Shift Resolve Parsing

Simple, Linear Time, Unbounded Lookahead

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Standard ML

Milner et al. [1997]

Example

```
datatype 'a option = NONE | SOME of 'a

fun filter pred l =
  let
    fun filterP (x::r, l) =
          case (pred x)
            of SOME y => filterP(r, y::l)
             | NONE   => filterP(r, l)
      | filterP ([], l) = rev l
  in
    filterP (l, [])
  end
```

The Issue
SML Compilers Behaviour

```
| filterP ([], l) = rev l
```

- MLton
- Moscow ML
- Poly/ML
- SML/NJ

```
Error: match.sml 9.25.
  Syntax error: replacing  EQUALOP with  DARROW.
```

The Issue
SML Compilers Behaviour

```
  |   filterP ([], l) = rev l
```

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```
! Toplevel input:
!      |  filterP ([], l) = rev l
!                         ^
! Syntax error.
```

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SML Compilers Behaviour

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| filterP ([], l) = rev l
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```
Error: => expected but = was found
```

The Issue
SML Compilers Behaviour

```
  | filterP ([], l) = rev l
```

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```
stdIn:7.24-7.29 Error: syntax error:
  deleting  EQUALOP ID
```

The Issue
Partial SML Grammar

$$\begin{aligned}
<\!dec\!> &\rightarrow \textbf{fun}\ \ <\!fvalbind\!> \\
<\!fvalbind\!> &\rightarrow <\!sfvb\!>|<\!fvalbind\!>\ \ '|'\ \ <\!sfvb\!> \\
<\!sfvb\!> &\rightarrow vid\ \ <\!atpats\!> = <\!exp\!> \\
<\!atpats\!> &\rightarrow <\!atpat\!>|<\!atpats\!>\ <\!atpat\!>
\end{aligned}$$

$$\begin{aligned}
<\!exp\!> &\rightarrow \textbf{case}\ \ <\!exp\!>\ \ \textbf{of}\ \ <\!match\!> \\
<\!match\!> &\rightarrow <\!mrule\!>|<\!match\!>\ \ '|'\ \ <\!mrule\!> \\
<\!mrule\!> &\rightarrow <\!pat\!>\ \ =>\ \ <\!exp\!>
\end{aligned}$$

$$<\!pat\!> \rightarrow vid\ \ <\!atpat\!>$$

The Issue

Shift/Reduce Conflict

- GNU/bison
- Unbounded lookahead needed

