Lexical Analysis

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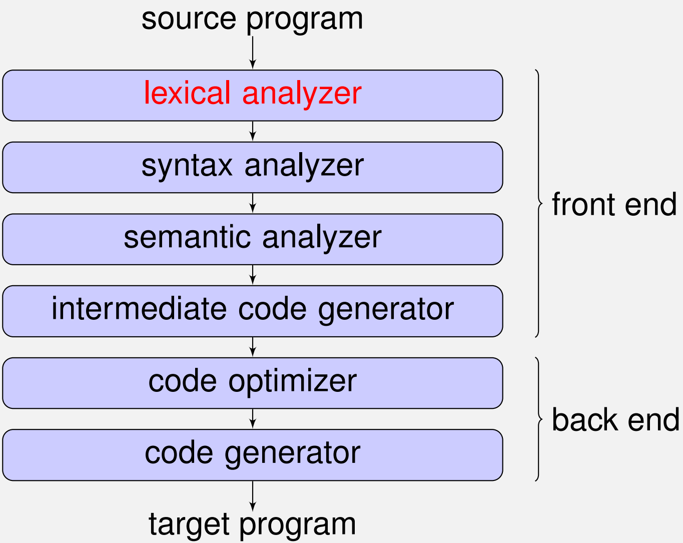
Outline

1. Introduction
2. Roles
3. Implementation
4. Use ANTLR to generate Lexer
5. Regex and Parser Libraries in Scala

Compilation Phases



source program

lexical analyzer

syntax analyzer

semantic analyzer

intermediate code generator

code optimizer

code generator

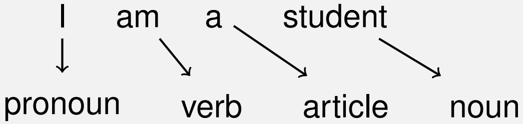
target program

front end

back end

Lexical Analysis

- Like a **word extractor**
  in ⇒ i n ⇒ in
- Like a **spell checker**
  I ogog to socholsochol
- Like a **classification**



I am a student

pronoun verb article noun

Lexical Analysis Roles

chuỗi con

- Identify **lexemes**: substrings of the source program that belong to a grammar unit
- Return **tokens**: a lexical category of lexemes
- Ignore **spaces** such as blank, newline, tab
- Record the **position** of tokens that are used in next phases

Example on Lexeme and Token

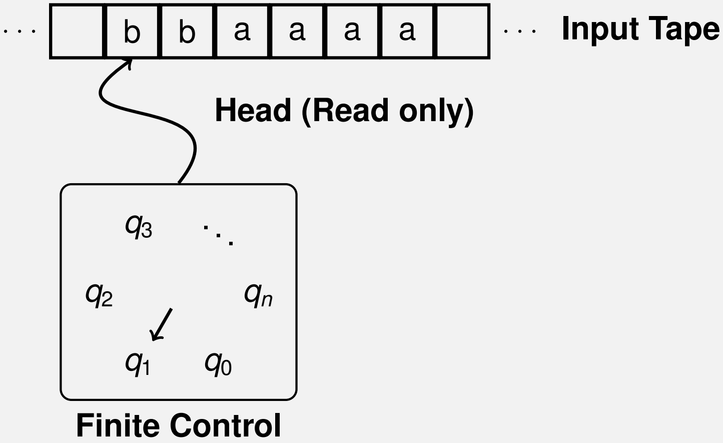
result = oldsum - value / 100;

Lexemes	**Tokens**
result	IDENT
=	ASSIGN_OP
oldsum	IDENT
-	SUBSTRACT_OP
value	IDENT
/	DIV_OP
100	INT_LIT
;	SEMICOLON

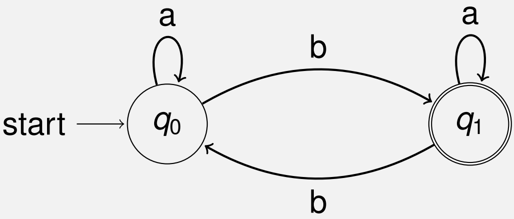
How to build a lexical analyzer?

