Lexing and Parsing

David Raymond Christiansen

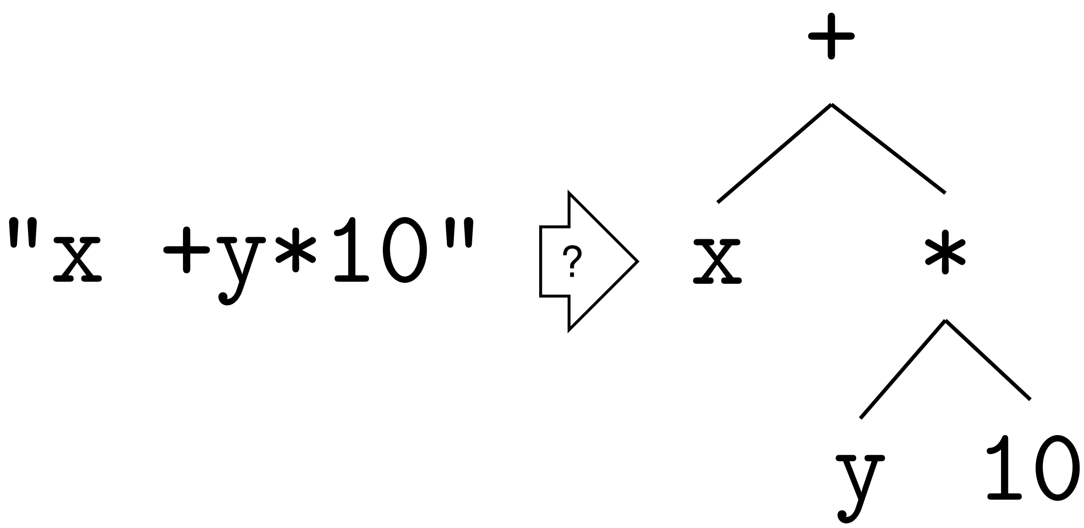
2 September, 2013

These slides have been shortened from the originals available at http://www.itu.dk/courses/BPRD/E2013/

Based on slides by Peter Sestoft

IT University of Copenhagen

From text file to abstract syntax



From text file to abstract syntax

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"x +y*10"
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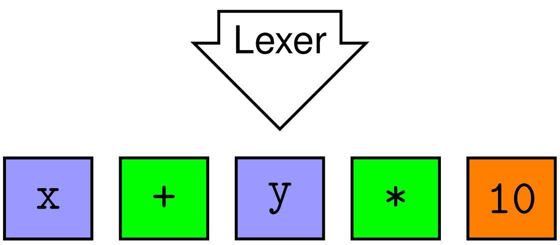

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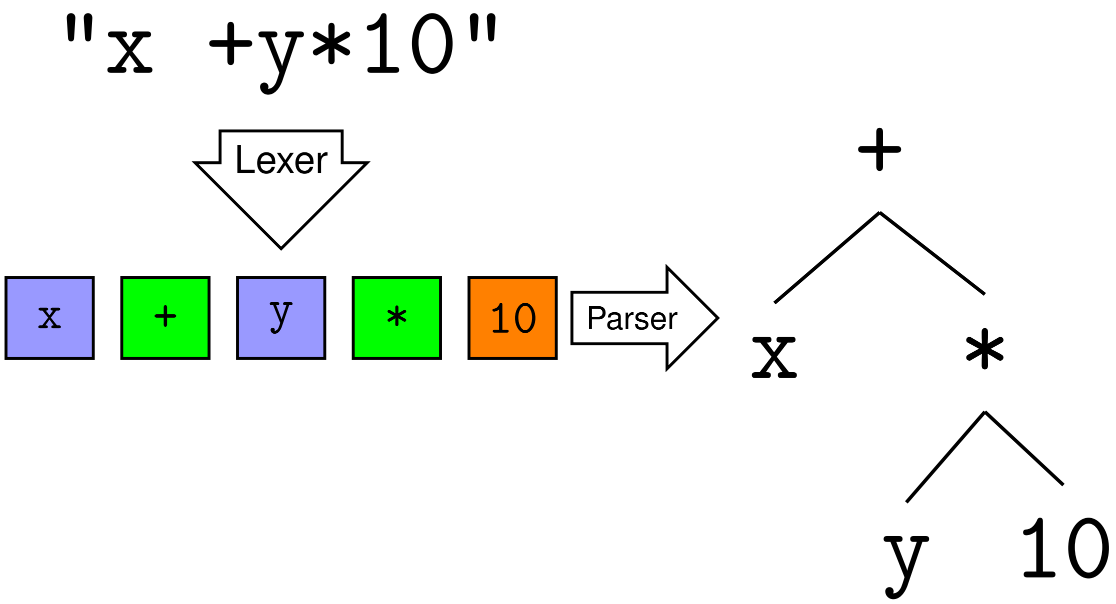

