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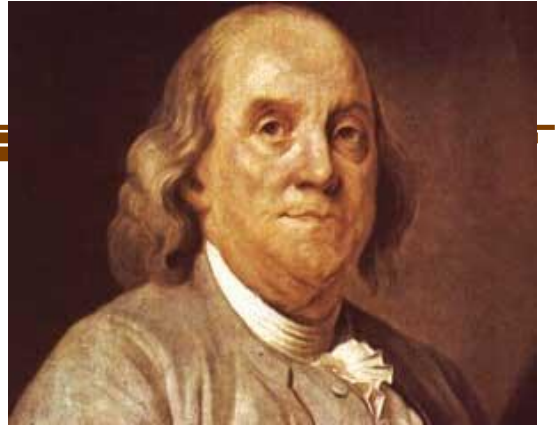
Franklin's 13 virtues and Puritan ethics



(1) Temperance: Eat not to dullness; drink not to elevation.

节制：食不过饱，饮不过量

This virtue is consistent with Puritan code of drinking in moderation so as to keep a sober mind.

(2) Silence: Speak not but what may benefit others or yourself; avoid trifling conversation.

缄默：言则于人于己有益，不做鸡毛蒜皮的闲扯。

Great minds discuss idea. Average minds discuss events. Small minds discuss people.

智者论道、能者谈事、庸者诽人

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Compiling and Running of Program

Dr. Zheng Xiaojuan
Professor

October. 2019

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What were introduced in Last Lecture

- **Formal Definition of NFA**
- **Differences between NFA & DFA**
- **From NFA to DFA**
- **Minimizing DFA**

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Summary of Homework

- **(1) Define data structure for Token**
  - **Be familiar with Data Structure**
  - **Be familiar with what a token is composed of;**

```
enum TkType {ID, Num,
                    if, else, while, int, real, ……
                     colon, comma, semi, ……}
```

```
Struct Token {TkType  type;
                    char sema[40];}
```

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Summary of Homework

- **(2) Find out token types of C programming language, and give their DFA definition.**
  - **Token Type: identifier, keywords, constant, special symbols;**
  - **How to deal with keyword?**
    - **Keywords are part of identifier --- do not need to define a separate DFA for keywords;**
    - **Establish keyword table;**
    - **Whenever an identifier is recognized, search for the keyword table at first to decide whether the identifier is a keyword;**
  - **DFA definition for each token type**
    - **Know how is a token of the token type is structured;**
    - **Lexical rules**

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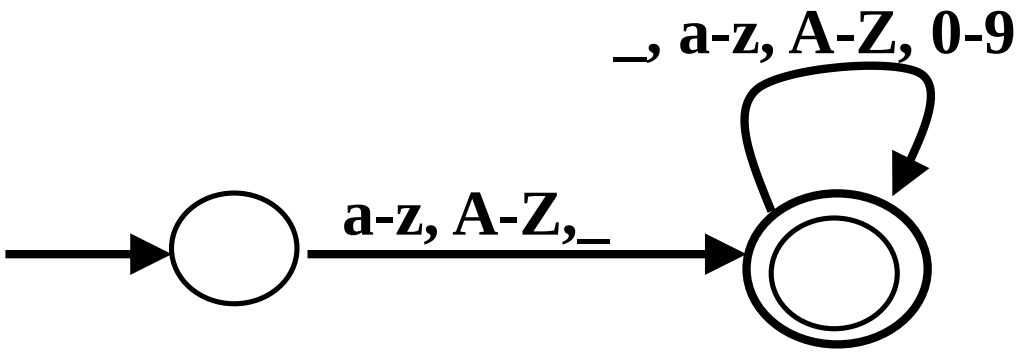
DFA definition for identifier



{ _, a, b, …, z, A, …, Z, _ _,
_a, …, _z, …, _A, …, _Z,_0, …, _9,
…….}

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Outline

- 2.1 Overview
  - 2.1.1 General Function of a Scanner
  - 2.1.2 Some Issues about Scanning
- 2.2 Finite Automata
  - 2.2.1 Definition and Implementation of DFA
  - 2.2.2 Non-Determinate Finite Automata
  - 2.2.3 Transforming NFA into DFA
  - 2.2.4 Minimizing DFA
- 2.3 Regular Expressions
  - 2.3.1 Definition of Regular Expressions
  - 2.3.2 Regular Definition
  - 2.3.4 From Regular Expression to DFA
- 2.4 Design and Implementation of a Scanner
  - 2.4.1 Developing a Scanner from DFA
  - 2.4.2 A Scanner Generator – Lex

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2.3 Regular Expressions

- **Definition of Regular Expressions**
- **Regular Definition**
- **From Regular Expression to DFA**

Definition of Regular Expressions (RE)

- Some Concepts
- Formal Definition of RE
- Example
- Properties of RE
- Extensions to RE
- Limitations of RE
- Using RE to define Lexical Structure

Some Concepts

- alphabet(字母表)：a non-empty finite set of symbols，which is denoted as ∑，one of its elements is called symbol.
- string(符号串)：finite sequence of symbols, we use λ or ε to represent empty string(空串);
- 空串集{λ} is different from empty set ∅ { } 。
- length of a string(符号串长度)：the number of symbols in a string, we use |β| to represent the length of the string β;
- concatenate operator for strings(符号串连接操作)：

  if α and β are strings，we use αβ as the concatenation of two strings, especially we have λβ = βλ = β ;

测试：ε是什么？

A. 字符

B. 符号串 √

C. 正规式 √

测试：∅是什么？

A. 集合 √

B. 字

C. 正规式 √

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Some Operators on Set of Strings

- product of set of strings（符号串集的乘积）:
  if A and B are two sets of strings, AB is called the product of two sets of strings, $AB=\{\alpha\beta \mid \alpha \in A, \beta \in B\}$
  especially $\varnothing A=A\varnothing=A$, where $\varnothing$ represents empty set。
- power of set of strings(符号串集合的方幂):
  if A is a set of strings, A^i is called ith power of A, where i is a non-negative integer(非负整数)。
  $A^0=\{\lambda\}$
  $A^1 = A$, $A^2 = AA$
  $A^K = AA.....A$ (k)
- positive closure(符号串集合的正闭包): $A^+ = A^1 \cup A^2 \cup A^3 \ldots\ldots$
- star closure(符号串集合的星闭包): $A^* = A^0 \cup A^1 \cup A^2 \cup A^3 \ldots\ldots$

{a,ab} {c,d,cd} ={ac,ad,acd,abc,abd,abcd}

{a,ab}+ = {a,ab}∪{a,ab}{a,ab}∪.....

= {a,ab,aa,aab,aba,abab,……}

{a,ab}* ={λ}∪{a,ab}∪{a,ab}{a,ab}∪.....

