# Lexical Analysis and Lexical Analyzer Generators

Cousins of Compiler

1. Preprocessors – Macro Processing
   File inclusion
   Rational preprocessors
   Language extensions
2. Assemblers – mnemonic version of m/c code
   MOV, Add, Sub
3. Loader & Linker –

# Lexical Analysis-Role of Lexical Analyzer

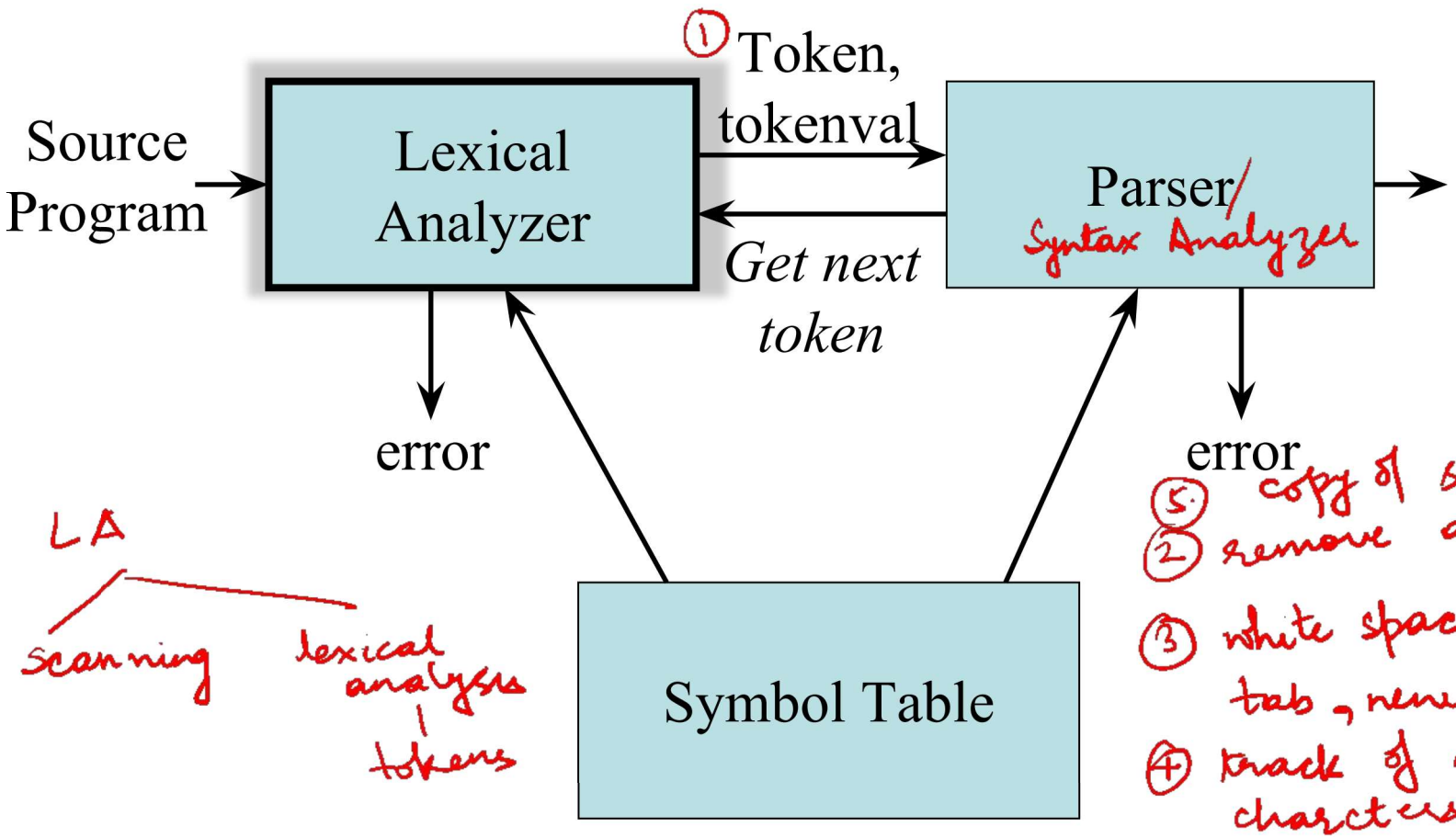
scans the input prog

generates tokens

1. scan + token
2. removes comments & white spaces
3. copy of prog with ~~se~~ error messages

while ( )

# Interaction of the Lexical Analyzer with the Parser




LA

scanning

lexical analysis | tokens

⑤ copy of source prog with errors

② remove all comments

③ white spaces, blanks, tab, newlinechar

④ track of newline characters

Analysis LA - Parsing -

# The Reason Why Lexical Analysis is a Separate Phase

- Simplifies the design of the compiler
  - LL(1) or LR(1) parsing with 1 token lookahead would not be possible (multiple characters/tokens to match)
- Provides efficient implementation
  - Systematic techniques to implement lexical analyzers by hand or automatically from specifications
  - Stream buffering methods to scan input
- Improves portability
  - Non-standard symbols and alternate character encodings can be normalized

Token Pattern Lexemes

Lexemes - smallest logical unit of a program

Token - Class of similar lexemes in a program

Pattern - Rules describes a token

```
main()
  { int i, a, b1;
      i = a + b1;
    printf ("i");
  }
```

| Lexeme | | Tokens |
|---|---|---|
| main | — | kw |
| ( ) | — | Delimiters |
| { } | — | Delim |
| int | — | Data type kw |
| i | — | id |
| a | — | id |
| b1 | — | id |
| , | — | Delim |
| ; | — | Delim |
| printf | — | kw |
| = | — | op |
| + | — | op |

Keyword ⇒ if | while | else | switch | & case | lexems

token

predefined in the language, cannot change & cannot be used as variable names

Rule

Pattern

# Attributes of Tokens <token, value>

id const|num

`y := 31 + 28*x` → Lexical analyzer

token

<id, "y"> <assign, > <num, 31> <'+', > <num, 28> <'*', > <id, "x">

token (lookahead)

**tokenval** (token attribute)

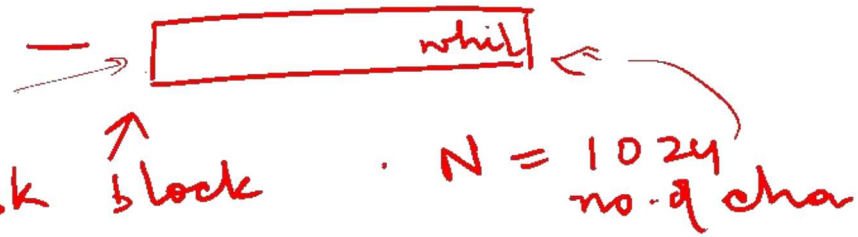
Parser

# Tokens, Patterns, and Lexemes

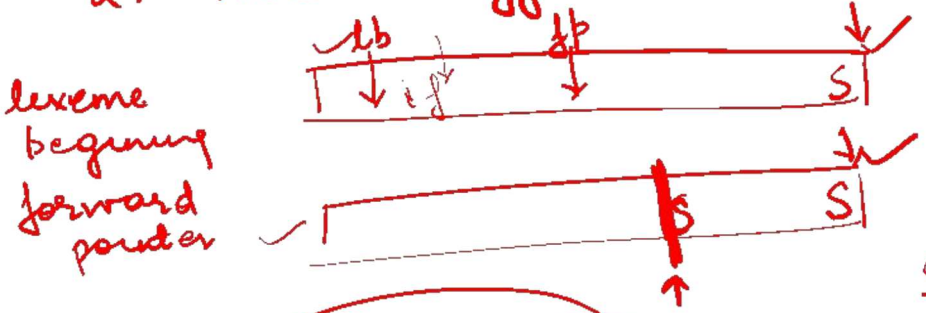
- A *token* is a classification of lexical units
  - For example: **id** and **num**
- *Lexemes* are the specific character strings that make up a token
  - For example: **`abc`** and **`123`**
- *Patterns* are rules describing the set of lexemes belonging to a token
  - For example: "*letter followed by letters and digits*" and "*non-empty sequence of digits*"

# Scanning the input/ Input buffering

1. One buffer scheme




2. Two buffer scheme




comments, white spaces

patterns that yield no token

S — eof

Sentinel — end of buffer

end of input

special Symbol

Token specification — Regular Expressions

for defining & recognizing patterns in strings.

