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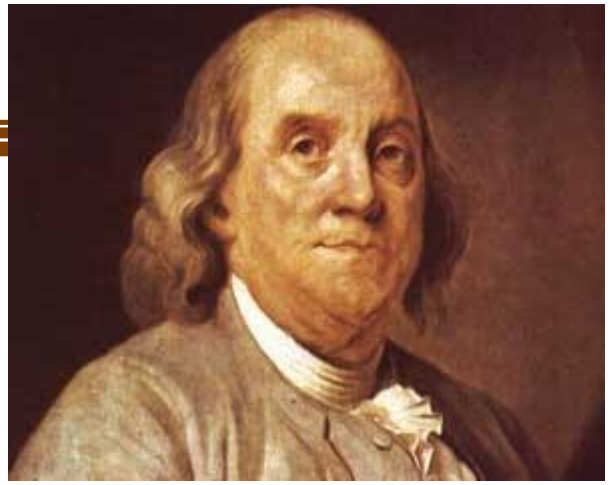
Benjamin Franklin (1706-1790)



Without continual growth and progress，such words as improvement, achievement , and success have no meaning.

没有持续的成长和进步，诸如成就和成功等词就没有意义。

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Compiling and Running of Program

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Professor

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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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2.2 Finite Automata

- **Definition of DFA**
- **Implementation of DFA**
- **Non-Determinate Finite Automata**
- **Transforming NFA into DFA**
- **Minimizing DFA**

Definition of DFA

- formal definition
- two ways of representations
- examples
- some concepts

Formal Definition of DFA

One DFA defines a set of strings;

each string is a sequence of characters in Σ;

Start state gives the start point of generating strings;

Terminal states give the end point;

Transforming function give the rules how to generate strings;

and returns either one unique state or Σ(no definition);

- **Features of a DFA**
  - **One start state;**
  - **For a state and a symbol, it has at most one edge;**

- **Functions of DFA**
  - **It defines a set of strings;**
  - **It can be used for defining lexical structure of a programming language**

Two ways of Representations

- **Table**
  - **Convenient for implementation**
- **Graph**
  - **easy to read and understand**

Two ways of Representations (Table)

- **Transforming Table**
  - **start state : S^0**
  - **terminal state: S***
  - **Row(行): characters**
  - **Column(列)： states**
  - **Cell(单元): states or ⊥**

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Example of Transforming Table

	a	b	c	d
S^0	S1	⊥	S2	S^*
S1	⊥	S1	⊥	S2
S2	S^*	⊥	⊥	⊥
S^*	⊥	⊥	S^*	⊥

$\sum$: {a, b, c, d}

SS: {S^0, S1, S2, S^*}

Start state: S^0

Set of terminal states: {S^*}

Φ: {(S^0,a)→ S1, (S^0,c)→S2,
(S^0,d)→S^*, (S1,b)→S1,
(S1,d)→S2, (S2,a)→S^*,
(S^*, c)→S^*}

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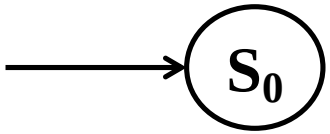
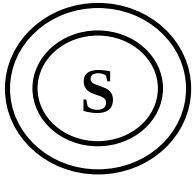
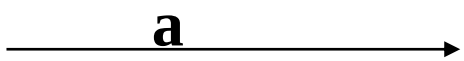
Two ways of Representations (graph)

- **Graph**
  - **start state:** 

  - **terminal state:** 

  - **State** 

  - **Edge:** 

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Example of Graphical DFA

∑: {a, b, c, d}

SS: {S^0, S1, S2, S^*}

Start state: S^0

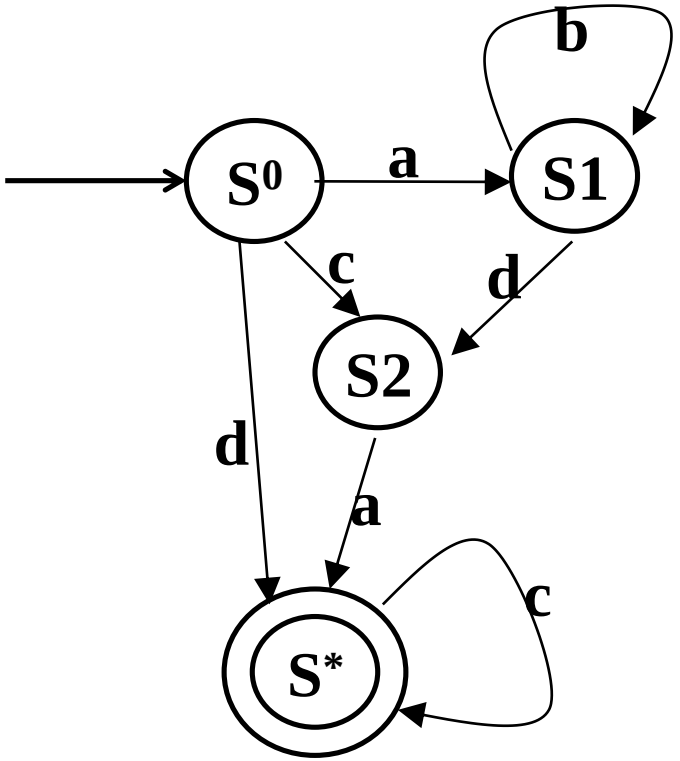
Set of terminal states: {S^*}

Φ: {(S^0,a)→ S1, (S^0,c)→S2,

(S^0,d)→S^*, (S1,b)→S1,

(S1,d)→S2, (S2,a)→S^*,

(S^*, c)→S^*}



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Some Concepts

- **String acceptable by a DFA**
  - **If *A* is a DFA, $a_1 a_2 \ldots a_n$ is a string, if there exists a sequence of states ($S_0, S_1, \ldots, S_n$), which satisfies**

