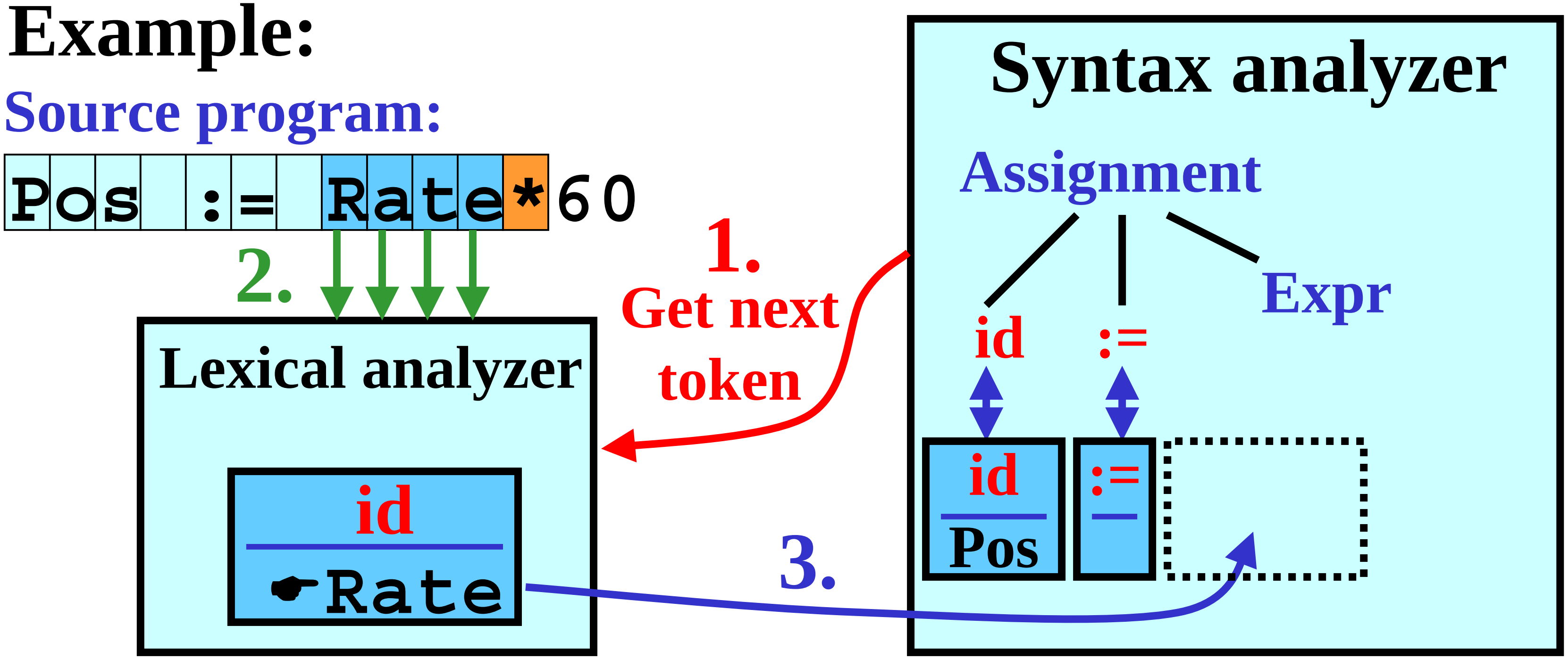
Part VI.
Lexical Analysis

Lexical Analyzer (Scanner)

Source program

Example:

Source program:



Scanner: Tasks

Main task

- recognition and classification of lexemes
- representing lexemes by their tokens

Other tasks

- removal of comments and whitespaces
- communication with symbol tables

Relation to Models for RLs

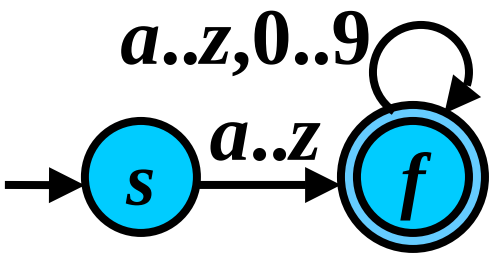
- **Regular expressions** specify lexemes
- **DFAs** underlie scanners

Lexemes Recognized by DFAs 1/2

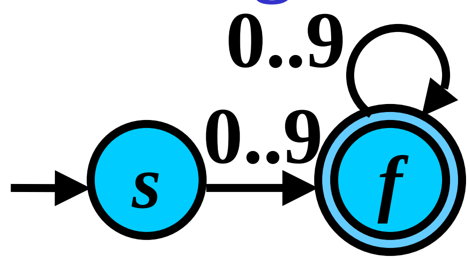
1) Recognition of lexemes by using DFA

Example:

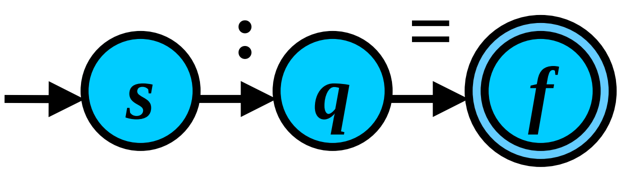
Identifier:



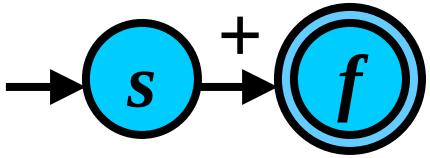
Integer:



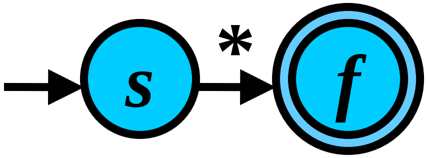
Assignment:



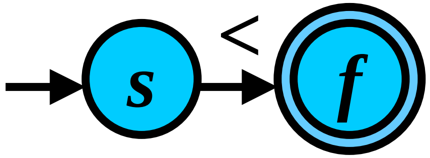
Operator +:



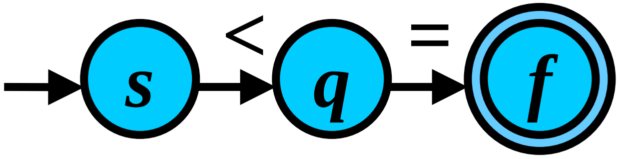
Operator *:



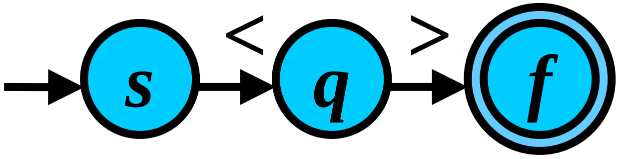
Comparator <:



Comparator <=:

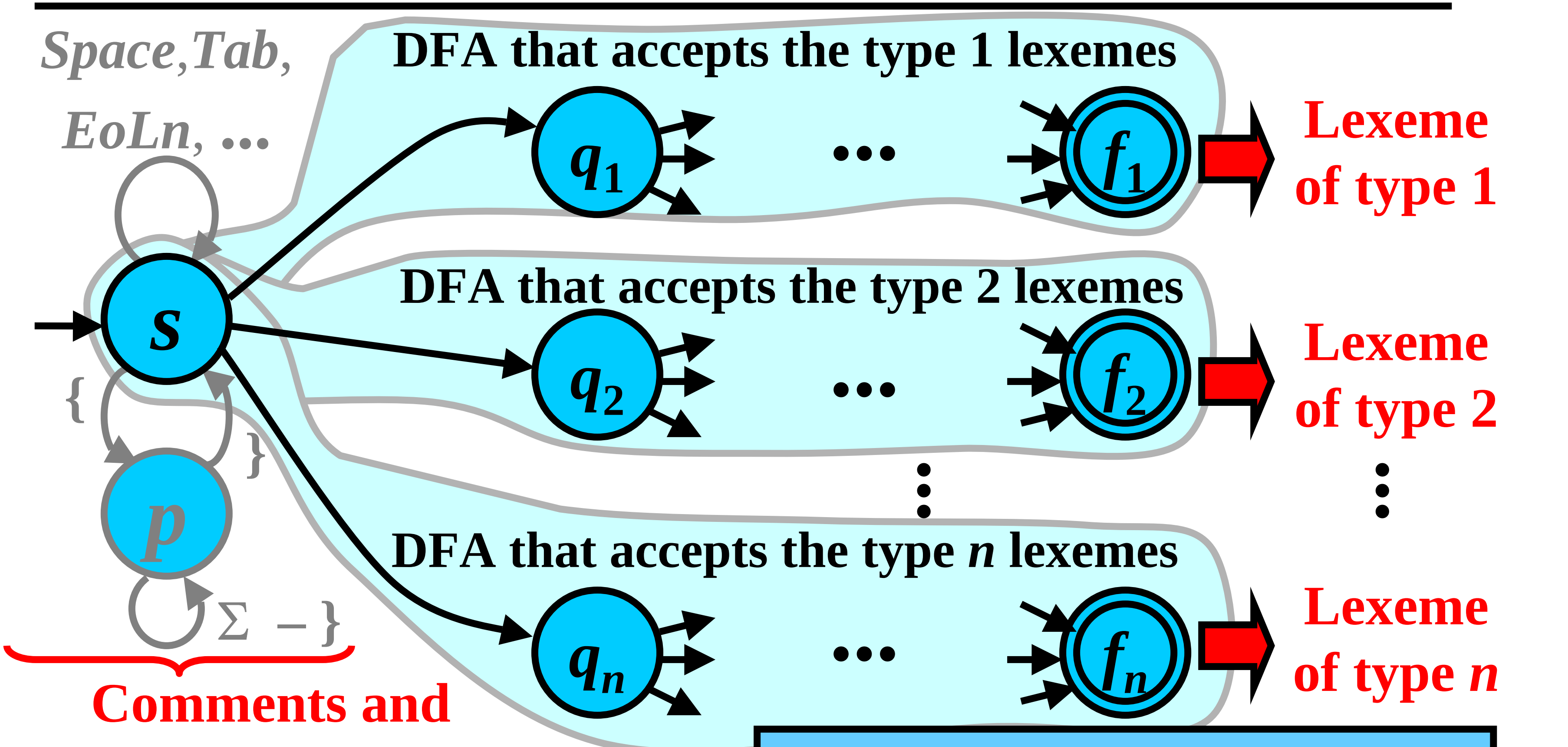


Comparator <>:



Lexemes Recognized by DFAs 2/2

2) Construction of an FA that accepts all lexemes:

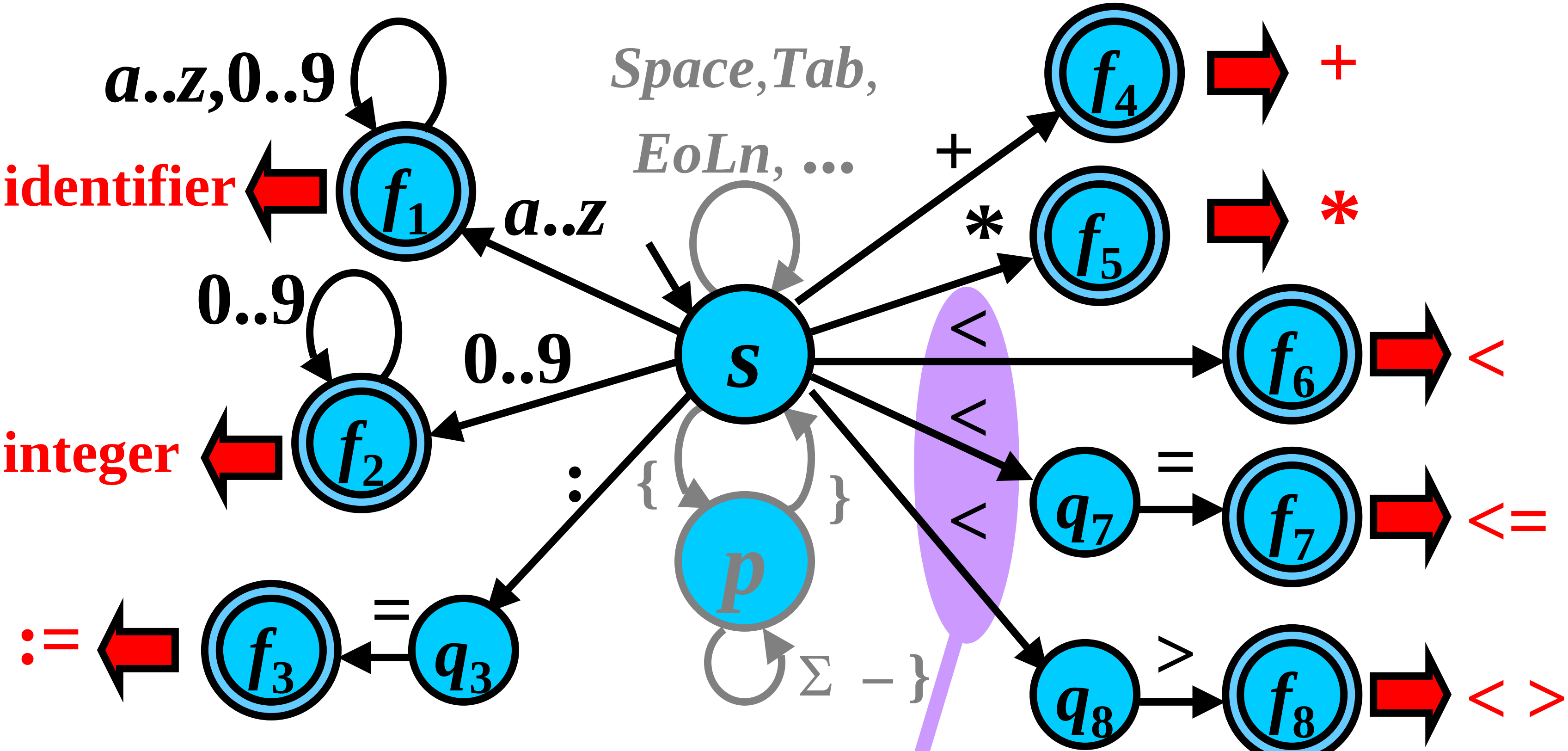


Comments and whitespaces are skipped before a new lexeme

Every final state corresponds to **one** type of lexeme

DFA for Lexemes : Example 1/2

- FA that accepts these lexemes:
  identifier, integer, :=, +, *, <, <=, < >

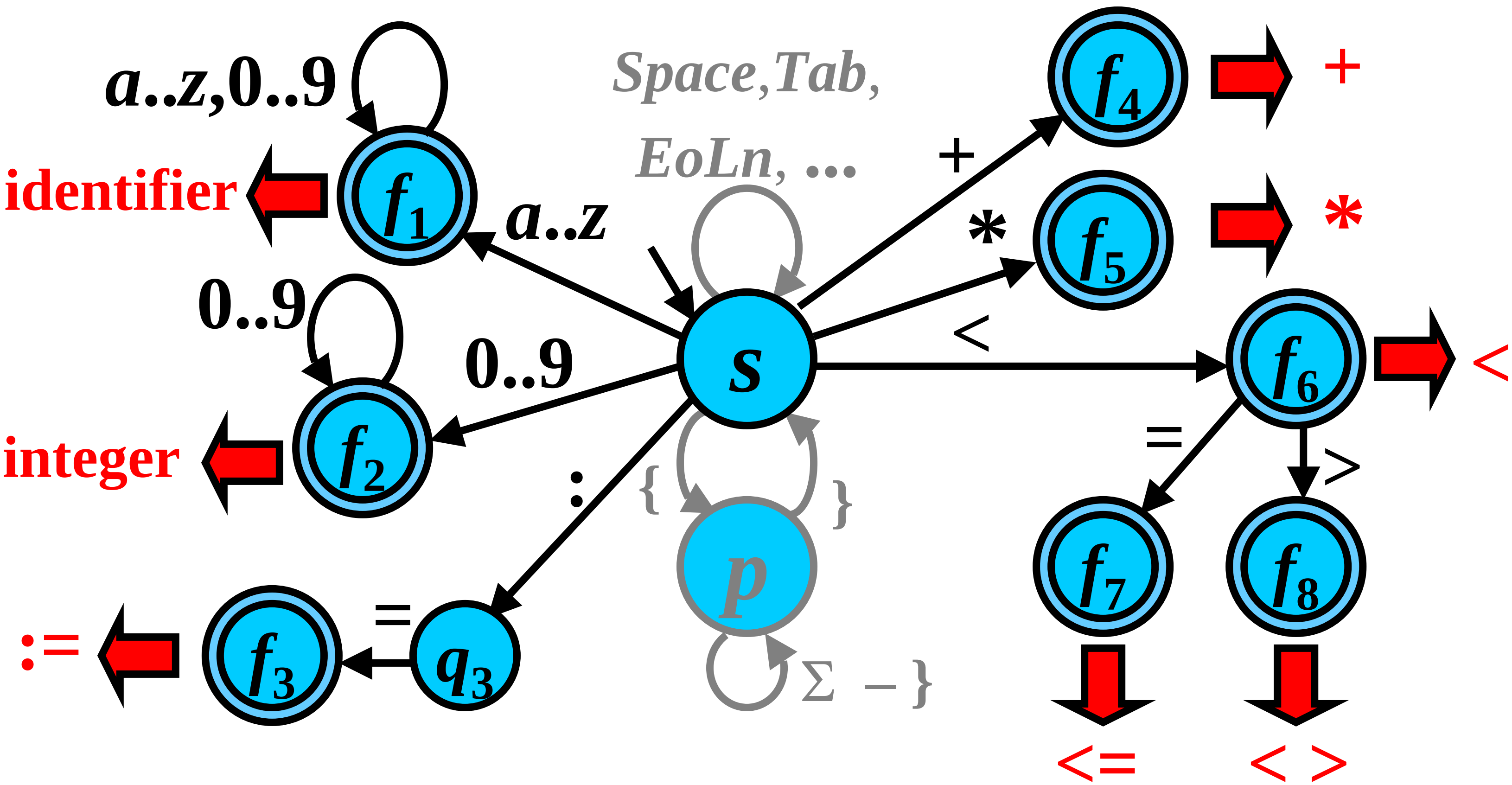


Convert this NFA to DFA.

DFAs for Lexemes: Example 2/2

- Equivalent DFA:

identifier, integer, :=, +, *, <, <=, < >

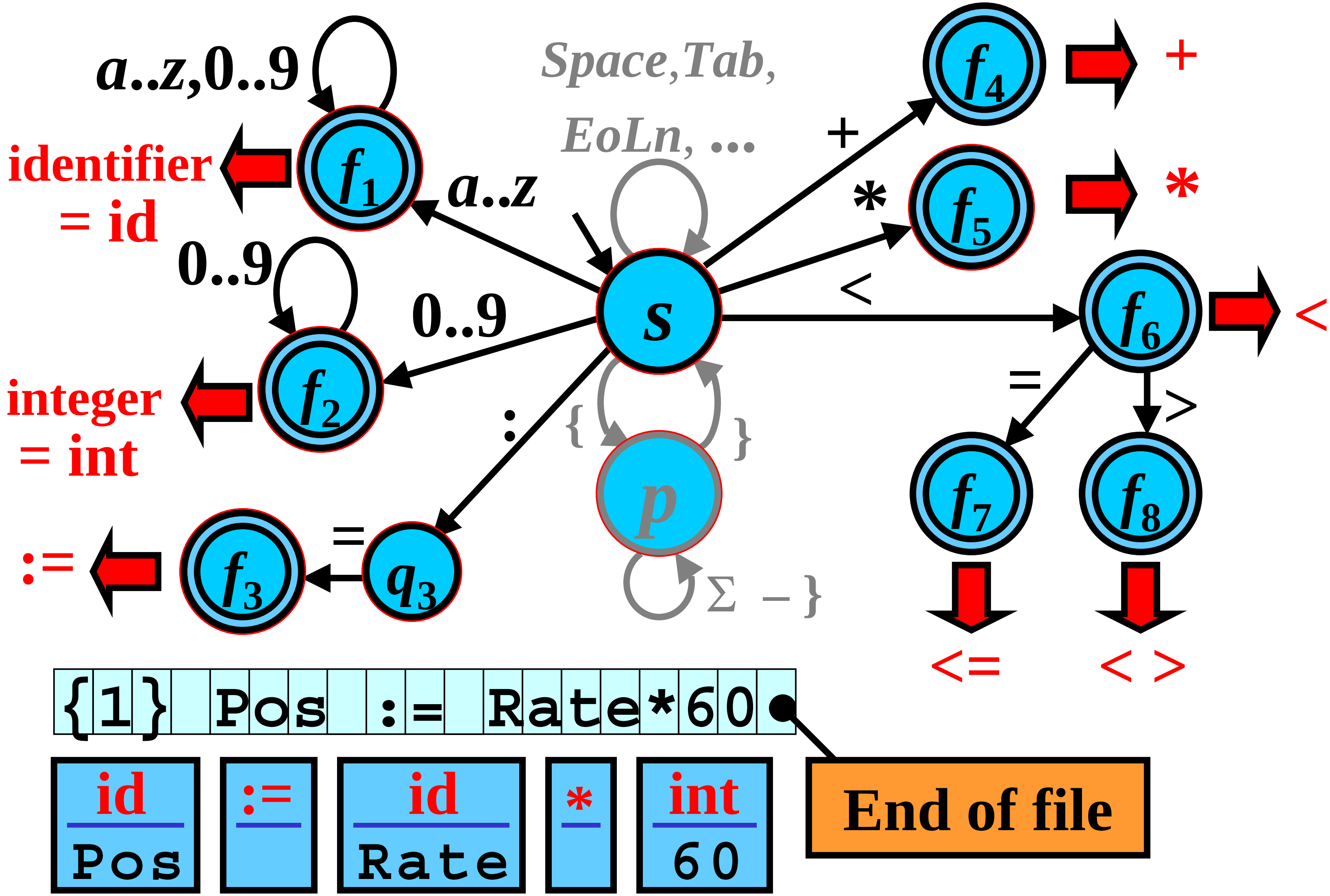


Algorithm: Type of Lexeme

- **Input:** DFA *M* for the source-program lexemes
- **Output:** determination of the lexeme type

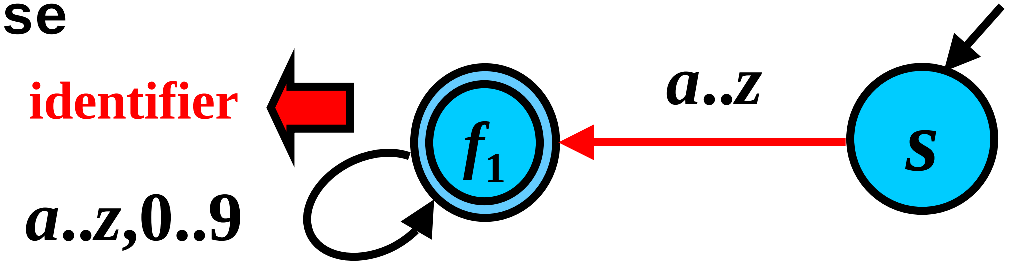
- **Method:**
- **while** ***a*** is the next symbol (character) in SP **and** *M* can make a move with ***a*** **do:**
  - read ***a***
  - make the move with ***a***
- **if** *M* is in a final state **then**
  determine the corresponding lexeme type
  else handle the lexical error (write message etc)

