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# Haskell, Do You Read Me?

## Constructing and Composing Efficient Top-down Parsers at Runtime

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# Symptoms

$$
\begin{aligned}
&\textbf{data}\ T1 = T1 :<: T1 \\
&\qquad\qquad \mid\ T1 :>: T1 \\
&\qquad\qquad \mid\ C \\
&\qquad\quad \textbf{deriving}\ (Read, Show) \\
&\textbf{infixl}\ 5\ :<: \\
&\textbf{infixr}\ 6\ :>: \\
&x \qquad\quad :: T1 \\
&x \ = C :<: C :<: C
\end{aligned}
$$

```
*Main> x
(C :<: C) :<: C
```

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\begin{aligned}
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&x \ = C :<: C :<: C \\
&x' = (read \circ show)\ \$\ C :<: C :<: C
\end{aligned}
$$

```
*Main> x'
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&\textbf{infixr}\ 6\ :>: \\
&x, x', x'' :: T1 \\
&x\ \ = C :<: C :<: C \\
&x' = (read \circ show)\ \$\ C :<: C :<: C \\
&x'' = read\ \texttt{"C :<: C :<: C"}
\end{aligned}
$$

```
*Main> x''
*** Exception: Prelude.read: no parse
```

# Symptoms

```
data T1 = T1 :<: T1
        |  T1 :>: T1
        |  C
        deriving (Read, Show)
infixl 5 :<:
infixr 6 :>:
x, x', x'' :: T1
x   = C :<: C :<: C
x'  = (read . show) $ C :<: C :<: C
x'' = read "C :<: C :<: C"
```

Ideally, you should be able to *read* every valid constant expression.

# Parentheses

```
*Main> time (read "C" :: T1)
C
CPU Time: 0 ms
```

# Parentheses

```
*Main> time (read "C" :: T1)
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CPU Time: 0 ms

*Main> time (read "(((((C)))))" :: T1)
C
CPU Time: 74 ms
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CPU Time: 389 ms
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*Main> time (read "((((((C))))))" :: T1)
C
CPU Time: 389 ms

*Main> time (read "(((((((C)))))))" :: T1)
C
CPU Time: 1753 ms
```

# Breadth-first Parsing

The language which is actually recognised by the generated *read* function is described by the non left-recursive grammar:

| | |
|---|---|
| $T1\ (n) \rightarrow\ T1\ (6)$ ":<:" $T1\ (6)$ | $(n \leqslant 5)$ |
| $\mid\ T1\ (7)$ ":>:" $T1\ (7)$ | $(n \leqslant 6)$ |
| $\mid$ "C" | $(n \leqslant 10)$ |
| $\mid$ "(" $T1\ (0)$ ")" | $(n \leqslant 10)$ |

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Three parallel parsers are started up for the first '(', and so on recursively.

# Common Left-factors

Unfortunately the problem also shows up for more reasonable expressions such as $C$ :>: ($C$ :>: ($C$ :>: ...)).

We remove the conditions, and encode them in the non-terminals.

$$
\begin{array}{lll}
T1\ (0..5) & \rightarrow & T1\ (6)\ \texttt{":<:"}\ T1\ (6) \mid T1\ (6) \\
T1\ (6) & \rightarrow & T1\ (7)\ \texttt{":>:"}\ T1\ (7) \mid T1\ (7) \\
T1\ (7..10) & \rightarrow & \texttt{"C"} \\
 & & \mid\ \texttt{"("}\ T1\ (0)\ \texttt{")"}
\end{array}
$$

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We see that some alternatives start with the same non-terminal symbol.

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- Derived $show$ functions generate the needed extra parentheses, in order to make $read \circ show$ work.
- These extra parentheses make parsing take exponential time.
- Common left-factors have a similar effect.

# How Does the Problem Arise?

```
infix 5 :+:
infix 6 :*:

