Announcements
Programming Languages
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def square(x):
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**Python 3 Byte Code**

<table>
<thead>
<tr>
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<tr>
<td>LOAD_FAST 0 (x)</td>
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from dis import dis
def square(x):
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dis(square)
```

**Python 3 Byte Code**
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Metalinguistic Abstraction

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To create a new programming language, you either need a:

- **Specification:** A document describe the precise syntax and semantics of the language
- **Canonical Implementation:** An interpreter or compiler for the language
Parsing
Reading Scheme Lists
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A Scheme list is written as elements in parentheses:
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\((\text{<element_0> <element_1> ... <element_n>})\)
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Reading Scheme Lists

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\((+ (* 3 (+ (* 2 4) (+ 3 5))) (+ (- 10 7) 6))\)
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(Demo)
http://composingprograms.com/examples/scalc/scheme_reader.py.html
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Parsing

A Parser takes text and returns an expression
Parsing

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Text  Expression
Parsing

A Parser takes text and returns an expression

Text  |  Lexical analysis  |  Expression
A Parser takes text and returns an expression
A Parser takes text and returns an expression.

1. **Lexical analysis**
2. **Tokens**
3. **Syntactic analysis**
4. **Expression**
A Parser takes text and returns an expression

\[
\begin{align*}
\text{Text} & \quad \text{Lexical analysis} & \quad \text{Tokens} & \quad \text{Syntactic analysis} & \quad \text{Expression} \\
\text{\texttt{(}+ 1\text{)}} & \quad \text{\texttt{(- 23)}} & \quad \text{\texttt{(* 4 5.6))}}
\end{align*}
\]
Parsing

A Parser takes text and returns an expression

Lexical analysis

Text

Tokens

Syntactic analysis

Expression

'(+ 1'
'   (- 23)'
'   (* 4 5.6))'
A Parser takes text and returns an expression.

**Lexical analysis**

Text:

'(+ 1'
'   (- 23)
'   (* 4 5.6))'

Lexical analysis:

Tokens:

'(', '+', 1
'  (− 23)'
'  (* 4 5.6))'

Syntactic analysis:

Expression:
Parsing

A Parser takes text and returns an expression

Text: '(+ 1'  
     '   (- 23)'  
     '   (* 4 5.6))'

Lexical analysis

Tokens: '(', '+', 1  
        '(', '+', 1  
        '(', '+', 1

Syntactic analysis

Expression: '(' ' + ' 1  
            '(' ' - ' 23  
            '(' ' * ' 4  5.6 ')'  
            ')'  
            ')'  
            ')'
A Parser takes text and returns an expression

Parsing

Lexical analysis

Tokens

Syntactic analysis

Expression

Text

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Text

Lexical analysis

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```

**Text** → **Lexical analysis** → **Tokens** → **Syntactic analysis** → **Expression**

- Text: `(+ 1
   (- 23)
   (* 4 5.6))`
- Tokens: `('+, '+', 1
   ('-', '23', ')'
   ('*', '4', 5.6, ')')`
- Expression: `('+, '+', 1
   ('-', '23', ')'
   ('*', '4', 5.6, ')')`
Parsing

A Parser takes text and returns an expression

• Iterative process
 Parsing

A Parser takes text and returns an expression

- Iterative process
- Checks for malformed tokens
A Parser takes text and returns an expression.

**Lexical analysis**
- Iterative process
- Checks for malformed tokens
- Determines types of tokens

**Text**
- `( + 1 )
- `( - 23 )
- `( * 4 5.6 )`

**Tokens**
- `( , '+', 1 )
- `( , '-', 23, ')'`
- `( , '*', 4, 5.6, ')', ')'`

**Syntactic analysis**
Parsing

A Parser takes text and returns an expression

- Iterative process
- Checks for malformed tokens
- Determines types of tokens
- Processes one line at a time
A Parser takes text and returns an expression.

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Parsing

A Parser takes text and returns an expression

- **Lexical analysis**
  - Iterative process
  - Checks for malformed tokens
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- **Tokens**
  
- **Syntactic analysis**
  
- **Expression**

Text: ('+', 1, '(', '-', 23, ')', '(', '*', 4, 5.6, ')', ')

Tokens: ('+', '1', '(', '-', '23', ')', '(', '*', '4', '5.6', ')', ')

Expression: Pair('+', Pair(1, ...))
A Parser takes text and returns an expression

Lexical analysis

Tokens

Syntactic analysis

Expression

- Iterative process
- Checks for malformed tokens
- Determines types of tokens
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Parsing

A Parser takes text and returns an expression

- **Lexical analysis**
  - Text: 
    - '(+ 1'
    - '(- 23)' 
    - '(* 4 5.6)'
  - Tokens: 
    - '(' , '+' , 1 
    - '(' , '-' , 23 , ')' 
    - '(' , '*' , 4 , 5.6 , ')' , ')' 
  - Syntax analysis:
    - Pair('+', Pair(1, ...))
    - printed as:
      - (+ 1 (- 23) (* 4 5.6))

- Iterative process
- Checks for malformed tokens
- Determines types of tokens
- Processes one line at a time

- Tree-recursive process
A Parser takes text and returns an expression

- **Lexical analysis**: Tokens
- **Syntactic analysis**: Expression

- **Iterative process**
- **Checks for malformed tokens**
- **Determines types of tokens**
- **Processes one line at a time**

- **Tree-recursive process**
- **Balances parentheses**
Parsing

A Parser takes text and returns an expression

- Iterative process
- Checks for malformed tokens
- Determines types of tokens
- Processes one line at a time

- Tree-recursive process
- Balances parentheses
- Returns tree structure