LEX | FLEX ✓
YACC | BISON

words — classes — identifier — pattern

lexeme — token — rule

1. it should start with an alphabet → RE
2. zero | more alphabets or digits

int a;
int x;

int a1
int aa
int aa1
int aa1a
int aa1b

A = A ... Z | a ... z

D = 0 ... 9

id = A (A | D)*

RE

1. construct Symbol Table C | C++ | JAVA and show the concept <u>Hashing</u>

2. <u>LEX</u>

set char — language

# Specification of Patterns for Tokens: *Definitions*

notation RE

- An *alphabet* Σ is a finite set of symbols (characters)
- A *string* $s$ is a finite sequence of symbols from Σ
  - $|s|$ denotes the length of string $s$
  - ε denotes the empty string, thus $|\varepsilon| = 0$
- A *language* is a specific set of strings over some fixed alphabet Σ

character set
↓
alphabets
↓
strings
↓
language

# Specification of Patterns for Tokens: *String Operations*

word → token

- The *concatenation* of two strings $x$ and $y$ is denoted by $xy$
- The *exponentation* of a string $s$ is defined by

$$s^0 = \varepsilon$$
$$s^i = s^{i-1}s \quad \text{for } i > 0$$

note that $s\varepsilon = \varepsilon s = s$ epsilon

# Specification of Patterns for Tokens: *Language Operations*

- *Union*
  $L \cup M = \{s \mid s \in L \text{ or } s \in M\}$

  L = x
  M = y

- *Concatenation*
  $LM = \{xy \mid x \in L \text{ and } y \in M\}$
- *Exponentiation*
  $L^0 = \{\varepsilon\}; \quad L^i = L^{i-1}L$
- *Kleene closure*
  $L^* = \cup_{i=0,\ldots,\infty} L^i$

  $L^*$ zero / more

- *Positive closure*
  $L^+ = \cup_{i=1,\ldots,\infty} L^i$

  $L^+$ one / more

# Specification of Patterns for Tokens: *Regular Expressions*

↳ Notation

- Basis symbols:
  - $\varepsilon$ is a regular expression denoting language $\{\varepsilon\}$
  - $a \in \Sigma$ is a regular expression denoting $\{a\}$
- If $r$ and $s$ are regular expressions denoting languages $L(r)$ and $M(s)$ respectively, then
  - $r|s$ is a regular expression denoting $L(r) \cup M(s)$
  - $rs$ is a regular expression denoting $L(r)M(s)$
  - $r^*$ is a regular expression denoting $L(r)^*$
  - $(r)$ is a regular expression denoting $L(r)$
- A language defined by a regular expression is called a *regular set*

# Specification of Patterns for Tokens: *Regular Definitions*

- Regular definitions introduce a naming convention with name-to-regular-expression bindings:

  $d_1 \rightarrow r_1$
  $d_2 \rightarrow r_2$
  $\ldots$
  $d_n \rightarrow r_n$

  where each $r_i$ is a regular expression over
  $\Sigma \cup \{d_1, d_2, \ldots, d_{i\text{-}1}\}$
- Any $d_j$ in $r_i$ can be textually substituted in $r_i$ to obtain an equivalent set of definitions

# Specification of Patterns for Tokens: *Regular Definitions*

example

l - Letter → A | B | . . . . | z | a . . . . . | z

d - digit → 0 | 1 | . . . . | 9

identifier → letter ( letter | digit )*

→ i → l ( l | d )*

Rule/Pattern

lexemes

a
aa
aa1
ab1
a1
abA

c | c++

token — identifier

# Specification of Patterns for Tokens: *Regular Definitions*

Po

RE

- Example:

regular definition

**letter** → **A**|**B**|…|**Z**|**a**|**b**|…|**z**

**digit** → **0**|**1**|…|**9**

**id** → **letter** ( **letter**|**digit** )*

id → l(l|d)*

i = a

i = A

i = aA  i = a0

i = a01

i = a0A

Pattern

int i = 1;

id  i

Token  lexeme

- Regular definitions cannot be recursive:

**digits** → **digit digits**|**digit**  *wrong!*

# Specification of Patterns for Tokens: *Notational Shorthand*

- The following shorthands are often used:

$$r^+ = rr^*$$
$$r? = r \mid \varepsilon$$
$$[\mathtt{a}\text{-}\mathtt{z}] = \mathtt{a} \mid \mathtt{b} \mid \mathtt{c} \mid \ldots \mid \mathtt{z}$$

num = 1
= 1.0
num = $2^2$

- Examples:

**digit** → [**0-9**] — [0|1|2 ... |9]

**num** → **digit**$^+$ (. **digit**$^+$)? ( **E** (+|-)? **digit**$^+$ )?

ε

# Regular Definitions and Grammars

word

↳ sentence

Grammar

*stmt* → **if** *expr* **then** *stmt*
| **if** *expr* **then** *stmt* **else** *stmt*
| ε

*expr* → *term* **relop** *term*
| *term*

*term* → **id**
| **num**

expr = a + 1

Regular definitions

**if** → `if`

**then** → `then`

**else** → `else`

**relop** → **<** | **<=** | **<>** | **>** | **>=** | **=**

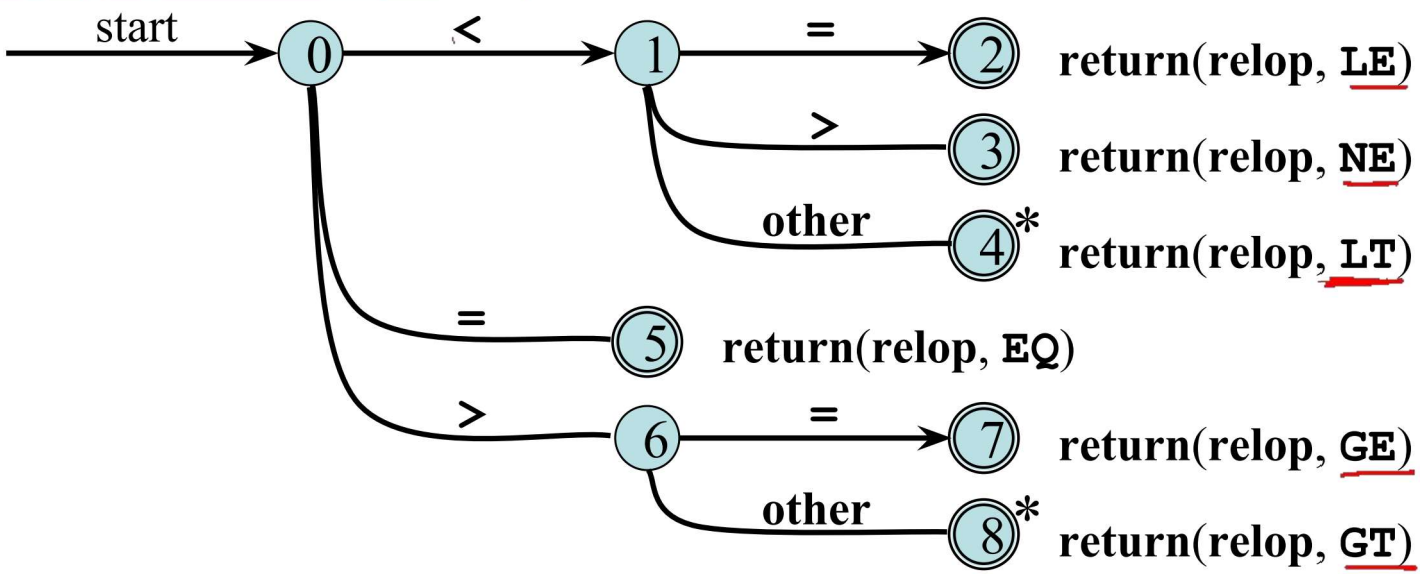
**id** → **letter ( letter** | **digit )**$^*$

