Parser Generators

Concepts of Programming Languages
Lecture 13

CAS CS 320

Outline

» Extend our BNF syntax to be a bit more convenient

» Introduce **parser generators**

» Discuss **lexical analysis**

» Demo **Menhir**, the parser generator for this course

Recap

Recall: Example

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tokens (terminal symbols)

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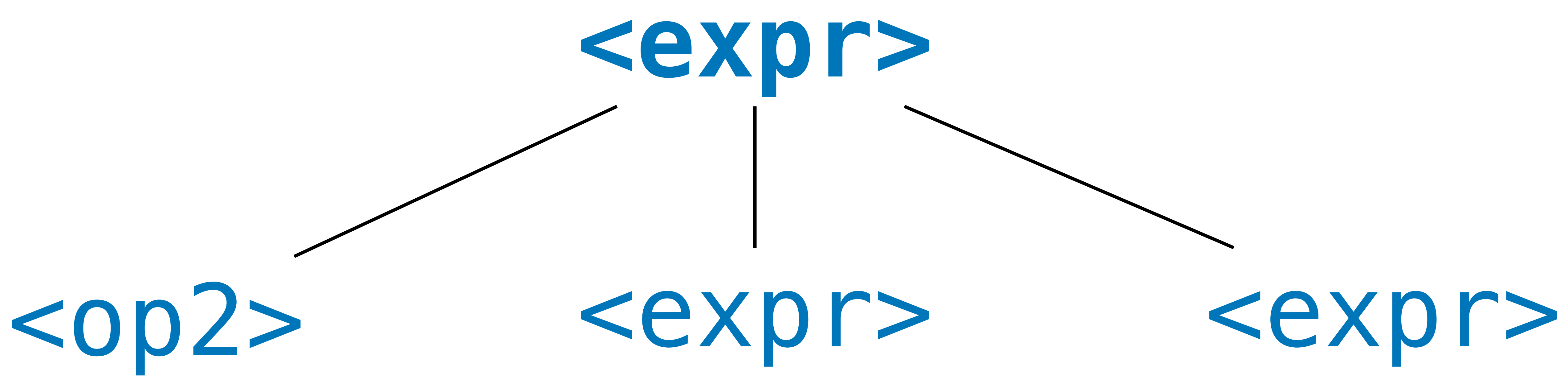

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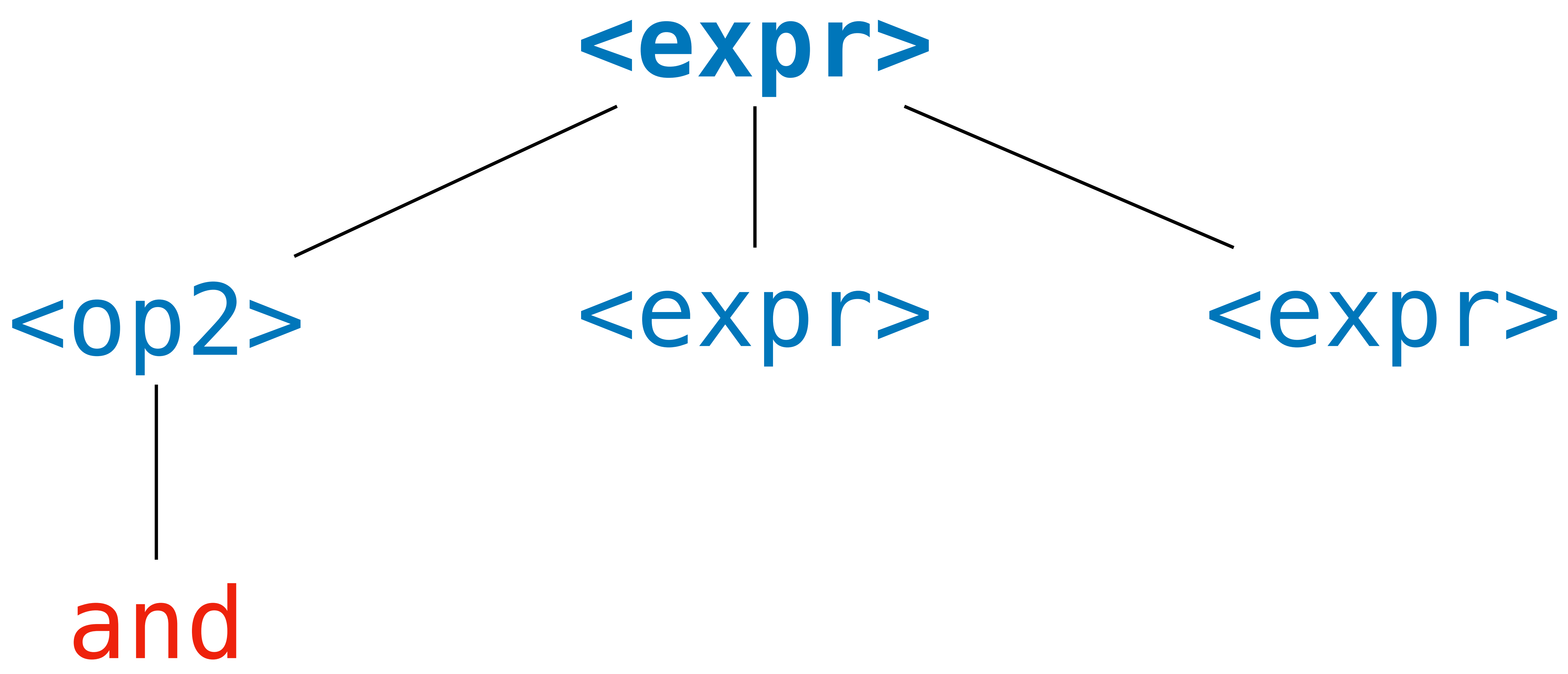

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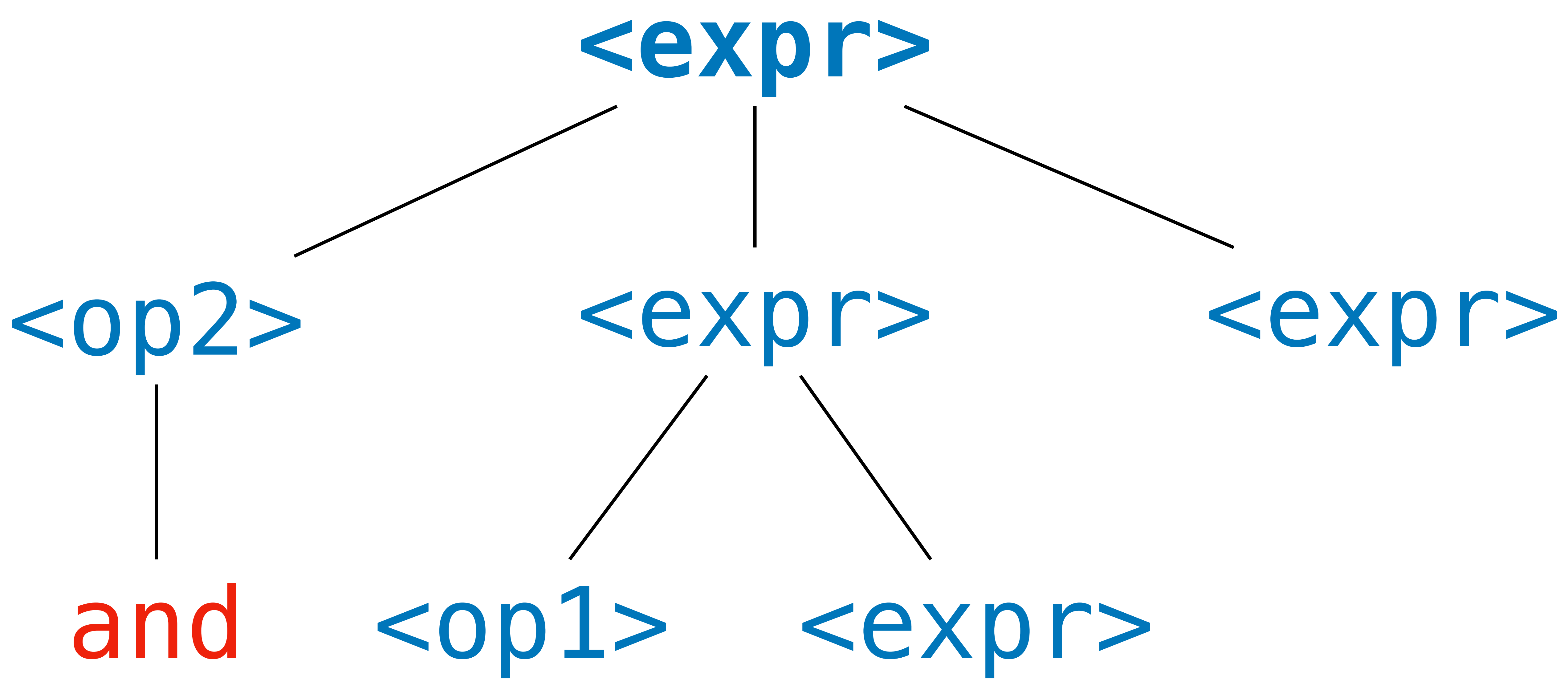