data T2 a = T2 a :+: T2 a
          | a    :*: T2 a
          | C2
          deriving Read
t2 :: T2 (T2 Int)
t2 = read "(3 :*: C2) :*: C2"
```

The function *read* is a member of the class *Read*:

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- *read* functions are elements in dictionaries
- **instance**-declarations compose new dictionaries out of existing dictionaries at run-time
- hence *read* functions are to be composed at run-time

# The Bad News

- Bottom-up parsers do not compose at all, and all perform an analysis of the complete grammar (YACC, Happy)
- Top-down parsers do not compose efficiently for arbitrary grammars, and may lead to left-recursive parsers if no care is taken:

$$\begin{array}{l} \textbf{data}\ T1\ a = a \quad\quad\ \ :*: Int\ \textbf{deriving}\ Read \\ \textbf{data}\ T2 \quad = T1\ T2 :+: Int\ \textbf{deriving}\ Read \end{array}$$

# The Bad and the Good News

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- Grammars can be composed!

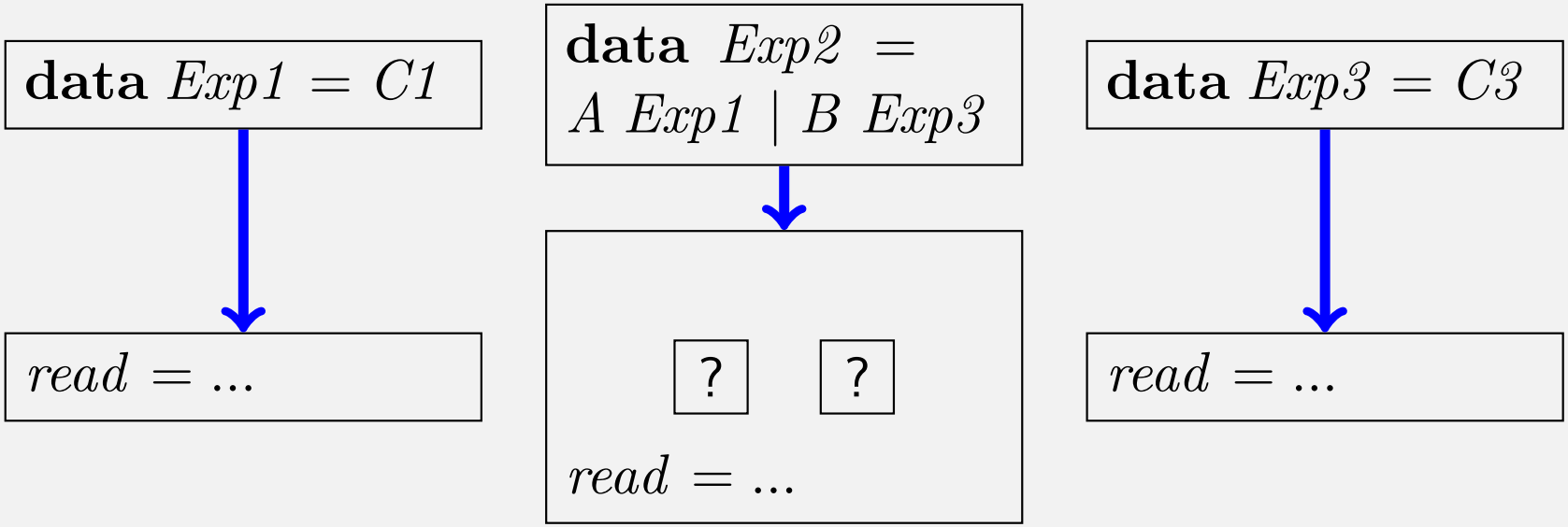
# Using Grammars instead of Parsers

$$\boxed{\textbf{data}\ Exp1 = C1}$$

$$\boxed{\begin{array}{l}\textbf{data}\ Exp2 = \\ A\ Exp1 \mid B\ Exp3\end{array}}$$

$$\boxed{\textbf{data}\ Exp3 = C3}$$

# Using Grammars instead of Parsers




derive