**num** → **digit**$^+$ (**.** **digit**$^+$)? ( **E** (+ | **-**)? **digit**$^+$ )?

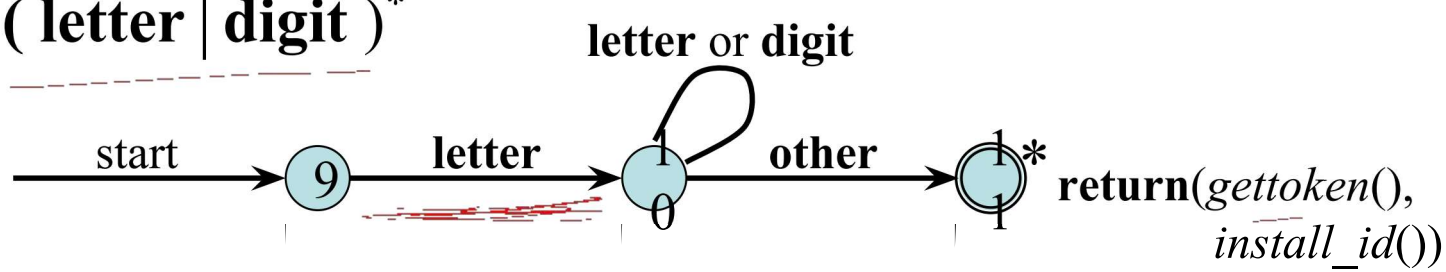
exponenta

# Coding Regular Definitions in *Transition Diagrams*

**relop → < | <= | <> | > | >= | =**




**id → letter ( letter | digit )***



# Coding Regular Definitions in Transition Diagrams: Code



```
token nexttoken()
{ while (1) {
    switch (state) {
    case 0: c = nextchar();
       if (c==blank || c==tab || c==newline) {
         state = 0;
         lexeme_beginning++;
       }
       else if (c==‘<’) state = 1;
       else if (c==‘=’) state = 5;
       else if (c==‘>’) state = 6;
       else state = fail();
       break;
     case 1:
       …
     case 9: c = nextchar();
       if (isletter(c)) state = 10;
       else state = fail();
       break;
     case 10: c = nextchar();
       if (isletter(c)) state = 10;
       else if (isdigit(c)) state = 10;
       else state = 11;
       break;
     …
```

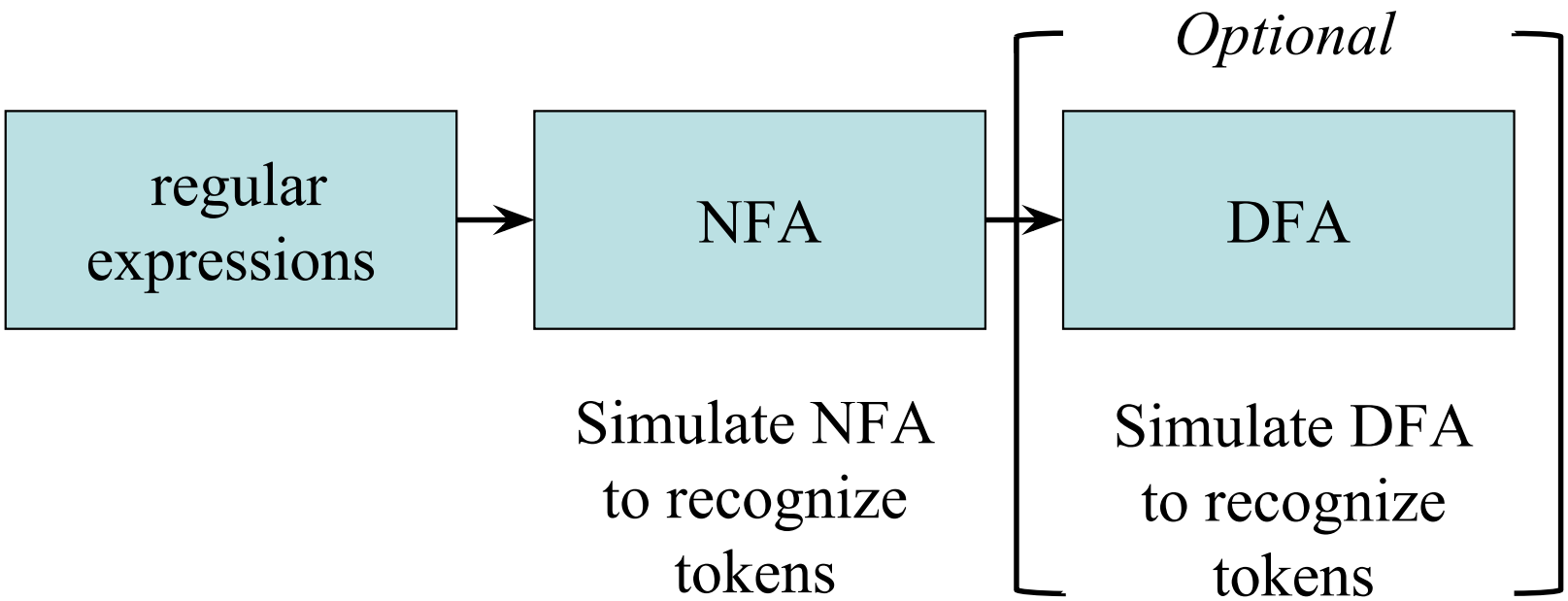
Decides the next start state to check

```
int fail()
{ forward = token_beginning;
  swith (start) {
  case  0: start =  9; break;
  case  9: start = 12; break;
  case 12: start = 20; break;
  case 20: start = 25; break;
  case 25: recover(); break;
  default: /* error */
  }
  return start;
}
```

# Design of a Lexical Analyzer Generator

recognizer – language
Automata
x
Yes | No

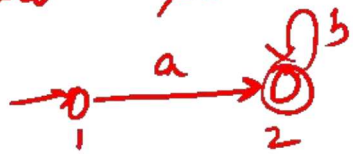
- Translate regular expressions to NFA
- Translate NFA to an efficient DFA



**NFA** $\{S, \Sigma, TF, S_0, F)$

- $\epsilon$
- one input — transition to more than one separate states

SDiag, STable




SDiag

| | a | b | $\epsilon$ |
|---|---|---|---|
| → 1 | 2 | — | 3 |
| 2 | — | 2,3 | |

STable

**DFA** $\{S, \Sigma, TF, S_0, F)$

- $\epsilon$ ✗ not allowed
- one ip — transition one and only one

| | a | b | ~~$\epsilon$~~ |
|---|---|---|---|
| → 1 | 2 | — | — |
| 2 | — | ~~2,3~~ | — |

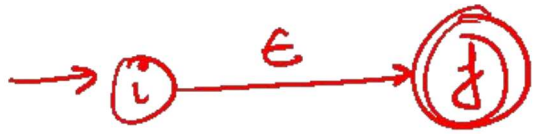
→ making language recognizer using NFA & DFA