Plan for today

LEXER SPECIFICATIONS
- Regular expressions
- The fslex lexer generation tool
- Automata

PARSER SPECIFICATIONS
- Grammars
- Parsing
- The fsyacc parser generation tool

PARSING ALGORITHMS
- Top-down
- Bottom-up

LANGUAGES AND AUTOMATA

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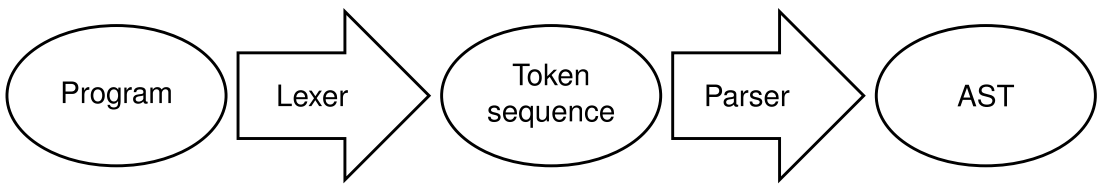
LANGUAGES AND AUTOMATA

Lexers and lexer generators



Regular expressions

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`a`	Character `a`	{"a"}

Regular expressions

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EXAMPLES

$\mathtt{ab}^*$ represents $\{"\mathtt{a}", "\mathtt{ab}", "\mathtt{abb}", \ldots\}$

$(\mathtt{ab})^*$ represents $\{"", "\mathtt{ab}", "\mathtt{abab}", \ldots\}$

$(\mathtt{a}|\mathtt{b})^*$ represents $\{"", "\mathtt{a}", "\mathtt{b}", "\mathtt{aa}", "\mathtt{ab}", "\mathtt{ba}", \ldots\}$

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EXERCISE

What does $(\mathtt{a}|\mathtt{b})\mathtt{c}^*$ represent?

Regular expression abbreviations

Abbrev.	Meaning	Expansion
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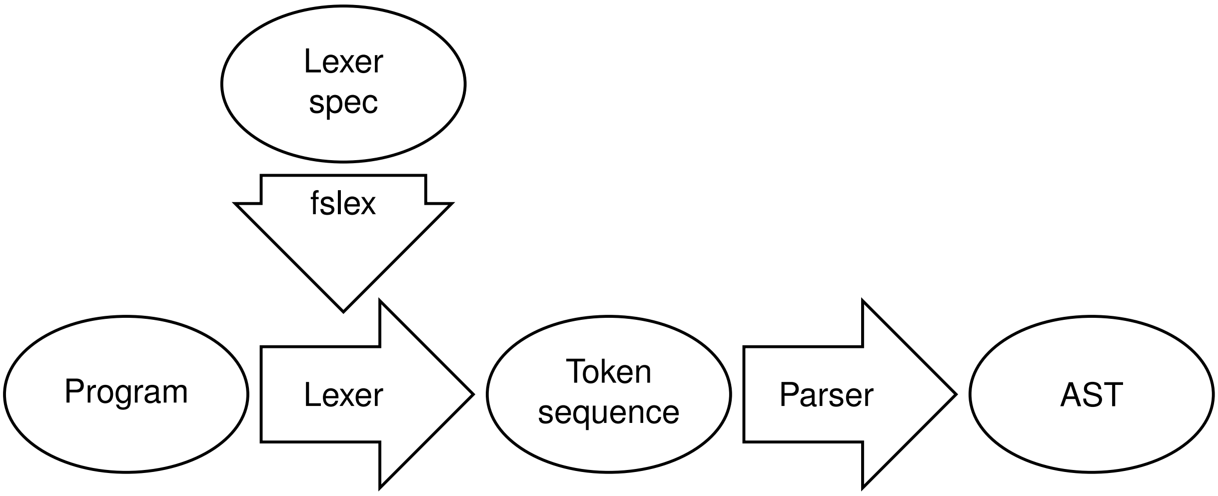
$r?$	Zero or one *r*	$r\|\varepsilon$
r^+	One or more *r*	$r\, r^*$