```
 9 exp: "case" exp "of" match .
12 match: match . '|' mrule

  '|'  reduce using rule 9 (exp)
  '|'  shift, and go to state 38
```

The Issue
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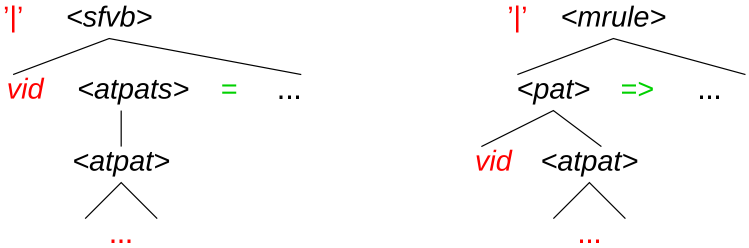

Solutions

1. No human intervention
2. Unambiguity
3. Linear parsing time

- Syntactic predicates
- LR-Regular parser
- Noncanonical LR(1) parser
- Noncanonical DR parser
- Generalized LR parser

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Solutions?

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- LR-Regular parser
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- Noncanonical DR parser
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Solutions?

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Solutions?

1. No human intervention
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Solutions?

No solution with

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A solution with

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} Shift Resolve parser

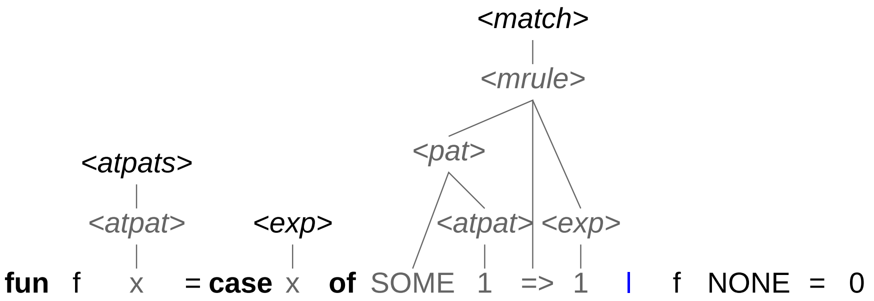
Shift-Resolve Parsing

- noncanonical
- $k = 1$ reduced lookahead symbol
- resolve $=$ reduce $+$ pushback: emulates a bounded reduced lookahead without any preset bound

Shift-Resolve Parsing

- noncanonical
- $k = 1$ reduced lookahead symbol
- resolve = reduce + pushback: emulates a bounded reduced lookahead without any preset bound

fun f x = **case** x **of** SOME 1 => 1 | f NONE = 0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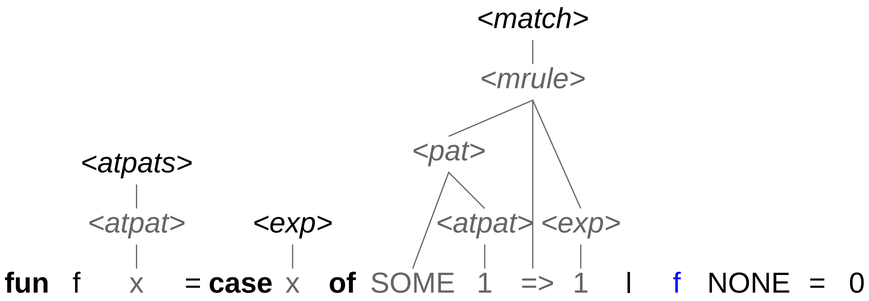

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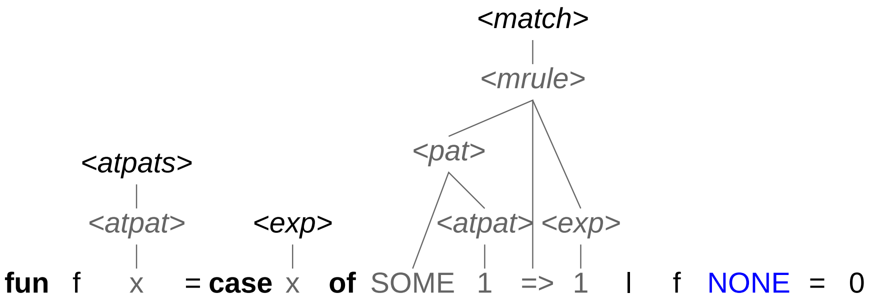
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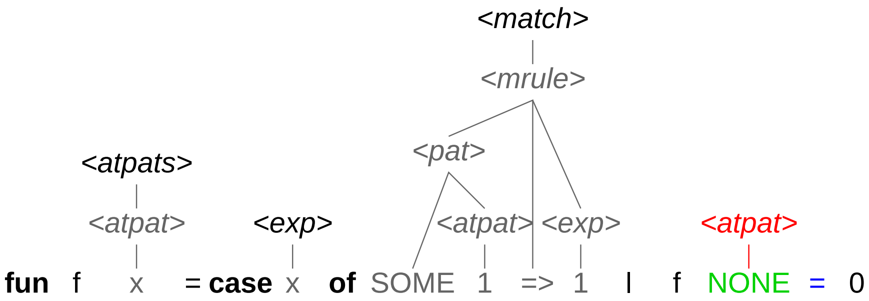
