Lexical Analysis

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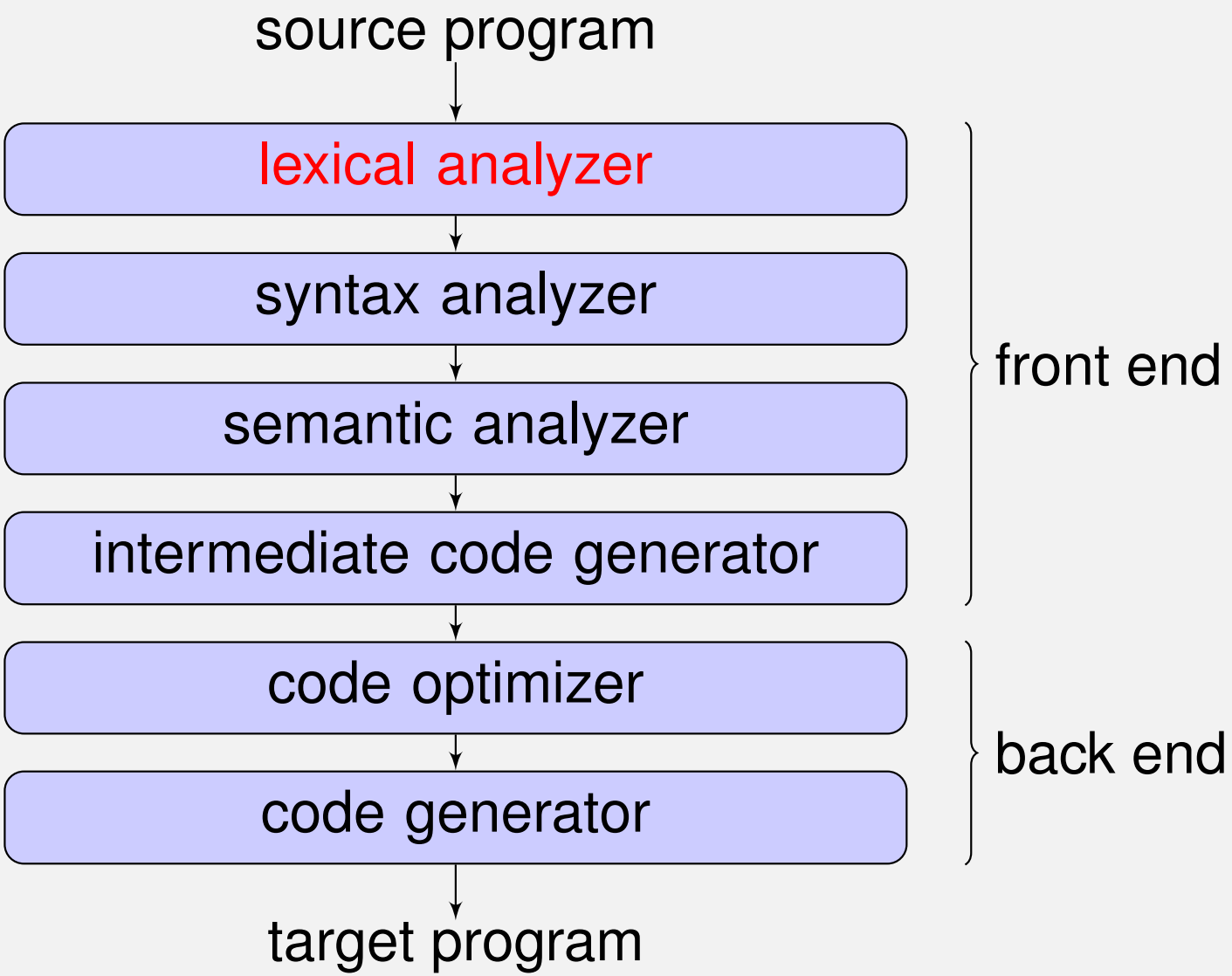
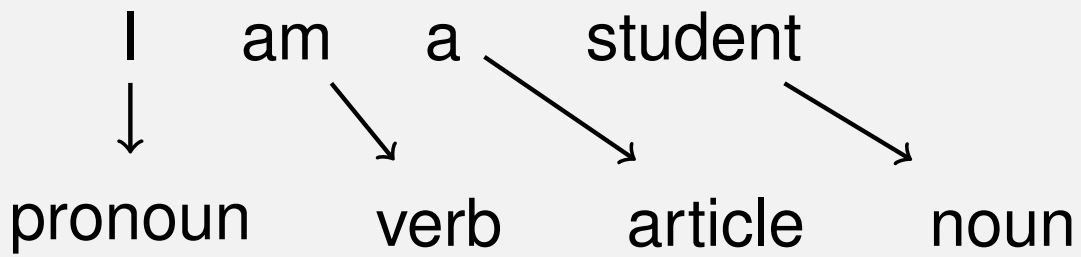
Outline