= {λ,a,ab,aa,aab,aba,abab,……}

Formal Definition

- For a given alphabet $\sum$, a regular expression for $\sum$ defines a set of strings of $\sum$,
- If we use R_Σ to represent a regular expression for $\sum$, and $L(R_\Sigma)$ to represent the set of strings that R_Σ defines.

Formal Definition

- ∅ is a regular expression，L(∅)={ }
- λ is a regular expression，L(λ)={ λ }
- for any c ∈Σ, c is a regular expression, L(c)={c}
- if A and B are regular expressions, following operators can be used
  - (A) , L((A))= L(A)
  - choice among alternatives A | B，L(A | B)=L(A)∪L(B)
  - concatenation A B , L(A B)= L(A)L(B)
  - repetation A* , L(A*)= L(A)*

Example

- ∑={ a,b }

RE	Set of strings
1. ab*	1. {a, ab, abb, abbb, ……}
2. a(a|b)*	2. {a, aa, ab, aaa, aab, aba, abb, ……}

Comparing with DFA

- **Equivalent in describing the set of strings;**
- **Can be conversed into each other;**
- **DFA is convenient for implementation;**
- **RE is convenient for defining and understanding;**
- **Both of them can be used to define the lexical structure of programming languages;**

Properties

- A | B = B | A　　| 的可交换性
- A | (B | C) =(A | B) C　　| 的可结合性
- A (B C) =(A B)C　　连接的可结合性
- A (B | C) =A B | A C　　连接的可分配性
- (A | B) C =A C | B C　　连接的可分配性
- A** =A*　　幂的等价性
- A=λA=Aλ　　λ是连接的恒等元素

Extensions

- **Some extensions can be made to facilitate definition**
  - **A^+**
  - **any symbol: “.”**
  - **range: [0-9] [a-z] [A-Z]**
  - **not in the range: ~(a|b|c)**
  - **optional: r?=(λ|r)**

Limitations

- **RE can not define such structure like**
  - **Pairing 配对，（）**
  - **Nesting嵌套，**
- **RE can not describe those structures that include finite number of repetitions**

  for example：w c w , w is a string containing a and b;

(a|b)* c (a|b)* can not be used, because it cannot guarantee that the strings on both sides of c are the same all the time;

Regular Definition

Definition

- **It is inconvenient to define set of long strings with RE, so another formal notation is introduced, which is called "*Formal Definition*";**
- **The main idea is that naming some sub-expressions in RE;**
- **Example:**

(1|2|...|9) (0|1|2|...9)*

NZ_digit= 1|2|...|9

digit = *NZ_digit* | 0

*NZ_digit digit**

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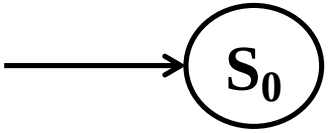
Defining Lexical Structure of *C0*

- letter = a|…|z|A|…|Z
- digit = 0|…|9
- NZ-digit = 1|…|9
- Reserved words:
  Reserved = {| }| read| write
- Identifiers: =letter(letter|digit)*
- Constant:
  integer: int = NZ-digit digit* | 0
- Other symbols: syms = +|*| := | ;
- Lexical structure:
  lex = Reserved | identifier |int | syms