- How to build a lexical analysis for English?
    - 65000 words
    - Simply build a dictionary: {(I,pronoun);(We,pronoun);(am,verb);...}
    - Extract, search, compare
- But for a programming language?
    - How many words?
        - Identifiers: abc, cab, Abc, aBc, cAb, ...
        - Integers: 1, 10, 120, 20, 210, ...
        - ...
    - Too many words to build a dictionary, so how?

Finite Automata



State Diagram



Input: abaabb

Current state	Read	New State
q_0	a	q_0
q_0	b	q_1
q_1	a	q_1
q_1	a	q_1
q_1	b	q_0
q_0	b	q_1

Deterministic Finite Automata

Definition

Deterministic Finite Automaton(DFA) is a 5-tuple M =(K,Σ,δ,s,F) where

- K = a finite set of state
- Σ = alphabet
- s $\in$ K = the initial state
- F $\subseteq$ K = the set of final states
- δ = a transition function from K $\times\Sigma$ to K

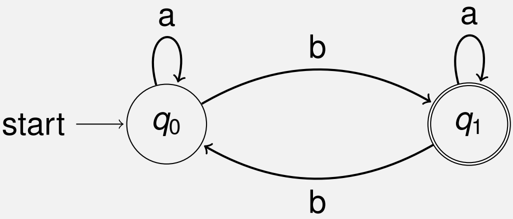
Example

M =(K,Σ,δ,s,F)

where K = $\{q_0, q_1\}$ Σ = {a,b} s=q_0 F=$\{q_1\}$

and δ

K	Σ	$\delta(K,\Sigma)$
q_0	a	q_0
q_0	b	q_1
q_1	a	q_1
q_1	b	q_0

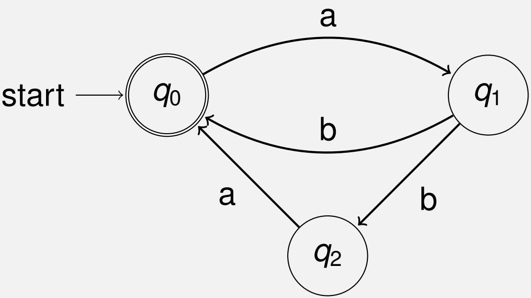


Nondeterministic Finite Automata

- Permit several possible “next states” for a given combination of current state and input symbol
- Accept the empty string ϵ in state diagram
- Help simplifying the description of automata
- Every NFA is equivalent to a DFA

Example

Language L = ({ab} ∪ {aba})*



Example

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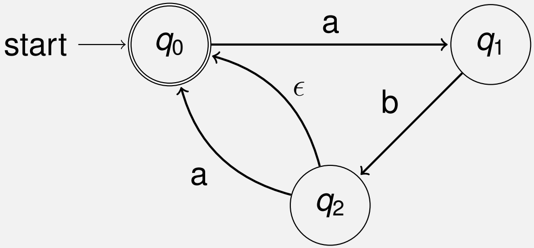


Regular Expression (regex)

- Describe regular sets of strings
- Symbols other than ( ) | * stand for themselves
- Use ϵ for an empty string
- Concatenation $\alpha\ \beta$ = First part matches α, second part β
- Union α | β = Match α or β
- Kleene star α^* = 0 or more matches of α
- Use ( ) for grouping

Example

(i|I)(f|F)

Keyword **if** of language Pascal

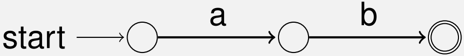
- if
- IF
- If
- iF

E(0|1|2|3|4|5|6|7|8|9)*

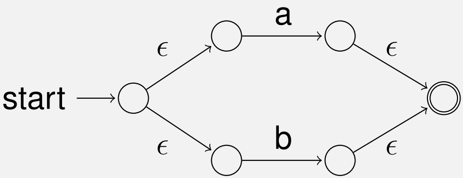
An E followed by a (possibly empty) sequence of digits

