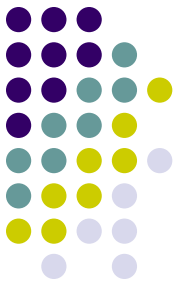


# Multi-Symbol Words - Lexical Analysis

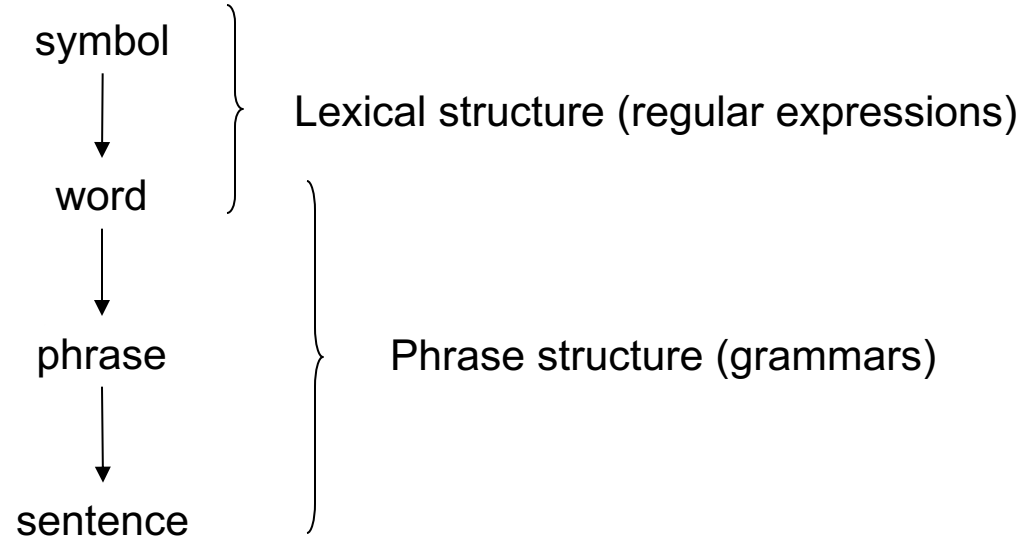


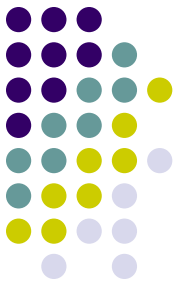
- In our exp0 programming language we only had words of length one
- However, most programming languages have words of lengths more than one
- The lexical structure of a programming language specifies how symbols are combined to form words
  - Not to be confused with the phrase structure which tells us how words are combined to form phrases and sentences
- The lexical structure of a programming language can be specified with regular expressions
  - whereas the phrase structure is specified with grammars.
- The “parser” for the lexical structure of a programming language is called a lexical analyzer or lexer
- The output of a lexer is usually given in terms of tokens.

# Multi-Symbol Words - Lexical Analysis



- This gives us the following hierarchy:





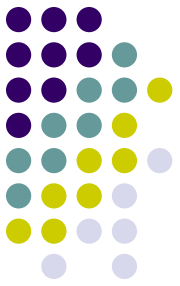
# The Calc Language

EBNF notation stating that exp can appear zero or more times

Listing 2.7: The grammar for the calc language.

```
1  explist : (exp)*
2
3  exp : NUM ← Tokens
4      | op exp exp
5      | LPAREN op exp exp (exp)* RPAREN
6
7  op : PLUS ← Tokens
8     | MINUS
```

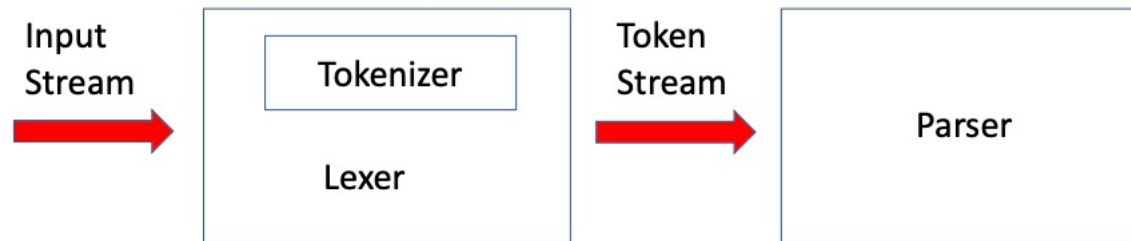
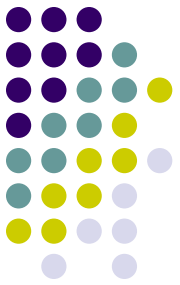
- This language allows us to write expression like,
  - 125
  - + 36 14
  - (+ 1 2 3)
  - Note that actual values and op names are now encoded as tokens in the grammar, e.g. NUM, PLUS

