Monash University
Faculty of Information Technology

Lecture 8
Lexical Analysis

Slides by David Albrecht (2011), minor modifications by Graham Farr (2013, 2018).

FIT2014 Theory of Computation

Overview

- Lexical Analyzer
- Tokens and lexemes
- Implementing Lexical Analyzer
- Other Algorithms

Simple Calculator Example

-	2	.	4	5		+		3	.	9	8		*		0	.	4	5	6	\n

Lexemes:

-2.45		+		3.98		*		0.456	\n

Tokens:

- Numbers, spaces, operators, newlines

Java

c	l	a	s	s		H	e	l	l	o	{	\n	p	u	b	l
i	c		s	t	a	t	i	c		v	o	i	d		m	a
i	n	(	S	t	r	i	n	g		a	r	g	s	[	]	)
{	S	y	s	t	e	m	.	o	u	t	.	p	r	i	n	t
l	n	(	“	H	e	l	l	o	”	)	;	}	}			

class		Hello	{	\n	public	
static		void		main	(	String
	args	[	]	)	{	System	.
out	.	println	(| “Hello” |)	;	}	}

Tokens:

- reserved keywords, identifiers, brackets, etc.

Terminology

- A **token** is a name of a pattern.
  - It may also have an attribute value associated with it.
- A **lexeme** is a sequence of characters that matches the pattern corresponding to a token.
- A **pattern** is a description of the form that the lexemes of a token may take.
  - Often described using regular expressions.

Lexical Analyzer

- Reads the input one character at a time.
- Splits the input up into tokens.
- Implemented using a **Finite Automaton** or **NFA**.

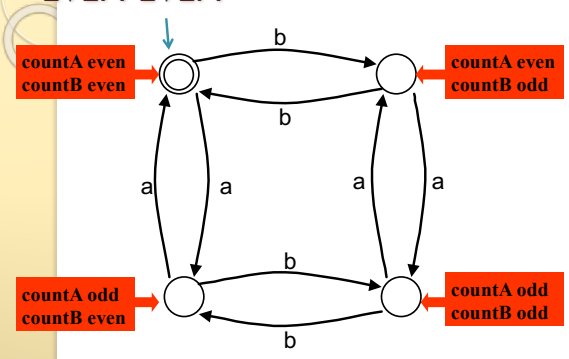
EVEN-EVEN

Write a program which reads in a character string, consisting of **a**'s and **b**'s, one character at a time and identifies whether or not the string belongs to **EVEN-EVEN**.

```
class EvenEven {
   public static void main(String args[]) throws java.io.IOException {
      int countA = 0;
      int countB = 0;
      int peek = System.in.read();

      while (peek != -1) {
         switch(peek) {
               case 'a':
                     countA++;
                     break;
               case 'b':
                     countB++;
                     break;
               default:
                     break;
               }
               peek = System.in.read();
            }
            if (countA % 2 == 0 && countB % 2 == 0)
               System.out.println("Match");
            else
               System.out.println("No Match");
   }
}
```

EVEN-EVEN

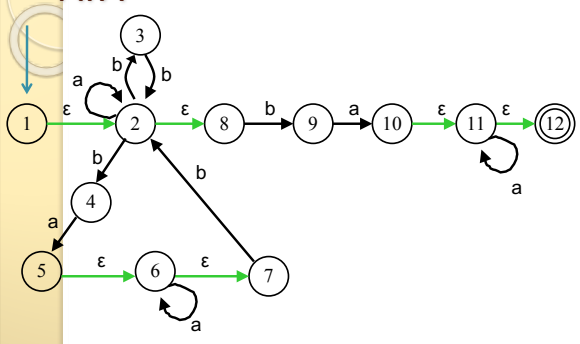


Matching a Regular Expression

Write a program which reads in a character string, consisting of **a**'s and **b**'s, one character at a time and identifies whether or not the string matches the following regular expression.

(a ∪ bb ∪ baa*b)*baa*

NFA



DFA

	a	b
Start {1,2,8}	{2,8}	{3,4,9}
{2,8}	{2,8}	{3,4,9}
{3,4,9}	{5,6,7,10,11,12}	{2,8}
Final {5,6,7,10,11,12}	{6,7,11,12}	{2,8}
Final {6,7,11,12}	{6,7,11,12}	{2,8}

Can we simplify this DFA?

DFA

A **Final State** and a **non-Final State** are *fundamentally different.*
They *cannot be combined.*
So: give all **Final States** one colour,
and all **non-Final States** a *different* colour.

Different colours $\Longrightarrow$
different states; they cannot be combined.
Same colours $\not\Rightarrow$ same states;
the states *may or may not* be combined.
We have not yet ruled out combining them.