↓

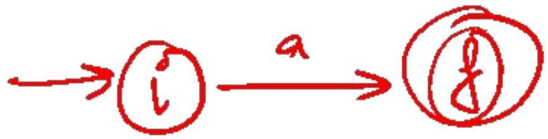
RE → NFA → DFA

# Conversion of RE to NFA
## Thompson's Construction method

1. For $\epsilon$, construct NFA

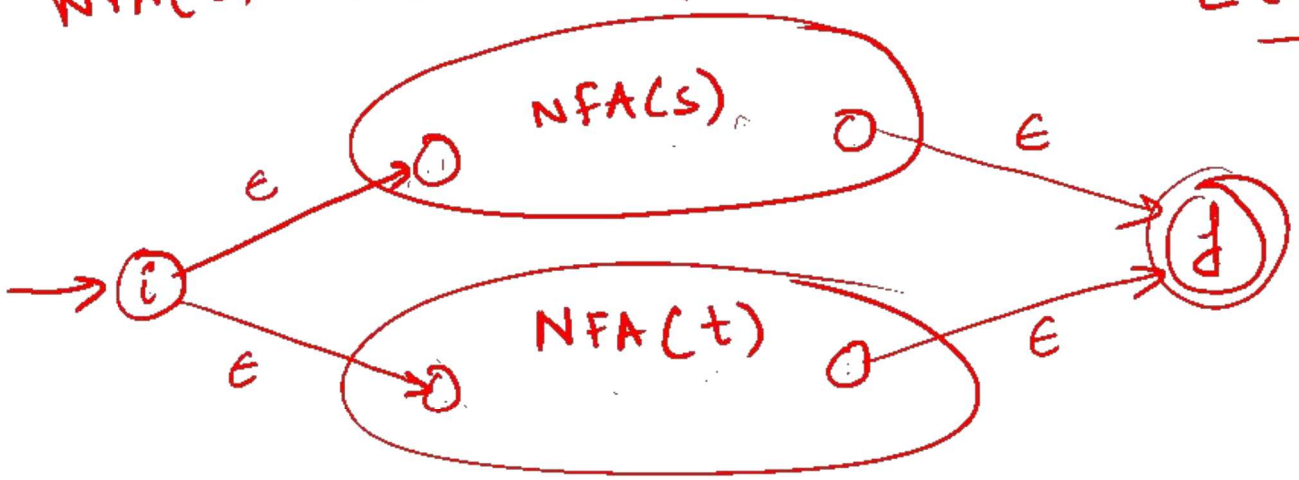



2. For 'a' in $\Sigma$ construct NFA




3. RE s and t and RE = s|t NFA(s) NFA(t) → NFA (s|t)

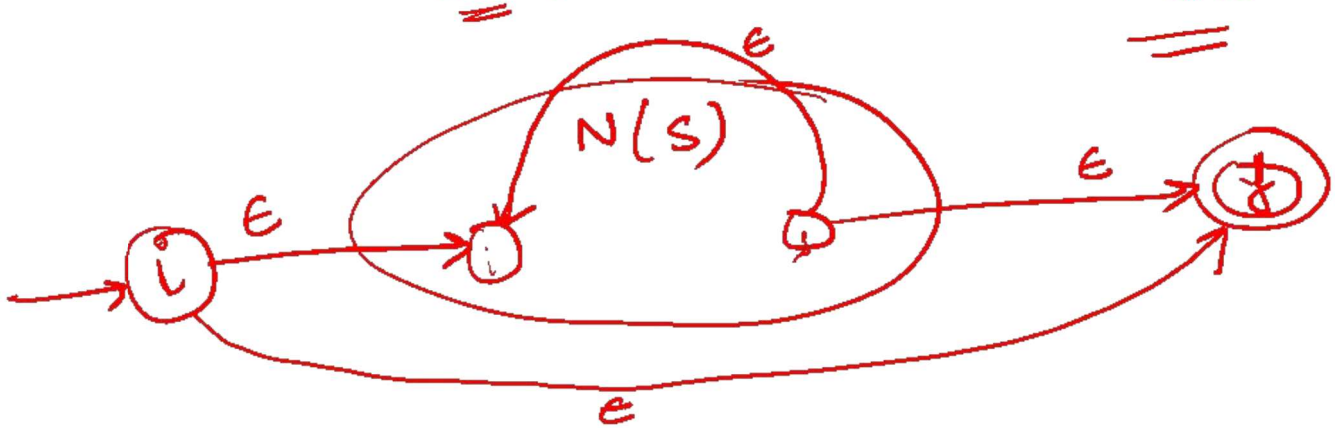
L(s) ∪ L(t)



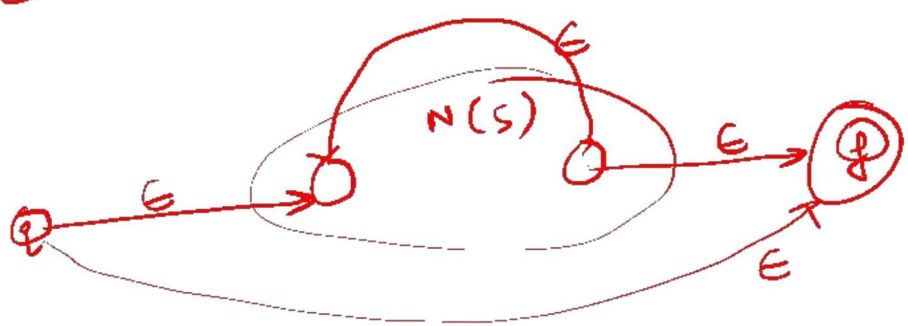
④ RE s , RE t , RE(st) , NFA (st)

L(s) L(t)

