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Parsing

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Parsing

Definition ([1])

Parsing is a process of analyzing a string of symbols, either in programming languages or data structures, conforming to the rules of a formal grammar by breaking it into parts.

Context-Free Grammar

The context-free grammar [2] describing arithmetic expressions with addition, subtraction, and parentheses is as follows:

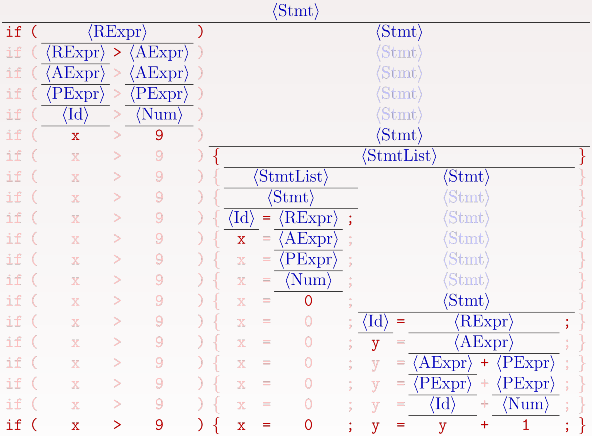
$$
\begin{aligned}
E &\rightarrow E + T \\
&\mid E - T \\
&\mid T \\
T &\rightarrow (E) \\
&\mid \text{id}
\end{aligned}
$$

Here:

- E: Represents an expression.
- T: Represents a term.
- id: Represents an identifier, which can be a number or variable.
- The operators $+$ and $-$ denote addition and subtraction respectively.
- Parentheses (E) group sub-expressions for precedence.

A Fragment of C Grammar

```
    ⟨Stmt⟩ → ⟨Id⟩ = ⟨RExpr⟩ ;
    ⟨Stmt⟩ → { ⟨StmtList⟩ }
    ⟨Stmt⟩ → if ( ⟨RExpr⟩ ) ⟨Stmt⟩
⟨StmtList⟩ → ⟨Stmt⟩
⟨StmtList⟩ → ⟨StmtList⟩ ⟨Stmt⟩
   ⟨RExpr⟩ → ⟨RExpr⟩ >  ⟨AExpr⟩
   ⟨RExpr⟩ → ⟨RExpr⟩ <  ⟨AExpr⟩
   ⟨RExpr⟩ → ⟨RExpr⟩ >= ⟨AExpr⟩
   ⟨RExpr⟩ → ⟨RExpr⟩ <= ⟨AExpr⟩
   ⟨RExpr⟩ → ⟨AExpr⟩
   ⟨AExpr⟩ → ⟨AExpr⟩ + ⟨PExpr⟩
   ⟨AExpr⟩ → ⟨AExpr⟩ - ⟨PExpr⟩
   ⟨AExpr⟩ → ⟨PExpr⟩
   ⟨PExpr⟩ → ⟨Id⟩
   ⟨PExpr⟩ → ⟨Num⟩
      ⟨Id⟩ → x
      ⟨Id⟩ → y
     ⟨Num⟩ → 0
     ⟨Num⟩ → 1
     ⟨Num⟩ → 9
```



```
⟨Stmt⟩
if ( ⟨RExpr⟩ ) ⟨Stmt⟩
if ( ⟨RExpr⟩ > ⟨AExpr⟩ ) ⟨Stmt⟩
if ( ⟨AExpr⟩ > ⟨AExpr⟩ ) ⟨Stmt⟩
if ( ⟨PExpr⟩ > ⟨PExpr⟩ ) ⟨Stmt⟩
if ( ⟨Id⟩ > ⟨Num⟩ ) ⟨Stmt⟩
if ( x > 9 ) ⟨Stmt⟩
if ( x > 9 ) { ⟨StmtList⟩ }
if ( x > 9 ) { ⟨StmtList⟩ ⟨Stmt⟩ }
if ( x > 9 ) { ⟨Stmt⟩ ⟨Stmt⟩ }
if ( x > 9 ) { ⟨Id⟩ = ⟨RExpr⟩ ; ⟨Stmt⟩ }
if ( x > 9 ) { x = ⟨AExpr⟩ ; ⟨Stmt⟩ }
if ( x > 9 ) { x = ⟨PExpr⟩ ; ⟨Stmt⟩ }
if ( x > 9 ) { x = ⟨Num⟩ ; ⟨Stmt⟩ }
if ( x > 9 ) { x = 0 ; ⟨Stmt⟩ }
if ( x > 9 ) { x = 0 ; ⟨Id⟩ = ⟨RExpr⟩ ; }
if ( x > 9 ) { x = 0 ; y = ⟨AExpr⟩ ; }
if ( x > 9 ) { x = 0 ; y = ⟨AExpr⟩ + ⟨PExpr⟩ ; }
if ( x > 9 ) { x = 0 ; y = ⟨PExpr⟩ + ⟨PExpr⟩ ; }
if ( x > 9 ) { x = 0 ; y = ⟨Id⟩ + ⟨Num⟩ ; }
if ( x > 9 ) { x = 0 ; y = y + 1 ; }
```