Type of Lexemes: Example



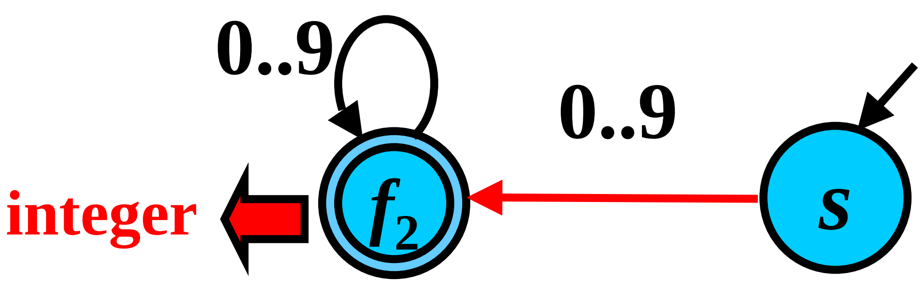
Implementation of DFA 1/10

```
procedure get_Next_Token(var TOKEN: ....);

...                                {declaration, ...}

str    := '';                      {read string}
state  := S;                       {actual state}
repeat
  symbol = getchar();              {read next character}
  case state of
    s : begin                      {start state}
          if symbol in ['a'..'z'] then
          begin
            state:= f1;            {identifier}
            str  := symbol;
          end else
```



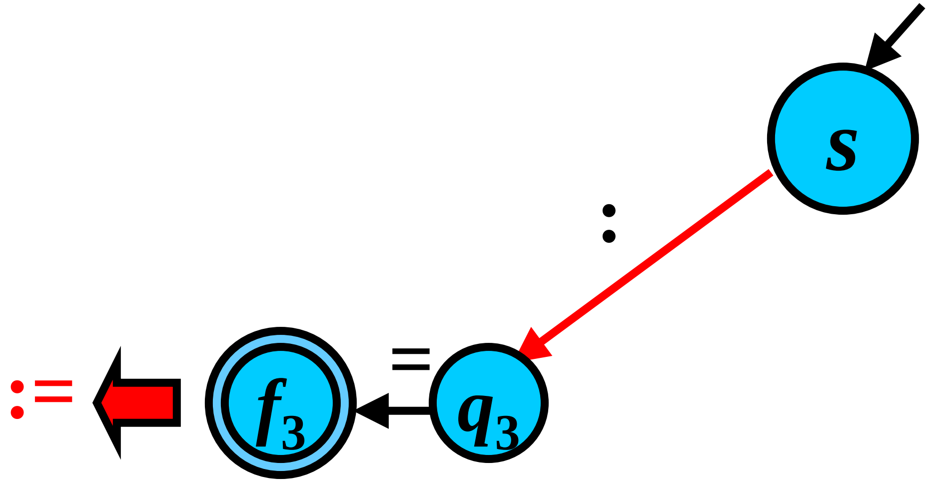
Implementation of DFA 2/10

```
case state of
  s : begin                              {start state}

        ...

        if symbol in ['0'..'9'] then
        begin
          state:= f2;        {integer}
          str  := symbol;
        end else
```



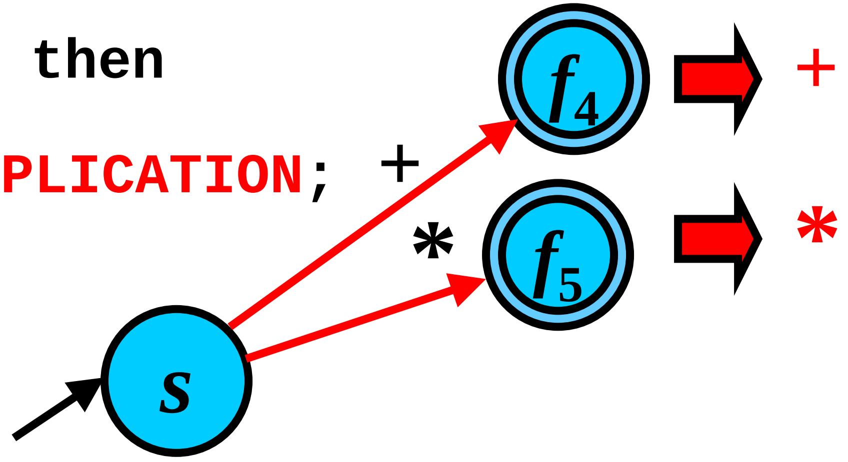
Implementation of DFA 3/10

```
case state of
  s : begin                         {start state}

        ...

        if symbol = ':' then
          state:= q3;               {assignment}
        else
```



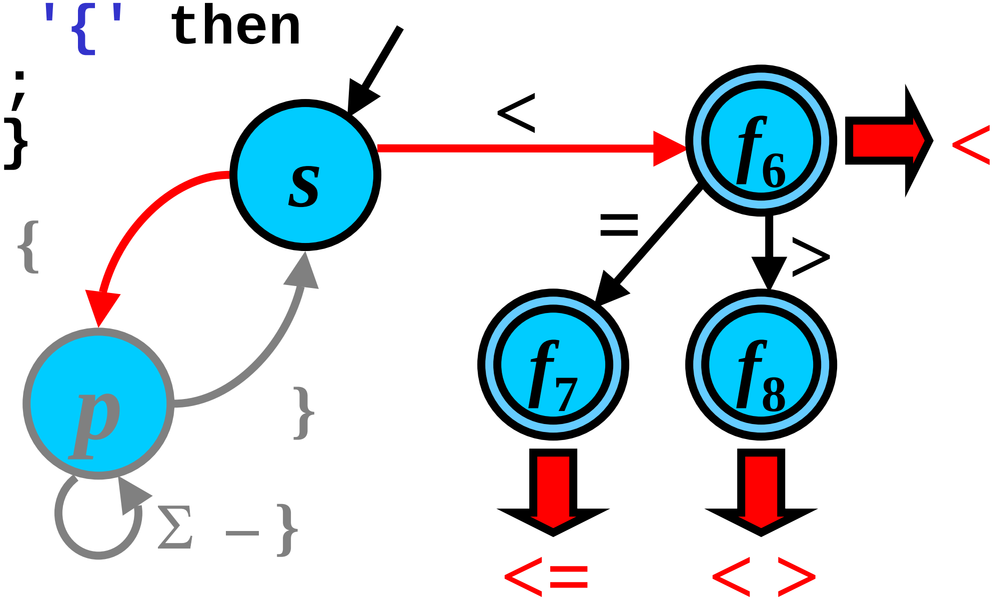
Implementation of DFA 4/10

```
case state of
  s : begin                              {start state}

        ...

        if symbol = '+' then
        begin
          TOKEN:= ADDITION;
          break;
        end else
        if symbol = '*' then
        begin
          TOKEN:= MULTIPLICATION;
          break;
        end else
```



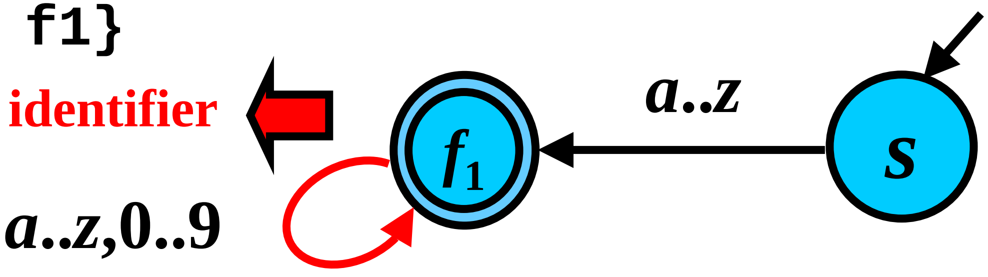
Implementation of DFA 5/10

```
case state of
  s : begin                              {start state}

        ...

        if symbol = '<' then
          state:= f6;
        else
        if symbol = '{' then
          state:= p;
      end; {state s}
```