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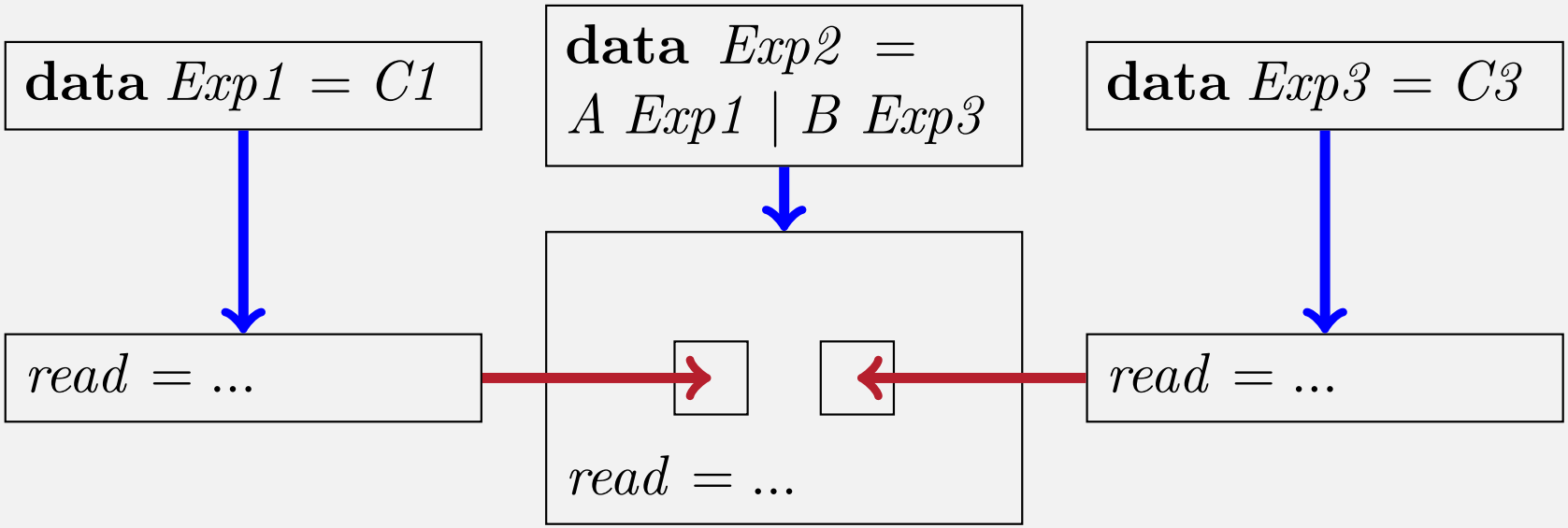


derive parameterise

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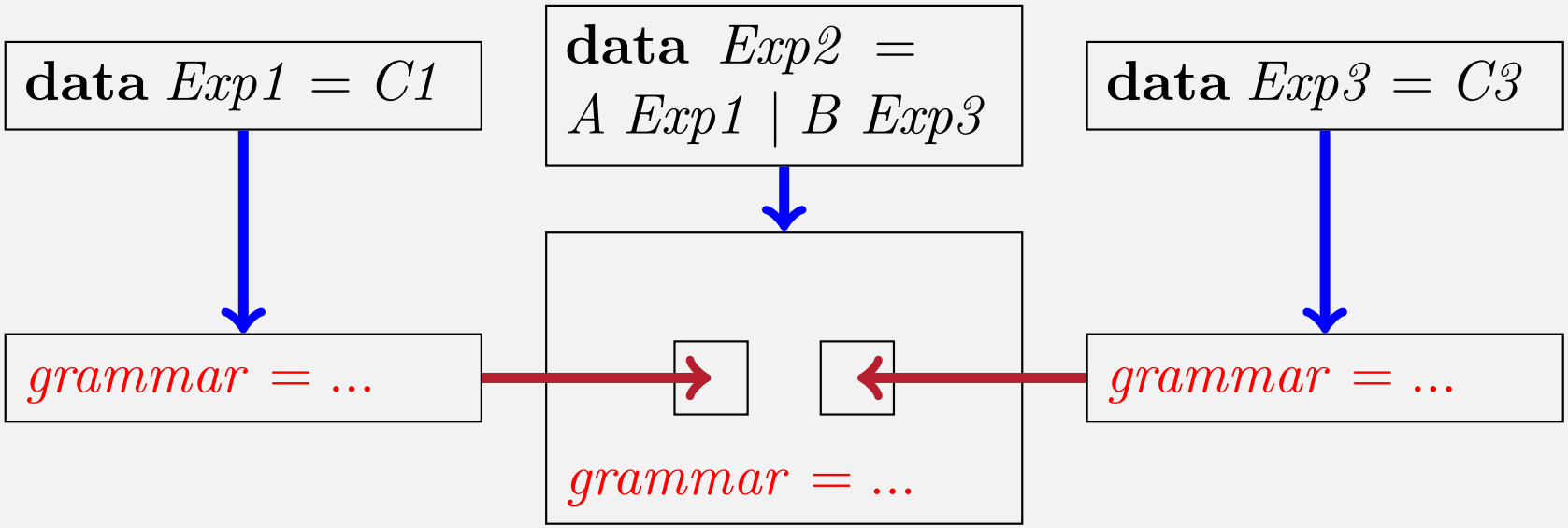


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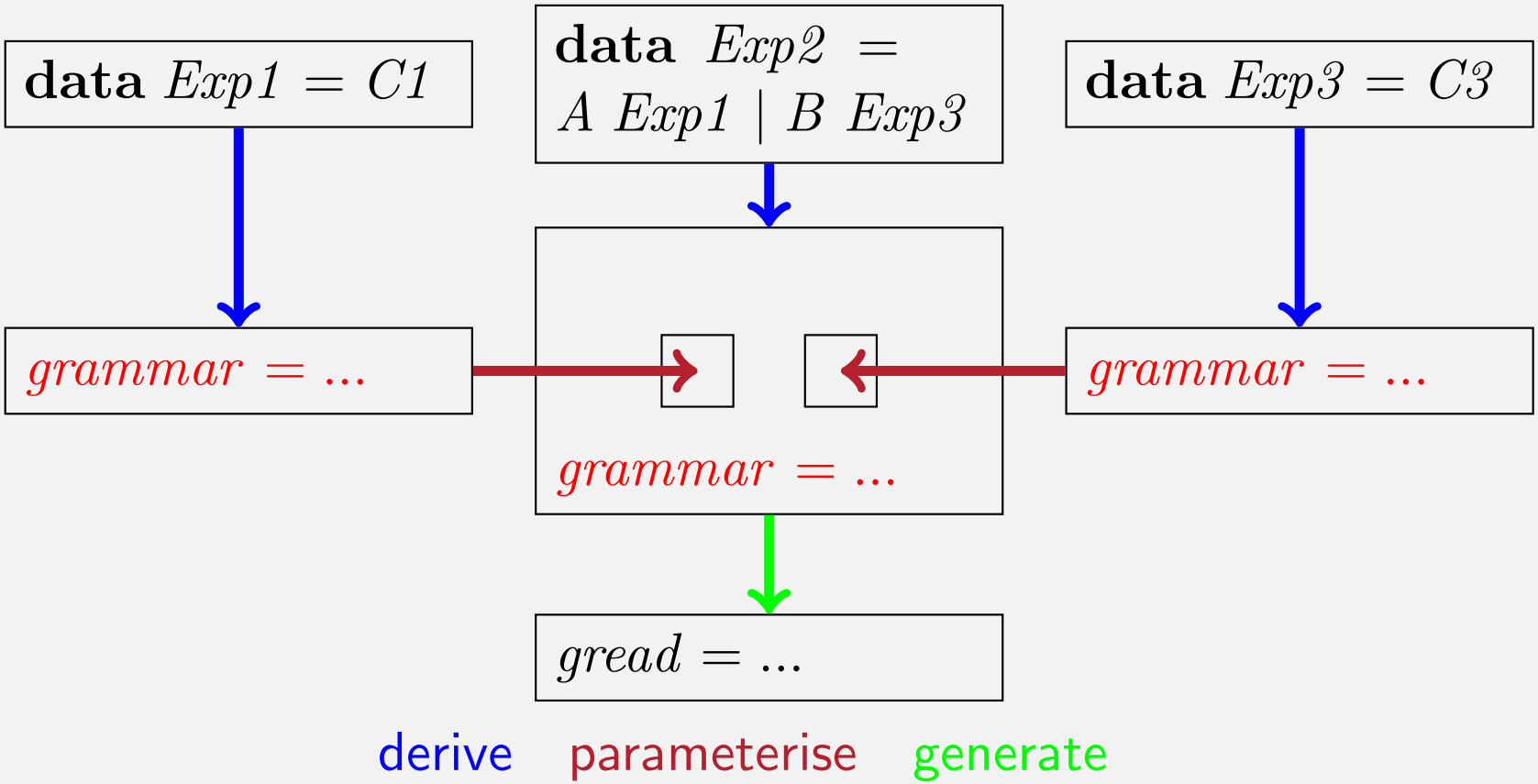

# The Class *Gram*

Instead of the class *Read* we introduce:

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class Gram a where
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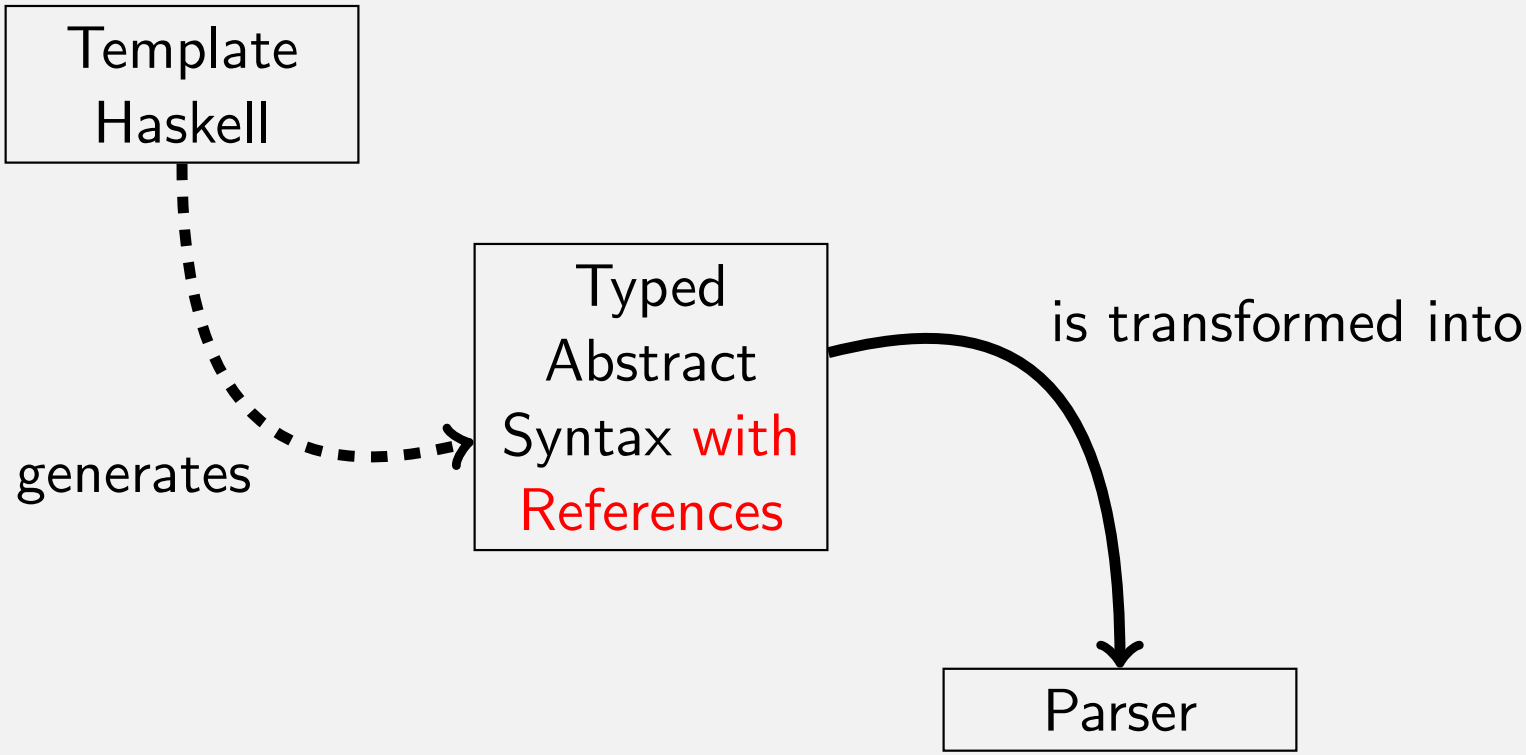
Note that it is labelled with a type $a$, which is the data type described by a value of type $DGrammar\ a$.
Now we can, just as for *read* define:

```
read  :: Read a  => String -> a
gread :: Gram a => String -> a
```

# Generating parsers from Data Types



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$$
\begin{aligned}
&gread :: Gram\ a \Rightarrow String \rightarrow a \\
&gread = (parse \circ compile \quad \circ leftfactoring \\
&\qquad\qquad \circ leftcorner \circ group)\ grammar
\end{aligned}
$$

# Types Abstract Syntax with Explicit References

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- Right hand sides of productions contain references to non-terminals
- We want to be able to inspect and transform the grammar
- We want to inspect the underlying graph structure
- Of which the nodes are labelled with different types
- So we use heterogeneous collections, i.e. we use nested cartesian products, henceforth called $Env$-ironments

# References and Environments I

We introduce natural numbers, labelled with a type $a$ describing what is referred to, and a list of types $env$ describing the structure in which this $a$ labelled object lives:

$$
\begin{aligned}
&\textbf{data}\ \mathit{Ref}\ a\ \mathit{env}\ \textbf{where}\\
&\quad \mathit{Zero} :: \qquad\qquad\quad \mathit{Ref}\ a\ (a, \mathit{env})\\
&\quad \mathit{Suc}\ \ :: \mathit{Ref}\ a\ \mathit{env}' \to \mathit{Ref}\ a\ (x, \mathit{env}')\\
&\textbf{data}\ \mathit{Equal}\ a\ b\ \textbf{where}\\
&\quad \mathit{Eq} :: \mathit{Equal}\ a\ a\\
&\mathit{match} :: \mathit{Ref}\ a\ \mathit{env} \to \mathit{Ref}\ b\ \mathit{env} \to \mathit{Maybe}\ (\mathit{Equal}\ a\ b)\\
&\mathit{match}\ \mathit{Zero}\ \ \ \mathit{Zero}\ \ \ \ = \mathit{Just}\ \mathit{Eq}\\
&\mathit{match}\ (\mathit{Suc}\ x)\ (\mathit{Suc}\ y) = \mathit{match}\ x\ y\\
&\mathit{match}\ \_\ \ \ \_\ \ \ \ = \mathit{Nothing}
\end{aligned}
$$

# References and Environments II

$$
\begin{array}{l}
\textbf{data}\ \mathit{Env}\ t\ \mathit{use}\ \mathit{def}\ \textbf{where} \\
\quad \mathit{Empty} :: \mathit{Env}\ t\ \mathit{use}\ () \\
\quad \mathit{Cons} \quad :: t\ a\ \mathit{use} \to \mathit{Env}\ t\ \mathit{use} \qquad \mathit{def}' \\
\qquad\qquad\qquad\qquad \to \mathit{Env}\ t\ \mathit{use}\ (a, \mathit{def}')
\end{array}
$$

$t\ a\ use$ :: a term of type $t$, describing a value of type $a$ contains references pointing into an environment labelled by $use$. The parameter $def$ describes the values actually existing in the $Env$. If $use$ equals $def$ the environment is closed.

# *DGrammar*

$$
\begin{aligned}
&\textbf{data}\ DGrammar\ a \\
&\quad = \forall env.DGrammar\ (Ref\ a\ env) \\
&\qquad\qquad\qquad\qquad (Env\ DGram\ env\ env) \\
&\textbf{data}\ DGram\ a\ env = DGD\ (DLNontDefs\ a\ env) \\
&\qquad\qquad\qquad\qquad\quad \mid\ DGG\ (DGrammar\ a)
\end{aligned}
$$

$$
\textbf{newtype}\ DRef\ a\ env = DRef\ (Ref\ a\ env, Int)
$$

$$
\begin{aligned}
&\textbf{newtype}\ DLNontDefs\ a\ env \\
&\quad = DLNontDefs\ [(DRef\ a\ env, DProductions\ a\ env)]
\end{aligned}
$$

# Continued ..