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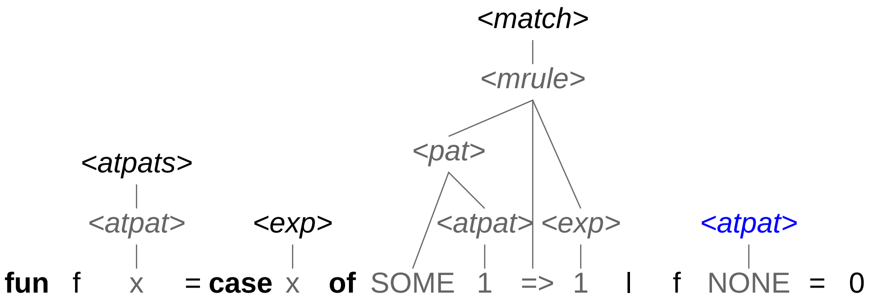

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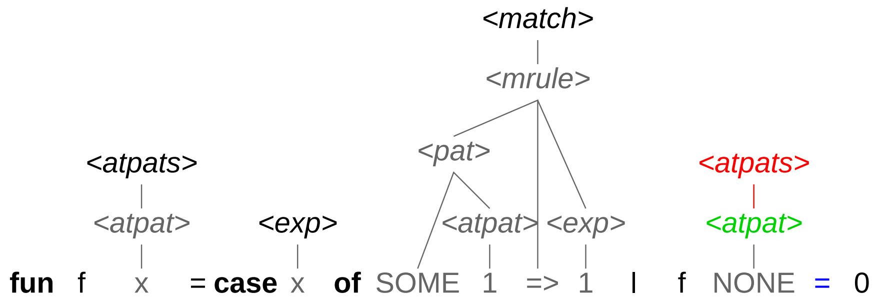
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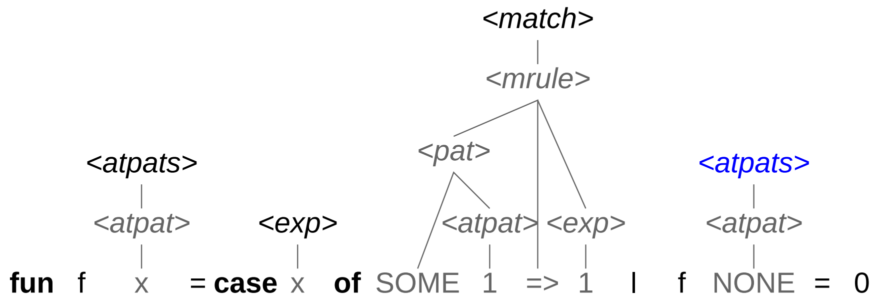
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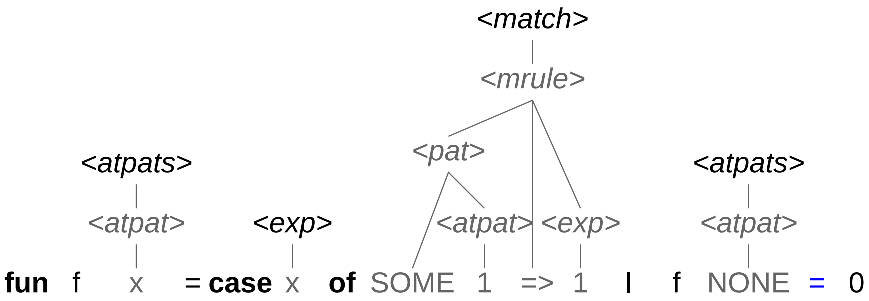
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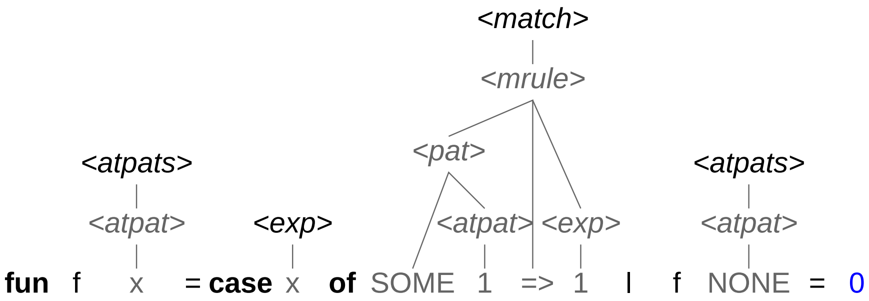
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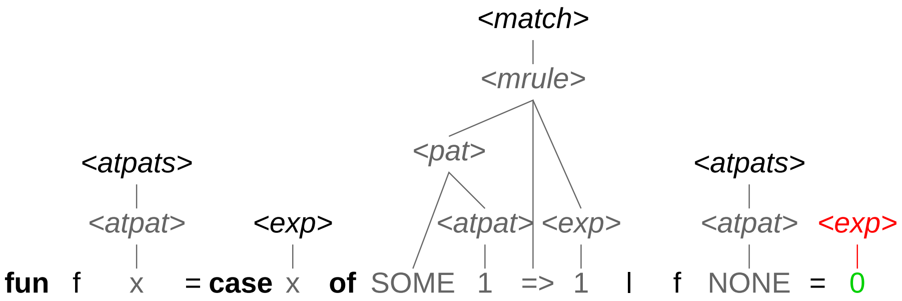

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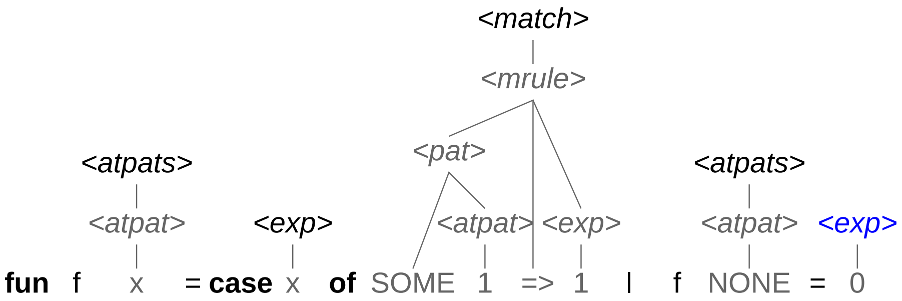
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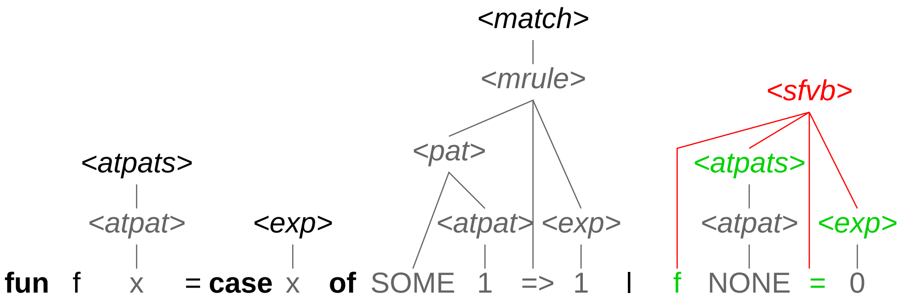
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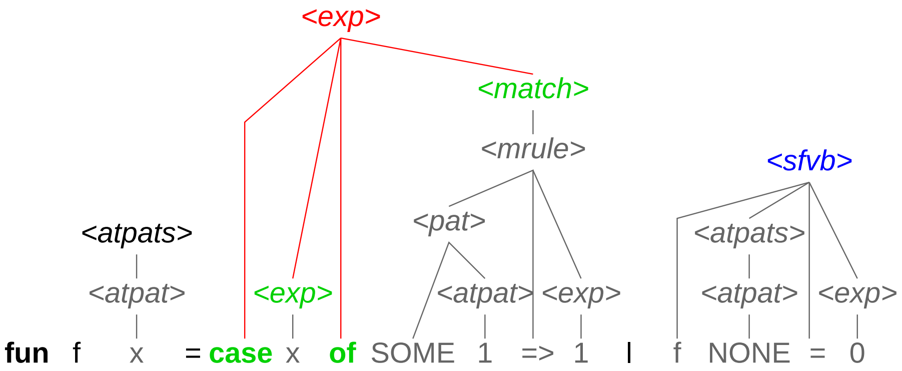
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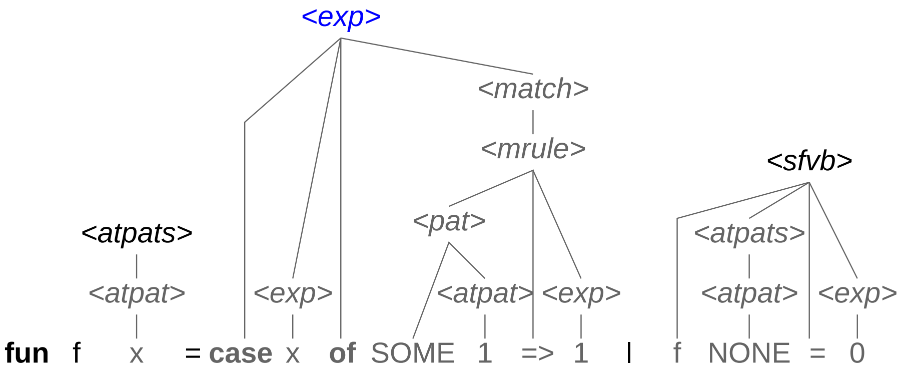
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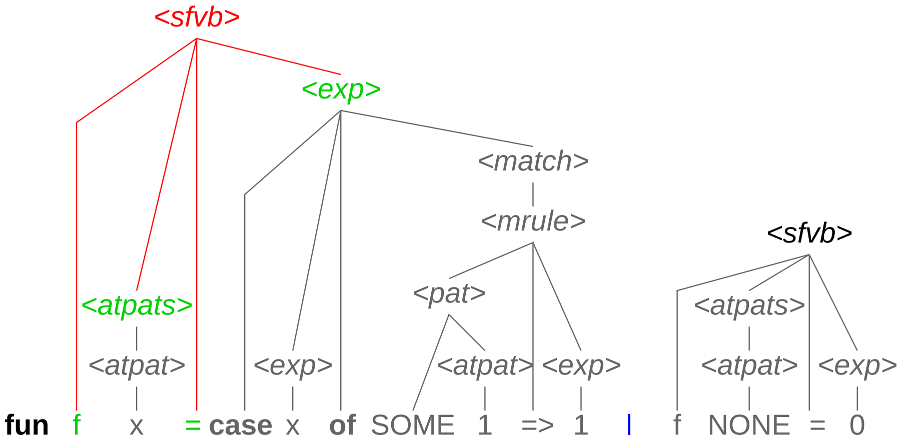

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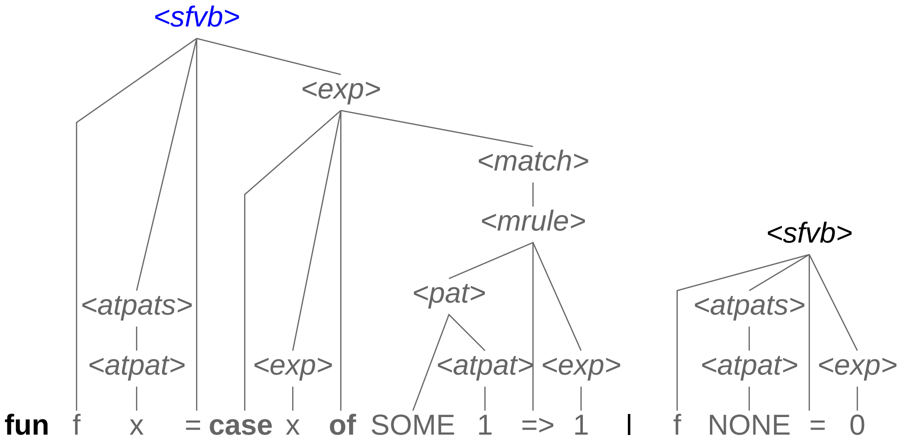
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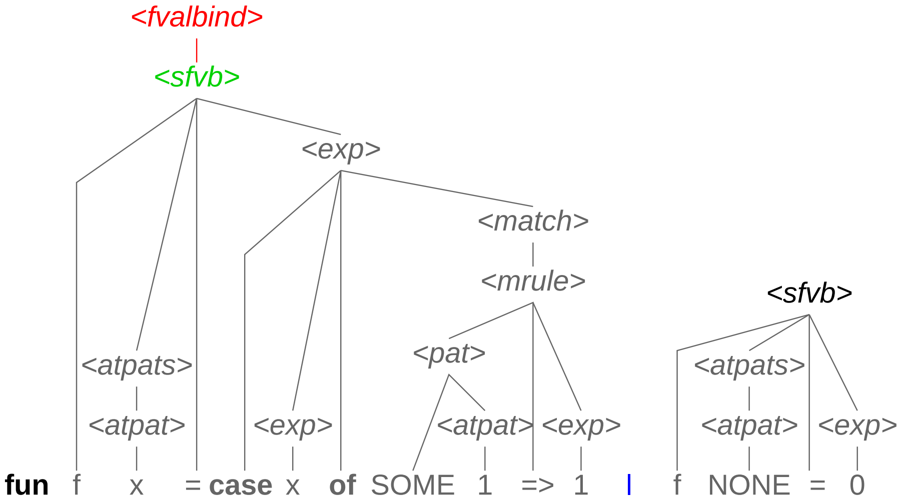

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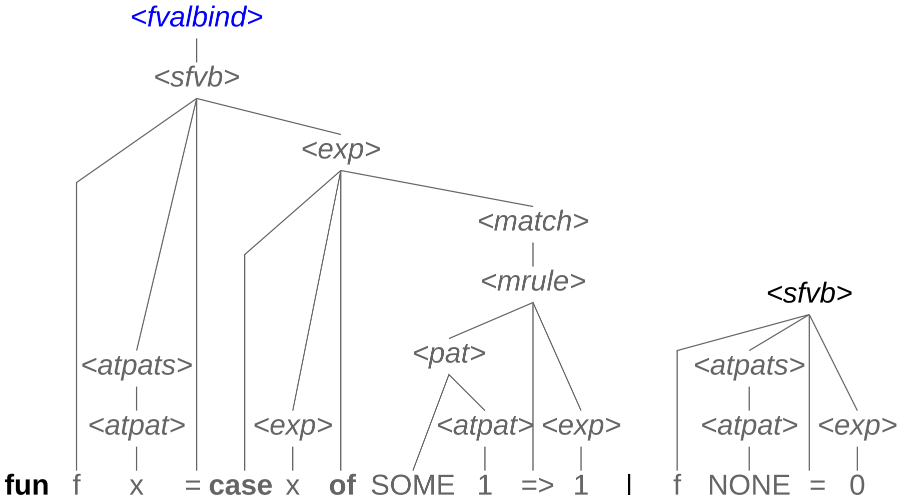
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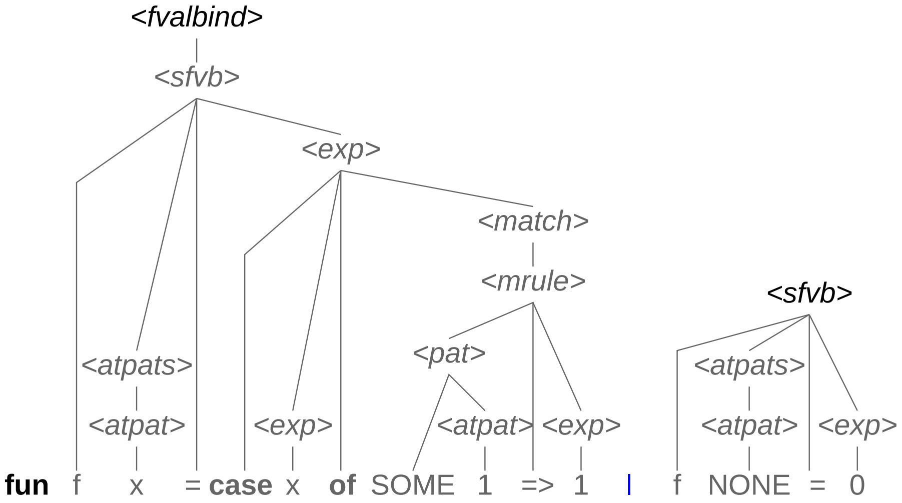

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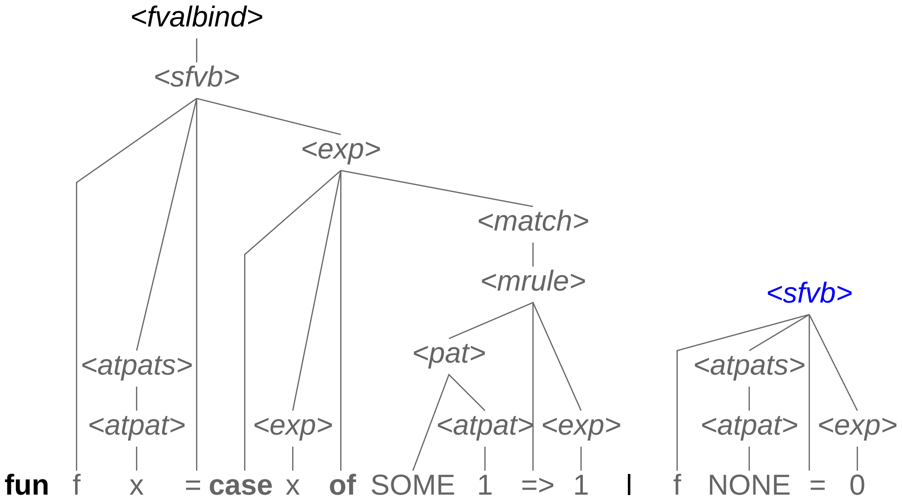

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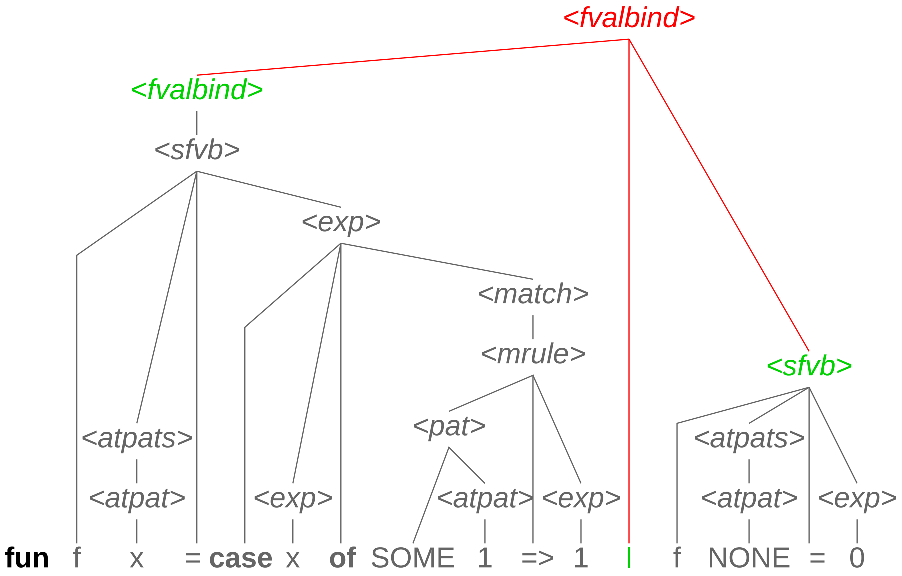
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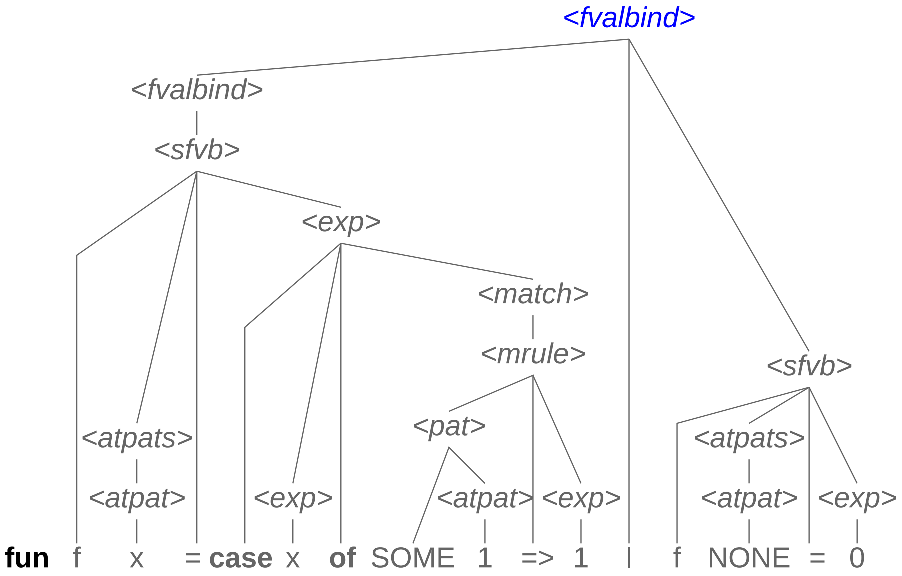
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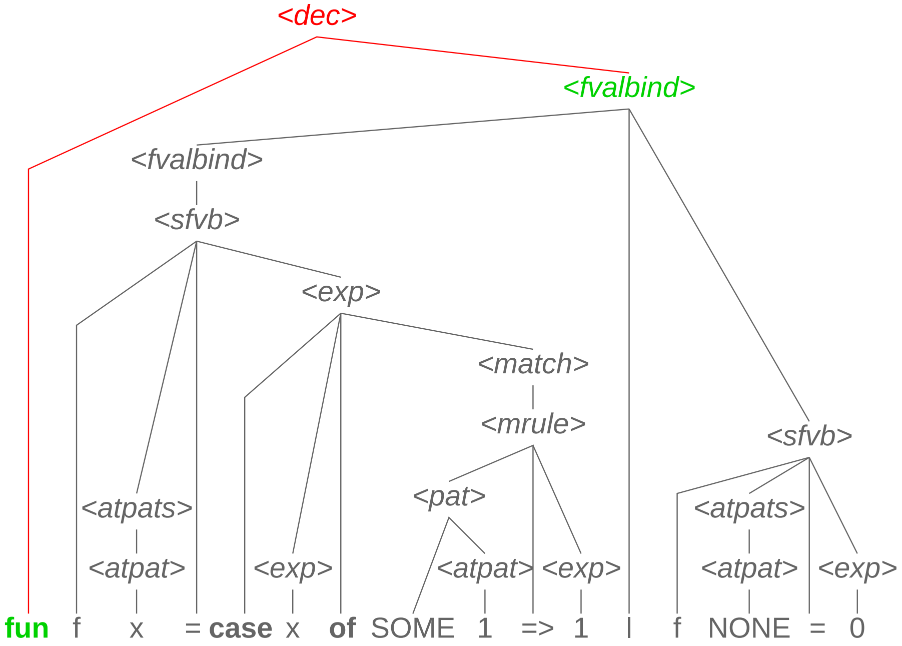
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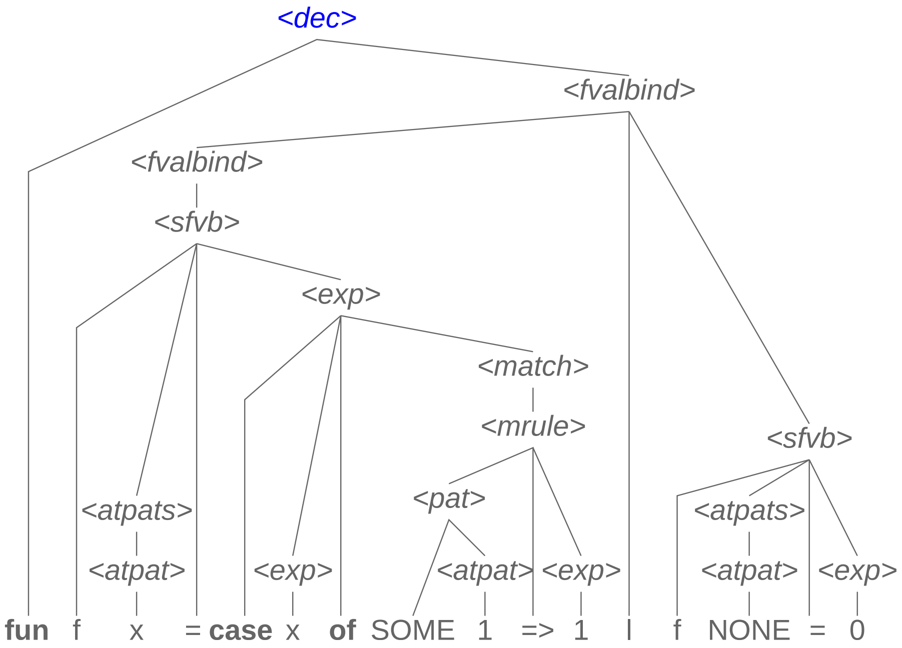