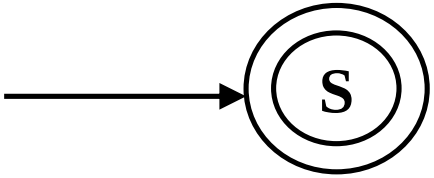
From RE to NFA

Rules

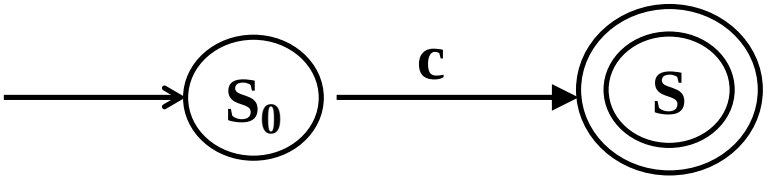
- ∅ is a regular expression，L(∅)={ }



- λ is a regular expression，L(λ)={ λ }

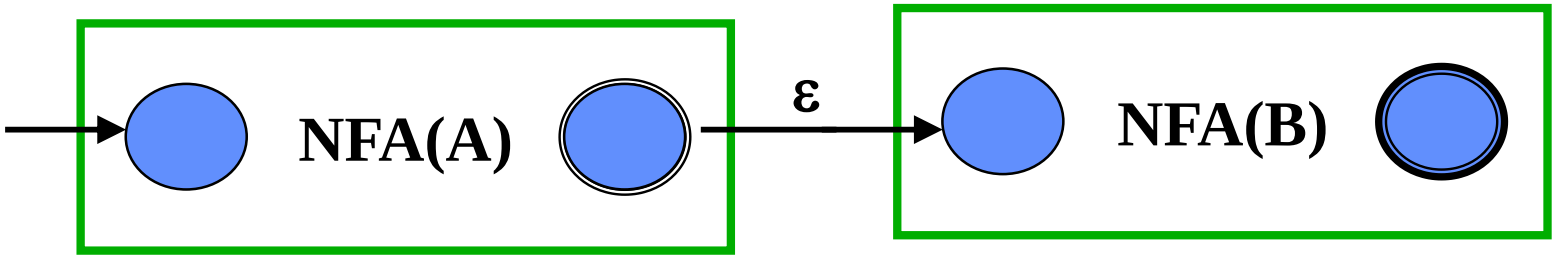


- for any c ∈Σ, c is a regular expression, L(c)={c}



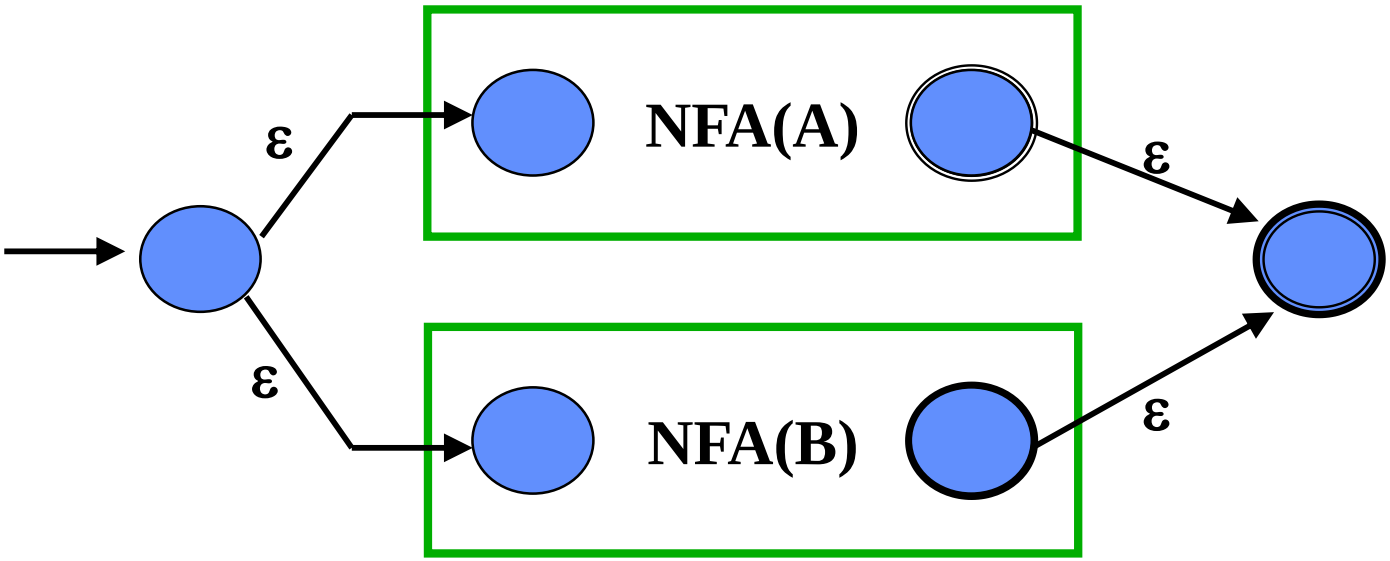
Rules

- (A), L((A)) = L(A), no change;
- A B, L(A B)= L(A)L(B)



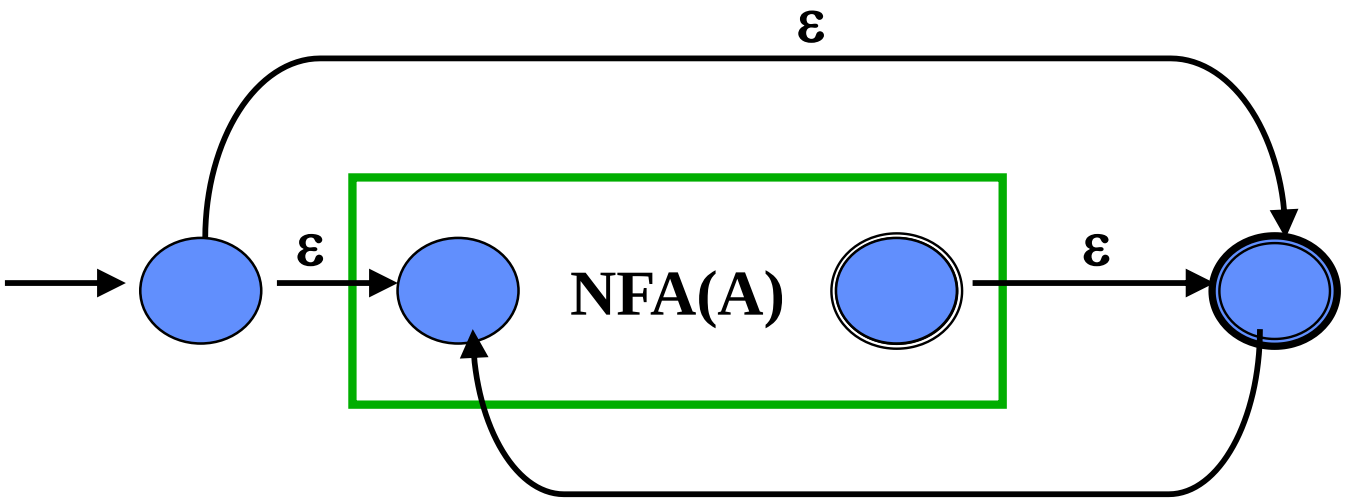
Rules

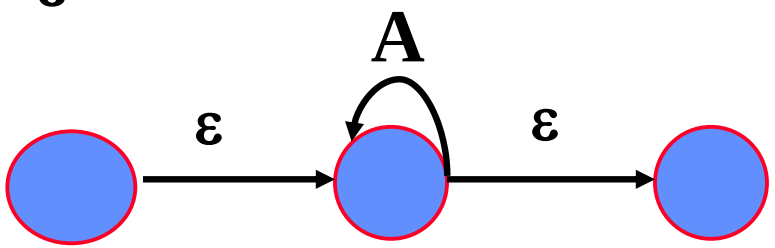
■ A | B，L(A | B)=L(A)∪L(B)