$$S_0 \xrightarrow{a1} S_1 \ , S_1 \xrightarrow{a2} S_2 \ , \ldots\ldots , \ S_{n-1} \xrightarrow{an} S_n$$

where S_0 is the start symbol, S_n is one of the accept states, the string $a_1 a_2 \ldots a_n$ is acceptable by the DFA *A*.

Some Concepts

- **Set of strings defined by DFA**
  - **The set of all the strings that are acceptable by a DFA *A* is called the set of strings defined by *A*, which is denoted as *L(A)***

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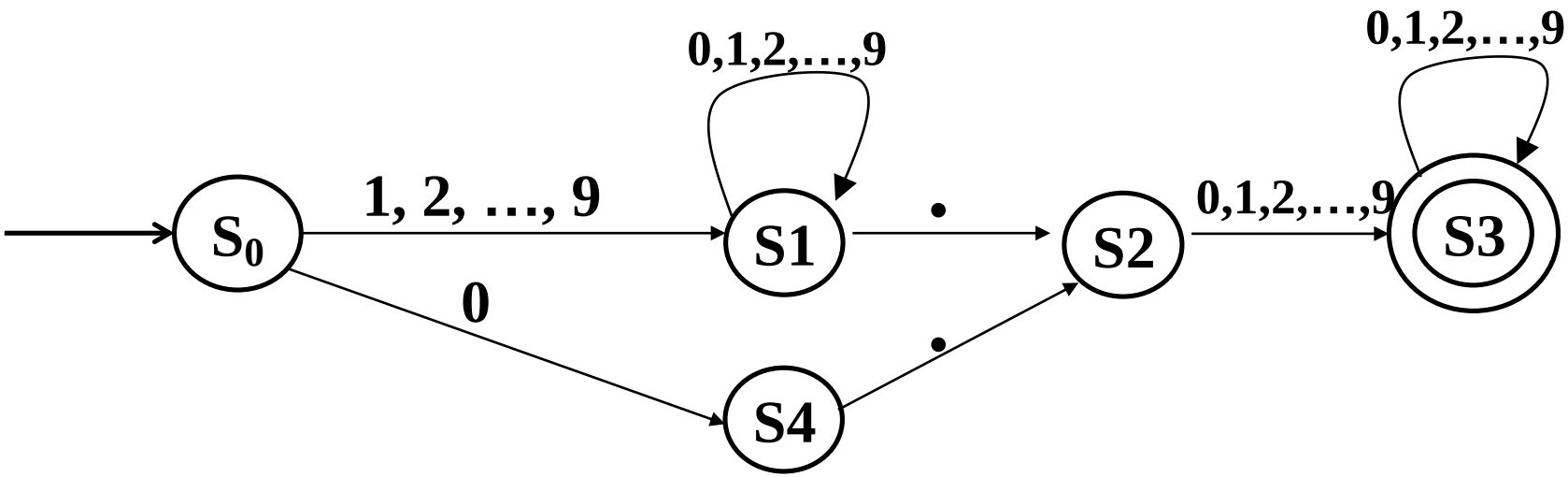
Relating DFA to Lexical Structure of a Programming language

- **Use a DFA to define the lexical structure of one word-type in a programming language**
  - **usigned real number (无符号实数)**



Relating DFA to Lexical Structure of a Programming language

- A DFA can be defined for the lexical structure of all the words in a programming language;

- The set of strings defined by the DFA is the set of allowed words in the programming language;

- The implementation of the DFA can be used as a scanner for the programming language;

Summary

- **Some concepts**
  - **DFA (五元组)**
  - **String acceptable by a DFA**
  - **Set of strings (language) defined by a DFA**
- **Two forms of DFA (table, graphical)**
- **How to define**
  - **Structure of a set of strings;**
  - **Lexical structure of a programming language**

Assignment

- **For standard C programming language**
  - **Find out the token types and their lexical structures;**
  - **Try to write down DFA for each token type;**