⑤ s* NFA (s*) N(s*) zero/more concatenation




re = (a|b)* abb



$R = (a|b)^* abb$ — NFA using Thompson's construction

$= R_1 \; R_2$

$R_1 = (a|b)^*$ ✓

$R_3 = a|b$ ✓

$R_4 = a$

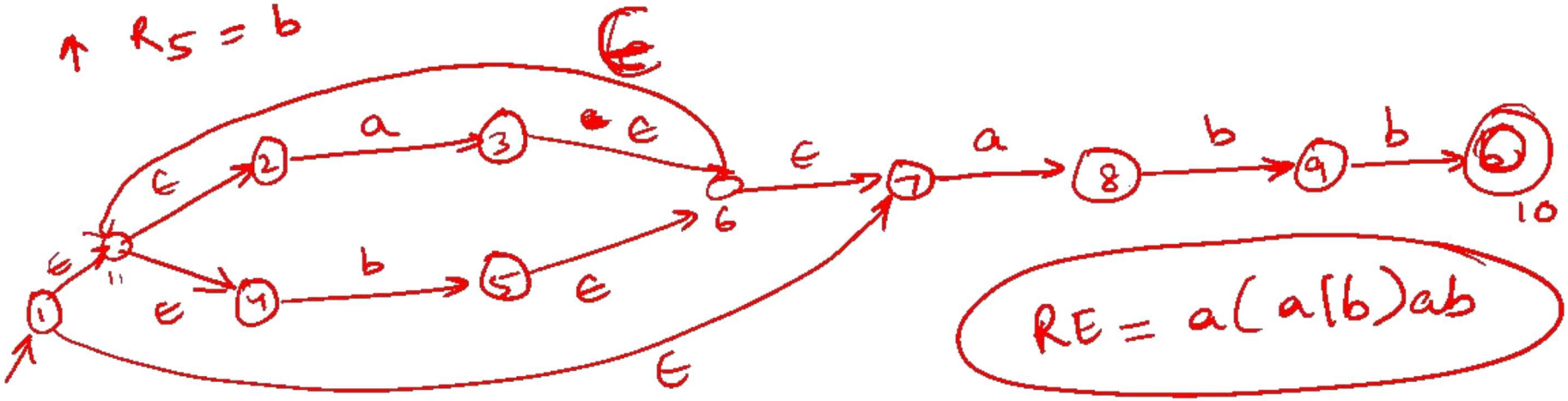
$R_5 = b$

$R_2 = abb$

$R_6 = a$

$R_7 = b$

$R_8 = b$




RE = a(a|b)ab

$(a|b)^*$

ε, a, b, aa, bb

aabb 1,112367 8910

abb 178910

$R = (a|b)^* \; abb \longrightarrow$

$= R_1 \quad R_2$

$R_1 = (a|b)^*$

$R_1 = (R_3|R_4)^*$

$R_5 = R_3 | R_4$

$R_3 = a$

$R_4 = b$

$R_2 = abb$

$R_6 = a$

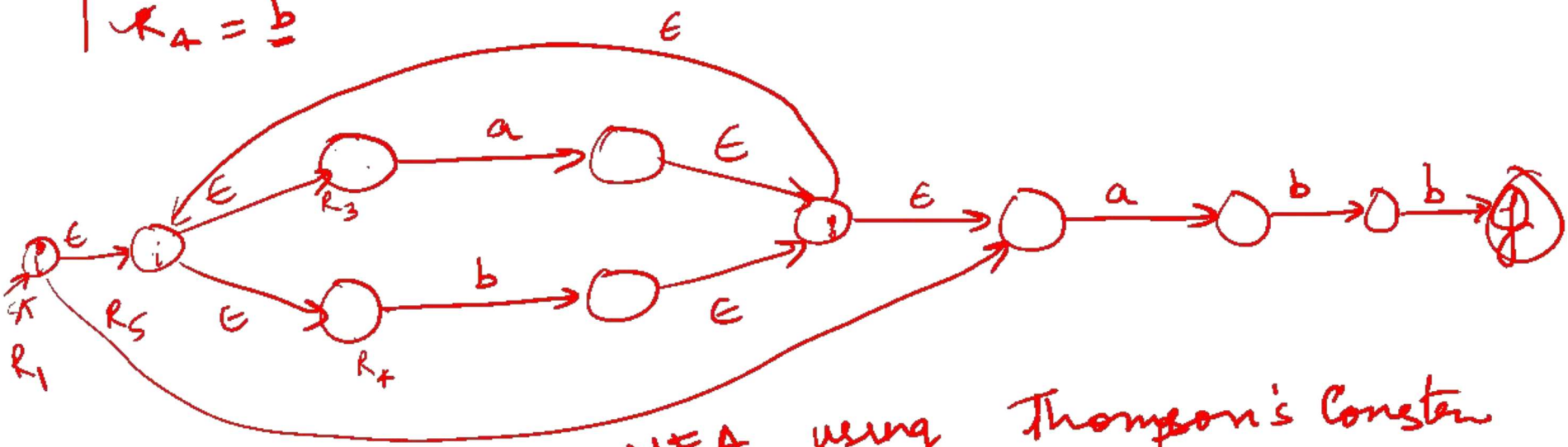
$R_7 = b$

$R_8 = b$

$\rightarrow \circ \xrightarrow{a} \circ$

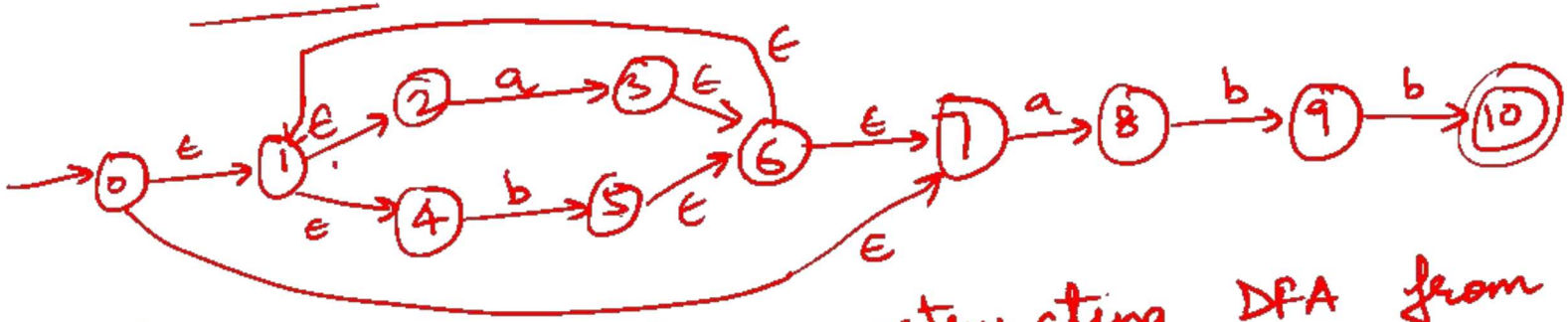
$\rightarrow \circ \xrightarrow{b} \circ$

$\rightarrow \circ \xrightarrow{b} \circ$




NFA using Thompson's Constr

NFA to DFA to minimized DFA  RE = $(a|b)^* abb$




Subset construction for constructing DFA from NFA.

ε-closure(0) = {0, 1, 2, 4, 7} → A ← st start

ε-closure(move(A, a)) = ε-cl(3, 8) = {3, 8, 6, 1, 2, 4, 7} → B

ε-closure(move(A, b)) = ε-cl(5) = {5, 6, 1, 7, 2, 4} → C

ε-cl(move(B, a)) = ε-cl(3, 8) = {3, 8, 6, 1, 2, 4, 7} → B

ε-cl(move(B, b)) = ε-cl(9, 5) = {9, 5, 6, 7, 1, 2, 4} → D

ε-cl(move(C, a)) = ε-cl(8, 3) = {3, 8, 6, 1, 2, 4, 7} → B

ε-cl(move(C, b)) = ε-cl(5) = {5, 6, 1, 7, 2, 4} → C

ε-cl(move(D, a)) = ε-cl(8, 3) = B

ε-cl(move(D, b)) = ε-cl(10, 5) = {10, 5, 6, 1, 2, 4, 7} → E

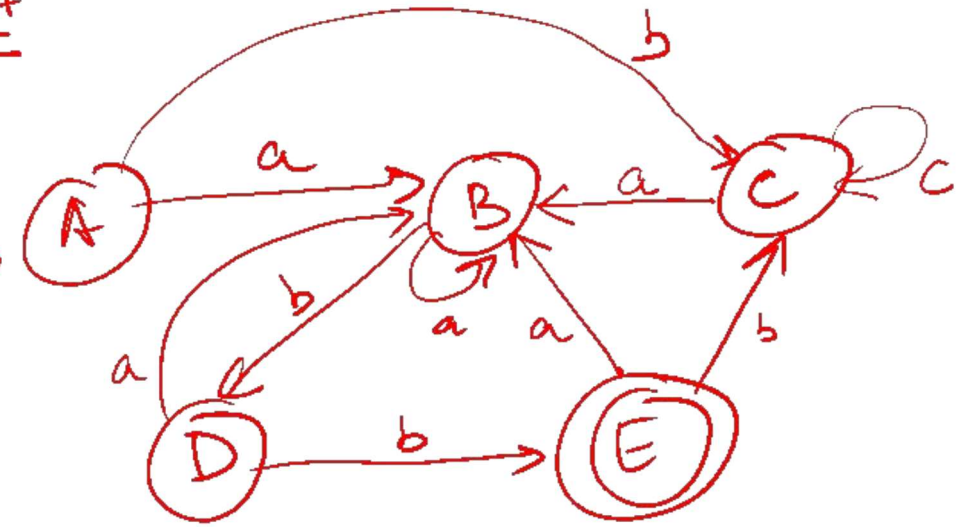
ε-cl(move(E, a)) = ε-cl(3, 8) = B

ε-cl(move(E, b)) = C

RE = (a|b)* abb

DFA

| | a | b |
|---|---|---|
| A | B | C ✓ |
| B | B | D |
| C | B | C ✓ |
| D | B | E |
| E | B | C ✓ |




$P_0$ = (ABCD) (E)

$P_1$ =

P = ABD E

= ABDE

| | a | b |
|---|---|---|
| A | B | A |
| B | B | D |
| D | B | E |
| E | B | A |

Final Minimized DFA

c

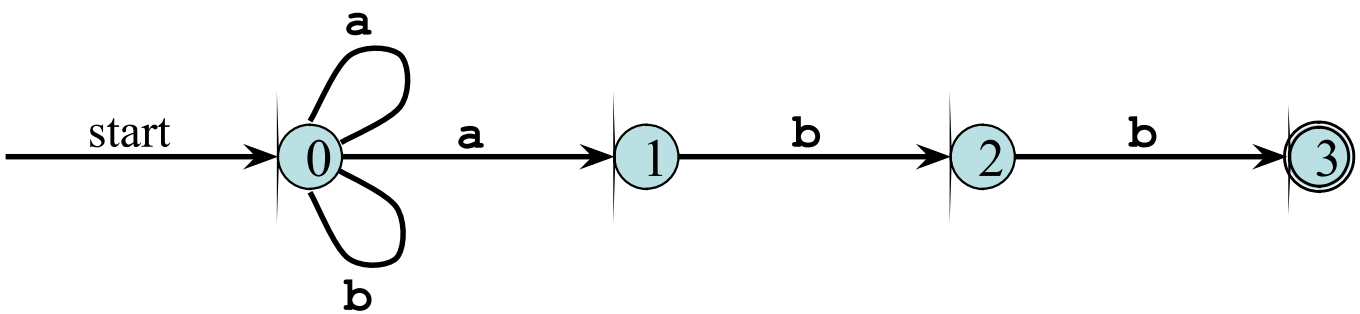
# Nondeterministic Finite Automata

- An NFA is a 5-tuple $(S, \Sigma, \delta, s_0, F)$ where

  $S$ is a finite set of *states*
  $\Sigma$ is a finite set of symbols, the *alphabet*
  $\delta$ is a *mapping* from $S \times \Sigma$ to a set of states
  $s_0 \in S$ is the *start state*
  $F \subseteq S$ is the set of *accepting (*or *final) states*

# Transition Graph

- An NFA can be diagrammatically represented by a labeled directed graph called a *transition graph*




$S = \{0,1,2,3\}$
$\Sigma = \{\mathbf{a},\mathbf{b}\}$
$s_0 = 0$
$F = \{3\}$

# Transition Table

- The mapping δ of an NFA can be represented in a *transition table*

$\delta(0,\mathbf{a}) = \{0,1\}$
$\delta(0,\mathbf{b}) = \{0\}$
$\delta(1,\mathbf{b}) = \{2\}$
$\delta(2,\mathbf{b}) = \{3\}$

→

| *State* | *Input* **a** | *Input* **b** |
|---|---|---|
| 0 | {0, 1} | {0} |
| 1 | | {2} |
| 2 | | {3} |