Rules

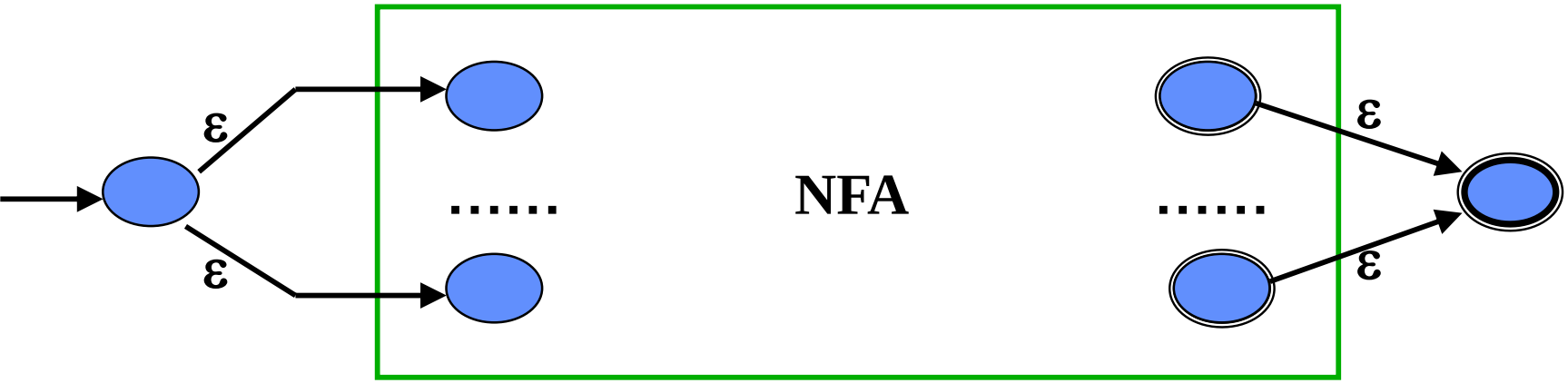
■ A* , L(A*) = L(A)*





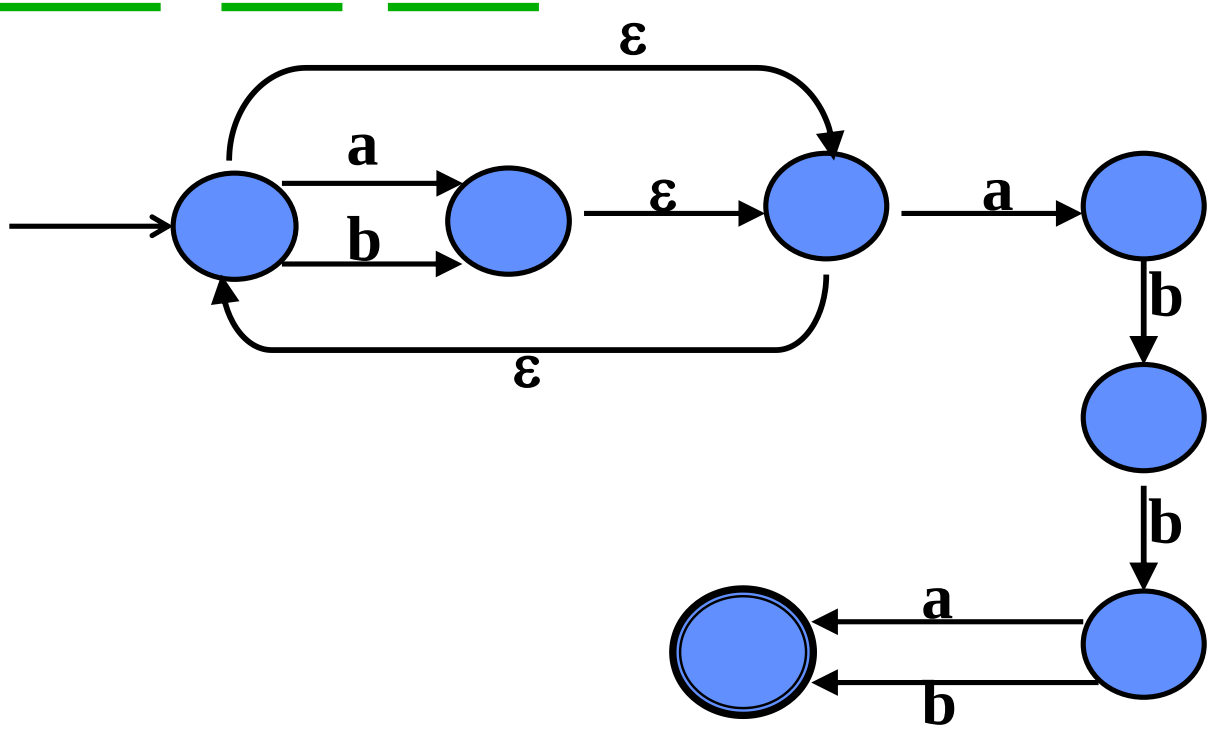
Attention

- **The rules introduced above are effective for those NFAs that have <u>one start state</u> and <u>one terminal state</u>;**
- **Any NFA can be extended to meet this requirement;**

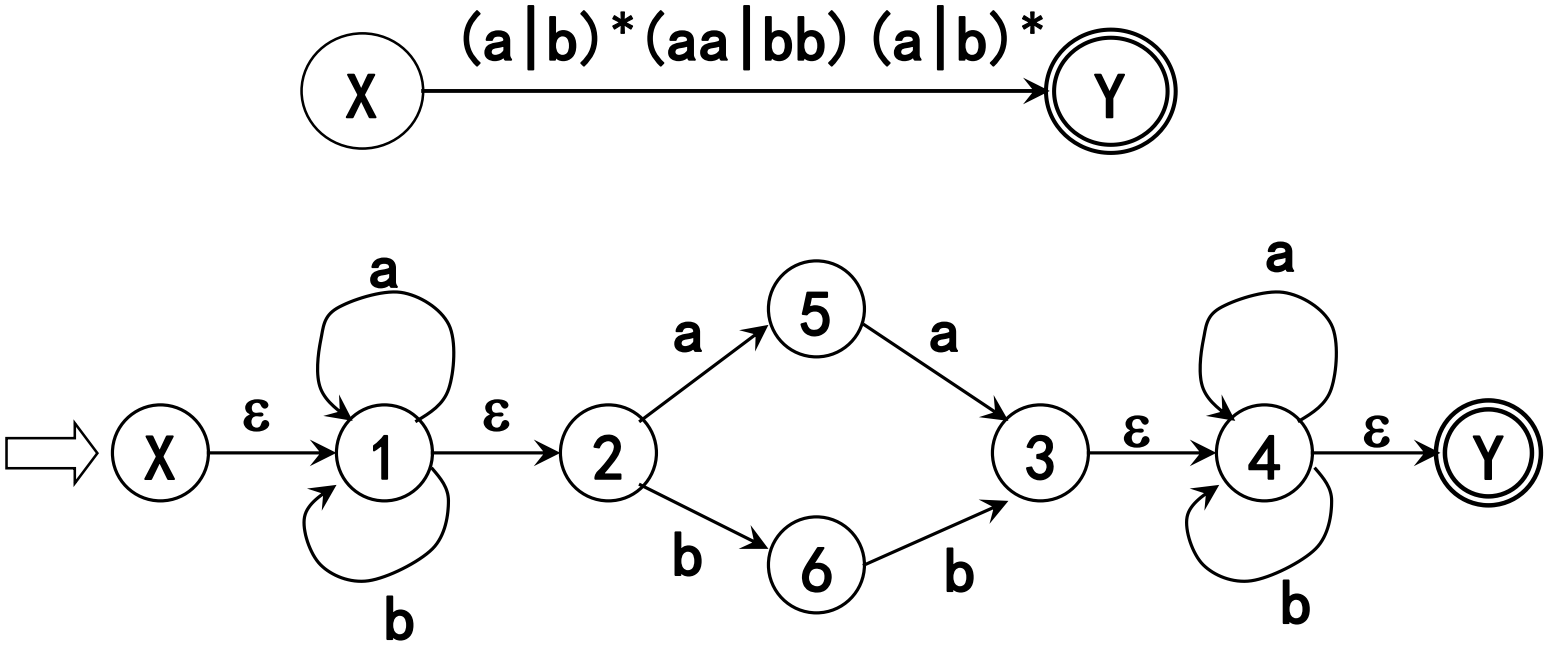


Example

- **(a | b)* a b b (a | b)**



- (a|b)*(aa|bb) (a|b)*



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2.4 Design and Implementation of a Scanner