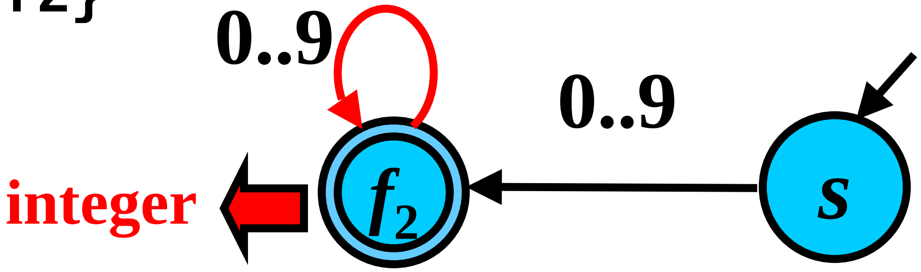
Implementation of DFA 6/10

```
case state of
   ...
   f1: begin                          {identifier}
         if symbol in ['a'..'z', '0'..'9'] then
           str  := str + symbol;
         else
         begin
           ungetchar(symbol);    {return symbol}
           if is_keyword(str) then     {keyword}
             TOKEN := get_keyword(str);
           else
             TOKEN := IDENTIFIER;
           break;
         end;
       end; {state f1}
```



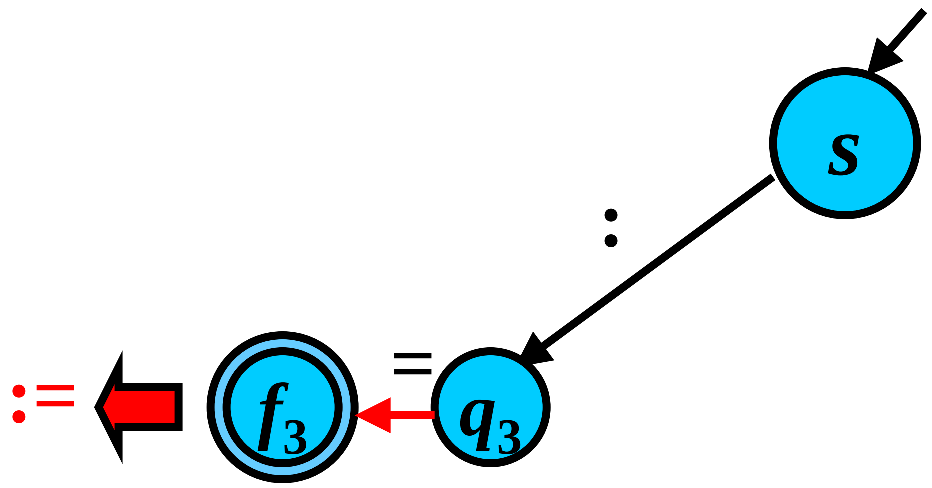
Implementation of DFA 7/10

```
case state of
  ...
  f2: begin                              {integer}
        if symbol in ['0'..'9'] then
          str  := str + symbol;
        else
        begin
          ungetchar(symbol);     {return symbol}
            TOKEN := INTEGER;
            {conversion value of str to integer}
          break;
        end;
      end; {state f2}
```

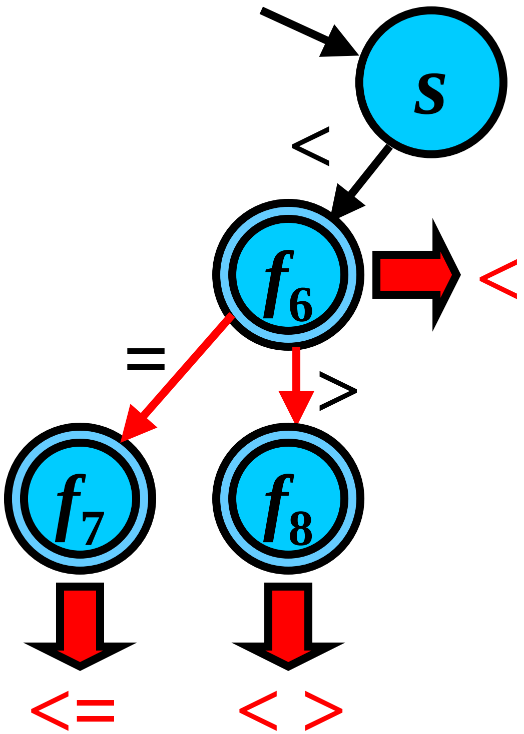


Implementation of DFA 8/10

```
case state of
  ...
  q3: begin                              {assignment}
        if symbol = '=' then
        begin
          TOKEN := ASSIGNMENT;
          break;
      end; {state q3}
```



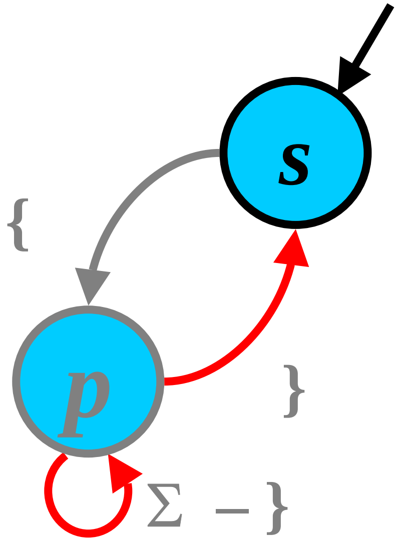
Implementation of DFA 9/10




```
case state of
    ...
    f6: begin
            if symbol = '=' then
            begin
              TOKEN := LEQ;     {<=}
              break;
            end else
            if symbol = '>' then
            begin
              TOKEN := NEQ;     {<>}
              break;
            end else
              ungetchar(symbol); {return symbol}
              TOKEN := LTN;     {<}
              break;
            end;
        end; {state f6}
```

Implementation of DFA 10/10

```
  case state of
    ...
    p : begin                              {comment}
          if symbol = '}' then
            state := s;              {start state}
        end; {state p}

until EOF;

...

end;
```



Tokens in Practice

- tokens represent every SP lexeme in a uniform way
- in general, their form is

[type, attribute]

---

1) Token **attributes** may vary

[id, ☛Pos], [int, 60], [*,]