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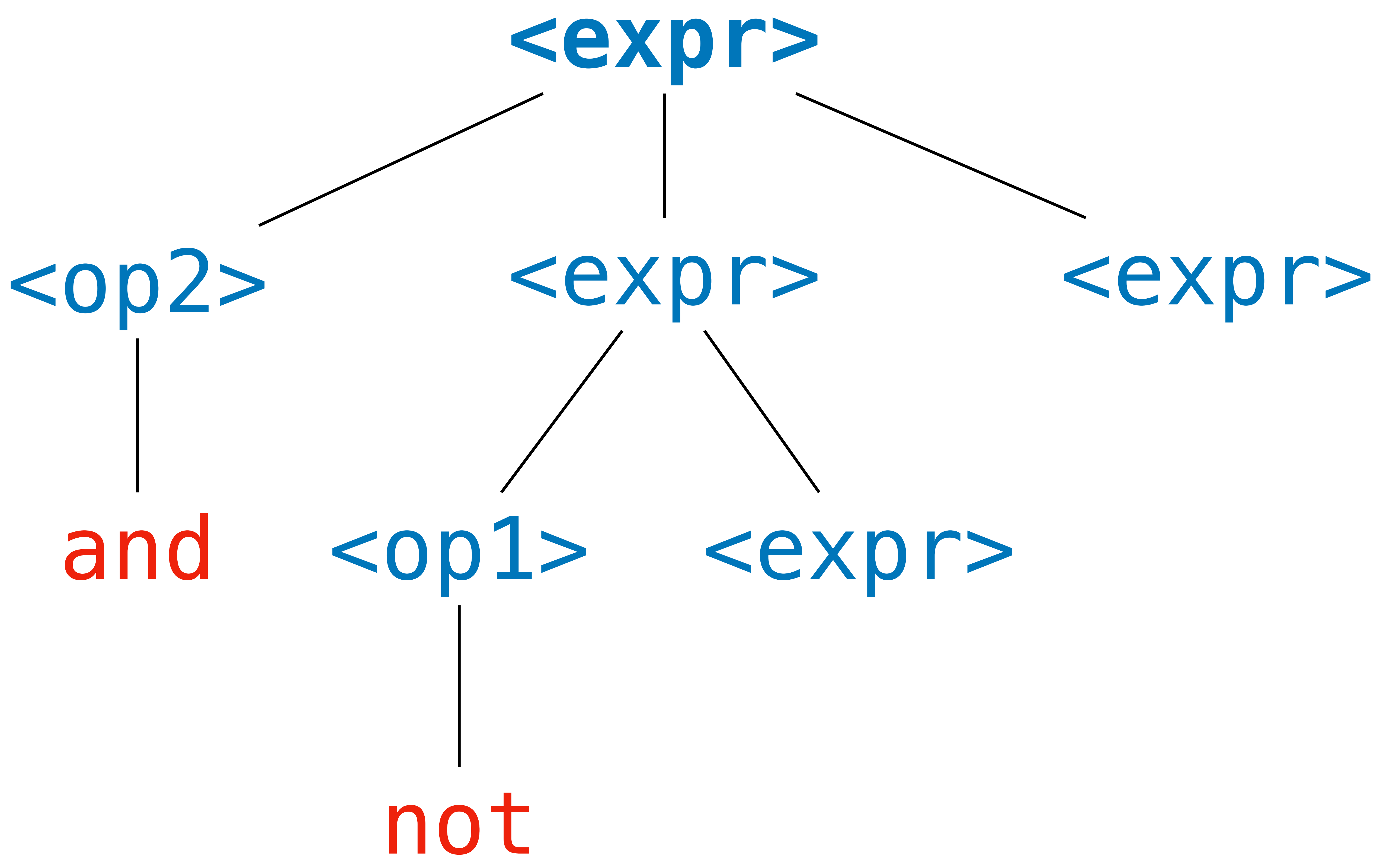

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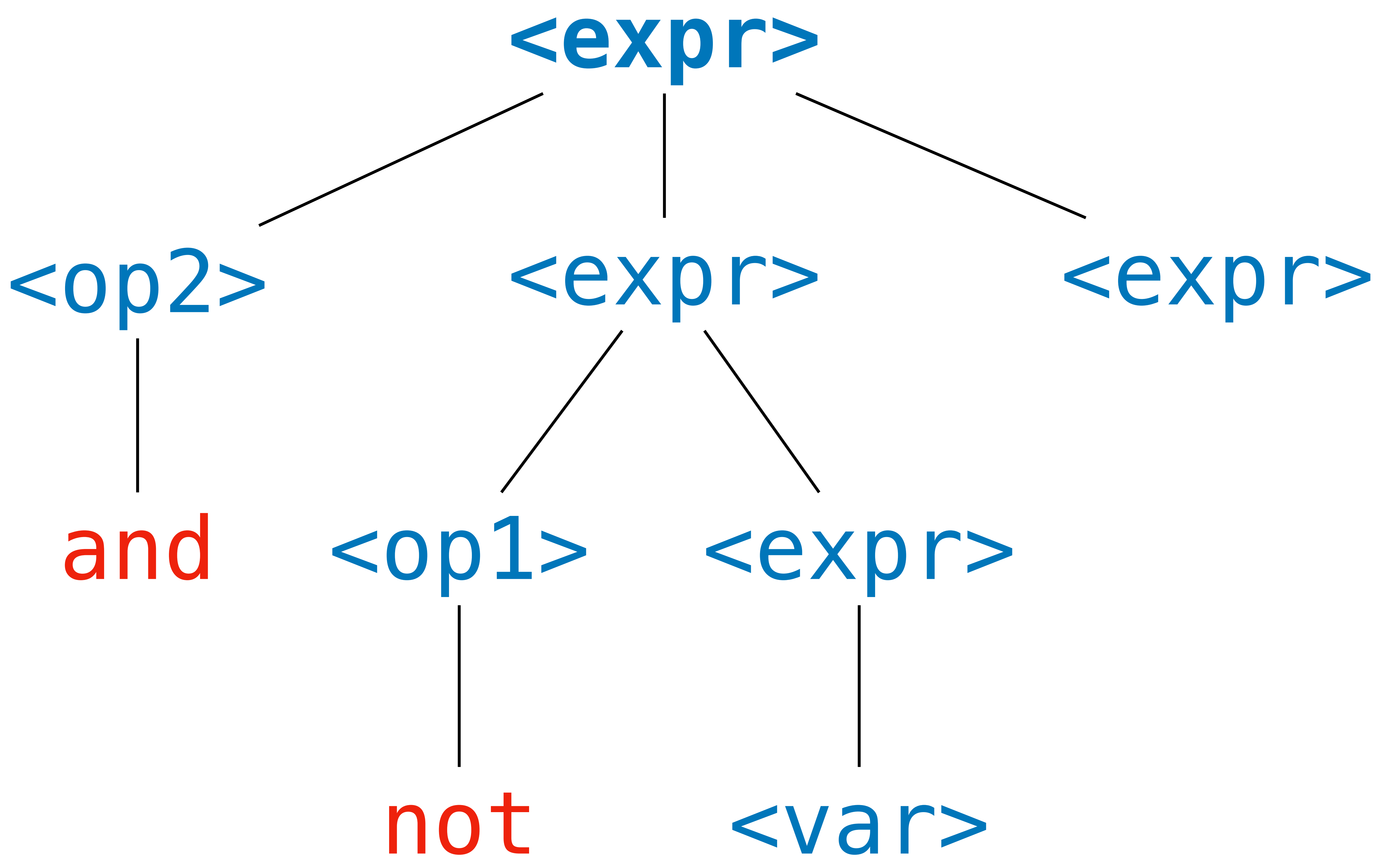