```
newtype DProductions a env
    = DPS {unDPS :: [DProd a env]}
```

```
data DProd a env where
   DSeq  :: DSymbol b env → DProd (b → a) env
                          → DProd a env
   DEnd :: a              → DProd a env
```

```
data DSymbol a env where
   DNont :: DRef a env → DSymbol a env
   DTerm :: Token      → DSymbol Token env
```

# Typed Abstract Syntax

```
data Exp = Exp :+: Exp
         | C
infixl 6 :+:
```

```
[
                    _Exp                    ":+:"
                    _Exp

,
                    "C"



]
```

# Typed Abstract Syntax

```
data Exp = Exp :+: Exp
         | C
infixl 6 :+:
```

```
[
                    _Exp                    ":+:"
                    _Exp

,
                    "C"
          ,         "("             _Exp
                    ")"

]
```

# Typed Abstract Syntax

```
data Exp = Exp :+: Exp
         | C
infixl 6 :+:
```

```
[ dNont (_Exp   ) .#. dTerm ":+:" .#.
  dNont (_Exp   )

, dTerm "C"
, dTerm "(" .#. dNont (_Exp   ) .#.
  dTerm ")"

]
```

# Typed Abstract Syntax

```
data Exp = Exp :+: Exp
         | C
infixl 6 :+:

[
    DPS [dNont (_Exp, 6) .#. dTerm ":+:" .#.
         dNont (_Exp, 7)                    ]

,
    DPS [dTerm "C"
        ,dTerm "(" .#. dNont (_Exp, 0) .#.
         dTerm ")"                      ]

]
```

# Typed Abstract Syntax

```
data Exp = Exp :+: Exp
         | C
infixl 6 :+:
```

```
[   (DRef (_Exp, 6)
    , DPS [dNont (_Exp, 6) .#. dTerm ":+:" .#.
           dNont (_Exp, 7)                    ]
    )
,   (DRef (_Exp, 10)
    , DPS [dTerm "C"
          , dTerm "(" .#. dNont (_Exp, 0) .#.
            dTerm ")"                       ]
    )
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# Typed Abstract Syntax

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data Exp = Exp :+: Exp
         | C
infixl 6 :+:

[   (DRef (_Exp, 6)
    , DPS [dNont (_Exp, 6) .#. dTerm ":+:" .#.
           dNont (_Exp, 7) .#. dEnd plus]
    )
,   (DRef (_Exp, 10)
    , DPS [dTerm "C" .#. dEnd (const C)
          , dTerm "(" .#. dNont (_Exp, 0) .#.
            dTerm ")" .#. dEnd parenT]
    )
]
plus e1 _ e2 = e2 :+: e1
```

# Typed Abstract Syntax

```
instance Gram Exp where
  grammar = DGrammar _0 envExp

envExp :: Env DGram (Exp, ()) (Exp, ())
envExp = consD (nonts _0) Empty
  where
    nonts _Exp = DLNontDefs
      [   (DRef (_Exp, 6)
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          )
      ]
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# An Intermediate result

$$
\begin{array}{lll}
A & \rightarrow & \texttt{"C1"}\ A\_C1 \mid \texttt{"("}\ A\_\ ( \\
A\_A & \rightarrow & \texttt{":<:"}\ B\ A\_A \mid \texttt{":<:"}\ B \\
A\_B & \rightarrow & A\_A \mid \epsilon \\
A\_C & \rightarrow & \texttt{":>:"}\ B\ A\_B \mid A\_B \\
A\_C1 & \rightarrow & A\_C \\
A\_\ ( & \rightarrow & A\ \texttt{")"}\ A\_C \\
B & \rightarrow & \texttt{"C1"}\ B\_C1 \mid \texttt{"("}\ B\_\ ( \\
B\_C & \rightarrow & \texttt{":>:"}\ B \mid \epsilon \\
B\_C1 & \rightarrow & B\_C \\
B\_\ ( & \rightarrow & A\ \texttt{")"}\ B\_C \\
C & \rightarrow & \texttt{"C1"}\ C\_C1 \mid \texttt{"("}\ C\_\ ( \\
C\_C1 & \rightarrow & \epsilon \\
C\_\ ( & \rightarrow & A\ \texttt{")"}
\end{array}
$$