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

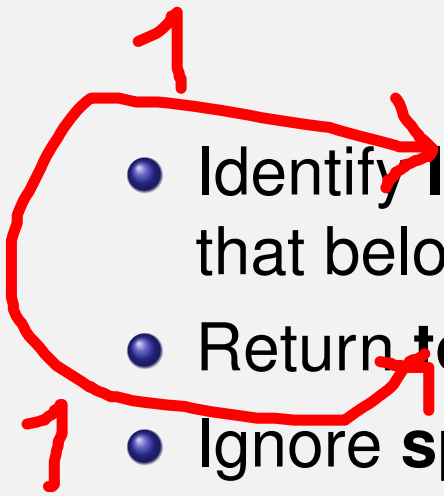
Compilation Phases



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



Lexical Analysis Roles



- 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

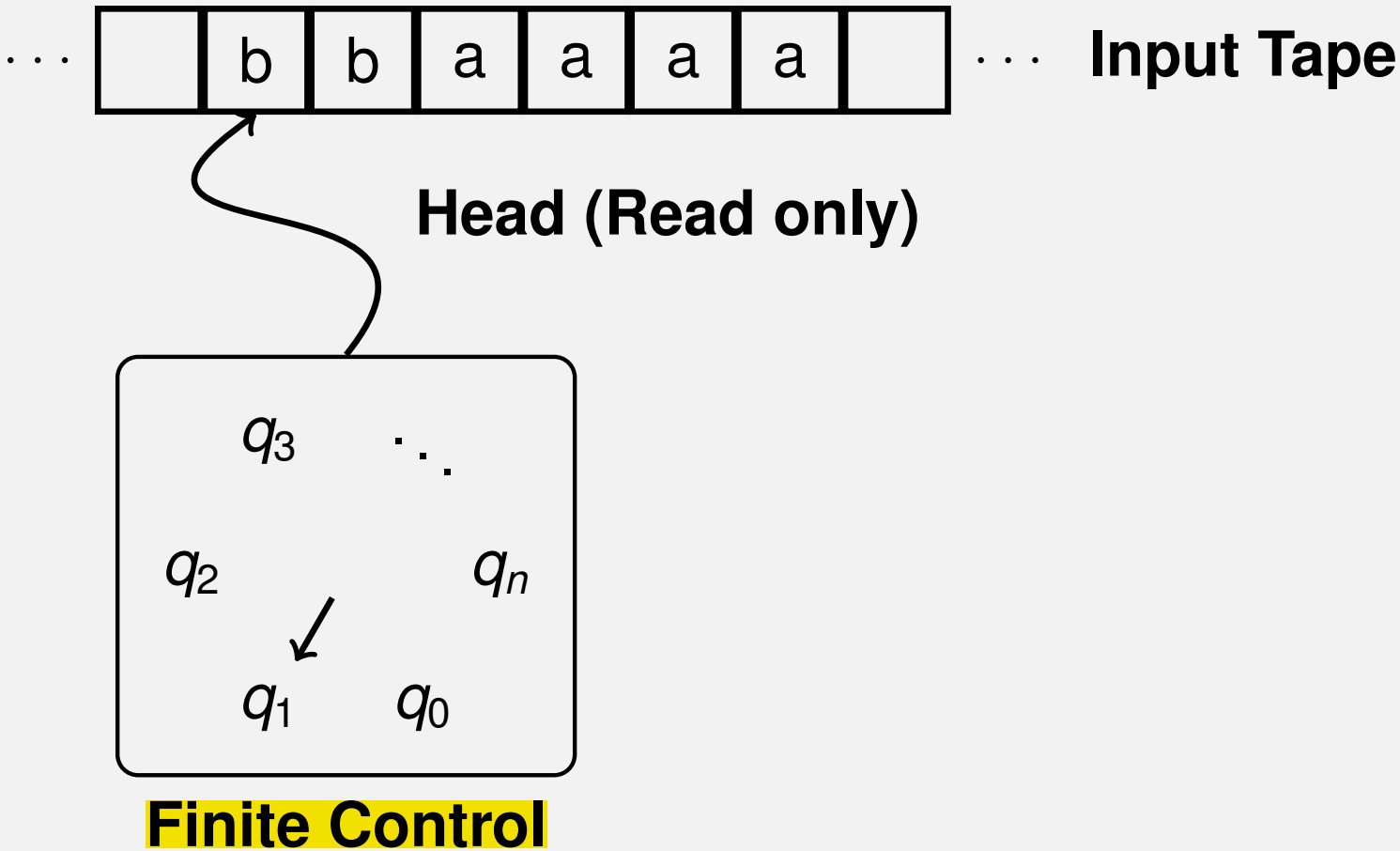
Example on Lexeme and Token

result = oldsum - value / 100;

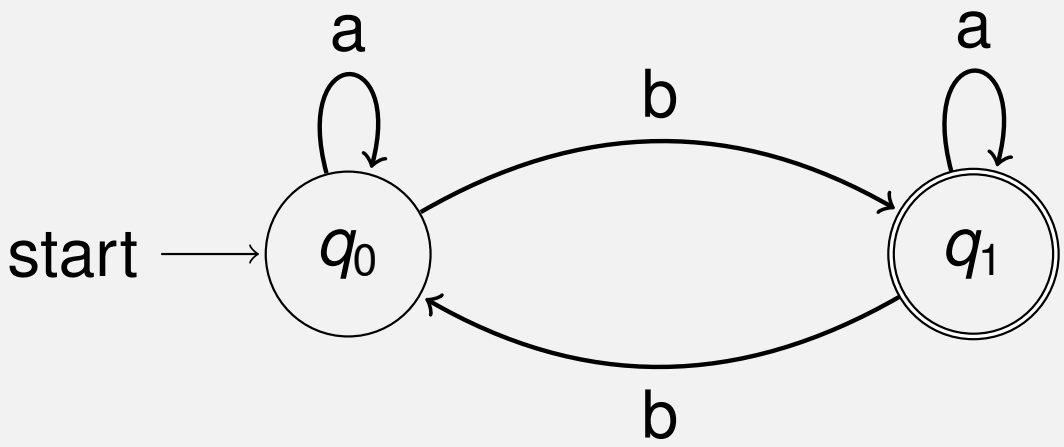
Lexemes	**Tokens**
result	IDENT
=	ASSIGN_OP
oldsum	IDENT
-	SUBSTRACT_OP
value	IDENT
/	DIV_OP
100	INT_LIT
;	SEMICOLON

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?