- **Developing a Scanner Manually**
- **A Scanner Generator – Lex**

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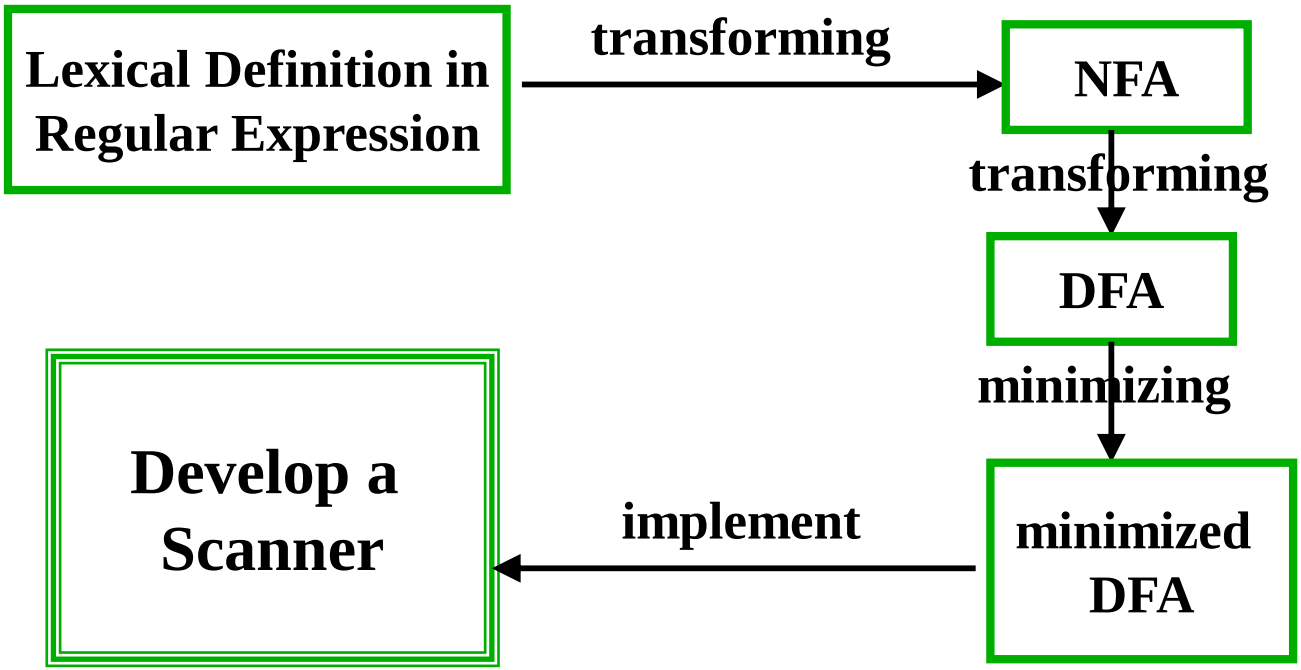
Developing a Scanner Manually



Implement Scanner with DFA

- **Implementation of DFA**
  - **Just checking whether a string is acceptable by the DFA;**
- **Implementation of a Scanner**
  - **not checking;**
  - **but recognizing an acceptable string(word) and establish its internal representation**
    - **<token-type, semantic information>**

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Implement Scanner with DFA

- **Some Issues**
  - **Independent or Attached**
  - **Skip these special characters**
    - **Blank, Tab, comments, return (line number)**
  - **When to stop scanning**
    - **At the end of the source file**
  - **Keywords & identifier**
  - **How to know the end of recognizing one token?**

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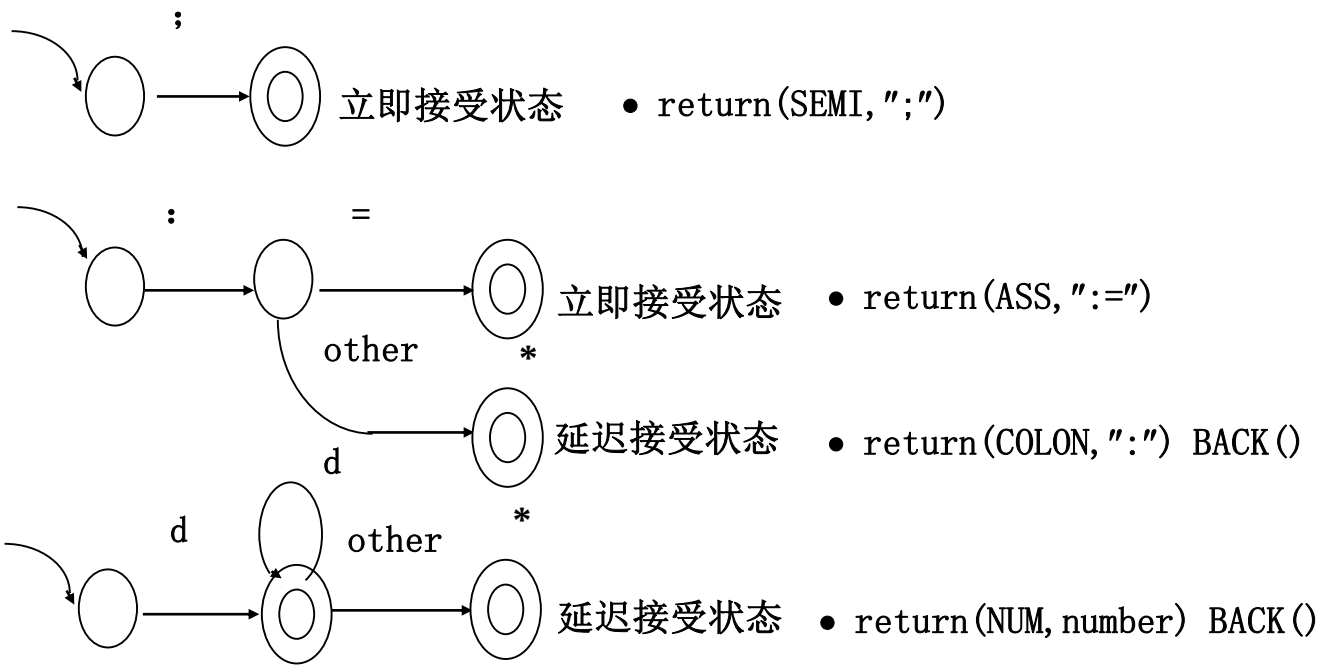
立即接受状态和延迟接受状态



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Defining Lexical Structure of *C0*