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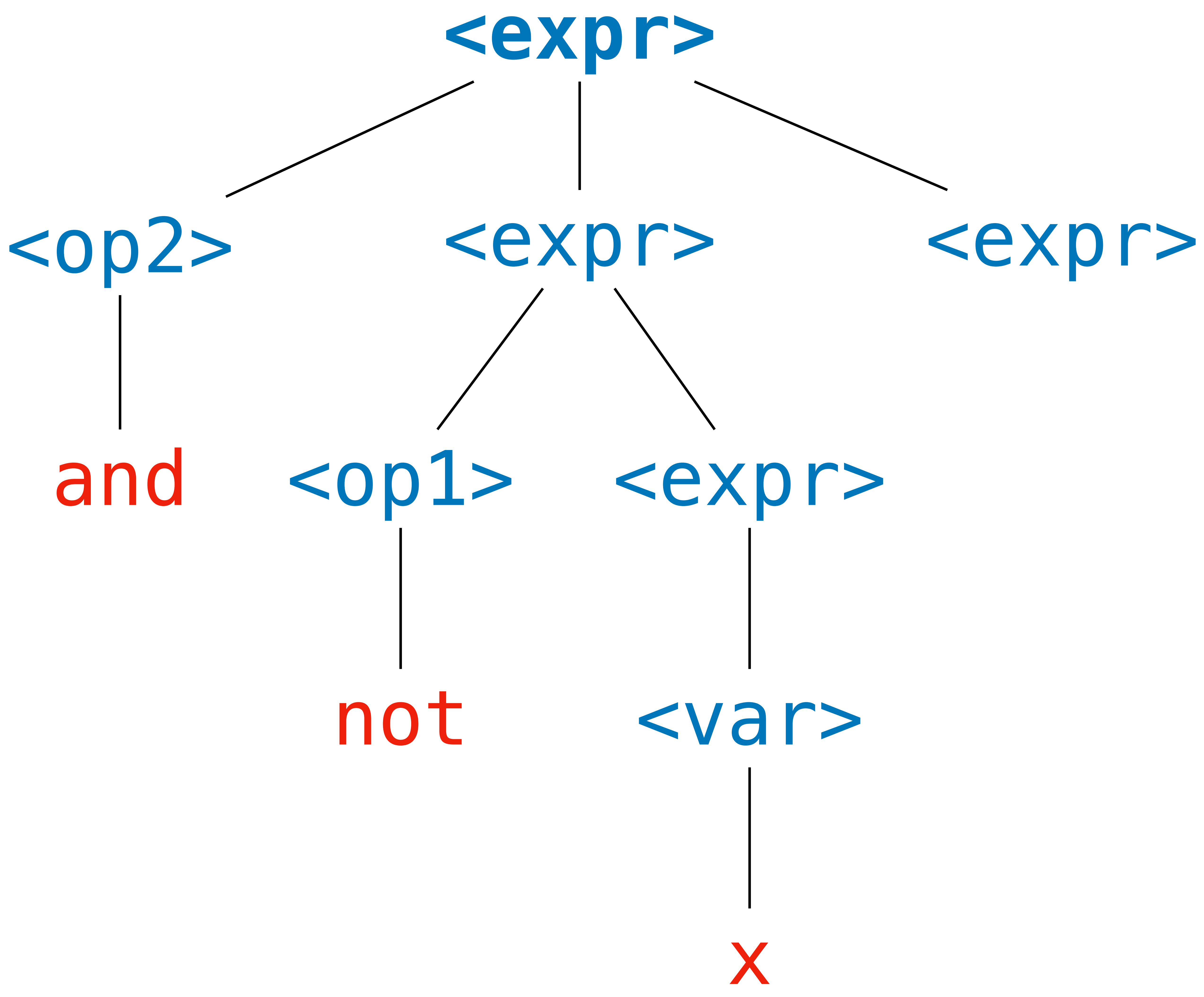

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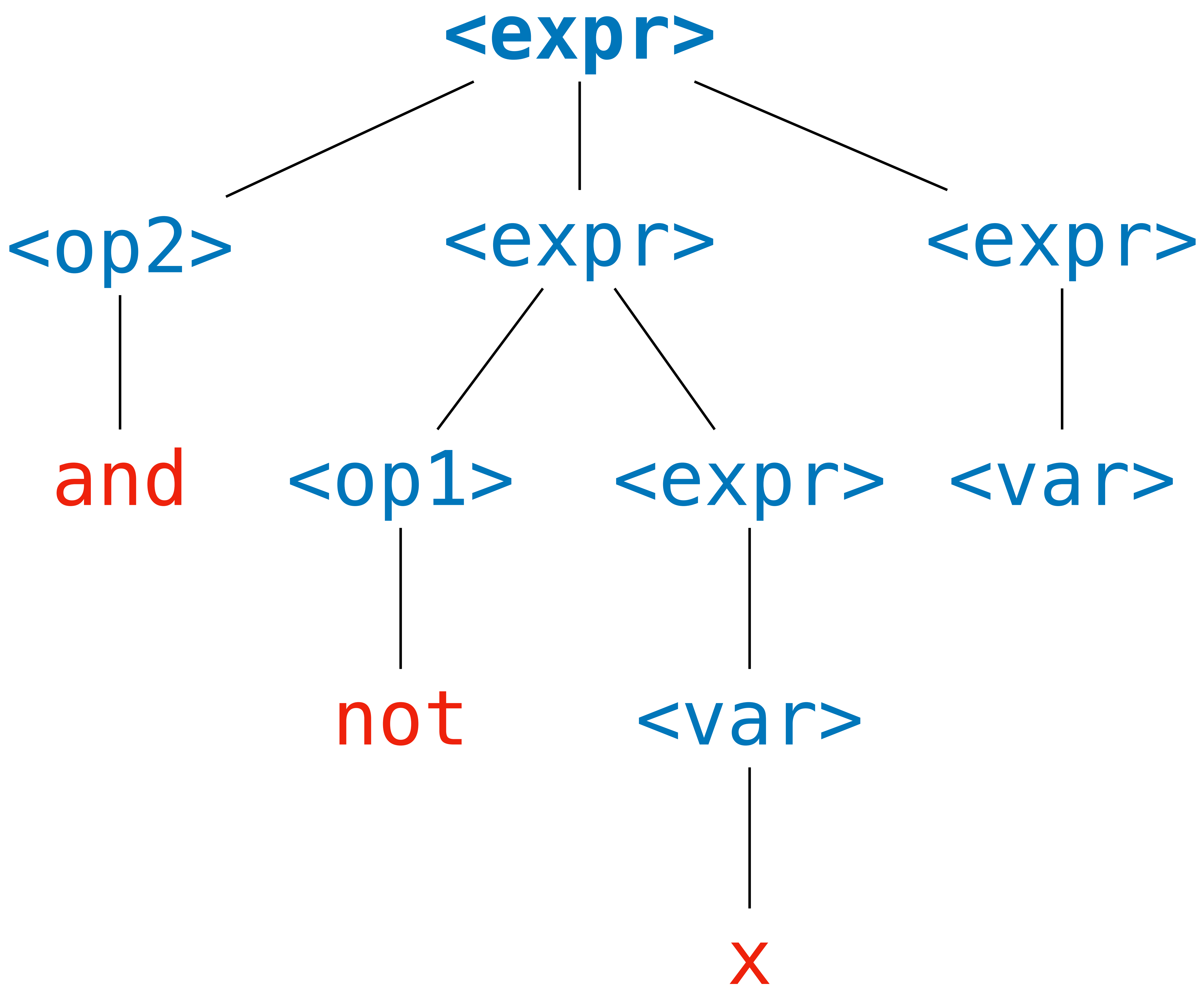

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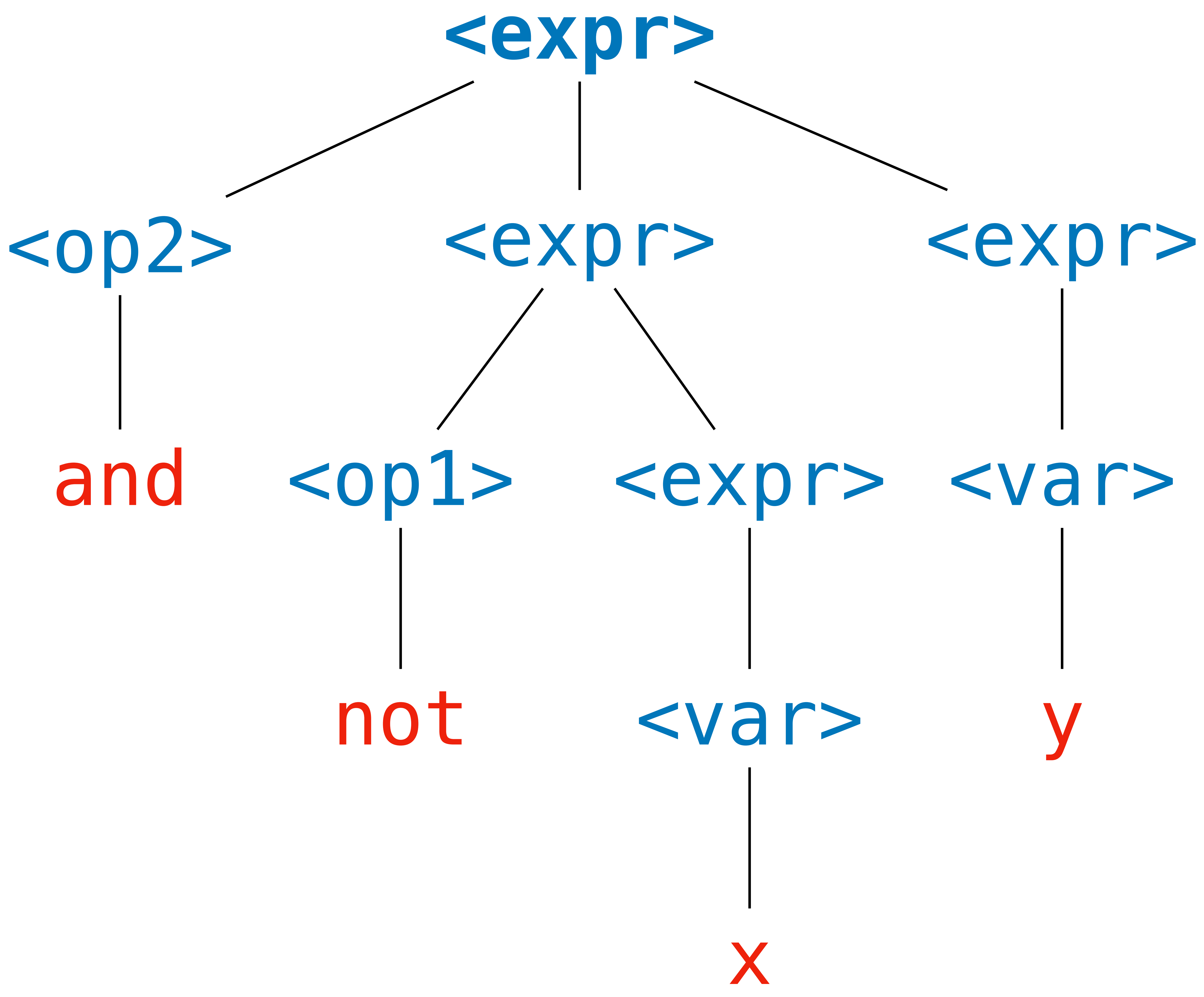