1. We have introduced new non-terminals
2. Old non-terminals have new productions

# The Transformations

All the transformations can be expressed in terms of an arrow-like type:

$$
\begin{aligned}
&\textbf{data}\ \mathit{Trafo}\ m\ t\ a\ b = \\
&\quad \mathit{Trafo}\ (\forall \mathit{env1}.m\ \mathit{env1} \rightarrow \\
&\qquad\quad \exists \mathit{env2}. \\
&\qquad\quad (m\ \mathit{env2} \\
&\qquad\quad ,\forall s.\quad a\ s \rightarrow T\ \mathit{env2}\ s \rightarrow \mathit{Env}\ t\ s\ \mathit{env1} \rightarrow \\
&\qquad\qquad\quad (b\ s,\quad T\ \mathit{env1}\ s\ ,\ \mathit{Env}\ t\ s\ \mathit{env2}) \\
&\qquad\quad )
\end{aligned}
$$

# Results I

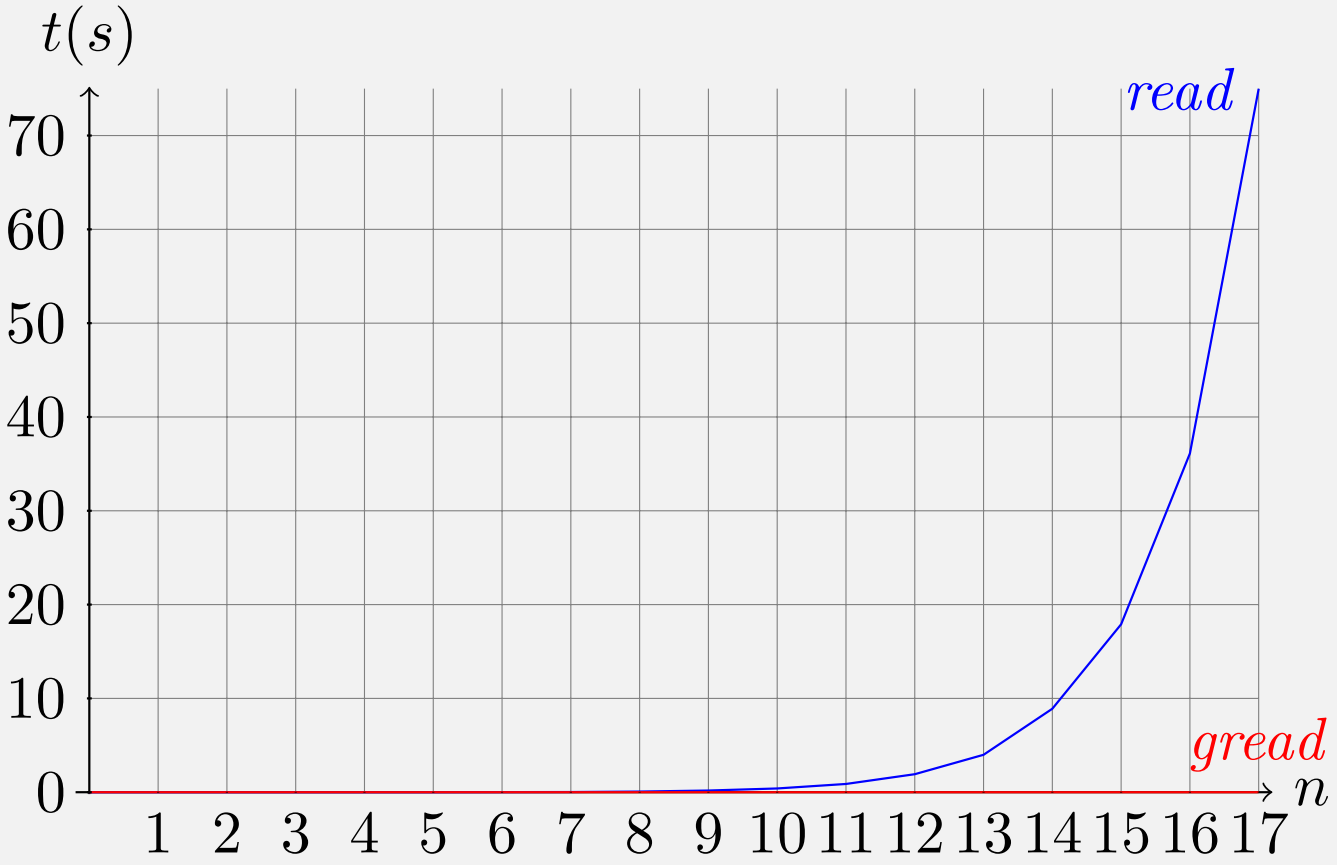


Figure: Execution times of reading $C :> (C :>: ...)$