- E123
- E9
- E

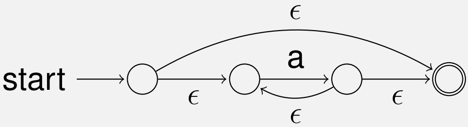
Regular Expression and Finite Automata



ab



a | b



a*

Convenience Notation

- α+ = one or more (i.e. $\alpha\alpha*$)
- α? = 0 or 1 (i.e. $(\alpha|\epsilon)$)
- [xyz]= x|y|z
- [x-y]= all characters from x to y, e.g. [0-9] = all ASCII digits
- [^x-y]= all characters other than [x-y]
- . matches any character

Example

- Integer:
- Hexadecimal number:
- Fixed-point number:
- Floating point number:
- String:

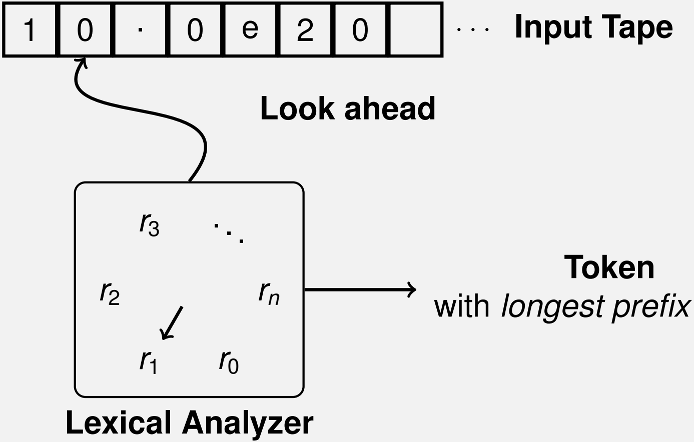
ANTLR [1]

- ANother Tool for Language Recognition
- Terence Parr, Professor of CS at the Uni. San Francisco
- powerful parser/lexer generator

Lexer

```
/**
 * Filename: Hello.g4
 */
lexer grammar Hello;

// match any digits
INT: [0-9]+;

// Hexadecimal number
HEX: 0[Xx][0-9A-Fa-f]+;

// match lower-case identifiers
ID : [a-z]+ ;

// skip spaces, tabs, newlines
WS : [ \t\r\n]+ -> skip ;
```

Lexical Analyzer



Token
with *longest prefix match*

Scala Regex Library

Library	import scala.util.matching.Regex
Construction	new Regex(String)
	new Regex("[0-9]+")
	"[0-9]+".r
Method	findFirstIn(String):Option[Match]
	findFirstMatchIn(String):Option[String]
	findPrefixOf(String):Option[String]
	findPrefixMatchOf(String):Option[String]
	findAllIn(String):MatchIterator
	...

Example

```
import scala.util.matching.Regex
val pat = new Regex("[0-9]+")
val pattern = "[a-z][a-z]*".r
val str = "123 abc 456"
pat.findFirstIn(str)
pattern.findFirstIn(str)
```

Scala Parser Library

Library	scala.util.parsing.combinator.Parsers.Parser	
Construction	new Parser[T]	
	new Parser[Token]	
	new Parser[Any]	
Method	~	p1 ~ p2: must match p1 followed by p2
	|	p1 | p2: must match either p1 or p2, with preference given to p1
	?	p1.? : may match p1 or not
	*	p1.*: matches any number of repetitions of p1
	^^	p1 ^^ f: combine for function application
	^^^	p1 ^^^ T: changes a successful result into the specified value
	...	...

Summary

- A lexical analyzer is a pattern matcher that isolates small-scale parts of a program
- Regular expressions are built based on Finite Automata
- How to write a lexical analyzer (lexer) in Scala

References I

[1] ANTLR, `http:antlr.org`, 19 08 2016.