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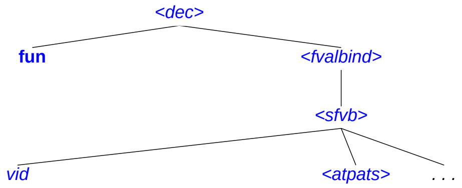
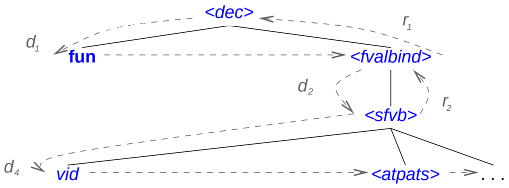
Generating the Parser

1. nondeterministic automaton
2. determinization by subset construction

Position Graph



Position Graph



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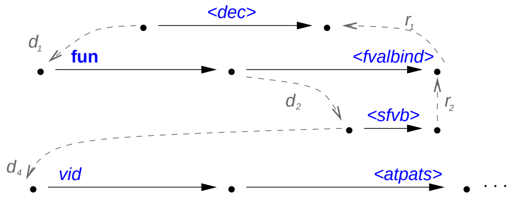

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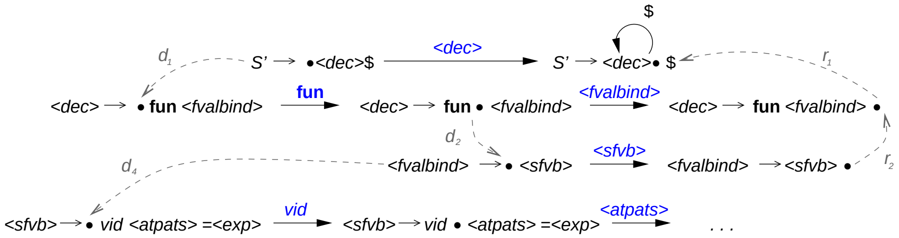

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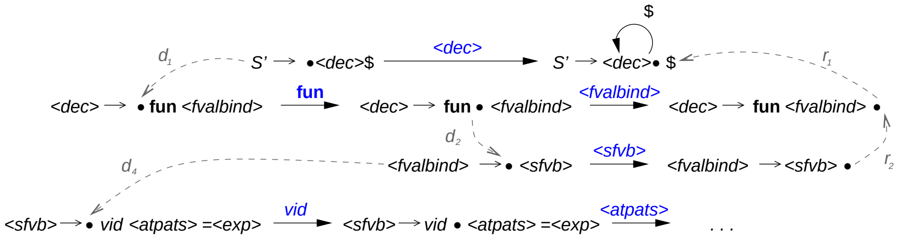

(Potentially) Infinite graph of all derivations trees.

Nondeterministic Automaton

Apply an equivalence relation on the nodes of the position graph.

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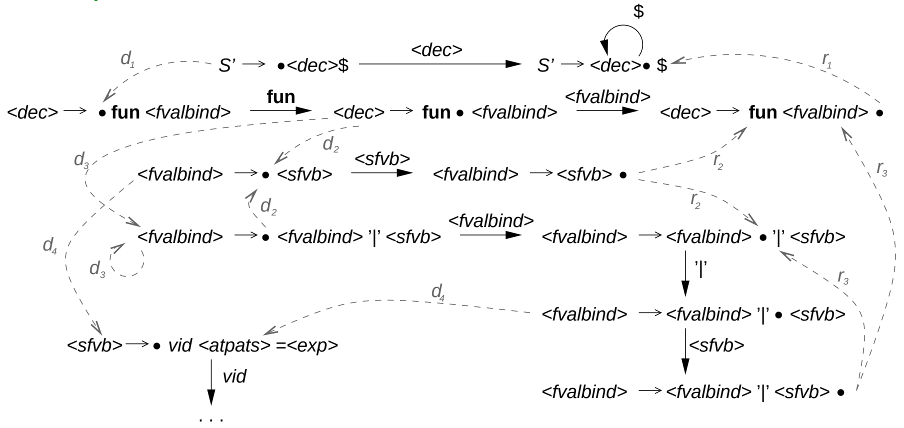
Apply an equivalence relation on the nodes of the position graph.

Example κ_0, same dotted label



Subset Construction

- d_i transitions denote traditional item closures
- r_i transitions denote a phrase that should be reduced
- other transitions denote shifts
- items in the construction hold
  1. a state of the nondeterministic automaton
  2. a parsing action
  3. a pushback length

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Subset Construction

$$\begin{aligned} \textit{<exp>} &\longrightarrow \textbf{case}\ \textit{<exp>}\ \ \textbf{of}\ \ \textit{<match>} \bullet \\ \textit{<match>} &\longrightarrow \textit{<match>} \bullet \text{'|'}\ \textit{<mrule>} \end{aligned}$$

Subset Construction

$$\begin{tikzcd}
\langle exp\rangle \longrightarrow \textbf{case}\ \langle exp\rangle\ \textbf{of}\ \langle match\rangle \bullet \arrow[dd, dashed, bend right, "r_5"'] \\
\langle match\rangle \longrightarrow \langle match\rangle \bullet \text{'|'}\ \langle mrule\rangle \\