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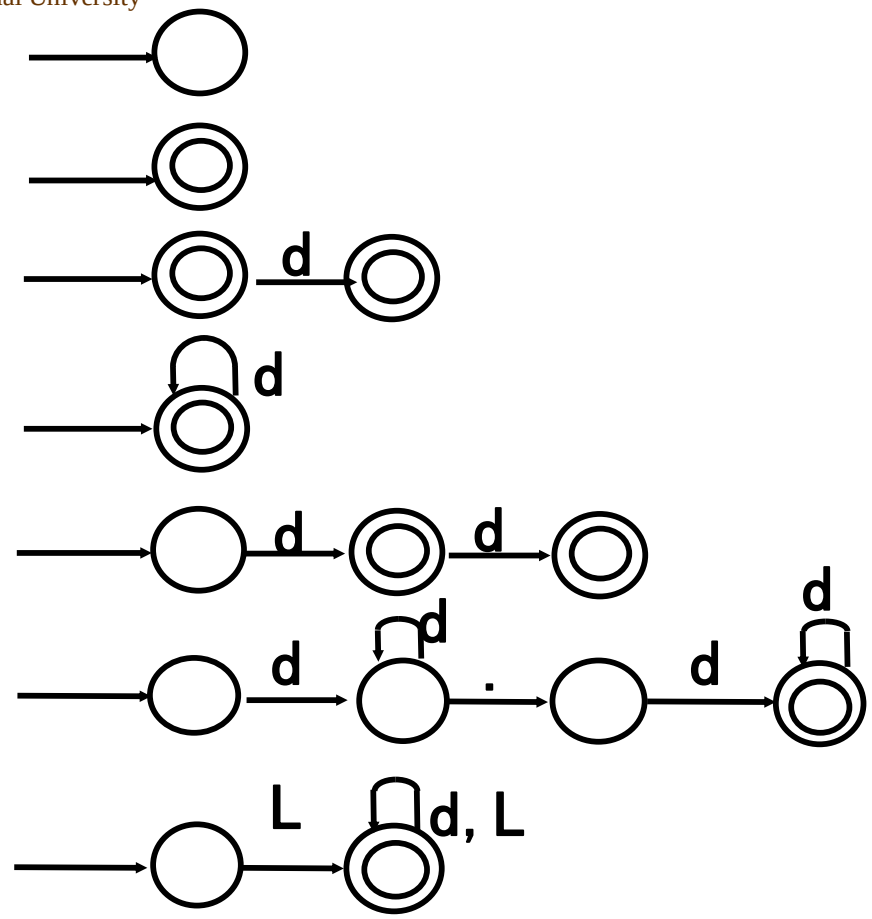
Some special case



{ }

{ε}　ε：什么符号也没有

{ε, d}

{ε, d, dd, ddd, ……}

{d, dd}

real number

identifier

Implementation of DFA

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Implementation of DFA

- **Objective (meaning of implementing a DFA)**
  - **Given a DFA which defines rules for a set of strings**
  - **Develop a program, which**
    - **Read a string**
    - **Check whether this string is accepted by the DFA**
- **If a string is accepted by a DFA,**
  - **Next state;**
  - **Stop in the final state;**
- **If a string is not accepted by a DAF,**
  - **No next state (⊥);**
  - **Not stop in the final state;**

Implementation of DFA

- **Two ways**
  - **Basing on transforming table of DFA**
  - **Basing on graphical representation of DFA**

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Transforming Table based Implementation

- **Main idea**
  - **Input : a string**
  - **Output: *true* if acceptable, otherwise *false***
  - **Data structure**
    - **Transforming table (two dimensional array *T*)**
  - **Two variables**
    - ***CurrentState*: record current state;**
    - ***CurrentChar*: record current character that is read in the string;**

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Transforming Table based Implementation

- **Main idea**
  - **General Algorithm**

1.*CurrentState* = S_0

2. read the first character as *CurrentChar*

3. if *CurrentChar* is not the end of the string,

if *T*(*CurrentState*,*CurrentChar*)≠ error,

***CurrentState* = *T*(*CurrentState*,*CurrentChar*),**

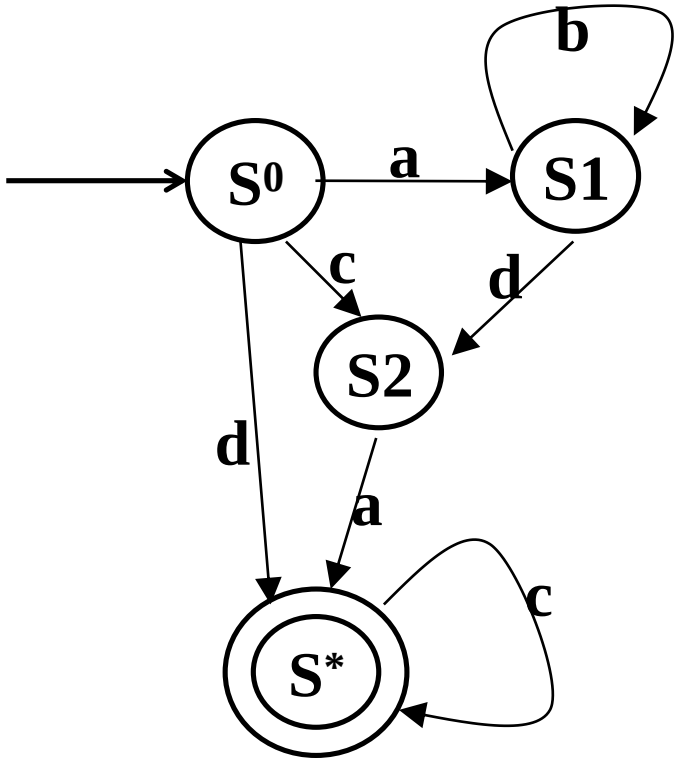
read next character of the string as *CurrentChar*,

goto 3;

4. if *CurrentChar* is the end of the string and *CurrentState* is one of the terminal states, return *true*; otherwise, return *false*.