pointer **integer** **nothing**

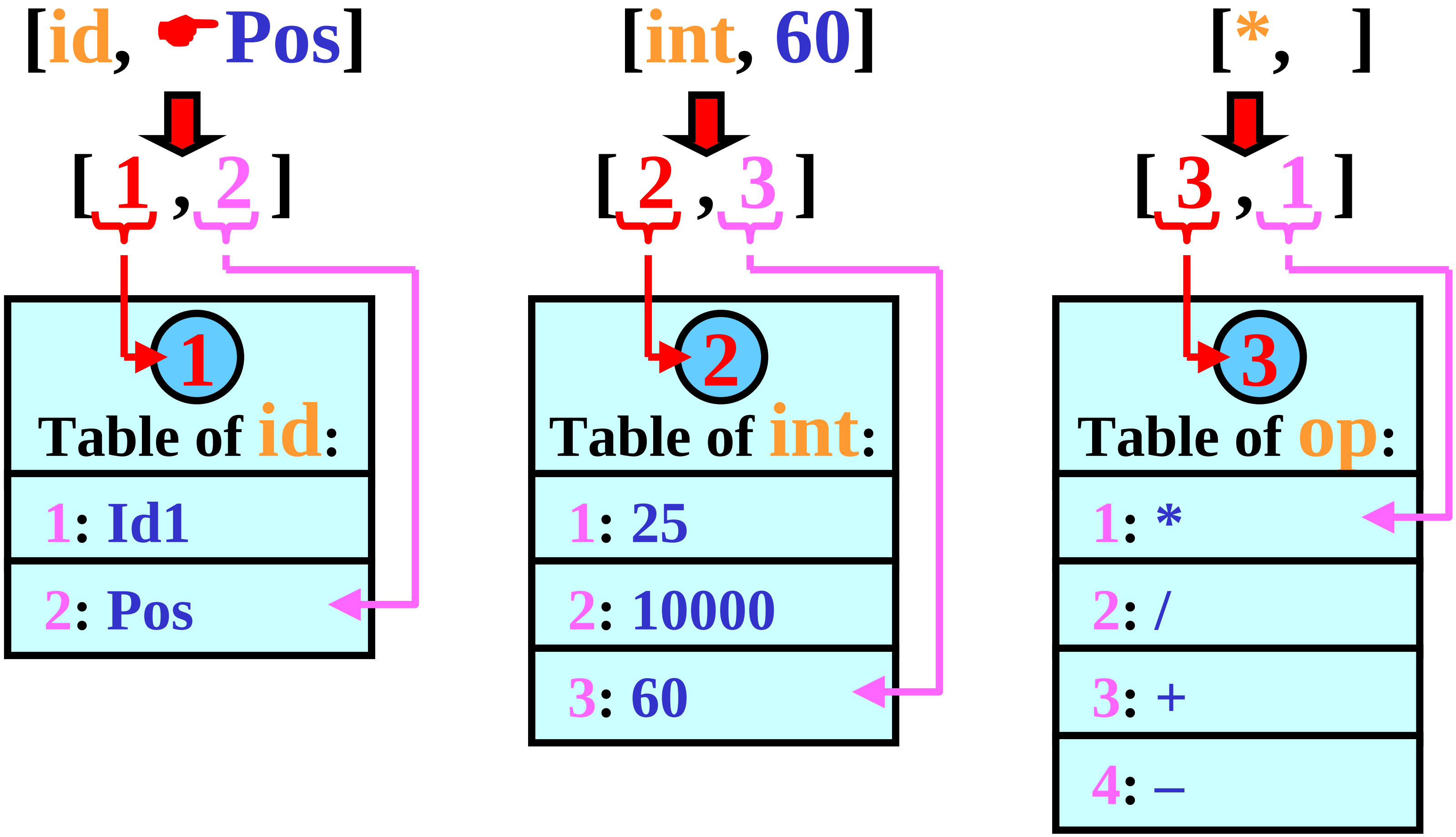
---

2) The same form of tokens

[1, 2], [2, 3], [3, 1]

NOTE: In practice, we often use tokens whose attributes vary.

The Same Form of Tokens



Uniform form of tokens: [1, 2]; [2, 3]; [3, 1]

Homogenous structure

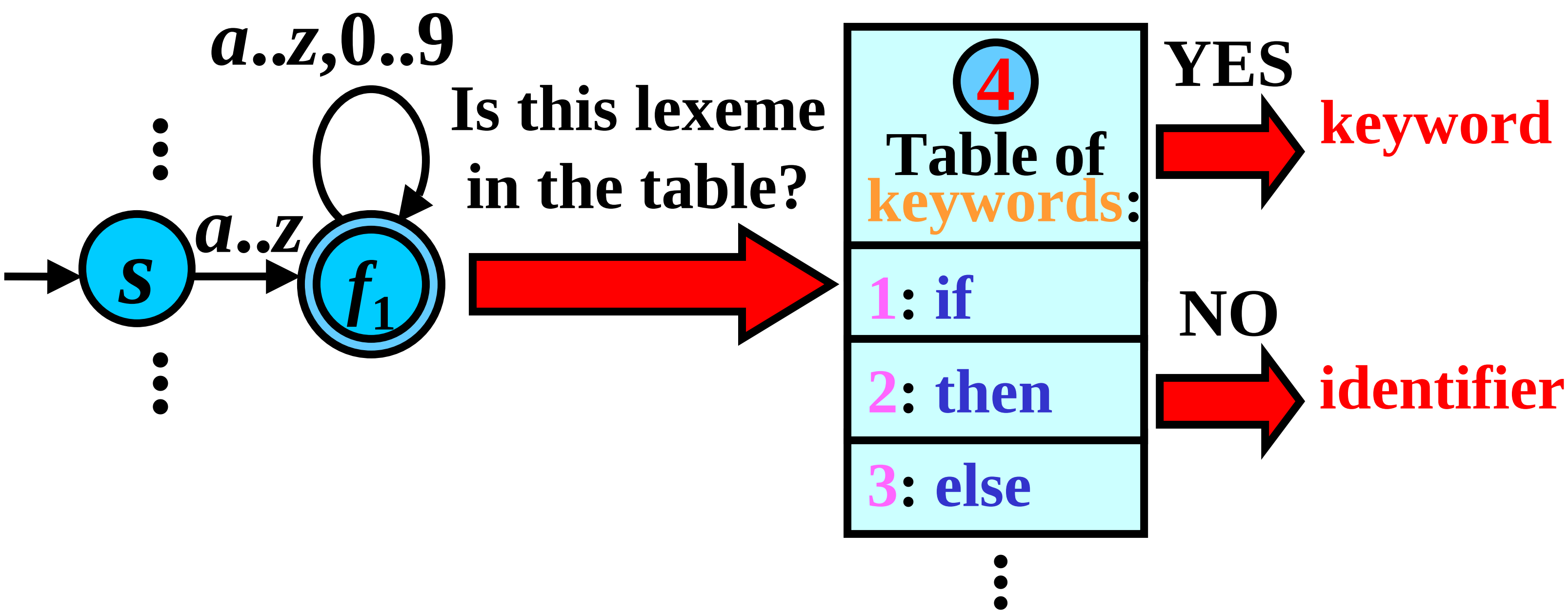
Identifiers × Keywords

Question: How to distinguish identifiers from keywords?

`if` ⇒ **keyword** × `ifj` ⇒ **identifier**

Answer: By a table of keywords.

(Tokens have the same form)



Symbol Table (Identifier Table)

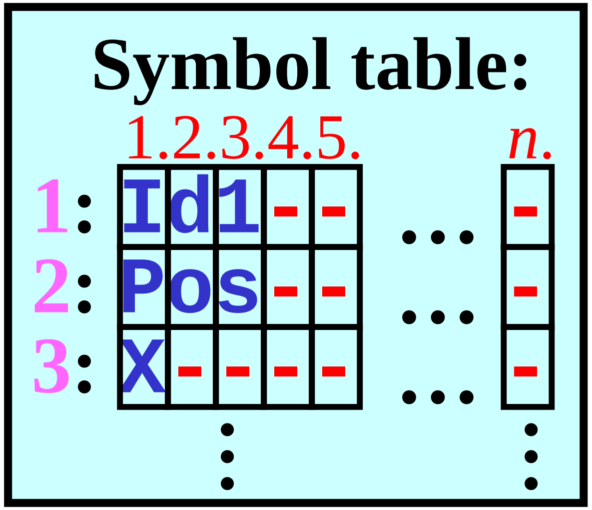
Practical problem:

1) Short identifiers:

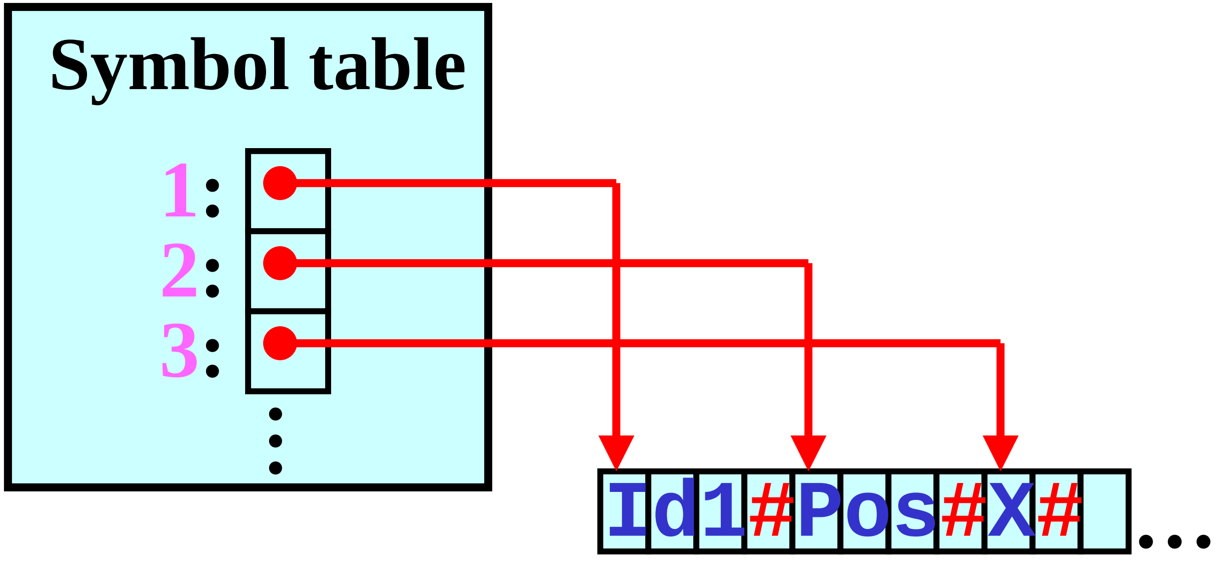
- Empty spaces in memory (**-**)

