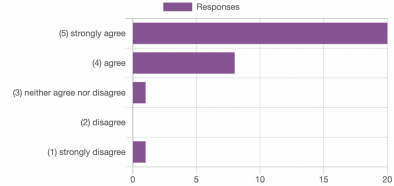
Average: 4.33

(keats) ...provides useful information on KEATS



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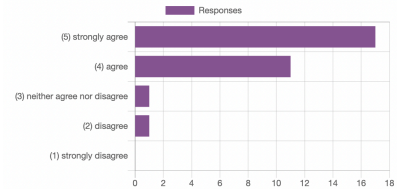
Average: 4.53

(objectives) ...has (have) made the module objectives clear



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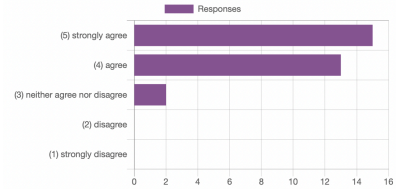
Average: 4.47

(amethods) ...has (have) made the assessment methods clear



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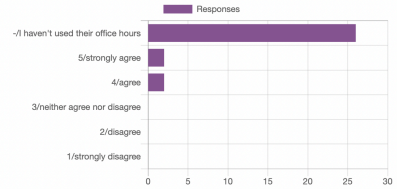
Average: 4.43

(ohours) ...is available to answer questions in office hours:



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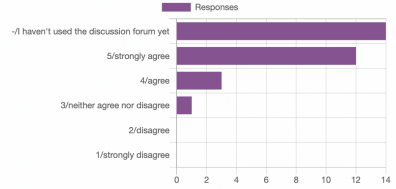
(forum) ...is available to answer questions on the discussion forum:



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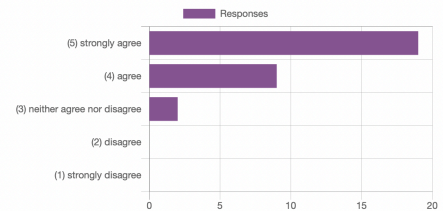
(Audible) The video lectures and other content on KEATS are helpful



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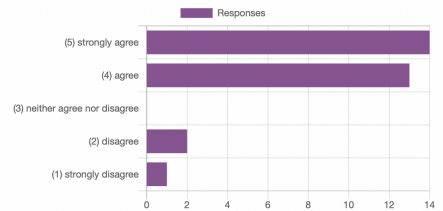
Average: 4.57

(facilities) The live teaching sessions are helpful



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Average: 4.23

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- The handouts and materials on KEATS are very helpful and your explanation is easy to understand especially after both reading the handout and watch the lectures. The LGT is also engaging and I will try my best to engage more. I am actually already impressed by your teaching since 5CCS2PEP.

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- The handouts and materials on KEATS are very helpful and your explanation is easy to understand especially after both reading the handout and watch the lectures. The LGT is also engaging and I will try my best to engage more. I am actually already impressed by your teaching since 5CCS2PEP.
- I believe the module is great, if possible, it would be nice to have a small handout that recaps Scala syntax from PEP last year.

- While I understand you want people to attend the small groups, not providing the solutions to the homework exercises disadvantages those with disabilities (e.g. processing difficulties) as most students take notes of the solutions during the SGTs, and those of us who are unable to do so cannot obtain the full benefit of the sessions. Even if the exam is based on those questions, it is closed-book anyway, so there is no harm in providing the answers. At least allow the TAs to give the solutions to those who attend the SGTs please?

- Really enjoy the content, but would appreciate uploads of the tutorial answers as sometimes we do not have time to go through all of them in the SGTs.

- CFL is a very interesting module and the LGTs are helpful to consolidate information. The homeworks and courseworks are useful for learning the content. My only criticism is that it feels like there is too much content crammed into each week. Between the time taken each week by 2h LGT, 1h SGT, 3-4h of videos, 1-2h homework and time for courseworks, I find it difficult making time for all aspects of this module each week.

- i like this course
- I could learn the material better if the LGTs could somehow be recorded because I've sometimes felt a need to go back to them while revising stuff
- I feel that, as with most modules, there is a lot happening at once. Since we only went through the first coursework it's too early to call, but the workload tends to pile up. I understand it's in the nature of the module, and the work, though difficult, is enjoyable, but there's gotta be a way to mitigate this. Other than that, I am enjoying this module and you, Chris, are a great lecturer!

- Strongly advise you, the lecturer, to take into account that your students have not been studying the subject for as long as you have. Also, that some of us are still waiting to be convinced of the interesting-ness and relevance of the subject, which you often fail to mention in the sessions and in the videos. I find myself lost trying to find a context for the things we are learning.

  …

  I thoroughly enjoy the SGTS where my concerns and questions are welcomed. But I feel uncomfortable to ask you questions in your LGTs because of the way I have heard you respond to other students.