Five-minute exercises

Write regular expressions for:

- Non-negative integer constants
- Integer constants
- Floating-point constants:
  - `3.14`
  - `3E8`
  - `+6.02E23`
- Java variable names:
  - `xy`
  - `x12`
  - `_x`
  - `$x12`

Lexer specification and generator



Lexer specifications: ExprLex.fsl

```
rule Token = parse
  | [' ' '\t' '\n' '\r']  { Token lexbuf }
  | ['0'-'9']+            { CSTINT (...) }
  | ['a'-'z''A'-'Z']['a'-'z''A'-'Z''0'-'9']*
                          { keyword (...) }
  | '+'                   { PLUS  }
  | '-'                   { MINUS }
  | '*'                   { TIMES }
  | '('                   { LPAR  }
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  | eof                   { EOF   }
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Regular Expressions

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F# to construct token

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LANGUAGES AND AUTOMATA

Context-free grammars

```
Main ::= Expr EOF                              (rule A)
Expr ::= NAME                                  (rule B)
       | CSTINT                                (rule C)
       | - CSTINT                              (rule D)
       | ( Expr )                              (rule E)
       | let NAME = Expr in Expr end           (rule F)
       | Expr *  Expr                          (rule G)
       | Expr + Expr                           (rule H)
       | Expr - Expr                           (rule I)
```

- Nonterminals
- Terminals (from lexer)
- Productions (called A–H)
- Start symbol (the nonterminal Main)

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Derivation: grammar as string generator

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	Main

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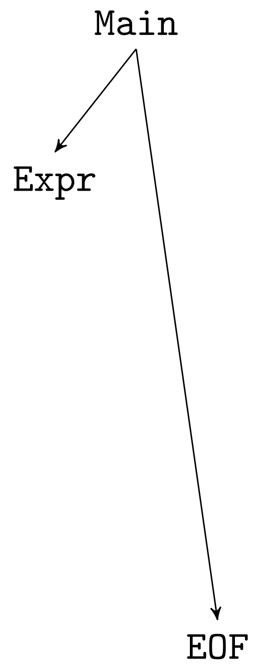
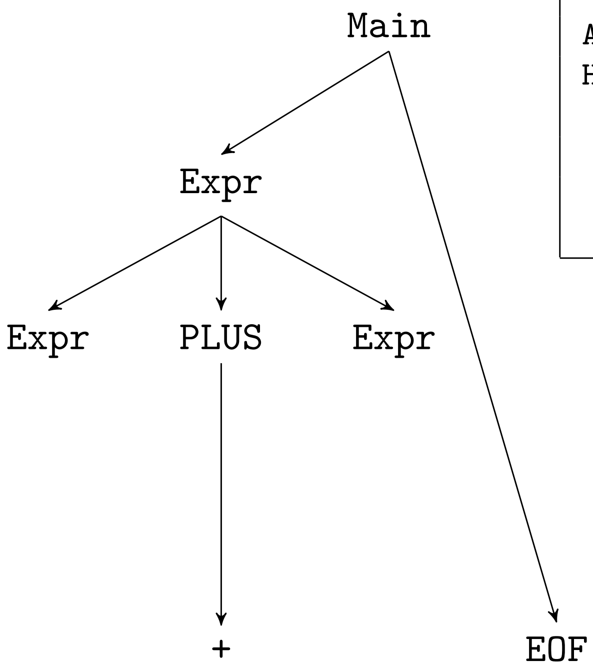


	Main
A	Expr EOF

Derivation: grammar as string generator



	Main
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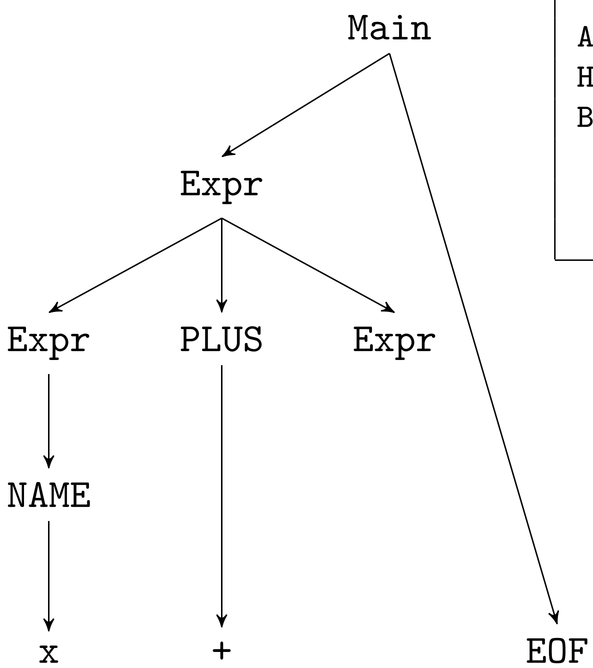
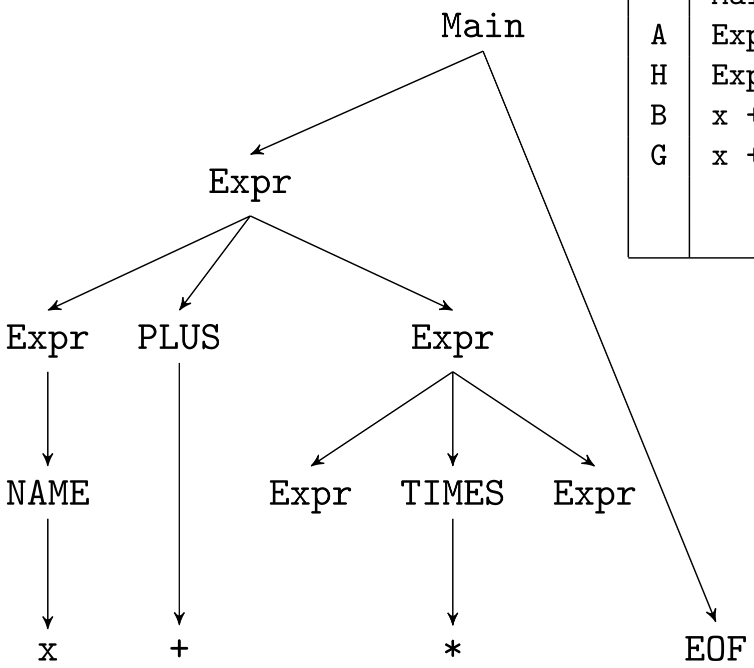
H	Expr + Expr EOF

Derivation: grammar as string generator



	Main
A	Expr EOF
H	Expr + Expr EOF
B	x + Expr EOF

Derivation: grammar as string generator



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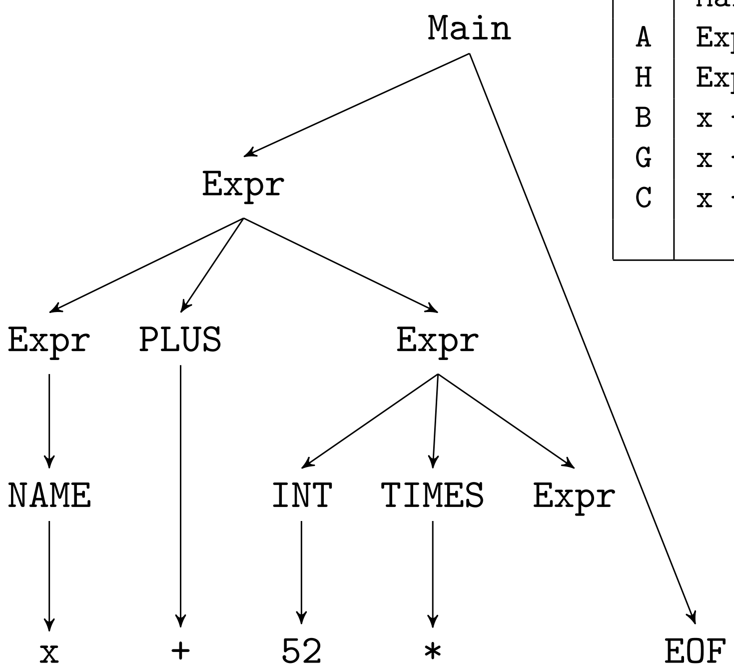