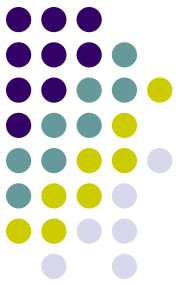


# Tokens

- The definition of Tokens usually has two parts:
  - A token type
  - A token value
- For example, in Calc we have
  - a token type PLUS with a token value of ‘+’
  - a token type NUM with an integer token value.
- That means lexers turn character/symbols streams into *token streams*
- Token streams is what is read by parsers.

# The Syntactic Analysis Phase





# The Lexer

- The lexer includes the tokenizer and implements a token stream with the following interface:

**pointer** – a function that points to the current token in the token stream.

**next** – a function that advances the pointer to the next token.

**match** – a function matches a token against the current token in the token stream.

**end-of-file** – a predicate that returns true if the pointer reached the end of the token stream.

Note: same interface as our earlier InputStream class.



# Calc Tokens

NUM – a number token describing an actual number in the input stream.

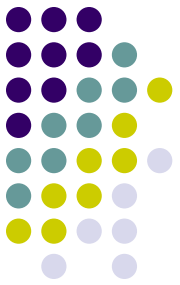
PLUS – a token describing the + operator.

MINUS – a token describing the - operator.

LPAREN – a token describing the left parenthesis.

RPAREN – a token describing the right parenthesis.

```
$ python3
Python 3.8.5 (default, Sep  4 2020, 02:22:02)
>>> from calc_lexer import tokenize
>>> for t in tokenize("+ 101 25"):
...     print(t)
...
Token(PLUS,+)
Token(NUM,101)
Token(NUM,25)
Token(EOF,\eof)
>>>
```



# Specifying Tokens

- In our `calc_lexer.py` file all we need to do is to define the token types and values
- The rest of the code is boiler plate implementing the tokenizer and lexer
- We use regular expression to specify the token values

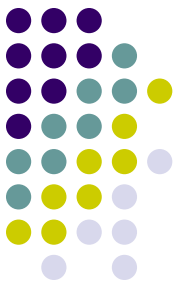
```
token_specs = [  
#   type:           value:  
    ('NUM',         r'[0-9]+'),  
    ('PLUS',        r'\+'),  
    ('MINUS',       r'-'),  
    ('LPAREN',      r'\('),  
    ('RPAREN',      r'\)'),  
    ('WHITESPACE',  r'[\t\n]+'),  
    ('UNKNOWN',     r'.')  
]
```



# Regular Expressions

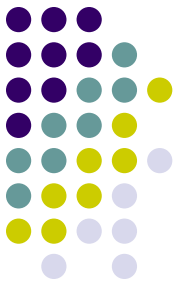


- Each letter A through Z and a through z is a regular expression.
- Each number 0 through 9 is a regular expression.
- Each printable character  $\backslash$ (,  $\backslash$ ), -,  $\backslash$ +, etc. is a regular expression.
- If A and B are regular expressions then AB is also a regular expression and represents the concatenation of the two regular expressions.
- If A is a regular expression then ( A ) is also a regular expression. Parentheses allow us to group regular expressions. Just as in grammars, the use of escaped parentheses in regular expressions is very important because the regular expression ( A ) is different from the regular expression  $\backslash$ (A). The former is the grouping of regular expression A and the latter is the concatenation of the three regular expressions.
- If A and B are regular expressions then A | B is also a regular expression and represents the choice between regular expression A and regular expression B.
- If A is a regular expression then A? is also a regular expression and specifies the regular expression A as optional.
- If A is a regular expression then A\* is also a regular expression and specifies that the regular expression A can appear zero or more times. We use the same operator in the EBNF notation for grammars.
- If A is a regular expression then A+ is also a regular expression and specifies that the regular expression A can appear one or more times. You can think of A+ as a shorthand for AA\*.