Example

	a	b	c	d
S^0	S1	⊥	S2	S*
S1	⊥	S1	⊥	S2
S2	S*	⊥	⊥	⊥
S*	⊥	⊥	S*	⊥



1) abdacc ⟶ *true*
2) cab ⟶ *false*

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Program structure for Table-based Implementation

Transforming table for the DFA

***Variables*: CurrentChar, CurrentState**

Read the string that want to be checked

***Checking process*:**

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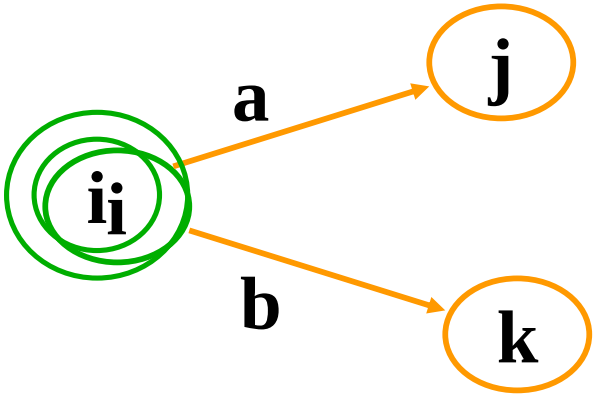
Graph based Implementation of DFA

- each state corresponds to a *case* statement
- each edge corresponds to a *goto* statement
- for accept state, add one more branch, if current char is the end of the string then accept;




```
Li: case CurrentChar of
    a     : goto Lj
    b     : goto Lk
    other : Error( )
```

```
Li: case Current
    a     :
    b     :
    #     : r
    other :
```

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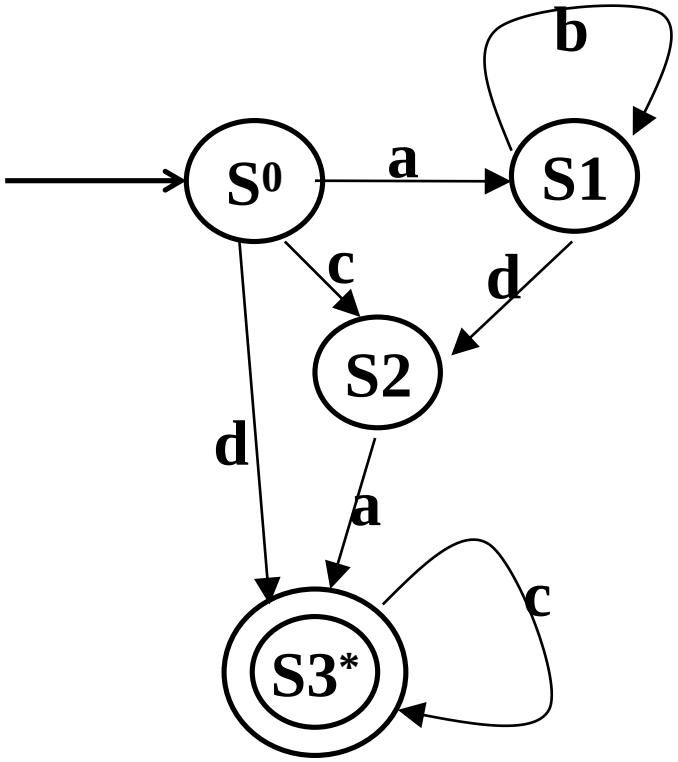

LS0: read character to ***CurrentChar;***
case CurrentChar ***of***
a: goto LS1;
c: goto LS2:
d: goto LS3;
other: return false;

LS1: read character to ***CurrentChar;***
case CurrentChar ***of***
b: goto LS1;
d: goto LS2:
other: return false;

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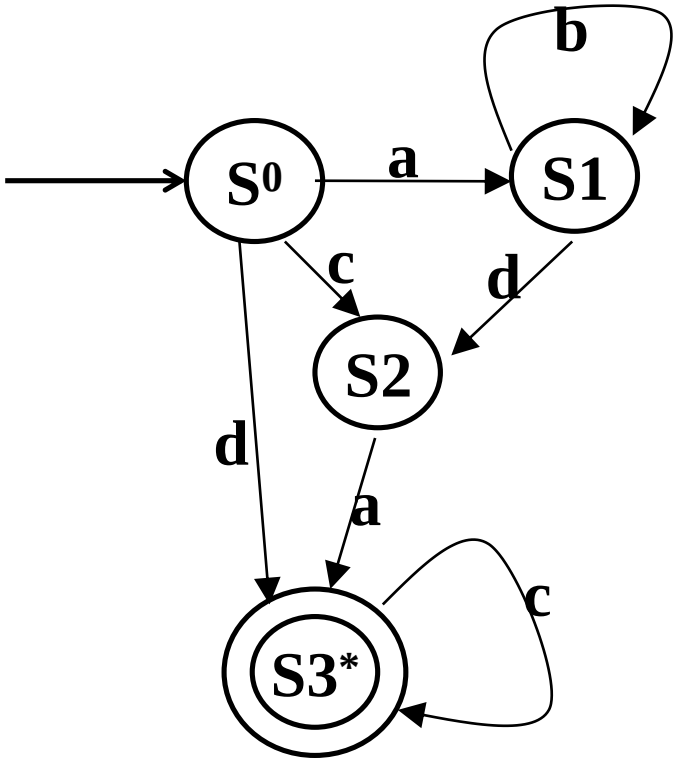