Derivation: grammar as string generator



	Main
A	Expr EOF
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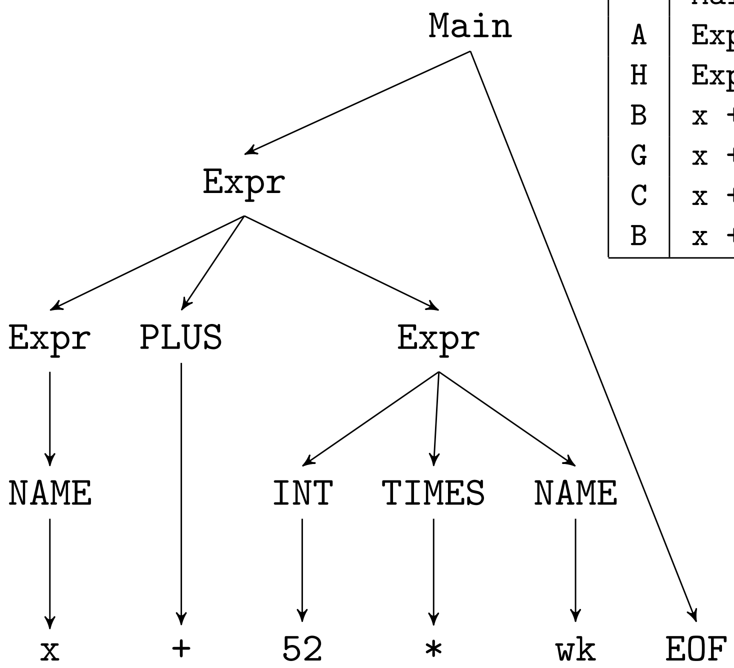
B	x + Expr EOF
G	x + Expr * Expr EOF
C	x + 52 * EXPR EOF

Derivation: grammar as string generator



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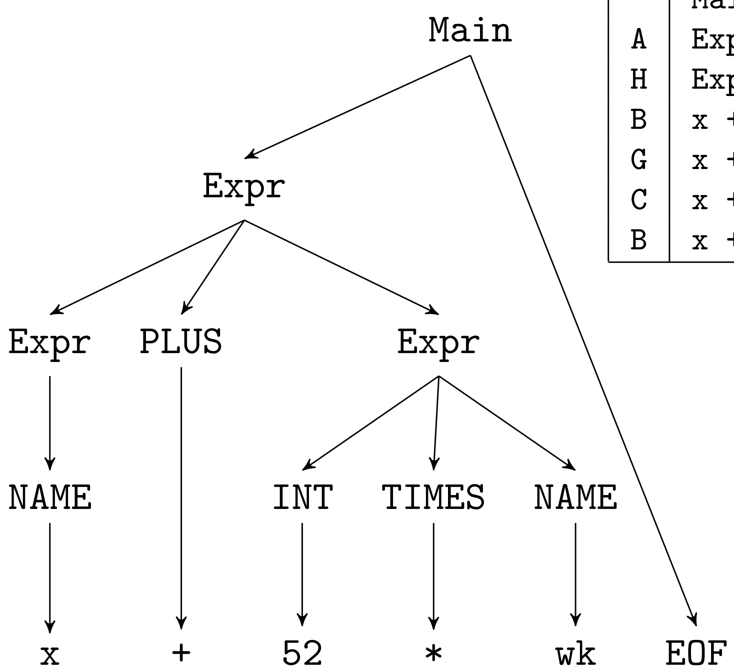

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Grammar ambiguity

A grammar is *ambiguous* if there exists a string with more than one derivation tree.

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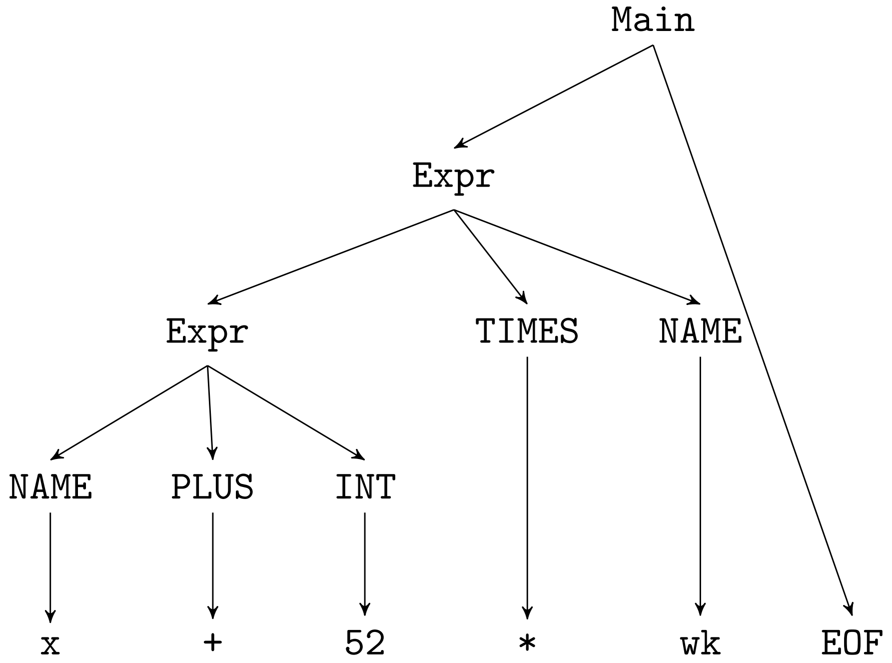

Leftmost and rightmost derivations

LEFTMOST DERIVATION
: Always expand the leftmost nonterminal.
See first example.

RIGHTMOST DERIVATION
: Always expand the rightmost nonterminal.
See second example.

Associativity

How to read $x \diamond y \diamond z$?

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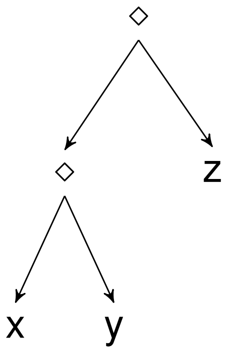
$\diamond$ is left-associative



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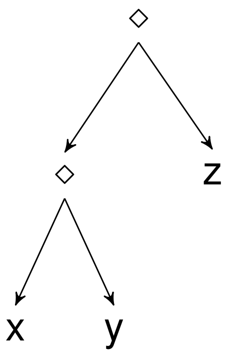
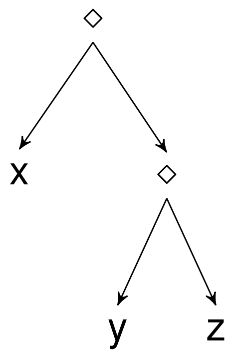


$\diamond$ is right-associative



Precedence