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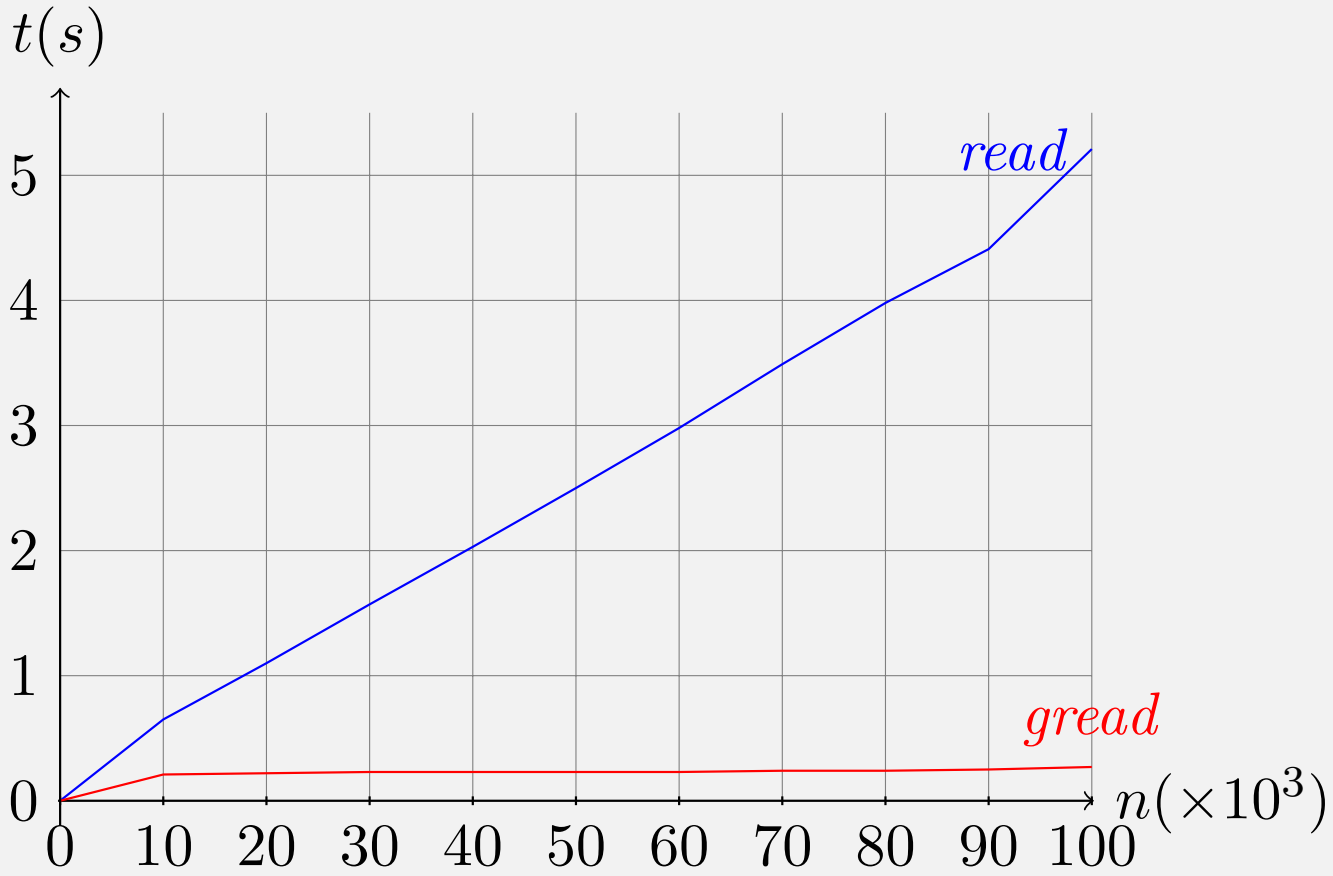
# Reading a Large Data Type




Overhead is very small, and that thanks to the use of the UU-parsers also parse times do hardly increase.

# Why is this so complicated ...

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$$
\begin{array}{l}
f :: \forall a.(a \rightarrow \exists b\ (b, a, b \rightarrow b \rightarrow Int)) \\
\textbf{let}\ (b, a, g) = f\ b \\
\textbf{in}\ \ g\ b\ a
\end{array}
$$

# To Take Home

- The transformation library has been used unmodified for all the transformations
- The library can be used for any collection of abstract syntax trees, which contain references to each other, and of which the structure has to be inspected