LS2: read character to ***CurrentChar;***
case CurrentChar ***of***
a: goto LS3;
other: return false;

LS3: read character to ***CurrentChar;***
case CurrentChar ***of***
c: goto LS2:
#: return true;
other: return false;

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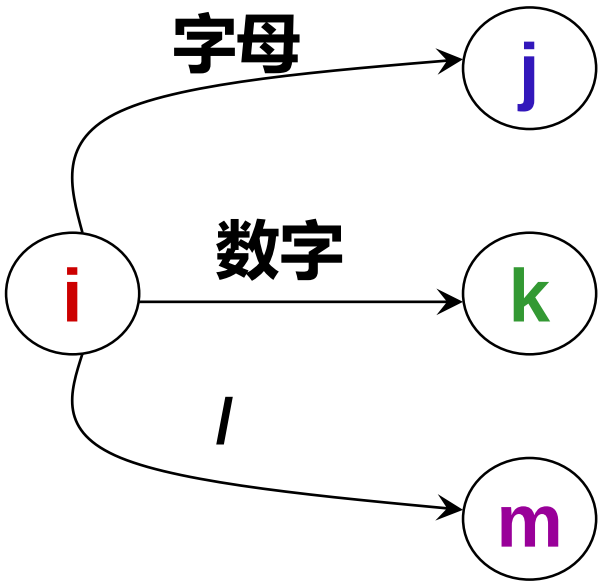
Graph based Implementation of DFA

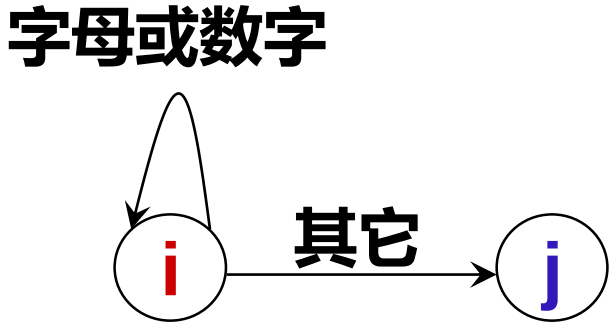
- 不含回路的分叉结点
  - 可用一个CASE语句或一组IF-THEN-ELSE语句实现




```
GetChar( );
if (IsLetter( ))
    {...状态j的对应程序段...;}
else if (IsDigit( ))
    {...状态k的对应程序段...;}
else if (ch='/')
    {...状态m的对应程序段...;}
else
    {...错误处理...;}
```

Graph based Implementation of DFA

- 含回路的状态结点
  - 对应一段由WHILE结构和IF语句构成的程序




```
GetChar( );
while (IsLetter( )or IsDigit( ))
      GetChar( );
...状态j的对应程序段...
```

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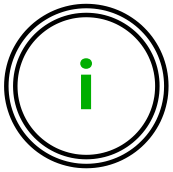
Graph based Implementation of DFA

- 终态结点
  - 表示识别出某种单词符号，对应返回语句



RETURN (C，VAL)

其中，C为单词种别，VAL为单词自身值

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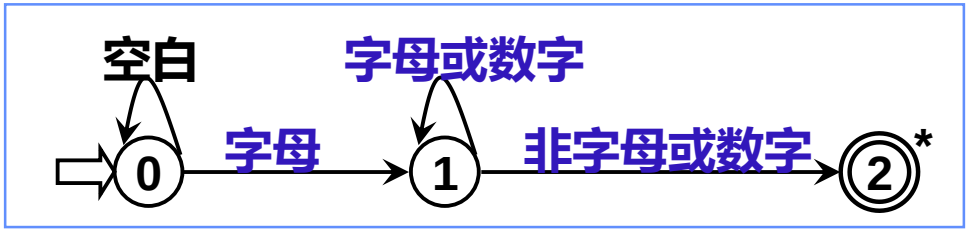


```
int code, value;
strToken := " ";      /*置strToken为空串*/
GetChar(); GetBC();
if (IsLetter())
begin
      while (IsLetter() or IsDigit())
      begin
            Concat(); GetChar();
      end
      Retract();
      code := Reserve();
      if (code = 0)
      begin
            value := InsertId(strToken);
            return ($ID, value);
      end
      else
            return (code, -);
end
```

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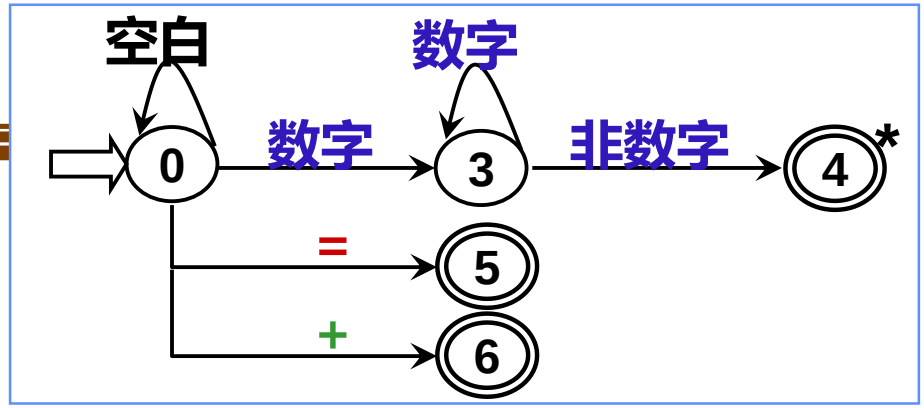


```
else if (IsDigit())
begin
      while (IsDigit())
      begin
            Concat( ); GetChar( );
      end
      Retract();
      value := InsertConst(strToken);
      return($INT, value);
end
else if (ch ='=') return ($ASSIGN, -
);
else if (ch ='+') return ($PLUS, -);
```