- **letter = a|…|z|A|…|Z**
- **digit = 0|…|9**
- **NZ-digit = 1|…|9**
- **Reserved = {| }| read| write**
- **Identifier =letter(letter|digit)***
- **Constant:**

  int = NZ-digit digit* | 0
- **Other symbols: syms = +|*| := | ;**
- **Lexical structure:**

  lex = Reserved | identifier |int | syms

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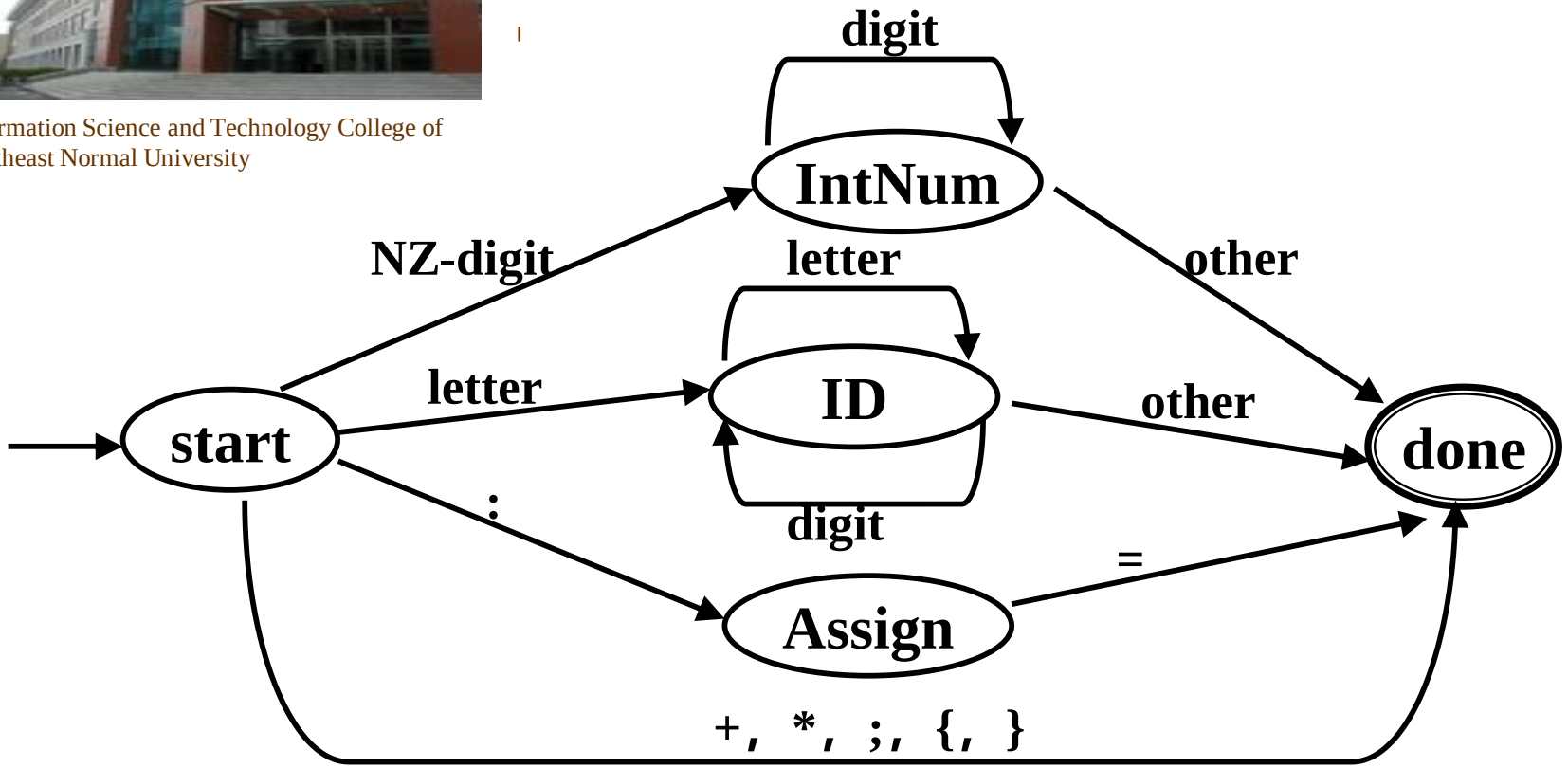
DFA for *C0*



Reserved(key)-words will be decided by checking identifier in reserved(key)-words table;

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Developing a Scanner from DFA

- **Input: a sequence of symbols, with a special symbol EOF as the end of the sequence;**
- **Output: a sequence of tokens;**

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Developing a Scanner from DFA

Token Type:

```
typedef  enum { IDE, NUM, ASS,    //标识符，整数，赋值号
                PLUS, MINUS, SEMI,    // +, *, ;
                ，{ ，READ, WRITE ，} //keywords
               } TkType
```

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Developing a Scanner from DFA

Data Structure for TOKEN:

```
struct Token {TkType  type;
              char val[50];}
```

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Developing a Scanner from DFA

Global Variables:

- char str[50]; ----- store the string has been read already;
- int len = 0; ----- the length of the str
- Token tk; ----- current token
- Token TokenList[100]; ---- the sequence of tokens
- int total = 0; ----- the number of tokens generated

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Developing a Scanner from DFA

Predefined Functions:

- **bool ReadNextchar() --- read current symbol to CurrentChar,**
  if current symbol is EOF returns false;
  else returns true;
- **int IsKeyword(str) --- checking whether str is one of keywords,**
  if str is a keyword, it returns the number
  of the keywords;
  else it returns -1;
- **void SkipBlank() -- skip blank characters & return until read one other character to CurrentChar;**

Developing a Scanner from DFA

```
SkipBlank();
start:    case CurrentChar of
            "1..9": str[len] = CurrentChar; len++;  goto IntNum ;
            "a..z", "A..Z": str[len] = CurrentChar; len++; goto ID;
            ":": goto Assign;
            "+" : tk.type =PLUS; SkipBlank() ;goto Done;
            "*": tk.type = MINUS; SkipBlank() ;goto Done;
            ";" :tk.type = SEMI ; SkipBlank() ;goto Done;
          EOF: exit;
          other: error();
```

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Developing a Scanner from DFA

```
IntNum:
    if  (not ReadNextchar())
     {if len !=0 {tk.type = NUM, strcpy(tk.val, str);
                  goto Done}}
    case CurrentChar of
        "0..9": str[len] = CurrentChar; len++; goto IntNum ;
        other:  tk.type = NUM, strcpy(tk.val, str);
```

Developing a Scanner from DFA

```
ID:
   if  (not ReadNextchar())
       {if len !=0 {tk.type = IDE, strcpy(tk.val, str);
                    goto Done}}

   case CurrentChar of

       "0..9": str[len] = CurrentChar; len++; goto ID;

       "a..z", "A..Z": str[len] = CurrentChar; len++; goto ID;

       other: if  IsKeyword(str)

                        {tk.type = IsKeyword(str) }

                  else  {tk.type = IDE, strcpy(tk.val, str) };

                  goto done;
```

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Developing a Scanner from DFA

Assign:

```
if  (not ReadNextchar())  {if len !=0 error; exit;};
case CurrentChar of
     "=": Tk.type = ASS;
          goto Done ;
     other:error();
```