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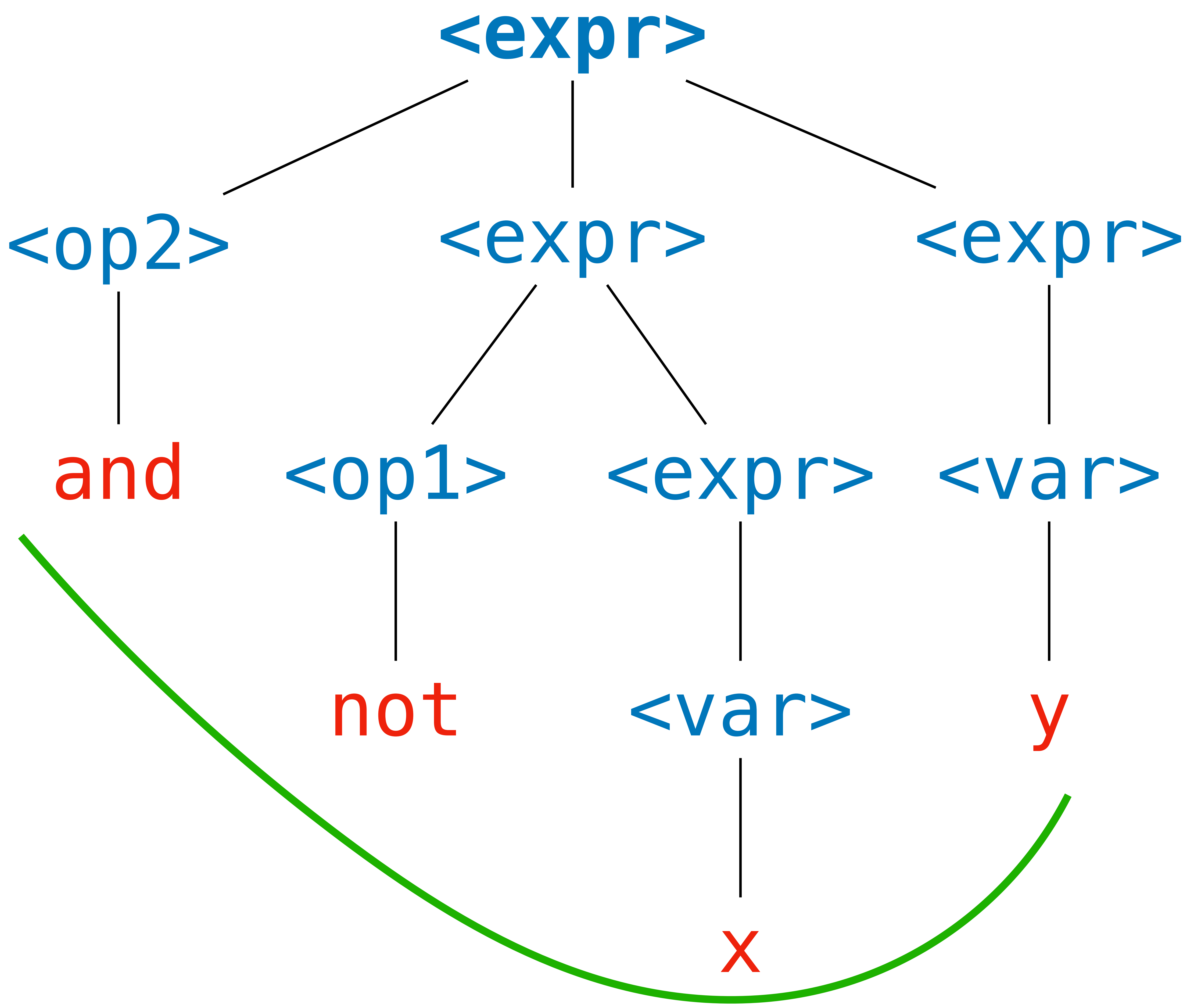

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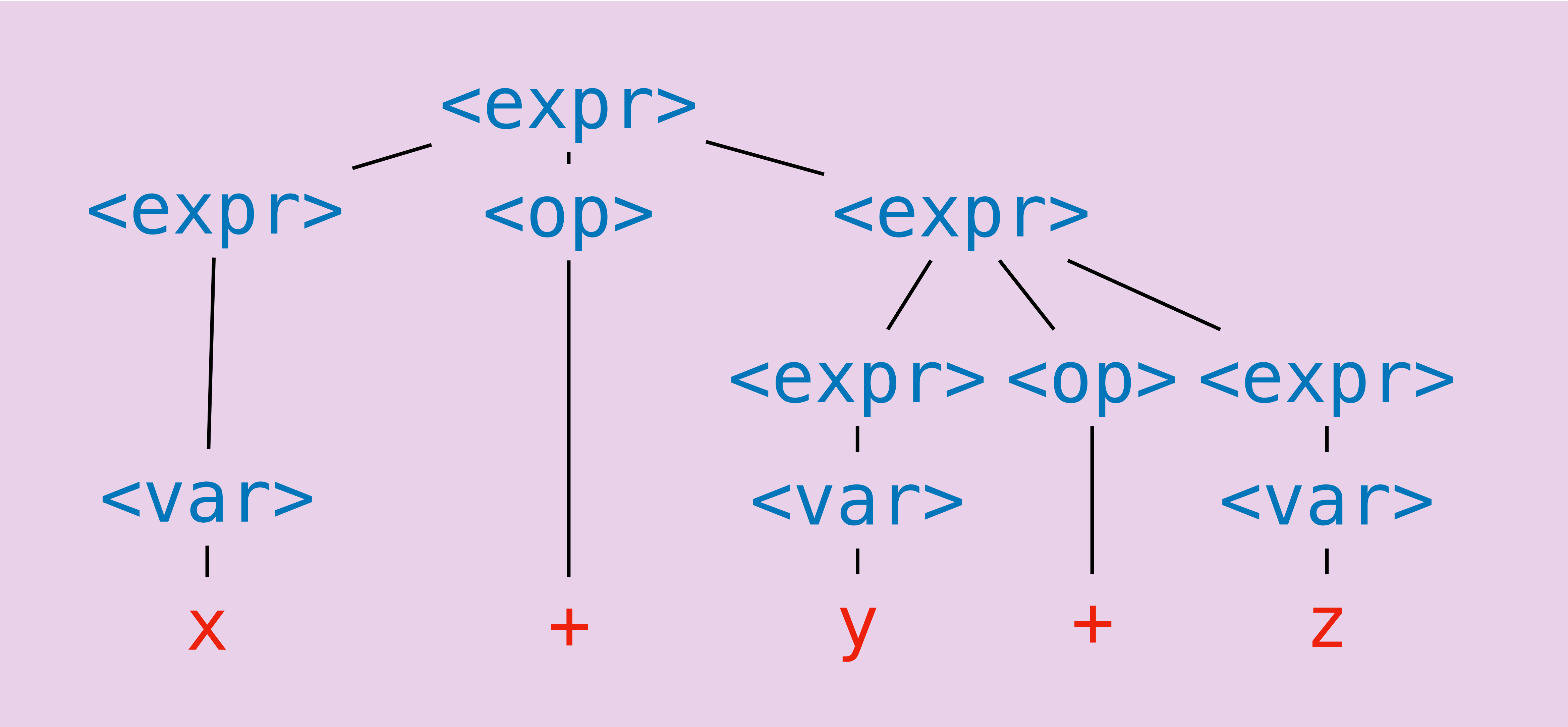