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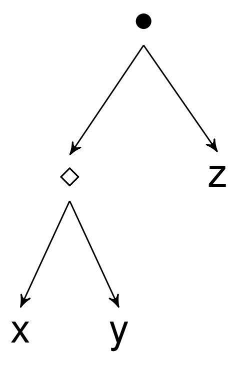
$\diamond$ has higher precedence



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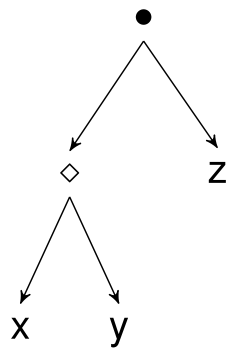

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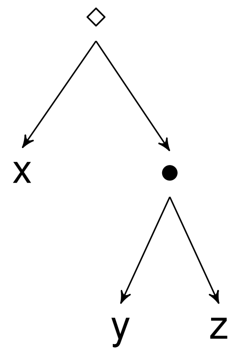


Exercise

What Java or C# operators

- are left-associative?
- are right-associative?
- have higher or lower precedence than others?

Java operator precedence

`() [] .`	Left
`x++ x--`	Right
`++x --x +x -x !x ~x (T)x`	Right
`* / %`	Left
`+ -`	Left
`<< >>`	Left
`< <= > >= instanceof`	Left
`== !=`	Left
`&`	Left
`^`	Left
`|`	Left
`&&`	Left
`||`	Left
`b ? tt : ff`	Right
`= += -= *= /= %= &= ^= |= <<= >>= >>>=`	Right

Parsing is inverse derivation

PARSING

Reconstruct the derivation for a string, if possible

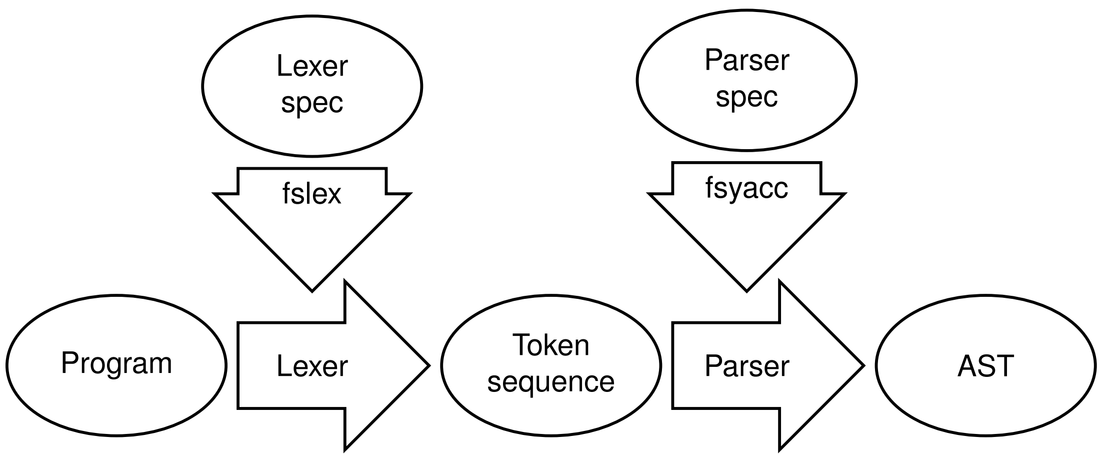
Parsing is inverse derivation

PARSING
Reconstruct the derivation for a string, if possible

METHODS

- Top-down: parser structured like grammar. Example next week.
- Generated bottom-up: parser generated using tool.

Parser specification and generator



Tokens, associativity and precedence in fsyacc