```
'(+ 1
' (− 23
' (* 4 5.6))'

'(' ' + ', 1
' (' ' − ', 23, ')'
' (' ' ⋆ ', 4, 5.6, ')', ')

Pair('+', Pair(1, ...))
```

```
printed as
(+ 1 (− 23) (* 4 5.6))
```
Parsing

A Parser takes text and returns an expression

Text | Lexical analysis | Tokens | Syntactic analysis | Expression

'(+ 1' | '(+', '+', 1 | 'Pair('+', Pair(1, ...))
'(- 23)' | '(+', '-', 23, ')'
'(.* 4 5.6))' | '(', '*', 4, 5.6, ')', ')

- Iterative process
- Checks for malformed tokens
- Determines types of tokens
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- Processes multiple lines

(pair '+', Pair(1, ...))

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Syntactic Analysis
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Syntactic analysis identifies the hierarchical structure of an expression, which may be nested.
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**Base case:** symbols and numbers
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**Recursive call:** scheme_read sub-expressions and combine them
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(Demo)
Calculator

(Demo)
The Pair Class

The Pair class represents Scheme pairs and lists. A list is a pair whose second element is either a list or nil.
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class Pair:
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    """
    def __init__(self, first, second):
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(1 . 2)
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(1 2 . 3)
>>> len(Pair(1, Pair(2, 3)))
Traceback (most recent call last):
  ...
TypeError: length attempted on improper list
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Scheme expressions are represented as Scheme lists! Source code is data
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Calculator Syntax
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The Calculator language has primitive expressions and call expressions. (That's it!)
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A primitive expression is a number: 2 -4 5.6
Calculator Syntax

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A primitive expression is a number: 2 -4 5.6

A call expression is a combination that begins with an operator (+, -, *, /) followed by 0 or more expressions: (+ 1 2 3) (/ 3 (+ 4 5))
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Expression

(* 3
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<td>((* 3 (+ 4 5) (* 6 7 8)))</td>
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**Expression**

\[
(\ast \ 5 \\
\quad (\ + \ 7 \ 6) \\
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(+ & 6 20 5))
\end{align*}
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Expression Tree

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2015 & \quad (\ast & 5 \\
13 & \quad (+ & 7 6) \\
31 & \quad (+ & 6 20 5))
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Evaluation
The Eval Function
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- A number evaluates... to itself
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Recursive call returns a number for each operand
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The apply function applies some operation to a (Scheme) list of argument values
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In calculator, all operations are named by built-in operators: +, −, *, /
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</tr>
<tr>
<td>return reduce(add, args, 0)</td>
<td></td>
</tr>
<tr>
<td>elif operator == '-':</td>
<td></td>
</tr>
<tr>
<td>...</td>
<td></td>
</tr>
<tr>
<td>elif operator == '*':</td>
<td></td>
</tr>
<tr>
<td>...</td>
<td></td>
</tr>
<tr>
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+: 

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+: 
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-
...
...
...
```

(Demo)
Interactive Interpreters
Read-Eval-Print Loop
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The user interface for many programming languages is an interactive interpreter.
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(Demo)
Raising Exceptions
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Exceptions are raised within lexical analysis, syntactic analysis, eval, and apply
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