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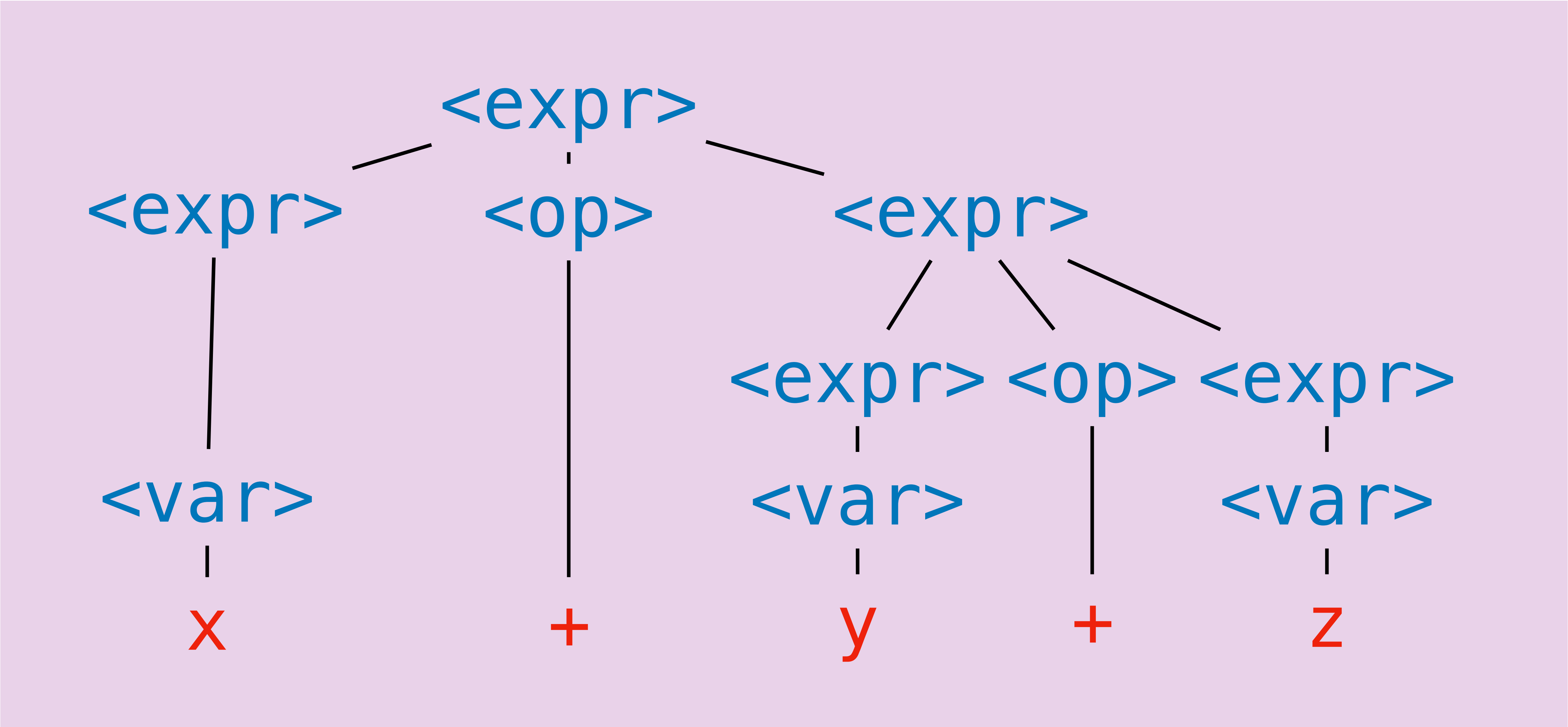
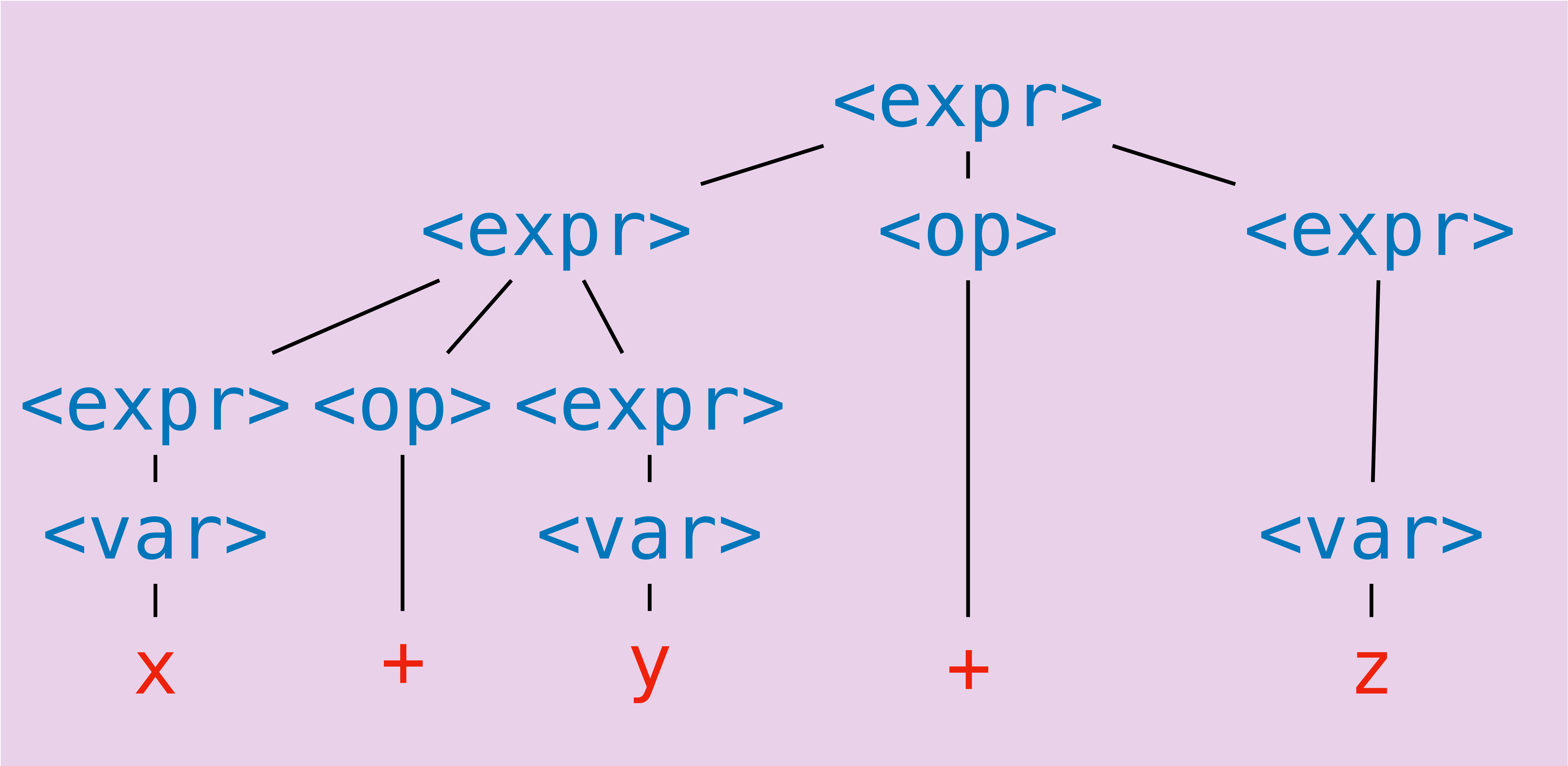