\langle sfvb\rangle \longrightarrow vid\ \langle atpats\rangle = \langle exp\rangle \bullet, 5, 0
\end{tikzcd}$$

Subset Construction

$$\begin{array}{rl}
\textit{<exp>} \longrightarrow & \textbf{case}\ \textit{<exp>}\ \ \textbf{of}\ \textit{<match>} \bullet \\
\textit{<match>} \longrightarrow & \textit{<match>} \bullet \text{'|'}\ \textit{<mrule>} \\
r \dashleftarrow \textit{<sfvb>} \longrightarrow & \textit{vid}\ \textit{<atpats>} = \textit{<exp>}\ \bullet, 5, 0 \\
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\textit{<sfvb>} \longrightarrow \textit{vid}\ \textit{<atpats>}\ =\textit{<exp>}\ \bullet, 5, 0 \arrow[dd, dashed, bend right, "r"'] \\
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Subset Construction

$$\begin{tikzcd}[row sep=small]
\textit{<exp>} \longrightarrow \textbf{case}\ \textit{<exp>}\ \textbf{of}\ \textit{<match>} \bullet \\
\textit{<match>} \longrightarrow \textit{<match>} \bullet \text{'|'}\ \textit{<mrule>} \\
\textit{<sfvb>} \longrightarrow \textit{vid}\ \textit{<atpats>} = \textit{<exp>} \bullet, 5, 0 \\
\textit{<fvalbind>} \longrightarrow \textit{<fvalbind>}\ \text{'|'}\ \textit{<sfvb>} \bullet, 5, 0 \arrow[dd, dashed, bend right] \arrow[ddd, dashed, bend right=60, "r"'] \\
\textit{<fvalbind>} \longrightarrow \textit{<sfvb>} \bullet, 5, 0 \\
\textit{<fvalbind>} \longrightarrow \textit{<fvalbind>} \bullet \text{'|'}\ \textit{<sfvb>}, 5, 0 \\
\textit{<dec>} \longrightarrow \textbf{fun}\ \textit{<fvalbind>} \bullet, 5, 0
\end{tikzcd}$$

Subset Construction

<exp> ⟶ **case** *<exp>* **of** *<match>* •

<match> ⟶ *<match>* • '|' *<mrule>*

<sfvb> ⟶ *vid <atpats>* =*<exp>* •, 5, 0

<fvalbind> ⟶ *<fvalbind>* '|' *<sfvb>* •, 5, 0

<fvalbind> ⟶ *<sfvb>* •, 5, 0

<fvalbind> ⟶ *<fvalbind>* • '|' *<sfvb>*, 5, 0