2) Long identifiers:

- Length(Id) ≤ ***n***



Solution:



Symbol Table: Structure

- We need many pieces of information about identifiers in ST:
  - **Variable**: name, type, length, …
  - **Constant**: type and value of constant
  - **Procedure**: the number and type of parameters

  ⋮

Final structure of the symbol table:

Symbol table		
	Name	**Info**
1:	**Id1**	**Variable**; **Type: integer**
2:	**Pi**	**Constant**; **Type: real**, **Value: 3.1415927**

Scope of Identifiers

- **Problem:**

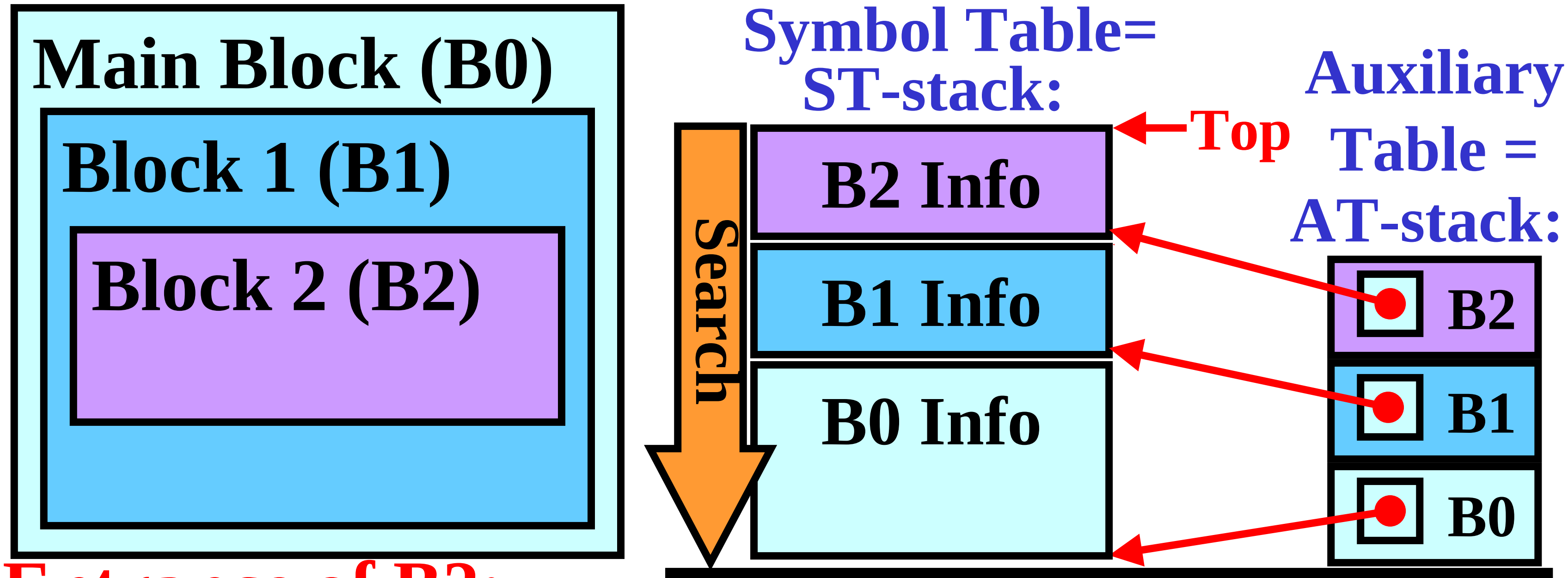
```
Program P1;
var x, y: integer;

Procedure Proc1;
var x, y: integer;
begin
 … x := 1; …
end;

begin
 … x := 2; …
end.
```

Symbol table

1:	x	…
2:	y	…
3:	Proc1	…
4:	x	…
5:	y	…

- **Solution: Scope Rules** (Stack structure of ST)

Scope Rules



Entrance of B2:

- Push a pointer to the ST-stack top onto AT-stack

Exit from B2:

- The top of B1 Info becomes the ST-stack top
- Remove the B2 pointer from the AT-stack top

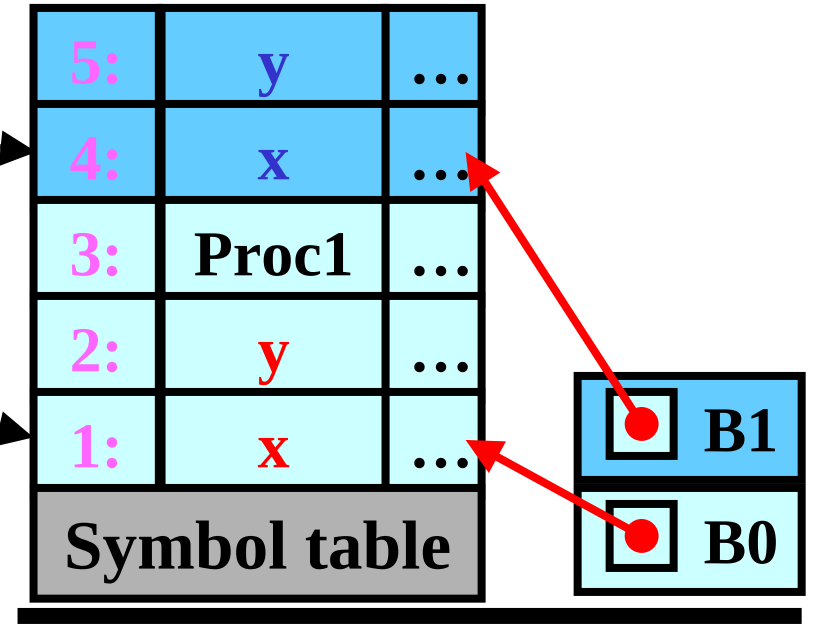
Search in ST:

- from the top towards the bottom

Scope Rules: Example

```
Program P1;
var x, y: integer;
Procedure Proc1;
var x, y: integer;
begin
  … x := 1; …
end;

begin
  … x := 2; …
end.
```