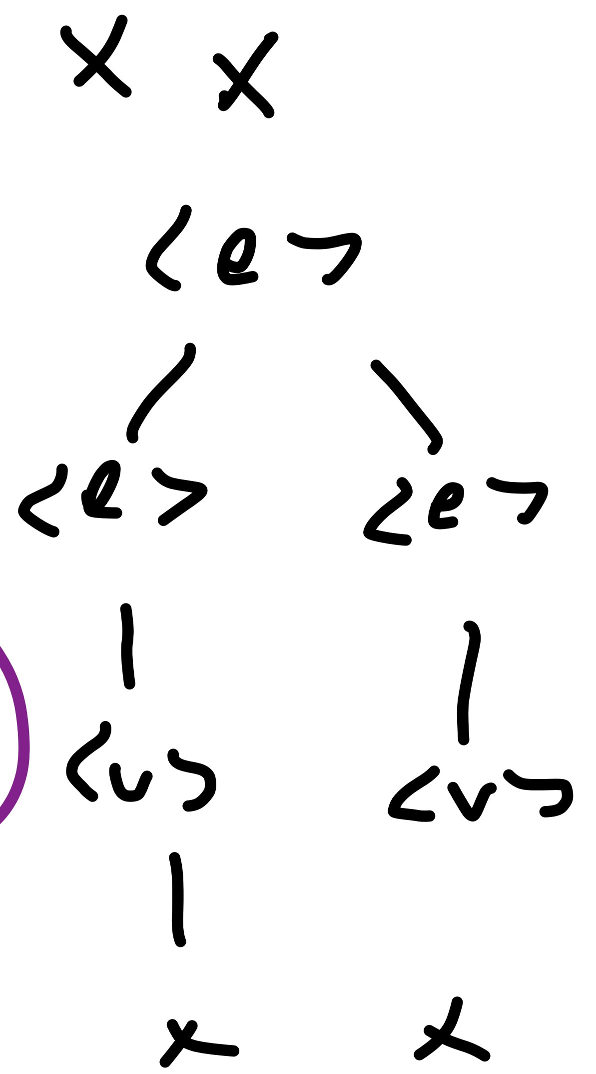


Practice Problem

```
<expr> ::= fun <var> -> <expr>
         | <expr> <expr>
         | <var>
<var>  ::= x
```

Demonstrate that the above grammar is ambiguous

Solution

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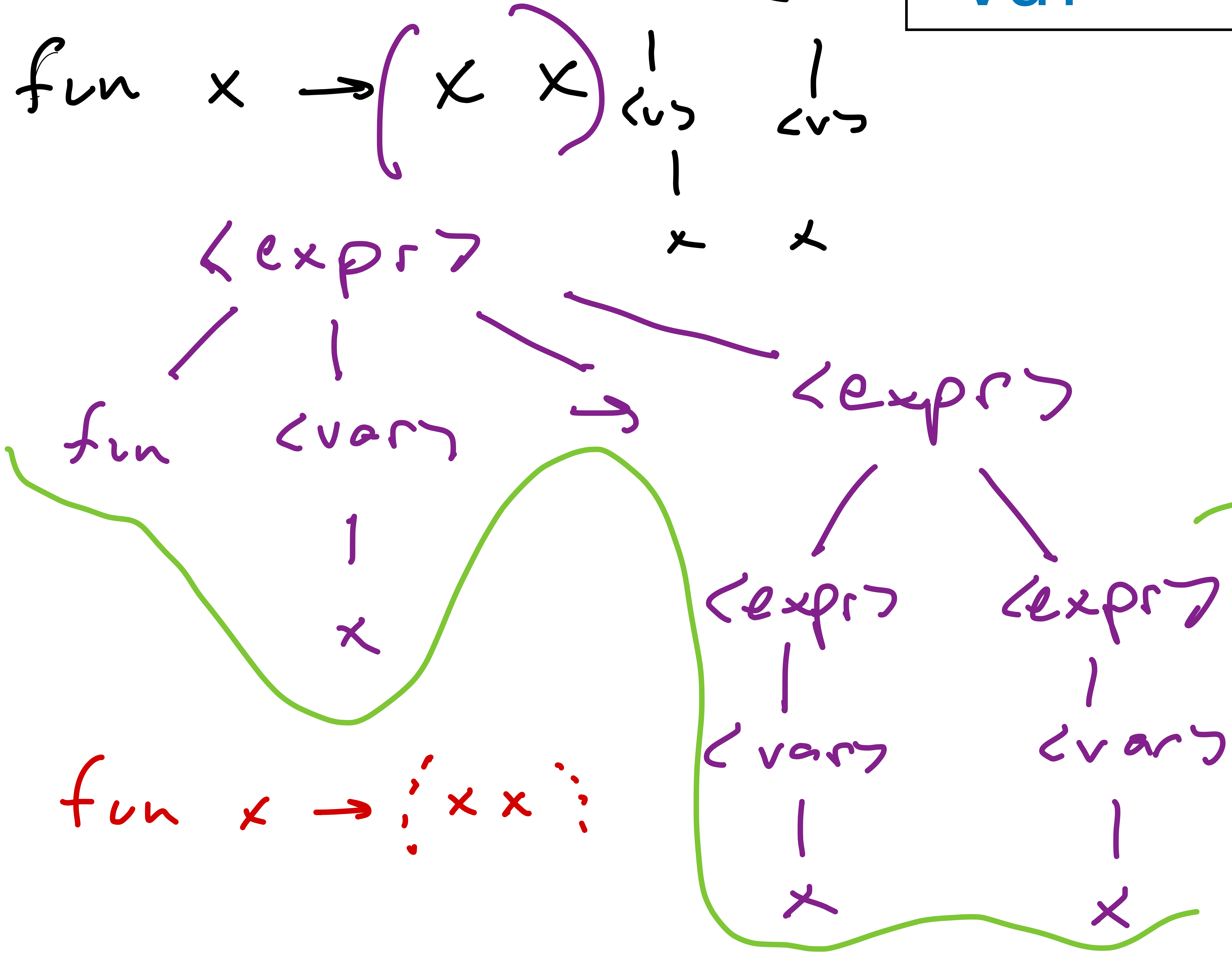
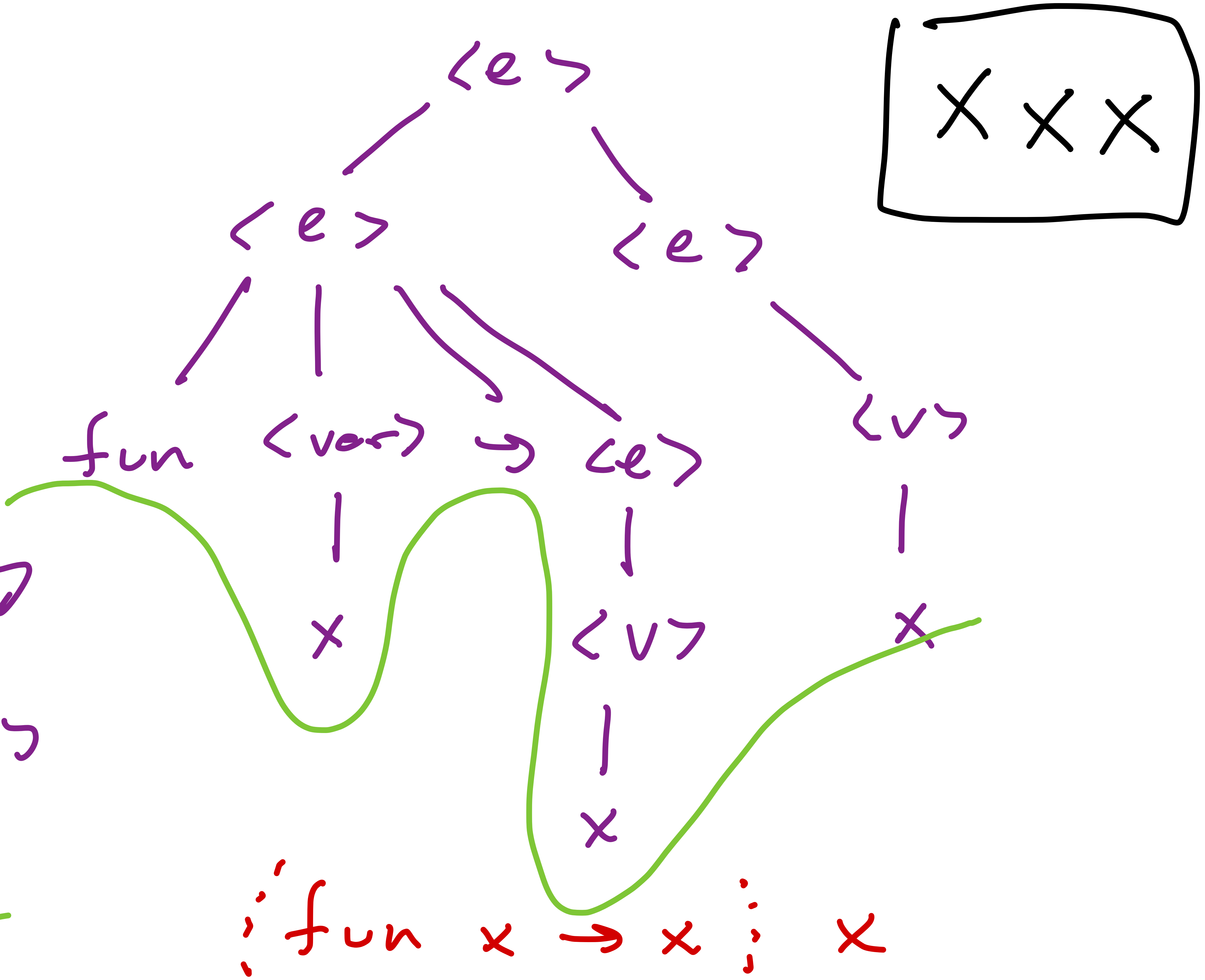