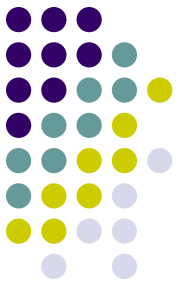
# Regular Expression

- The regular expression `[A-Z]` represents a single character between A and Z. Similarly for `[a-z]` and `[0-9]`.
- The special characters `\n`, `\t`, and `\r` are also regular expressions representing the newline character, the TAB character, and the carriage return character, respectively.
- The dot operator `.` is a regular expression that represents any single printable character. Most importantly, it does not represent the newline character `\n`.
- The `^` operator computes the complement of a set. For example, if we have the regular expression `[abc]` matching either a, b or c, then the complement `[^abc]` will match any character other than a, b, or c. This is useful in conjunction with character classes. For example, the regular expression `[A-Z][^A-Z]` specifies a word structure that starts with a capital letter followed by a single character that is not a capital letter.



# Parsing with Lexers

- Good news: the techniques of building top-down parser we have looked at so far apply to parsers that use lexers!
- Instead of using lookahead symbol we will now use lookahead tokens.



# Parsing with Lexers

- Consider our calc language again
- We compute the lookahead sets in terms of tokens

Listing 2.9: The grammar for the calc language with lookahead sets.

```
1  explist : ({NUM,PLUS,MINUS,LPAREN} exp)*
2
3  exp  : {NUM} NUM
4        | {PLUS,MINUS} op exp exp
5        | {LPAREN} LPAREN op exp exp ({NUM,PLUS,MINUS,LPAREN} exp)* RPAREN
6
7  op   : {PLUS} PLUS
8        | {MINUS} MINUS
```



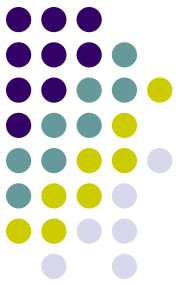
# Parsing with Lexers

- Now it is straightforward to build the parser

```
def explist(stream):  
    while stream.pointer().type in ['NUM', 'PLUS', 'MINUS', 'LPAREN']:  
        exp(stream)  
    return
```

```
def exp(stream):  
    token = stream.pointer()  
    if token.type in ['NUM']:  
        stream.match('NUM')  
        return  
    elif token.type in ['PLUS', 'MINUS']:  
        op(stream)  
        exp(stream)  
        exp(stream)  
        return  
    elif token.type in ['LPAREN']:  
        stream.match('LPAREN')  
        op(stream)  
        exp(stream)  
        exp(stream)  
        while stream.pointer().type in ['NUM', 'PLUS', 'MINUS', 'LPAREN']:  
            exp(stream)  
        stream.match('RPAREN')  
    else:  
        raise SyntaxError("syntax error at {}".format(token.type))
```

```
def op(stream):  
    token = stream.pointer()  
    if token.type in ['PLUS']:  
        stream.match('PLUS')  
        return  
    elif token.type in ['MINUS']:  
        stream.match('MINUS')  
        return  
    else:  
        raise SyntaxError("syntax error at {}".format(token.type))
```



# Parsing with Lexers

- Top-level driver function

```
def parse():
    from calc_lexer import Lexer
    from sys import stdin
    try:
        char_stream = stdin.read() # read from stdin
        token_stream = Lexer(char_stream)
        explist(token_stream) # call the parser function for start symbol
        if token_stream.end_of_file():
            print("parse successful")
        else:
            raise SyntaxError("bad syntax at {}".format(token_stream.pointer()))
    except Exception as e:
        print("error: " + str(e))
```



# Parsing with Lexers

- Running the parser

```
$ python3 calc_parser.py  
+ 10 25  
^D  
parse successful
```

```
$ python3 calc_parser.py  
(+ 1 2 3)  
^D  
parse successful
```

```
$ python3 calc_parser.py  
+ (+ 1 2 3) 4  
^D  
parse successful
```

# Class Exercise 1a

- Please see BrightSpace