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Developing a Scanner from DFA

```
Done:
  TokenList[total] = tk;          // add new token to the token list
  total ++;                       //
  len = 0;                        //start storing new token string
  strcpy(str, “”);                // reset the token string
  SkipBlank();                    // skip blank characters
  goto start;                     //start scanning new token
```

What are problems with this Scanner

- **str & TokenList use array, which is not practical;**
- **Not deal with errors;**
- **Not deal with line number;**

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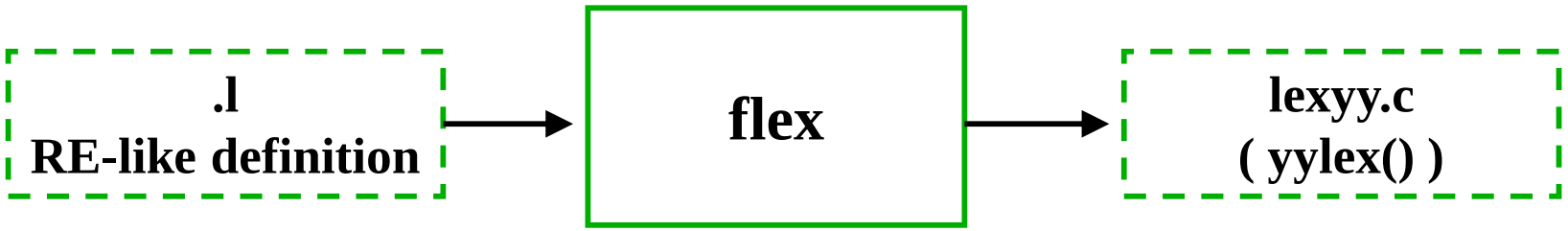
A Scanner Generator – Lex

- **Different versions of Lex;**
- **flex is distributed by GNU compiler package produced by the Free Software Foundation, which is freely available from Internet;**



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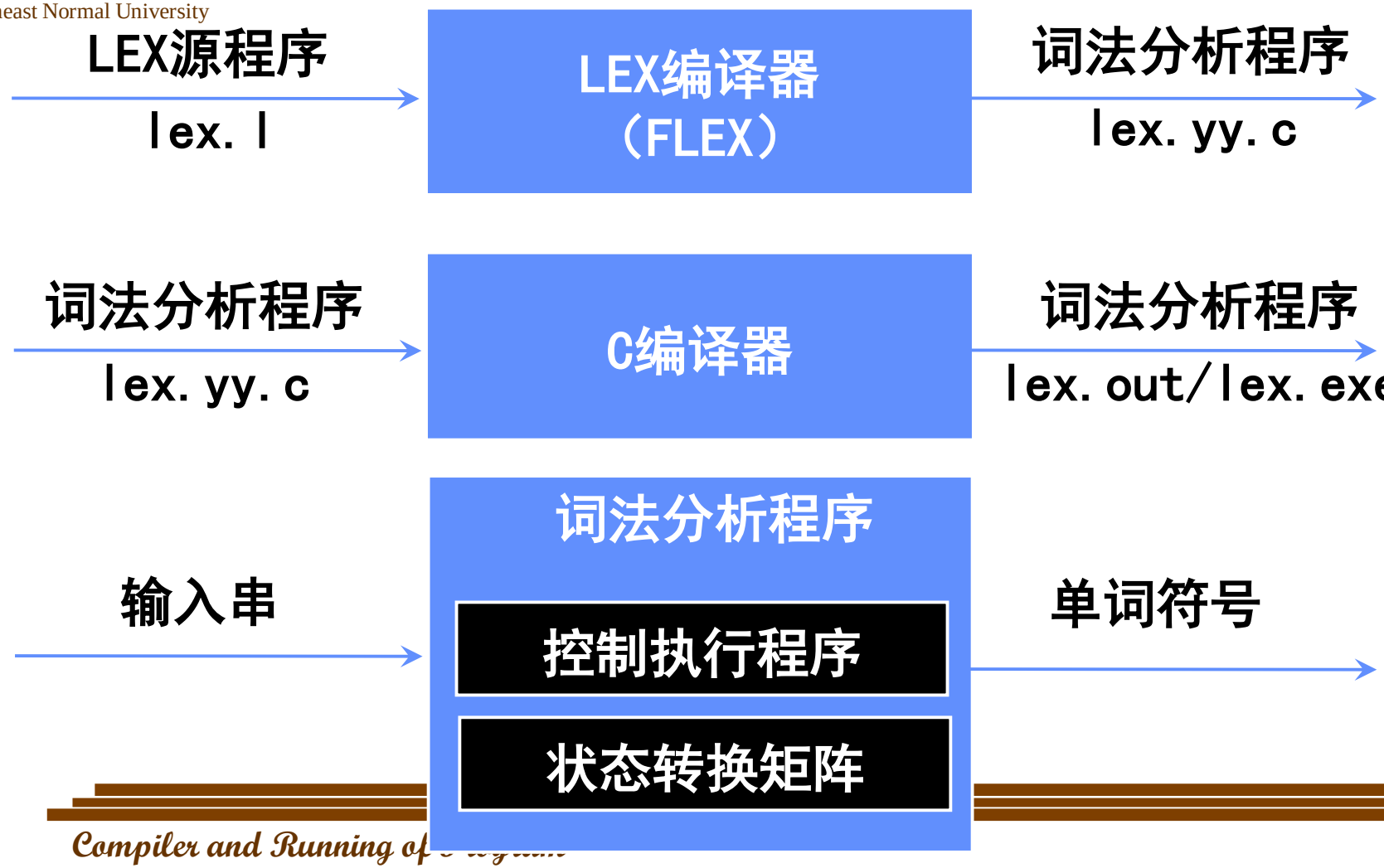
A Scanner Generator – Lex



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A Scanner Generator – Lex

AUXILIARY DEFINITION

letter→A|B|...|Z

digit →0|1|...|9

RECOGNITION RULES		
1	DIM	{ RETURN (1,-) }
2	IF	{ RETURN (2,-) }
3	DO	{ RETURN (3,-) }
4	STOP	{ RETURN (4,-) }
5	END	{ RETURN (5,-) }
6	letter(letter|digit)*	{ RETURN (6, TOKEN) }
7	digit(digit)*	{ RETURN (7, DTB) }
8	=	{ RETURN (8, -) }
9	+	{ RETURN (9,-) }
10	*	{ RETURN (10,-) }
11	**	{ RETURN (11,-) }
12	,	{ RETURN (12,-) }
13	(	{ RETURN (13,-) }
14	)	{ RETURN (14,-) }