DFA

	a	b
Start {1,2,8}	{2,8}	{3,4,9}
{2,8}	{2,8}	{3,4,9}
{3,4,9}	{5,6,7,10,11,12}	{2,8}
Final {5,6,7,10,11,12}	{6,7,11,12}	{2,8}
Final {6,7,11,12}	{6,7,11,12}	{2,8}

DFA

	a	b
Start {1,2,8}	{2,8}	{3,4,9}
{2,8}	{2,8}	{3,4,9}
{3,4,9}	{5,6,7,10,11,12}	{2,8}
Final {5,6,7,10,11,12}	{6,7,11,12}	{2,8}
Final {6,7,11,12}	{6,7,11,12}	{2,8}

DFA

Different colour pattern along row $\Longrightarrow$
different states; they cannot be combined.

The different colour patterns mean they *must* treat some strings differently.
So, give those states different colours.

Same colour patterns $\not\Rightarrow$ same states;
the states *may or may not* be combined.
We have not yet ruled out combining them.

DFA

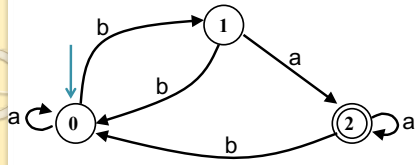
	a	b
Start {1,2,8}	{2,8}	{3,4,9}
{2,8}	{2,8}	{3,4,9}
{3,4,9}	{5,6,7,10,11,12}	{2,8}
Final {5,6,7,10,11,12}	{6,7,11,12}	{2,8}
Final {6,7,11,12}	{6,7,11,12}	{2,8}

DFA

	a	b
Start {1,2,8}	{2,8}	{3,4,9}
{2,8}	{2,8}	{3,4,9}
{3,4,9}	{5,6,7,10,11,12}	{2,8}
Final {5,6,7,10,11,12}	{6,7,11,12}	{2,8}
Final {6,7,11,12}	{6,7,11,12}	{2,8}

Minimum DFA

- Colour all **Final States** with one colour, and colour all **Non-Final States** with a different colour.
- Repeat until no new colour is added:
  - For each colour:
    - Consider all states with that colour.
    - If their rows in the transition table do not have the same pattern of colours, then
      - The states with different colour patterns along their rows must get different colours. So …
      - Give each different row pattern a different colour.
      - Each set of states having the same row pattern gets the colour for that row pattern.
- Give each colour a unique number, and use these numbers to form the transition table.



	a	b
Start 0	0	1
1	2	0
Final 2	2	0

```
class Match {
   public static void main(String args[]) throws java.io.IOException {
      int currentState = 0;
      int[][][] table = {{0, 1}, {2, 0}, {2, 0}};
      int peek = System.in.read();

       while (peek != -1) {
          switch(peek) {
                case 'a':
                      currentState = table[currentState][0];
                      break;
                case 'b':
                      currentState = table[currentState][1];
                      break;
                default:
                      break;
                }
                peek = System.in.read();
          }
          if (currentState == 2)
             System.out.println("Match");
          else
             System.out.println("No Match");
   }
}
```

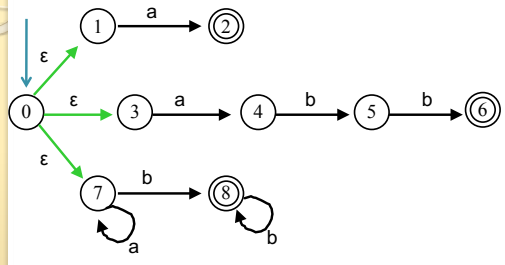
Matching Regular Expressions

Write a program which reads in a character string, consisting of **a**'s and **b**'s, one character at a time and identifies whether or not the string matches one the following regular expressions, and which one.

a, abb, a*b⁺

Conventions

- Often it is possible to split a sequence of characters up into tokens in more than one way.
  - Consider **abbbb**
  - **Convention**: Match the largest possible lexeme at each stage.
- Often a sequence of characters can match more than one token.
  - Consider **abb**
  - **Convention:** If the lexemes are the same length choose the first token that is listed.

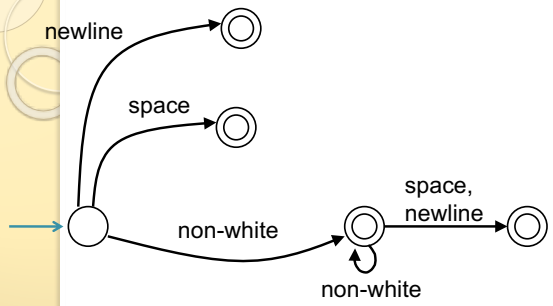


	a	b
Start {0,1,3,7}	{2,4,7}	{8}
Final a {2,4,7}	{7}	{5,8}
Final a^*b^+ {8}	f	{8}
{7}	{7}	{8}
Final a^*b^+ {5,8}	f	{6,8}
Final abb {6,8}	f	{8}

Word identification

Write a program which reads in one character at a time and identifies the following tokens:

- **newline**,
- **space**, and
- **word**.



Other Algorithms

- There are algorithms that can take a regular expression and produce a minimum state DFA without constructing a NFA.
- There are algorithms that produce fast and more compact representations of a DFA transition table than the straightforward two-dimensional table.

Revision

- Understand what a lexical analyzer does.
- Know how to find the DFA with the minimum number of states
- Know how to implement a finite automaton.