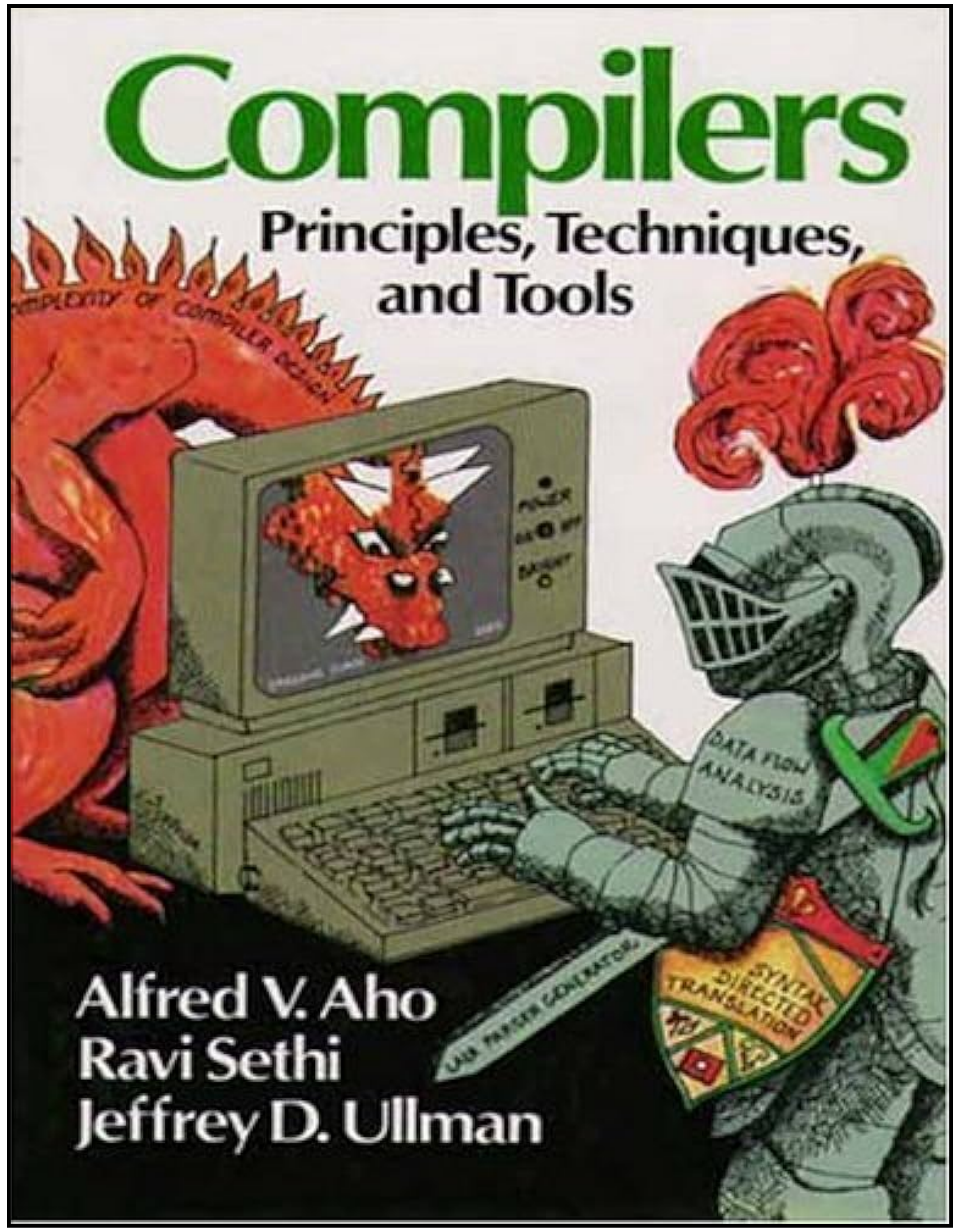
Motivation

A Note on "History"

Lexical analysis and parsing are typically associated with ***compiler design***

Compiler design was once a fundamental requirement in CS programs. *This is not really the case anymore*

Also, we have ***parser generators***



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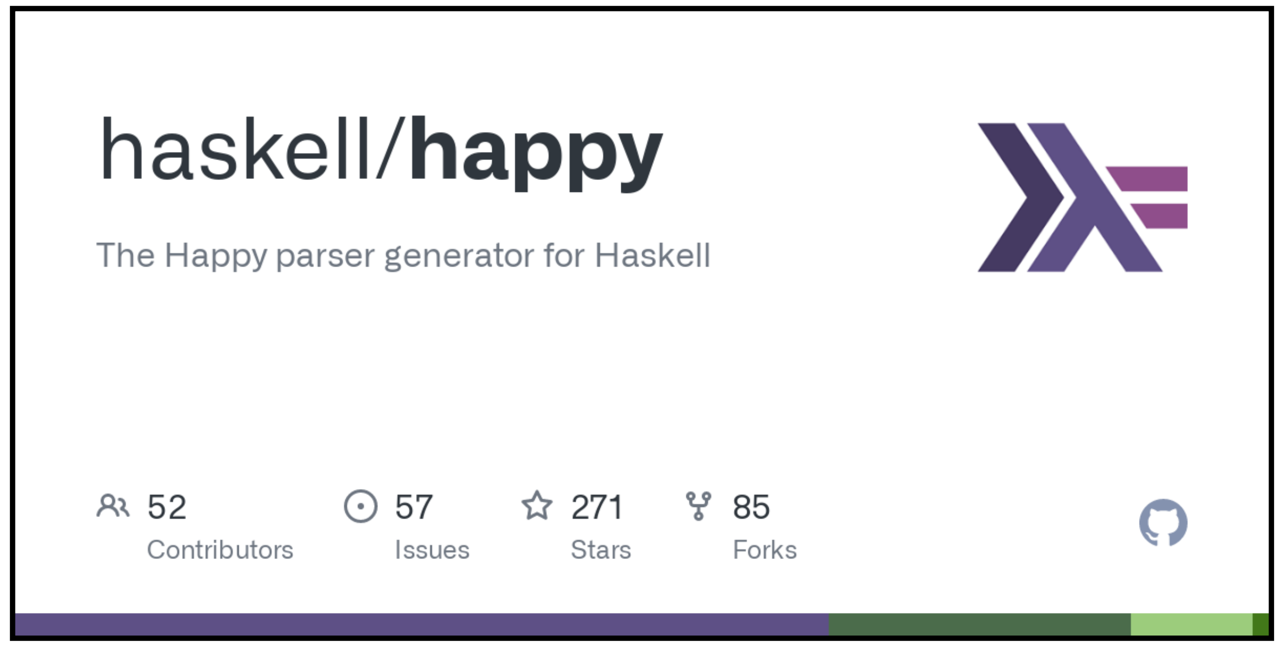


(Beaver)

Parser generators are programs which, given a representation of a language (e.g., as an ***EBNF grammar***), build a parser for you

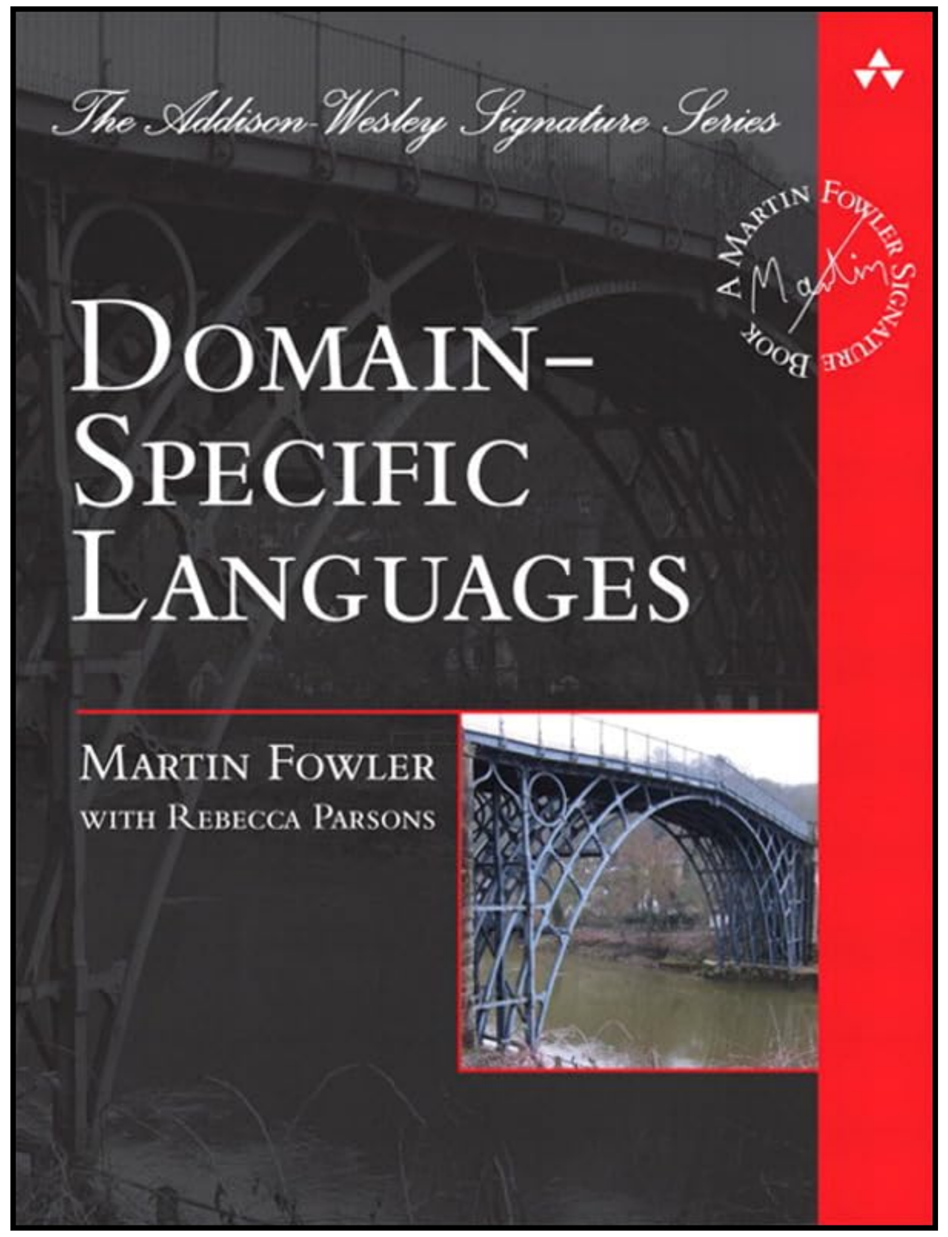
(So there was a point to learning (E)BNF for the "real-world")