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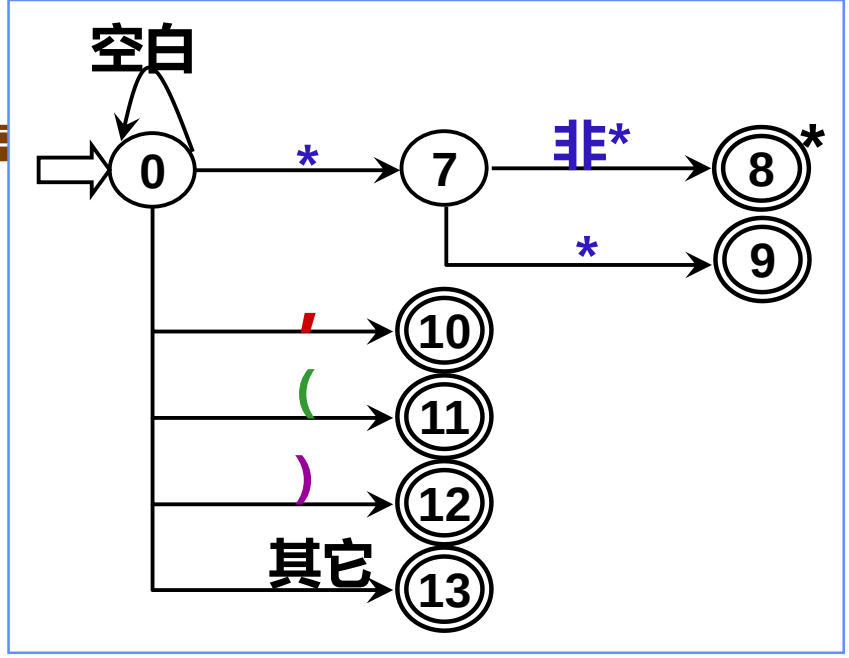


```
else if (ch ='*')
begin
      GetChar();
      if (ch ='*') return ($POWER, -);
      Retract(); return ($STAR, -);
end
else if (ch =',') return ($COMMA, -);
else if (ch ='(') return ($LPAR, -);
else if (ch =')') return ($RPAR, -);
else ProcError( );          /* 错误处理*/
```

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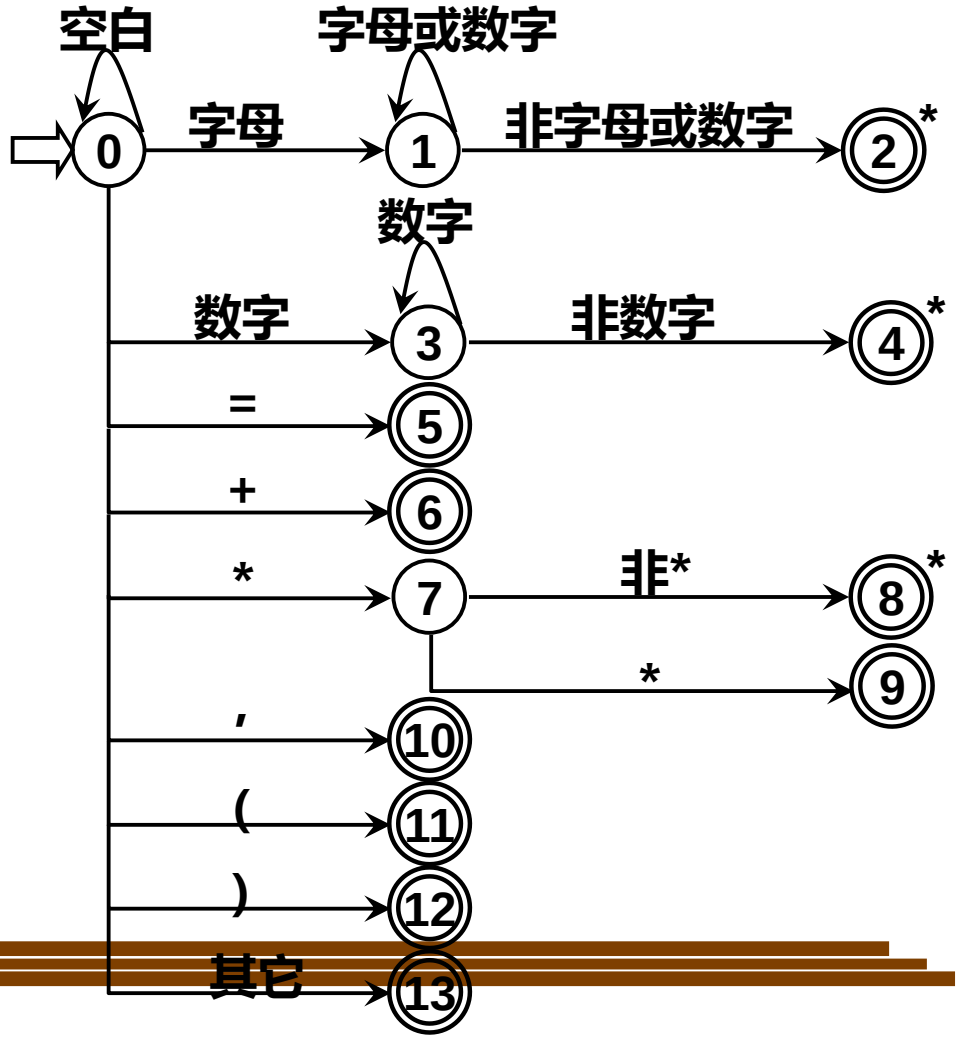
词法分析器的自动机设计示例