```
%token <int> CSTINT
%token <string> NAME
%token PLUS MINUS TIMES EQ
%token END IN LET
%token LPAR RPAR
%token EOF

%left MINUS PLUS   /* lowest precedence  */
%left TIMES        /* highest precedence */
```


Tokens, associativity and precedence in fsyacc

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%token &lt;int&gt; CSTINT
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Token specifications - expanded to a datatype

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Tokens carrying data

Tokens, associativity and precedence in fsyacc

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Precedence: `%left`, `%right`, and `%nonassoc` allowed

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Ordering of groups defines precedence levels

Parser specification

```
%start Main
%type <Absyn.expr> Main
%%
Main:
    Expr EOF                        { $1                 } A
Expr:
    NAME                            { Var $1             } B
  | CSTINT                          { CstI $1            } C
  | MINUS CSTINT                    { CstI (- $2)        } D
  | LPAR Expr RPAR                  { $2                 } E
  | LET NAME EQ Expr IN Expr END    { Let($2, $4, $6)    } F
  | Expr TIMES Expr                 { Prim("*", $1, $3) } G
  | Expr PLUS  Expr                 { Prim("+", $1, $3) } H
  | Expr MINUS Expr                 { Prim("-", $1, $3) } I
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  | MINUS CSTINT                  { CstI (- $2)         } D
  | LPAR Expr RPAR                { $2                  } E
  | LET NAME EQ Expr IN Expr END  { Let($2, $4, $6)     } F
  | Expr TIMES Expr               { Prim("*", $1, $3)   } G
  | Expr PLUS  Expr               { Prim("+", $1, $3)   } H
  | Expr MINUS Expr               { Prim("-", $1, $3)   } I
```

Non-terminals

Parser specification