b
b
a
a
a
a
Input Tape
Head (Read only)
q_3
q_2
q_n
q_1
q_0
Finite Control

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

Definition

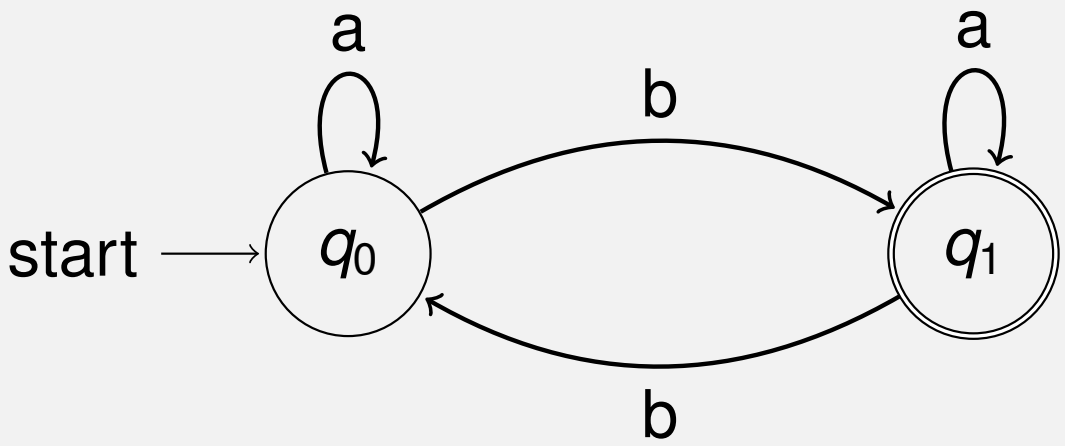
Deterministic Finite Automaton(DFA) is a 5-tuple M =(K,Σ,δ,s,F) where