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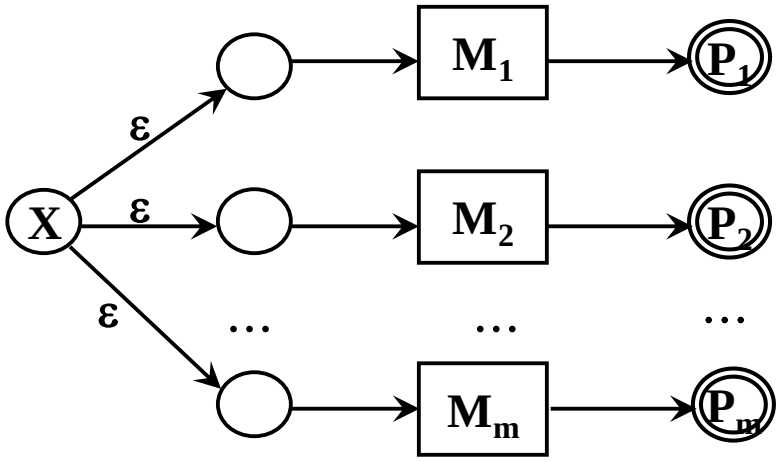
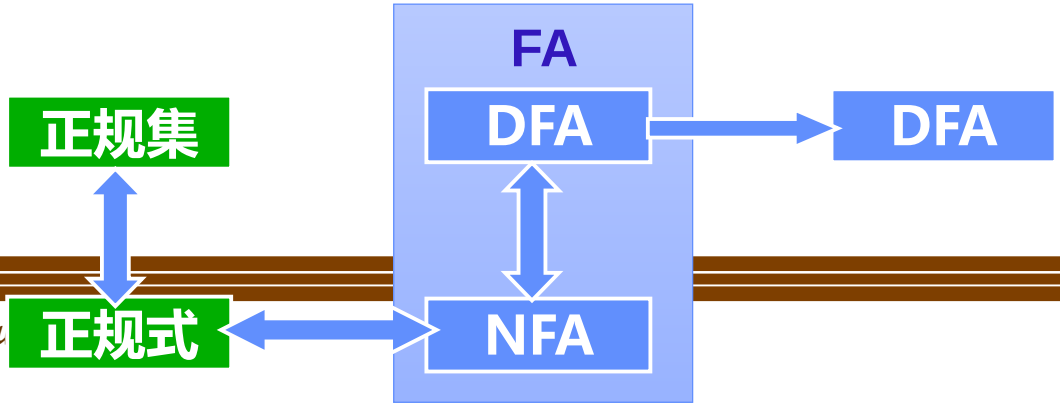
A Scanner Generator – Lex

- LEX的工作过程
  - 对每条识别规则P_i构造一个相应的非确定有限自动机M_i；
  - 引进一个新初态X，通过ε弧，将这些自动机连接成一个新的NFA；
  - 把M确定化、最小化，生成该DFA的状态转换表和控制执行程序





Practice（I）

- **Developing a Scanner Manually for *C0* ;**
- **Test the Scanner;**

Practice（II）

- **Get Lex-similar free software;**
- **Get to know its specification language;**
- **Try to define the lexeme of *C0* with the specification language;**
- **Implement Scanner for *C0* with the software;**
- **Test the Scanner;**

Summary for § 2. Scanning

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What have been introduced

- √ 2.1 Overview
  - 2.1.1 General Function of a Scanner
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  - 2.3.4 From Regular Expression to DFA
- √ 2.4 Design and Implementation of a Scanner
  - 2.4.1 Developing a Scanner from DFA
  - 2.4.2 A Scanner Generator – Lex

Summary

- About ***finite automata***
  - Definition of DFA
    - (∑, start state, set of states, set of terminate states, f)
  - Definition of NFA
    - (∑, set of start states, set of states, set of terminate states, f)
  - Differences between NFA and DFA
    - Number of start states
    - ε
    - Allows more than one ledges for a state and one same symbol

Summary

- About ***finite automata***
  - From NFA to DFA
    - main idea
    - solve problem
  - Minimizing DFA
    - main idea
    - solve problem
  - Implementing DFA
    - Table based
    - Graph based

Summary

- **About *regular expressions***
  - **Definition of regular expression**
  - **Regular definition**
  - **From regular expression to NFA**
  - **Defining lexical structure with regular expression**

Summary

- **About *scanner***
  - **Defining lexical structure of the programming language with regular expression**
  - **Transforming regular expression into NFA**
  - **Transforming NFA into DFA**
  - **Minimizing DFA**
  - **Implementing DFA**

Summary

- **Original Problem**
  - **Develop a Scanner**
    - **Read source program in the form of stream of characters, and recognize tokens with respect to lexical rules of source language;**
- **General techniques**
  - **Use RE to define Lexical structure;**
  - **RE -> NFA -> DFA -> minimized DFA -> implement**
- **General Problem**
  - **Use RE/FA to define the structural rules**
  - **Check whether the input meets the structural rules**

Summary

- **Application in similar problems**
  - **Use RE(DFA) to formally describe the structures**
    - **Strings**
    - **Security policies**
    - **Interface specification (component contract)**
  - **Check**
    - **whether a string meets the structural rules;**
    - **Whether certain execution meets security policies;**
    - **Properties checking**

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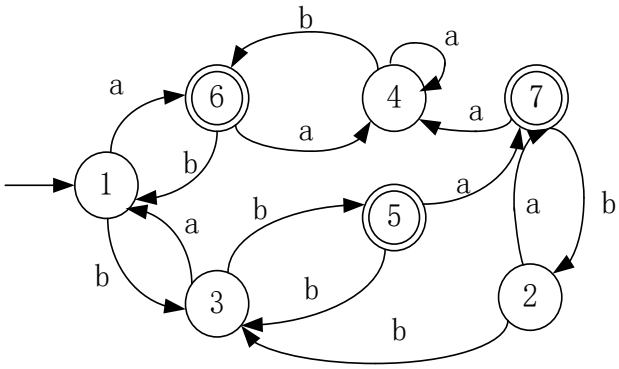
Any Questions?

Reading Assignment

- **Topic: How to develop a parser(语法分析器)?**
- **Objectives**
  - **Get to know**
    - **What is a parser? (input, output, functions)**
    - **The Syntactical structure of a C programs?**
    - **Different Parsing techniques and their main idea?**
- **References**
  - **Optional textbooks**
- **Hand in a report either in English or in Chinese, and one group will be asked to give a presentation at the beginning of next class;**
- **Tips:**
  - **Collect more information from textbooks and internet;**
  - **Establish your own opinion;**

1. 画出与正则表达式a（ab|c）*等价的确定有限自动机。
2. 请用状态分离法将下面的DFA化简。



3. 给出自动机DFA的正则表达式。