<dec> ⟶ **fun** *<fvalbind>* •, 5, 0

r ⇢ *S'* ⟶ *<dec>* • $, 5, 0

Subset Construction

<exp> $\longrightarrow$ **case** *<exp>* **of** *<match>* •
<match> $\longrightarrow$ *<match>* • '|' *<mrule>*
<sfvb> $\longrightarrow$ *vid <atpats> =<exp>* •, 5, 0
<fvalbind> $\longrightarrow$ *<fvalbind>* '|' *<sfvb>* •, 5, 0
<fvalbind> $\longrightarrow$ *<sfvb>* •, 5, 0
<fvalbind> $\longrightarrow$ *<fvalbind>* • '|' *<sfvb>*, 5, 0
<dec> $\longrightarrow$ **fun** *<fvalbind>* •, 5, 0
S' $\longrightarrow$ *<dec>* • $, 5, 0

Subset Construction

<exp> ⟶ **case** *<exp>* **of** *<match>* •
<match> ⟶ *<match>* • '|' *<mrule>*
<sfvb> ⟶ *vid <atpats>* =*<exp>* •, 5, 0
<fvalbind> ⟶ *<fvalbind>* '|' *<sfvb>* •, 5, 0
<fvalbind> ⟶ *<sfvb>* •, 5, 0
<fvalbind> ⟶ *<fvalbind>* • '|' *<sfvb>*, 5, 0
<dec> ⟶ **fun** *<fvalbind>* •, 5, 0
S' ⟶ *<dec>* • $, 5, 0

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<match> ⟶ *<match>* • '|' *<mrule>*

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<fvalbind> ⟶ *<fvalbind>* '|' *<sfvb>* •, 5, 0

<fvalbind> ⟶ *<sfvb>* •, 5, 0

<fvalbind> ⟶ *<fvalbind>* • '|' *<sfvb>*, 5, 0

<dec> ⟶ **fun** *<fvalbind>* •, 5, 0

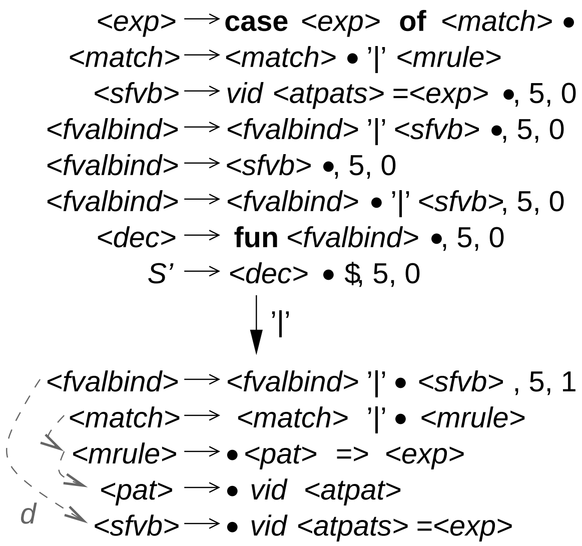
S' ⟶ *<dec>* • $, 5, 0

$$\Big\downarrow \text{'|'}$$

<fvalbind> ⟶ *<fvalbind>* '|' • *<sfvb>* , 5, 1

<match> ⟶ *<match>* '|' • *<mrule>*

Subset Construction



<exp> ⟶ **case** *<exp>* **of** *<match>* •
<match> ⟶ *<match>* • '|' *<mrule>*
<sfvb> ⟶ *vid <atpats>* =*<exp>* •, 5, 0
<fvalbind> ⟶ *<fvalbind>* '|' *<sfvb>* •, 5, 0
<fvalbind> ⟶ *<sfvb>* •, 5, 0
<fvalbind> ⟶ *<fvalbind>* • '|' *<sfvb>*, 5, 0
<dec> ⟶ **fun** *<fvalbind>* •, 5, 0
S' ⟶ *<dec>* • $, 5, 0

$\downarrow$ '|'

<fvalbind> ⟶ *<fvalbind>* '|' • *<sfvb>* , 5, 1
<match> ⟶ *<match>* '|' • *<mrule>*
<mrule> ⟶ • *<pat>* => *<exp>*