# The Language Defined by an NFA

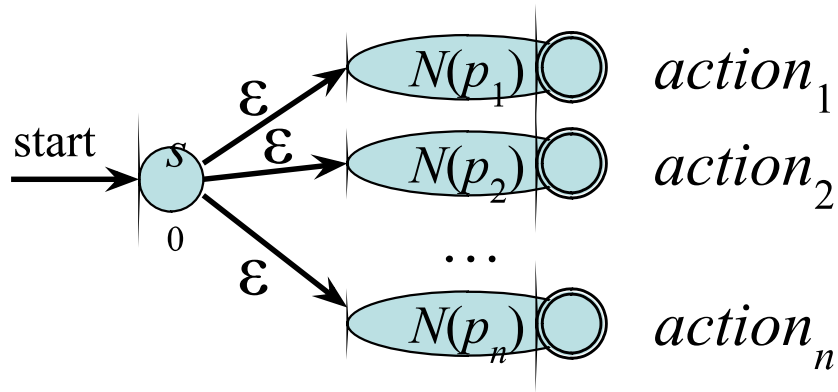
- An NFA *accepts* an input string *x* if and only if there is some path with edges labeled with symbols from *x* in sequence from the start state to some accepting state in the transition graph
- A state transition from one state to another on the path is called a *move*
- The *language defined by* an NFA is the set of input strings it accepts, such as (**a**|**b**)***abb** for the example NFA