Aside: Domain-Specific Languages

Domain-specific languages (DSLs) are simple programming languages for domain-specific tasks, e.g.

» Emacs Lisp
» SQL

*We need **parsers** for these languages if we want to use them...*



Extended BNF

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Note: EBNF means different things to different people

Optional Syntax

BNF:

```
<expr> ::= if <expr> then <expr>                 else
         | if <expr> then <expr> <else>
<else> ::= else <expr>
```

EBNF:

```
<expr> ::= if <expr> then <expr> [ else <expr> ]
```

Menhir:

```
expr =
  | IF; e1 = expr; THEN; e2 = expr; e3_opt = else?
    { match e3_opt with
      | None -> It (e1, e2)
      | Some e3 -> Ite (e1, e2, e3)
    }
else =
  | ELSE; e = expr { e }
```

Repetition Syntax

BNF:

```
<word> ::= <letter> | <letter> <word>
```

EBNF:

```
<word> ::= <letter> { <letter> }
```

Menhir:

```
word =
  | l = letter; ls = letter*
    { String.of_list (l :: ls) }
```

Interlude: Regular Expressions

<a> ::= b <c> d

<a> ::= <b> c

Regular Grammars

<nonterminal> ::= terminal
<nonterminal> ::= terminal <nonterminal>
<nonterminal> ::= ϵ (the empty string)

A **regular grammar** is a BNF grammar with the above kinds of rules

Regular grammars are easier to parse

Example

<s> ::= a <s>
<s> ::= b <a>
<a> ::= ϵ
<a> ::= c <a>

<s>
a <s>
a a <s>
a a a <s>
a a a b <a>
aaa b c <a>
aaa b c c <a>
aaa b cc

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» **exp**+ is a regex describing one or more occurrences of **exp**

» **exp**? is a regex describing zero or one occurrences of **exp**

Example

```
<s> ::= a <s>
<s> ::= b <a>
<a> ::= ϵ
<a> ::= c <a>
```

is equivalent to

0 or more 0 or more

```
a*bc*
```

or

```
'a'* 'b' 'c'*
```

in ocamllex syntax

Example: Numbers and Variables

1 or more

lowercase letter

1 or more

```
-?[0-9]+                    [a-z][a-zA-Z0-9_']*
```

option

numbers

variables

-103

123

9967

x

xyz_ZYX'

a___'''___

We'll leave it there, take CS332 if you want more, or read the Wikipedia page...

Lexical Analysis

The "Lexing" Problem

"let" $\approx$ ['l', 'e', 't'] $\mapsto$ ***LET***

"fun" $\approx$ ['f', 'u', 'n'] $\mapsto$ ***FUN***

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$$\texttt{"let"} \approx \texttt{['l', 'e', 't']} \mapsto \textit{LET}$$

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The Goal. *Convert a stream of characters into a stream of tokens*

- Characters are grouped so together so they correspond to the *smallest units* at the level of the language
- Whitespace and comments are *ignored*
- Syntax errors are caught, when possible

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» keywords, names, literals

Syntactic Analysis (Parsing) is about *large-scale* language constructs

» expressions, statements, modules

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- **Simplicity.** It's *easier to think about* parsing if we don't need to worry about whitespace, characters, etc.

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<u>But there are benefits for larger projects:</u>

- » **Simplicity.** It's *easier to think about* parsing if we don't need to worry about whitespace, characters, etc.
- » **Portability.** Files are finicky things, handled differently across different operating systems. *Abstracting this away* for parsing is just good software engineering

Lexemes and Tokens

```
input program:   fun       l    ->        l          ++   [           100   ]

     lexemes: "fun"     "l"  "->"     "l"       "++" "["        "100" "]"

      tokens:   FUN  (ID "l") ARR  (ID "l") (OP "++") LBRAK (INT 100)  RBRAK
```

Lexemes and Tokens

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lexemes:	"fun"	"l"	"->"	"l"	"++"	"["	"100"	"]"
tokens:	FUN	(ID "l")	ARR	(ID "l")	(OP "++")	LBRAK	(INT 100)	RBRAK

A **lexeme** is a sequence of characters associated a syntactic unit in a language

Lexemes and Tokens

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      tokens:   FUN  (ID "l") ARR  (ID "l") (OP "++") LBRAK (INT 100)  RBRAK
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A **lexeme** is a sequence of characters associated a syntactic unit in a language

A **token** is a lexeme together with information about what kind of unit it is

Lexemes and Tokens

input program:	fun	l	->	l	++	[	100	]	
lexemes:	"fun"	"l"	"->"	"l"	"++"	"["	"100"	"]"	
tokens:	FUN	(ID "l")	ARR	(ID "l")	(OP "++")	LBRAK	(INT 100)	RBRAK	

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- » "12" and "234" are both INT_LITS, whereas "let" is a KEYWORD.

Lexemes and Tokens

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lexemes:	"fun"	"l"	"->"	"l"	"++"	"["	"100"	"]"
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A **lexeme** is a sequence of characters associated a syntactic unit in a language

A **token** is a lexeme together with information about what kind of unit it is

» "12" and "234" are both INT_LITS, whereas "let" is a KEYWORD.

We typically represent tokens as an ADT

Aside: One Token at a time

```
"  let@#_)($#@_J_@O#GKJ"  --next_token-->  (LET, "@#_)($#@_J_@O#GKJ")

"le x = 2"                --next_token-->  FAILURE
```

Aside: One Token at a time

```
"  let@#_)($#@_J_@0#GKJ"  --next_token-->  (LET, "@#_)($#@_J_@0#GKJ")

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The approach:

Aside: One Token at a time

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The approach:

» Given a stream of characters, determine if there is a valid lexeme at the *beginning*

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```

The approach:

- Given a stream of characters, determine if there is a valid lexeme at the *beginning*
- If there is, return its corresponding token and the *remainder of the stream*

Parsing with Menhir

General Parsing

General Parsing

In Theory. *Determine if a given sentence is recognized by a given grammar*

General Parsing

In Theory. *Determine if a given sentence is recognized by a given grammar*

In Practice. *Given a grammar, write a program which converts a string recognized by that grammar into an ADT*

Today

```
<prog>  ::= <expr>

<expr>  ::= let <var> = <expr> in <expr>
          | <expr1>

<bop>   ::= + | - | * | /

<expr1> ::= <expr1> <bop> <expr1>
          | <num>
          | <var>
          | ( <expr> )

<num>   ::= 0 ; DUMMY VALUE
<var>   ::= x ; DUMMY VALUE

; In lex.mll:
;
; let num = '-'? ['0'-'9']+
; let var = ['a'-'z' '_'] ['a'-'z' 'A'-'Z' '0'-'9' '_' '\'']*
```

Operators in order of increasing precedence:

Operator	Associativity
+, -	left
*, /	left

We'll be building a parser for the this grammar

A Rough Sketch

1. Specify the tokens (i.e., terminal symbols) of the grammar
2. Specify the rules of the grammar (using a BNF-like syntax)
3. Specify the rules of the lexer (i.e., which strings go to which tokens)