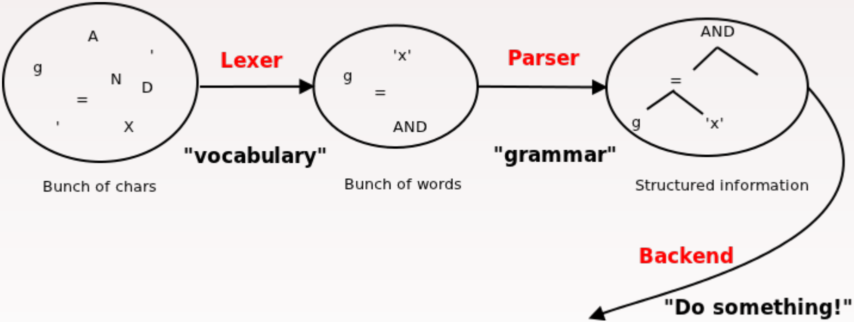
Backus–Naur Form

The Backus–Naur Form (BNF) [3] is a notation system for defining the syntax of programming languages:

```
E ::= T (('+' | '-') T)*
T ::= '(' E ')' | id
```

- `E ::= T ((’+’ | ’-’) T)` an expression E consists of a term T optionally followed by zero or more sequences of addition “+” or subtraction “-” operators, each paired with another term T. The “*” indicates repetition (zero or more occurrences).
- `T ::= ’(’ E ’)’ | id` means a term T can either be an expression E enclosed in parentheses to group subexpressions (E), or an identifier id, which represents variables or literals like numbers.

Separation of Concerns in Parsers



Lexer Example

A lexer represents a stream of tokens:

```
import re

class Lexer:
    def __init__(self, input_text):
        self.tokens = re.findall(r'\d+|[()+\-]', input_text)
        self.position = 0

    def get_next_token(self):
        if self.position < len(self.tokens):
            token = self.tokens[self.position]
            self.position += 1
            return token
        return None

    def peek(self):
        if self.position < len(self.tokens):
            return self.tokens[self.position]
        return None
```

Recursive Descent Parser

Definition ([4])

A kind of top-down parser built from a set of mutually recursive procedures where each such procedure implements one of the nonterminals of the grammar.

Recursive Descent Parser Example

```
class Parser:
    def __init__(self, lexer):
        self.lexer = lexer
        self.current_token = self.lexer.get_next_token()

    def consume(self):
        self.current_token = self.lexer.get_next_token()

    def parse_E(self):
        node = self.parse_T()
        while self.current_token in ('+', '-'):
            op = self.current_token
            self.consume()
            node = (op, node, self.parse_T())
        return node

    ...
```

Recursive Descent Parser Example (Continued)

```
...

def parse_T(self):
    if self.current_token == '(':
        self.consume()  # Consume '('
        node = self.parse_E()
        if self.current_token == ')':
            self.consume()  # Consume ')'
            return node
        else:
            raise SyntaxError("Missing closing parenthesis")
    elif self.current_token.isdigit():
        node = int(self.current_token)  # Convert id (number) to integer
        self.consume()
        return node
    else:
        raise SyntaxError(f"Unexpected token: {self.current_token}")
```

Recursive Descent Parser Example

Client code:

```
if __name__ == "__main__":
    input_text = "1 + (2 - 3)"
    lexer = Lexer(input_text)
    parser = Parser(lexer)
    syntax_tree = parser.parse_E()
    print(syntax_tree)
```

Parser Generator

Parser generators such as generate parsers based on grammar descriptions such as BNF. Popular generations include:

- Bison for C/C++
- ANTRL for Java and other languages
- Lark for Python

ANTRL Notation

```
grammar ExpressionGrammar;

// parser

expr   : left=expr op=('*'|'/') right=expr #opExpr
       | left=expr op=('+'|'-') right=expr #opExpr
       | '(' expr ')'                      #parenExpr
       | atom=INT                          #atomExpr
       ;

// lexer

INT : ('0' .. '9') +;

WS : [ \r\n\t] + -> skip ;
```

Lark Notation

```
?start: product
    | start "+" product -> add
    | start "-" product -> sub
?product: atom
    | product "*" atom  -> mul
    | product "/" atom  -> div
?atom: NUMBER           -> number
    | "-" atom          -> neg
    | "(" start ")"
%import common.NUMBER
%import common.WS_INLINE
%ignore WS_INLINE
```

Parser Combinators

Definition

A parser combinator is a higher-order function that accepts several parsers as input and returns a new parser as its output.

References I

[1] Wikipedia Authors.
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[3] John W Backus.
The syntax and the semantics of the proposed international algebraic language of the zurich acm-gamm conference.
In *ICIP Proceedings*, pages 125–132, 1959.

[4] Wikipedia Authors.
Recursive descent parser.
`https://en.wikipedia.org/wiki/Recursive_descent_parser`, 2025.