单词	词码	词义
DIM	1	-
IF	2	-
DO	3	-
STOP	4	-
END	5	-
标识符	6	内部字符串
常数(数)	7	标准二进制形式
=	8	-
+	9	-
*	10	-
**	11	-
,	12	-
(	13	-
)	14	-



Application of DFA

Application of DFA for some Problems

- ***Problem 1***: **Develop a program for checking whether a string is a binary number can be divided by 3;**
- ***Problem 2***: **Document requirements for an embedding system;**
- ***Problem 3***: **Formal specification & checking of security policies;**
- ***Problem 4***: **Formal specification of component contract;**

Application of DFA for some Problems

- ***Problem 1***: **Develop a program for checking whether a string is a binary number can be divided by 3;**
- ***Problem Analysis***:
  - **The input string should be composed of either 0 or 1;**
  - **The binary number represented by the input string should be divided by 3;**

With DFA we can solve it!

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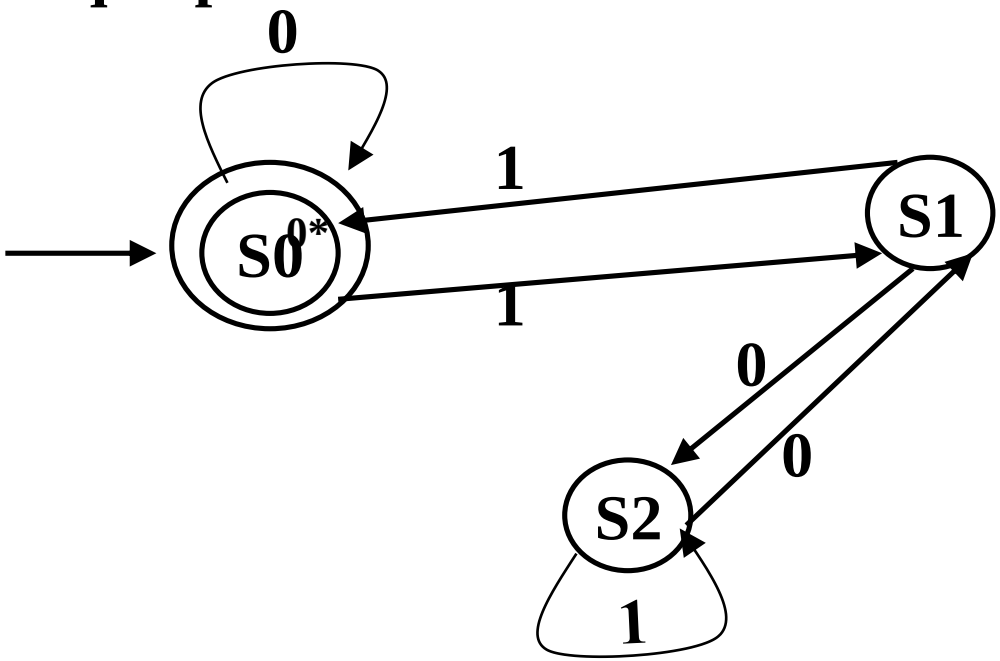
设二进制数i，后面跟一个0，产生符号串2i，后面跟一个1，产生符号串2i+1
余数： i/3=q， 2i/3=2q

	2i	2i+1
q=0	0	1
q=1	2	0
q=2	1	2

- ∑ = {0,1}
- SS = { S0, S1, S2},
- Sq represents the state that the remainder(余数) is q; (q=0,1,2)



Start State: S0
TS = {S0}

Implementation

Assignment

- **Define a DFA for accepting a set of binary numbers, each binary number can be divided by 5;**

  (定义一个DFA，它所接受的符号串为能被5整除的二进制数;)

- **Implementation of the DFA above;**

Application of DFA for some Problems

- ***Problem 2***: **Document requirements for an embedding system;**

- **The features of embedding system**
  - **Event driven**
  - **Changing in different states**
  - **Trigger corresponding devices to do the task;**

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Application of DFA for some Problems

- ***Problem 2***: **Document requirements for embedding systems;**

- **∑ = set of events**
- **SS = all states that the system has**
- **S0 = initial state**
- **TS = all the exit states**
- **Φ(Si, event) = Sj**