# Design of a Lexical Analyzer Generator: RE to NFA to DFA

Lex specification with regular expressions

$p_1$ { $action_1$ }
$p_2$ { $action_2$ }
…
$p_n$ { $action_n$ }

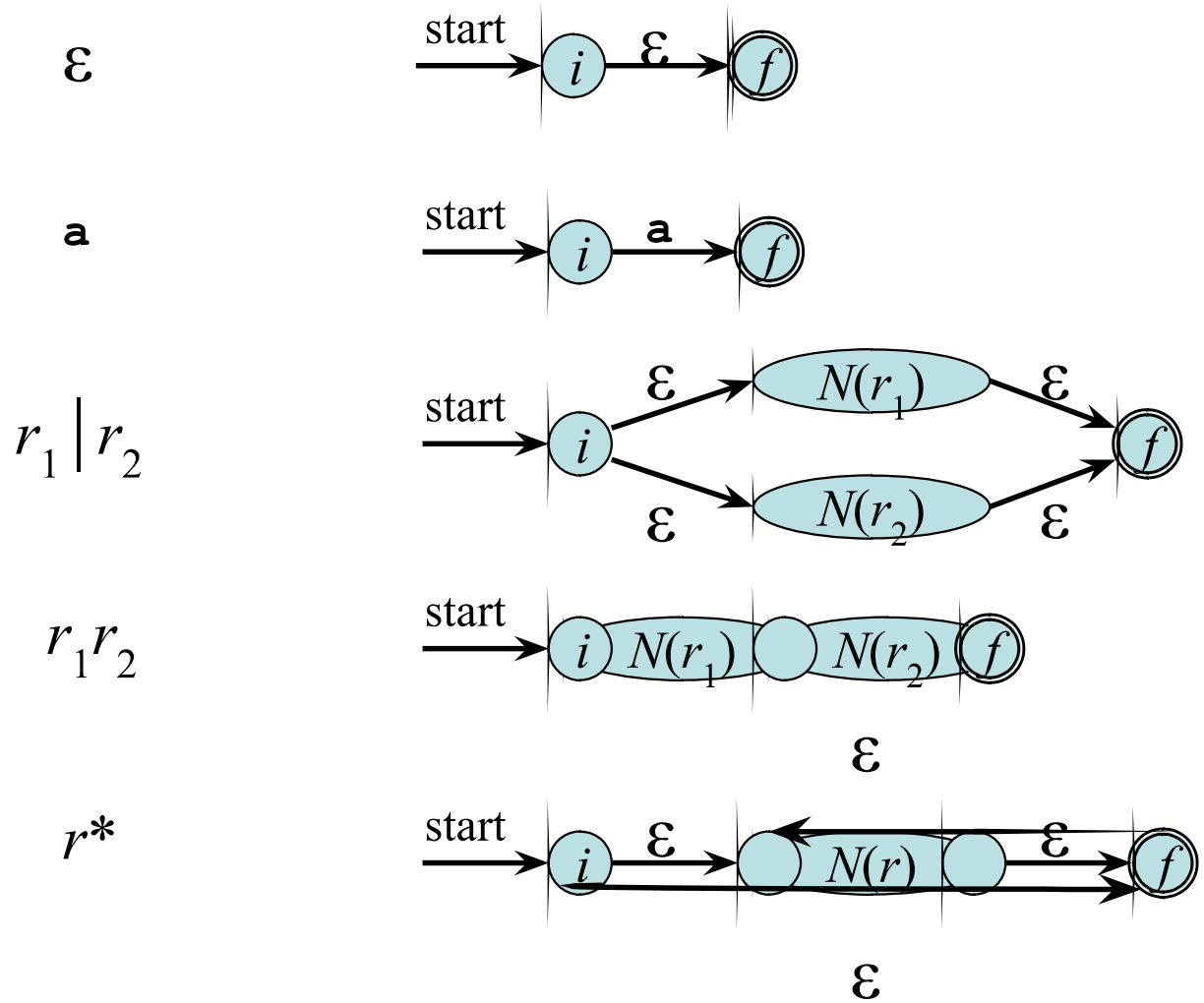
NFA




*Subset construction*

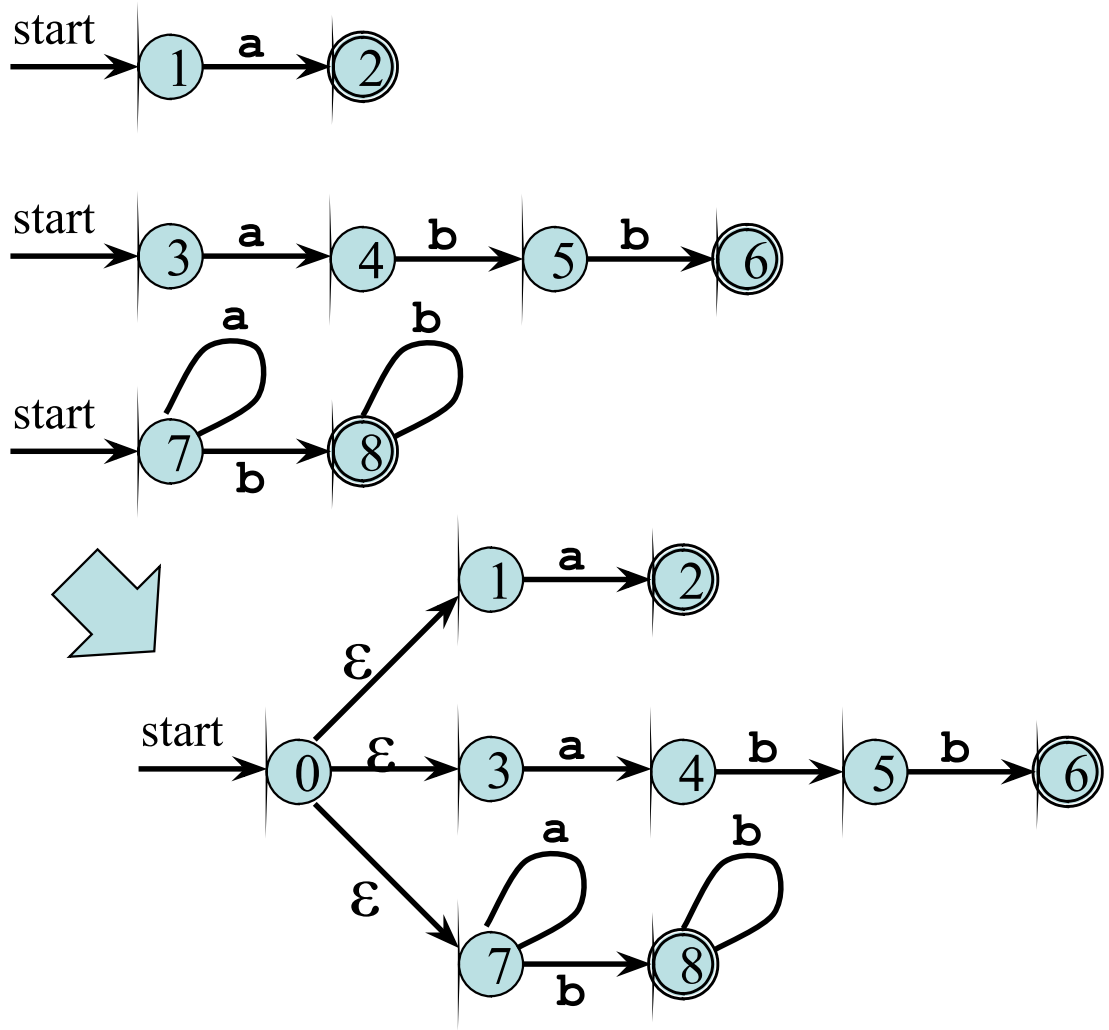
DFA

# From Regular Expression to NFA (Thompson's Construction)

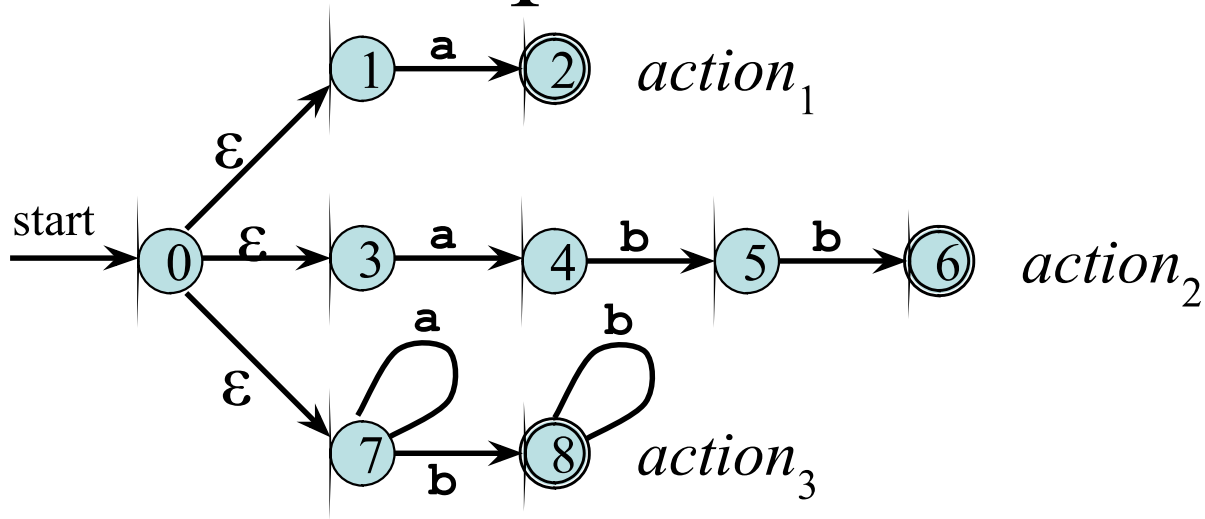


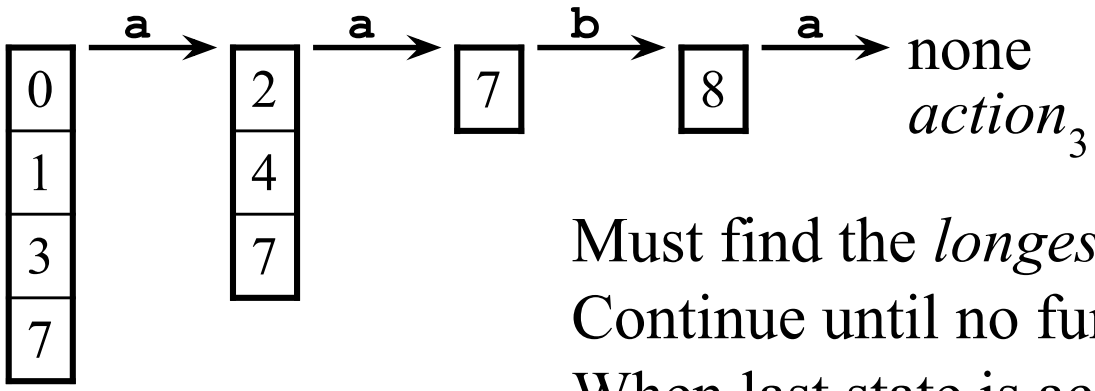
# Combining the NFAs of a Set of Regular Expressions

**a** { *action*$_1$ }
**abb** { *action*$_2$ }
**a*b+** { *action*$_3$ }



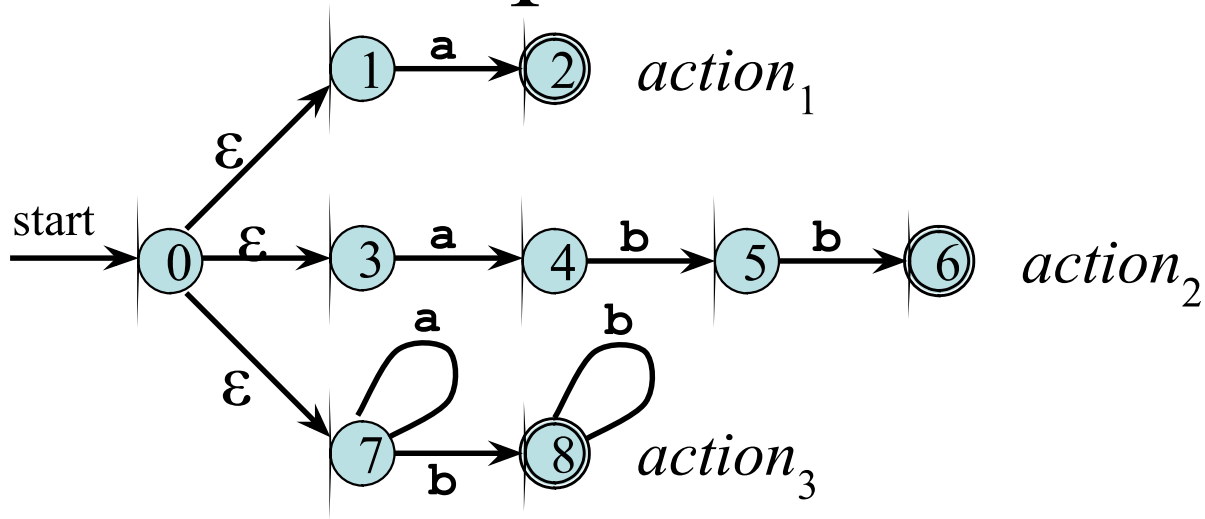
# Simulating the Combined NFA Example 1

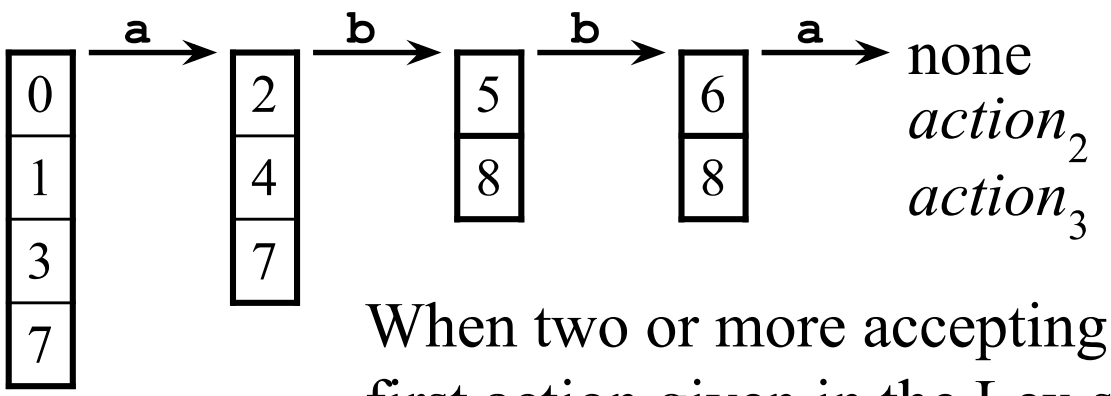



Must find the *longest match*:
Continue until no further moves are possible
When last state is accepting: execute action

# Simulating the Combined NFA Example 2



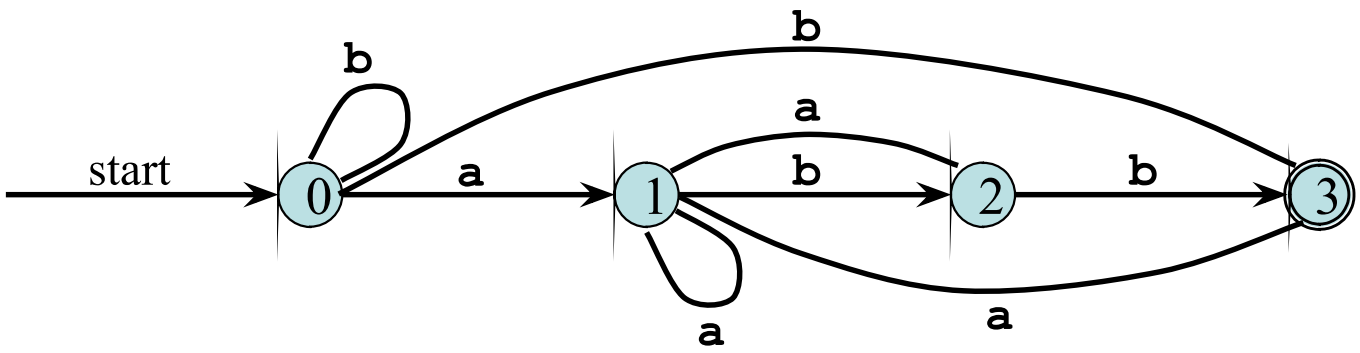

When two or more accepting states are reached, the first action given in the Lex specification is executed