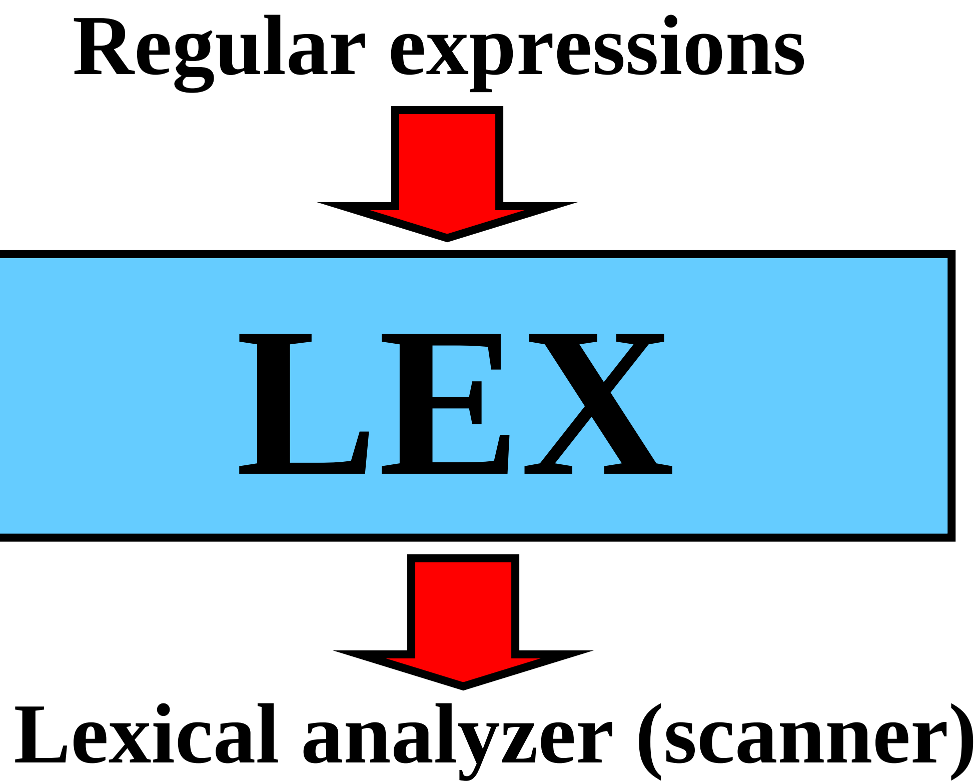
Symbol table:



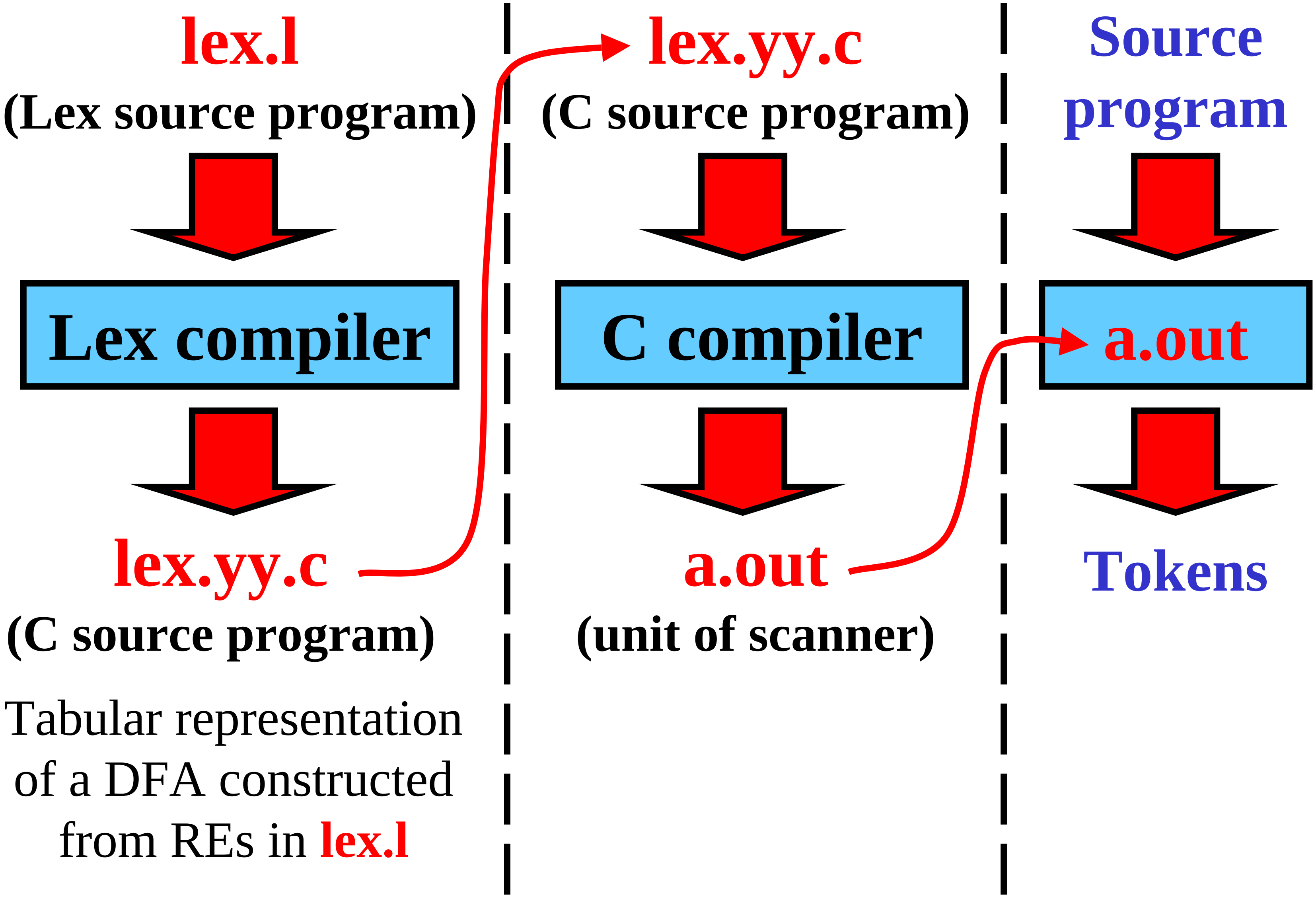
Lex: Basic Idea

- Automatic construction of a **scanner** from **RE**
- Lex compiler and Lex language

Illustration:



Lex: Phases of Compilation



Structure of Lex Source Program

/* Section I: Declaration */

$d_1, d_2, \ldots, d_i$

%% /* End of Section I*/

/* Section II: Translation rules */

$r_1, r_2, \ldots, r_j$

%% /* End of Section II*/

/* Section III: Auxiliary procedures*/

$p_1, p_2, \ldots, p_k$

Basic Regular Expressions in Lex

RE in LEX	Equivalent RE in theory of formal languages
`a`	a
`rs`	$r.s$
`r|s`	$r + s$
`r*`	r^*
`r+`	r^+
`r?`	$r + \varepsilon$
`[a-z]`	$a + b + c + \ldots + z$
`[0-9]`	$0 + 1 + 2 + \ldots + 9$

Section I: Declaration

1) Definitions of manifest constants = token types

2) Definitions based on REs are in the form:

```
Name_of_RE        RE
```

- **Name_of_RE** represents **RE**
- **{Name_of_RE}** is a reference to **Name_of_RE** used in other REs

Example:

```
#define   IF    256   /* constant for IF */
#define   THEN  257   /* constant for THEN */
#define   ID    258   /* constant for ID */
#define   INT   259   /* constant for NUM */
letter    [a-z]
digit     [0-9]
id        {letter}({letter}|{digit})*
integer   {digit}+
```

Section II: Translation Rules

- Translation rules are in the form:

```
RE          Action
```

- **Action** is a program routine that specifies what to do when a lexeme is specified by **RE**

Example:

```
if         return(IF);
then       return(THEN);
{id}       { yylval = install_id();
             return(ID); }
{integer}  { yylval = install_int();
             return(INT); }
```

yylval: value returned by install_id() = attribute of token

Section III: Auxiliary Procedures

- Auxiliary procedures are needed by translation rules

Example:

```
...
{id}        { yylval = install_id();
              return(ID); }
...
%%
...
int install_id() {
        /* Procedure to install the lexeme into the symbol
           table and return a pointer thereto */
}
...
```

Complete Source Program in Lex

```
#define    IF   256    /* constant for IF */
#define    THEN 257    /* constant for THEN */
#define    ID   258    /* constant for ID */
#define    INT  259    /* constant for NUM */
int yylval;            /* yylval is visible for parser */
letter     [a-z]
digit      [0-9]
id         {letter}({letter}|{digit})*
integer    {digit}+
%%
if         return(IF);
then       return(THEN);
{id}       {yylval = install_id() ;return(ID) ;}
{integer} {yylval = install_int();return(INT);}
%%
int install_id()  { … }
int install_int() { … }
```