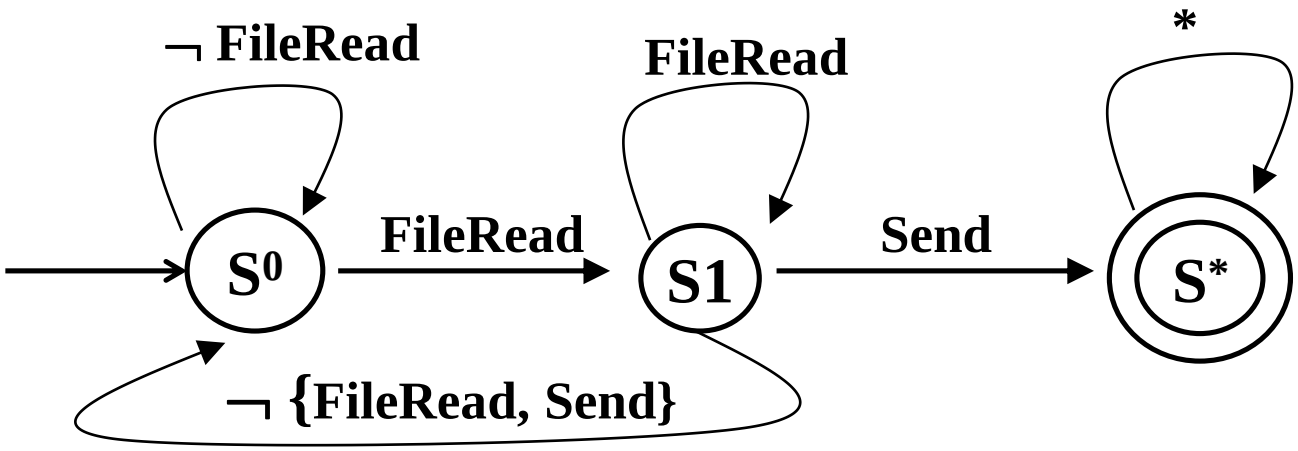
Application of DFA for some Problems

- ***Problem 3***: **formal specification & checking of security policies;**

- **Security policies**
  - **Formal specification with DFA;**
  - **Checking by implementing the DFA**

A simple security policy

- **Basing on system calls**



A security policy that prohibits execution of *send* after a *FileRead* has been executed.

Application of DFA for some Problems

- ***Problem 4***: **formal specification of component contract**
- **C. Szyperski, "Component Software – beyond Object-Oriented Programming", Addison-Wesley, 2002**
- **The definition of software components should come with the notion of contract in order to organize the guarantee of properties all along the software life cycle.**

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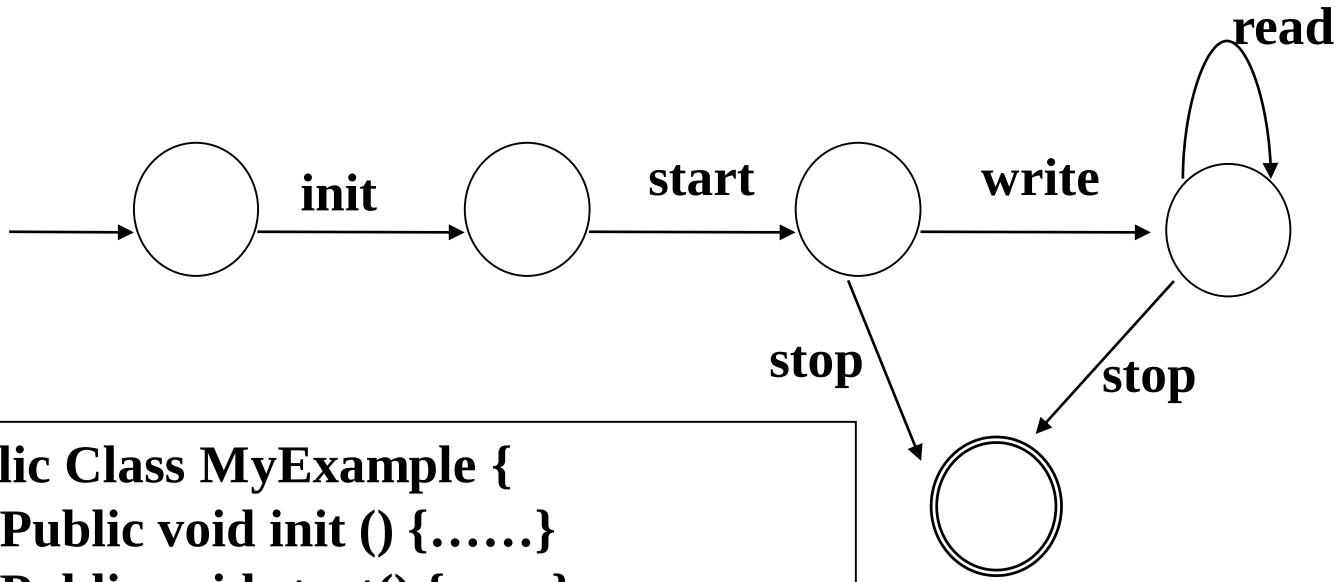
A simple Component Contract




```
Public Class MyExample {
      Public void init () {……}
      Public void start() {……}
      Public int read() {……}
      Public void write(int  n) {……}
      Public void stop() {……}
}
```