```
%start Main
%type <Absyn.expr> Main
%%
Main:
    Expr EOF                      { $1                  } A
Expr:
    NAME                          { Var $1              } B
  | CSTINT                        { CstI $1             } C
  | MINUS CSTINT                  { CstI (- $2)         } D
  | LPAR Expr RPAR                { $2                  } E
  | LET NAME EQ Expr IN Expr END  { Let($2, $4, $6)     } F
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Start symbol

Parser specification

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Semantic actions

Parser specification

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Arguments count from left

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  | Expr MINUS Expr                 { Prim("-", $1, $3) } I
```

Type annotation

Putting together lexer and parser

From file `Expr/Parse.fs`:

```
let fromString (str : string) : expr =
    let lexbuf = Lexing.LexBuffer<char>.FromString(str)
    in try
         ExprPar.Main ExprLex.Token lexbuf
       with
         | exn -> failwith "Lexing or parsing error ... "
```

Putting together lexer and parser

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Entry point in parser

Putting together lexer and parser

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       with
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```


Entry point in lexer

Invoking fslex and fsyacc

- Build the lexer and parser vs files ExprLex.fs and ExprPar.fs
- Compile as modules together with Absyn.fs and Parse.fs:

```
$ fsyacc --module ExprPar ExprPar.fsy
$ fslex --unicode ExprLex.fsl
$ fsi -r FSharp.PowerPack Absyn.fs ExprPar.fs
                          ExprLex.fs Parse.fs
```

- Open the Parse module and experiment:

```
open Parse;;
fromString "x + 52 * wk";;
```


Whiteboard

How do we change the lexer and/or parser to

- accept brackets `[ ]` in addition to parens `( )`?

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  instead of
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Whiteboard

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- accept brackets `[ ]` in addition to parens `( )`?
- accept the division operator (/) also?
- accept the syntax
  `{ x <- 2 in x * 3 }`
  instead of
  `let x = 2 in x * 3 end`
  ?
- accept function calls such as `max(x, y)`?

Plan for today

LEXER SPECIFICATIONS
- Regular expressions
- The fslex lexer generation tool
- Automata

PARSER SPECIFICATIONS
- Grammars
- Parsing
- The fsyacc parser generation tool

PARSING ALGORITHMS
- Top-down
- Bottom-up

LANGUAGES AND AUTOMATA

The Chomsky Hierarchy (1958)

TYPE 3: REGULAR GRAMMARS

Same expressiveness as regular expressions.

$$A \to cB \qquad A \to B \qquad A \to c \qquad A \to \varepsilon$$

TYPE 2: CONTEXT-FREE GRAMMARS

$$A \to cBd$$

TYPE 1: CONTEXT-SENSITIVE GRAMMARS

Non-abbreviating rules.

$$aAb \to acAdb$$

TYPE 0: UNRESTRICTED GRAMMARS

Same as term-rewrite systems.

$$0Ay \to 0$$

Chomsky hierarchy and computation

Grammar	Languages	Automaton
Type 3	Regular	Finite automata
Type 2	Context-free	Pushdown automata (finite + stack)
Type 1	Context-sensitive	Bounded Turing machines
Type 0	Recursively enumerable	Turing machines