- 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

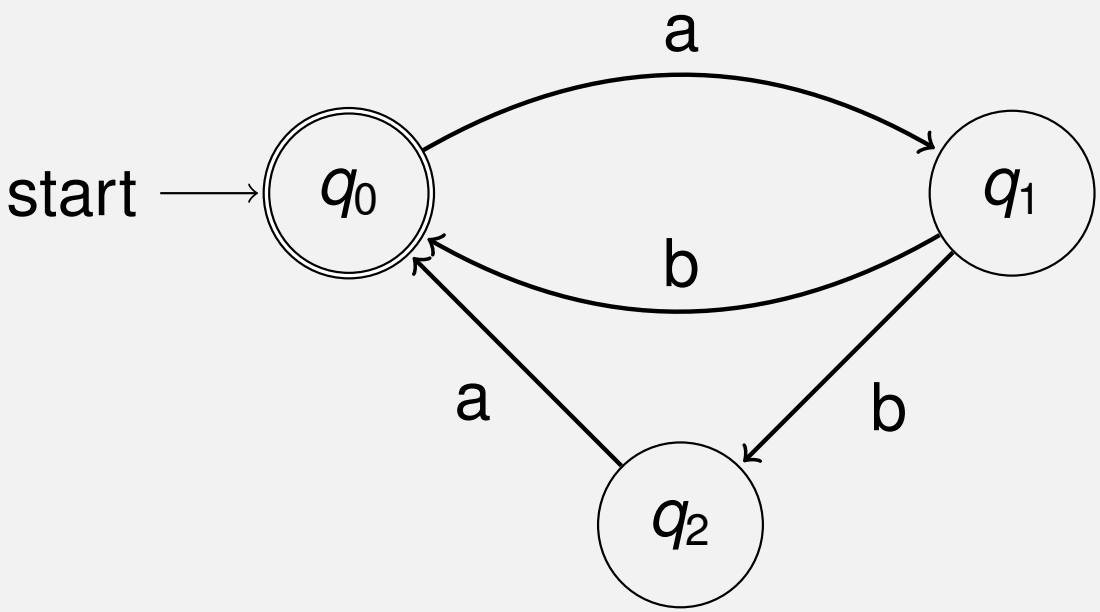


Nondeterministic Finite Automata

- 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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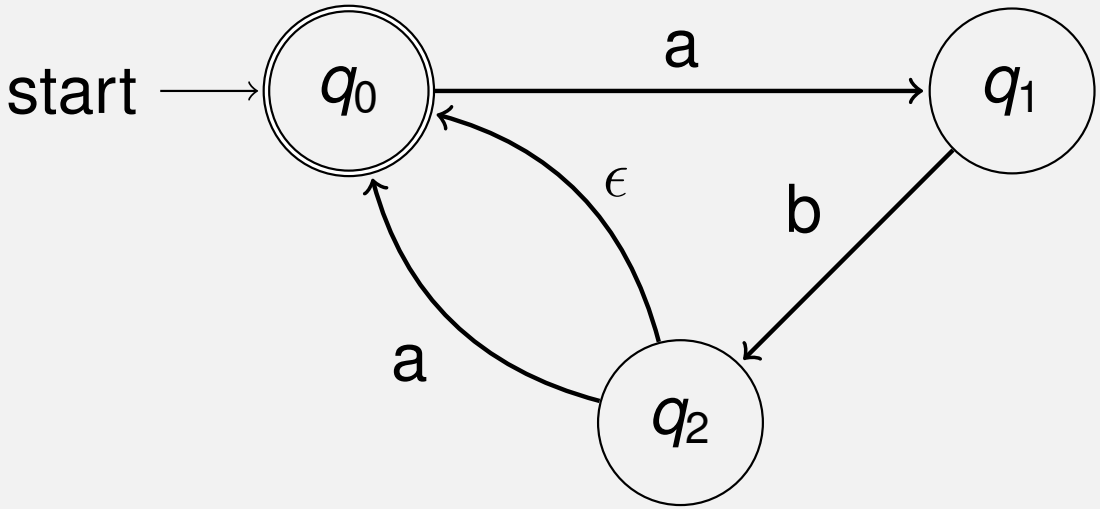


Regular Expression (regex)