<pat> ⟶ • *vid <atpat>*
<sfvb> ⟶ • *vid <atpats>* =*<exp>*

Construction Failure

$<$*exp*$>$ $\longrightarrow$ **case** $<$*exp*$>$ **of** $<$*match*$>$ $\bullet$
$<$*match*$>$ $\longrightarrow$ $<$*match*$>$ $\bullet$ '|' $<$*mrule*$>$
$<$*sfvb*$>$ $\longrightarrow$ *vid* $<$*atpats*$>$ =$<$*exp*$>$ $\bullet$, 5, 0
$<$*fvalbind*$>$ $\longrightarrow$ $<$*fvalbind*$>$ '|' $<$*sfvb*$>$ $\bullet$, 5, 0
$<$*fvalbind*$>$ $\longrightarrow$ $<$*sfvb*$>$ $\bullet$, 5, 0
$<$*fvalbind*$>$ $\longrightarrow$ $<$*fvalbind*$>$ $\bullet$ '|' $<$*sfvb*$>$, 5, 0
$<$*dec*$>$ $\longrightarrow$ **fun** $<$*fvalbind*$>$ $\bullet$, 5, 0
S' $\longrightarrow$ $<$*dec*$>$ $\bullet$ \$, 5, 0

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<dec> ⟶ **fun** *<fvalbind>* •, 5, 0

r_5 *S'* ⟶ *<dec>* • $, 5, 0

<mrule> ⟶ *<pat>* => *<exp>* •, 5, 0

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<exp> ⟶ **case** *<exp>* **of** *<match>* •

<match> ⟶ *<match>* • '|' *<mrule>*

<sfvb> ⟶ *vid <atpats>* =*<exp>* •, 5, 0

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<fvalbind> ⟶ *<sfvb>* •, 5, 0

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<dec> ⟶ **fun** *<fvalbind>* •, 5, 0

S' ⟶ *<dec>* • $, 5, 0

r *<mrule>* ⟶ *<pat>* => *<exp>* •, 5, 0

<match> ⟶ *<mrule>* •, 5, 0

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<exp> → **case** *<exp>* **of** *<match>* •

<match> → *<match>* • '|' *<mrule>*

<sfvb> → *vid <atpats>* =*<exp>* •, 5, 0

<fvalbind> → *<fvalbind>* '|' *<sfvb>* •, 5, 0

<fvalbind> → *<sfvb>* •, 5, 0

<fvalbind> → *<fvalbind>* • '|' *<sfvb>*, 5, 0

<dec> → **fun** *<fvalbind>* •, 5, 0

S' → *<dec>* • $, 5, 0

<mrule> → *<pat>* => *<exp>* •, 5, 0

<match> → *<mrule>* •, 5, 0

r

<match> → *<match>* • '|' *<mrule>*, 5, 0

Handling Ambiguity

Longest match rule:

```
case (pred x)
  of SOME y => case y
    of pattern => filterP(r, y::l)
   | NONE    => filterP(r, l)
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Differentiate two instances of the same shift/reduce conflict!

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$$<exp> \longrightarrow \textbf{case } <exp> \textbf{ of } <match> \bullet$$
$$<match> \longrightarrow <match> \bullet \text{'|'} <mrule>$$
$$<sfvb> \longrightarrow vid <atpats> =<exp> \bullet, 5, 0$$
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$$<dec> \longrightarrow \textbf{fun } <fvalbind> \bullet, 5, 0$$
$$S' \longrightarrow <dec> \bullet \$, 5, 0$$
$$<mrule> \longrightarrow <pat> => <exp> \bullet, 5, 0$$
$$<match> \longrightarrow <mrule> \bullet, 5, 0$$
$$<match> \longrightarrow <match> \bullet \text{'|'} <mrule>, 5, 0$$

Complexity

- $|\Gamma|$: size of the nondeterministic automaton
- $|\mathcal{A}|$: size of the parser: $\mathcal{O}(2^{|\Gamma|\,|P|})$
- parsing time complexity for input w: $\mathcal{O}(|w|)$

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  $|\Gamma_{\kappa_0}| = \mathcal{O}(|\mathcal{G}|\ |P|)$
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– incomparable with classical parsing techniques

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