- 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

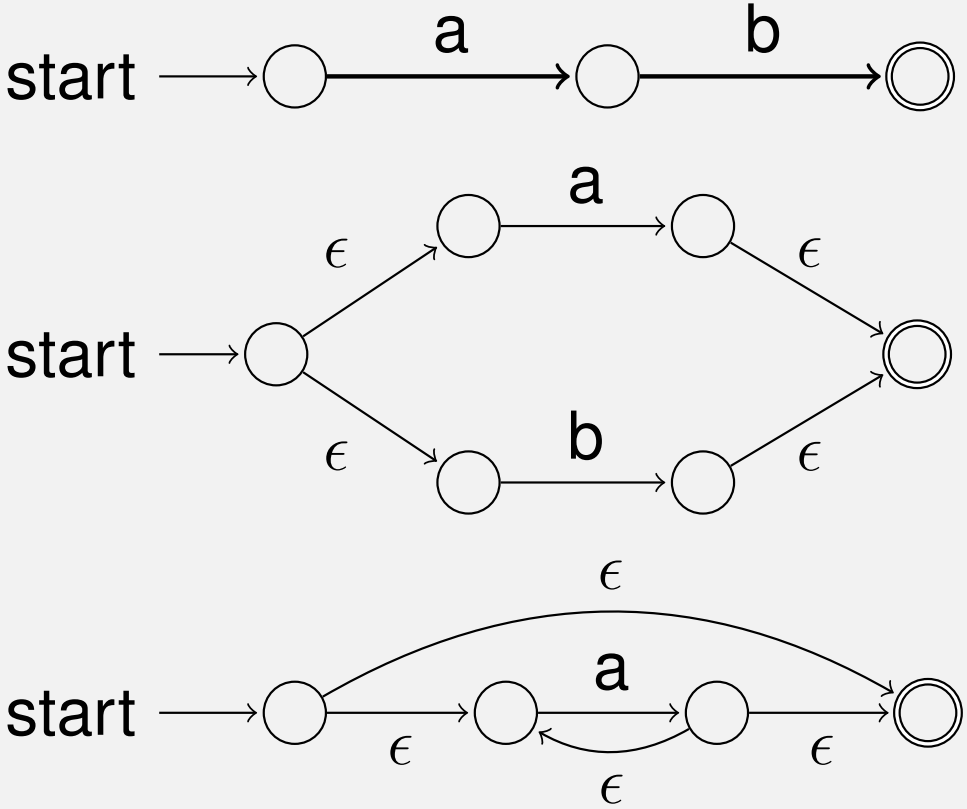
- if
- IF
- If
- iF

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



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

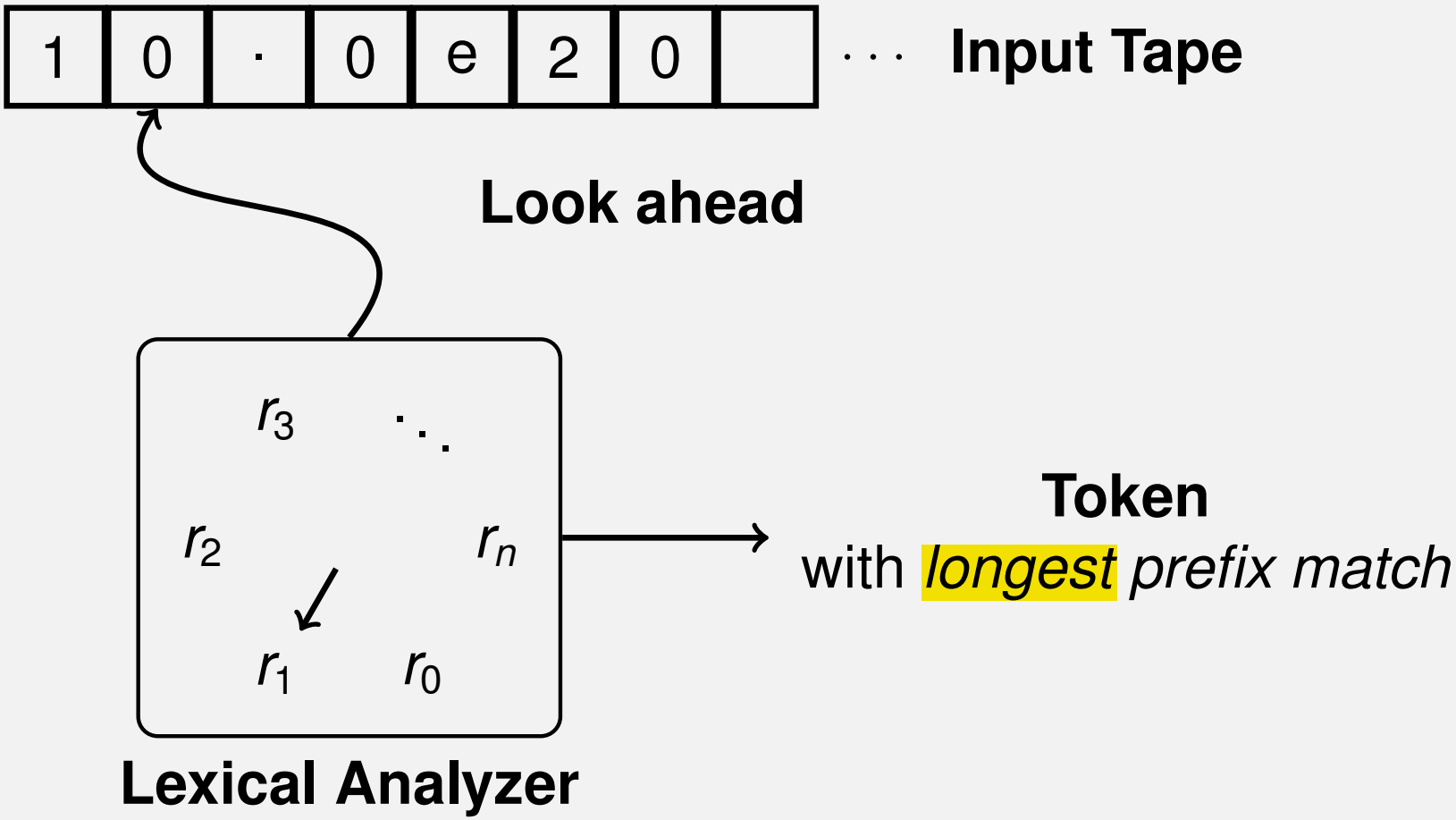
- Integer:
- Hexadecimal number:
- Fixed-point number:
- Floating point number:
- String:

ANTLR [1]

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

```
/**
 * 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



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.