# Deterministic Finite Automata

- A *deterministic finite automaton* is a special case of an NFA
  - No state has an ε-transition
  - For each state *s* and input symbol *a* there is at most one edge labeled *a* leaving *s*
- Each entry in the transition table is a single state
  - At most one path exists to accept a string
  - Simulation algorithm is simple

# Example DFA

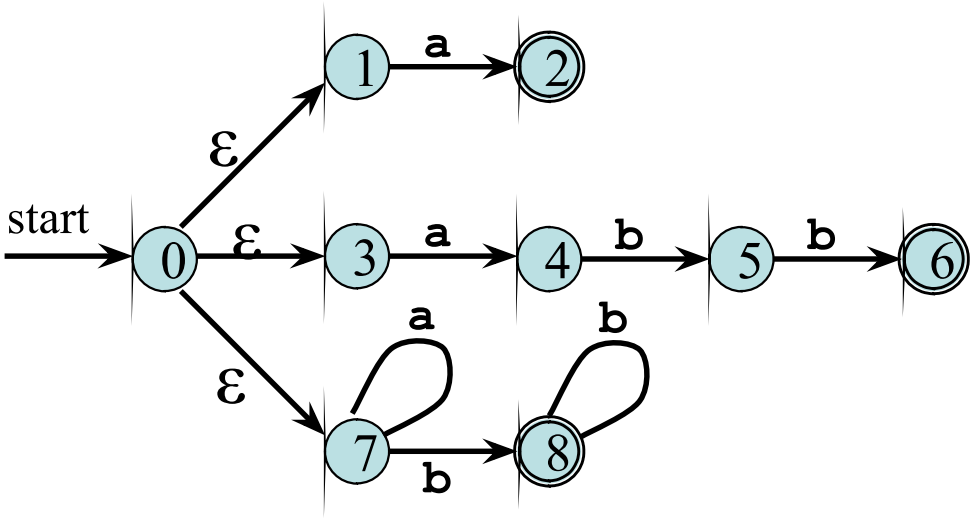
A DFA that accepts (**a**|**b**)***abb**



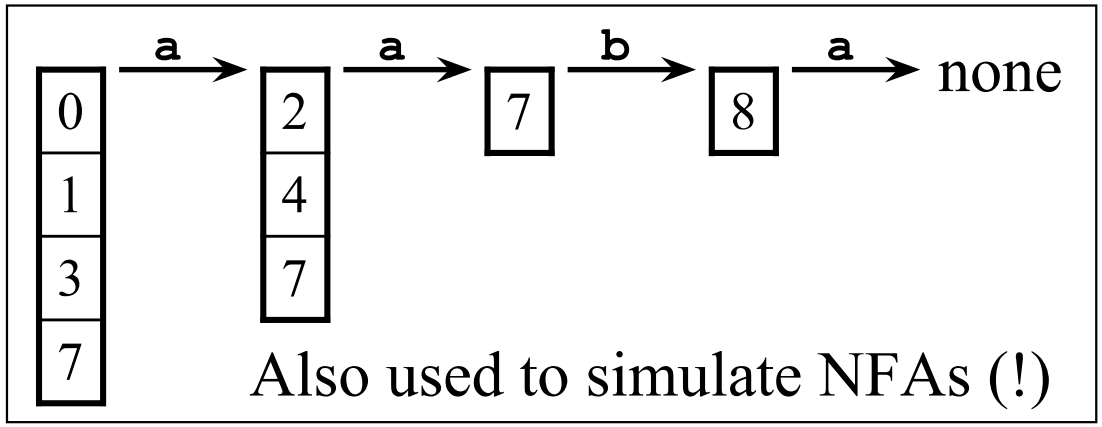
# Conversion of an NFA into a DFA

- The *subset construction algorithm* converts an NFA into a DFA using:
  $\varepsilon\text{-}closure(s) = \{s\} \cup \{t \mid s \rightarrow_{\varepsilon} \ldots \rightarrow_{\varepsilon} t\}$
  $\varepsilon\text{-}closure(T) = \cup_{s \in T} \varepsilon\text{-}closure(s)$
  $move(T,a) = \{t \mid s \rightarrow_{a} t \text{ and } s \in T\}$
- The algorithm produces:
  *Dstates* is the set of states of the new DFA consisting of sets of states of the NFA
  *Dtran* is the transition table of the new DFA

# ε-*closure* and *move* Examples




ε-*closure*({0}) = {0,1,3,7}
*move*({0,1,3,7},**a**) = {2,4,7}
ε-*closure*({2,4,7}) = {2,4,7}
*move*({2,4,7},**a**) = {7}
ε-*closure*({7}) = {7}
*move*({7},**b**) = {8}
ε-*closure*({8}) = {8}
*move*({8},**a**) = ∅



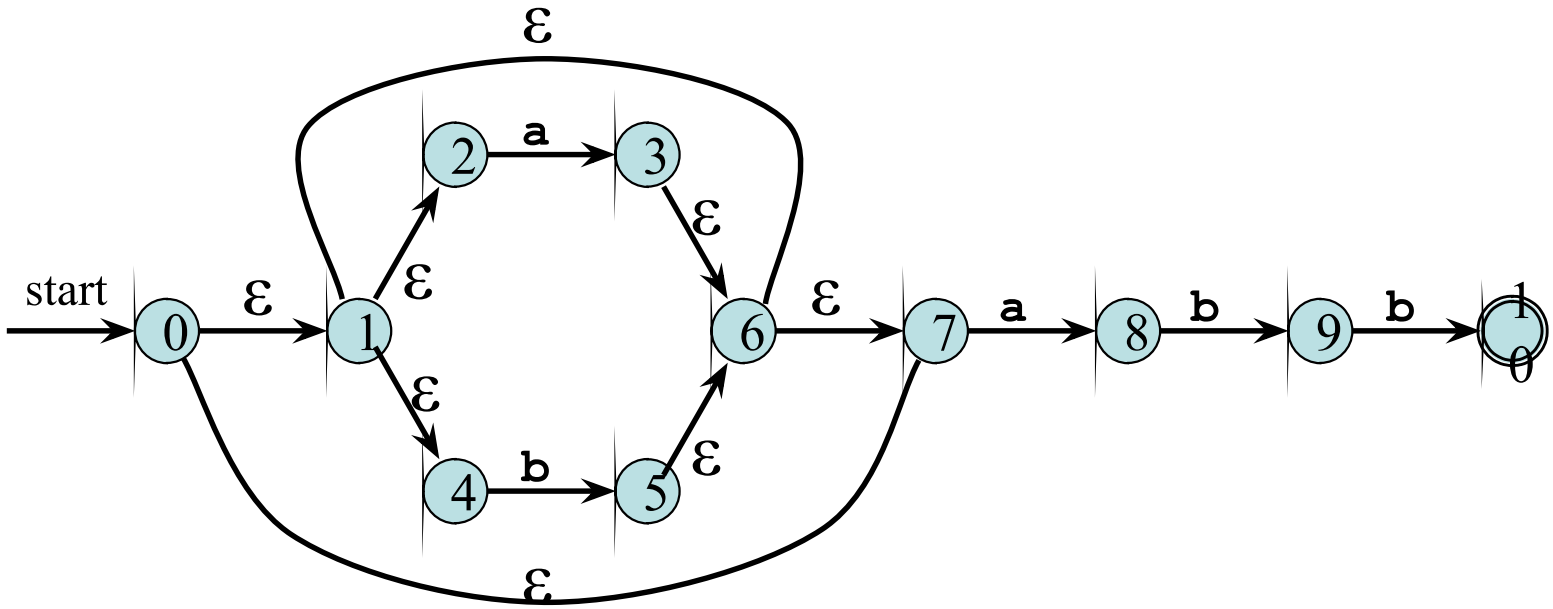
# Simulating an NFA using ε-*closure* and *move*

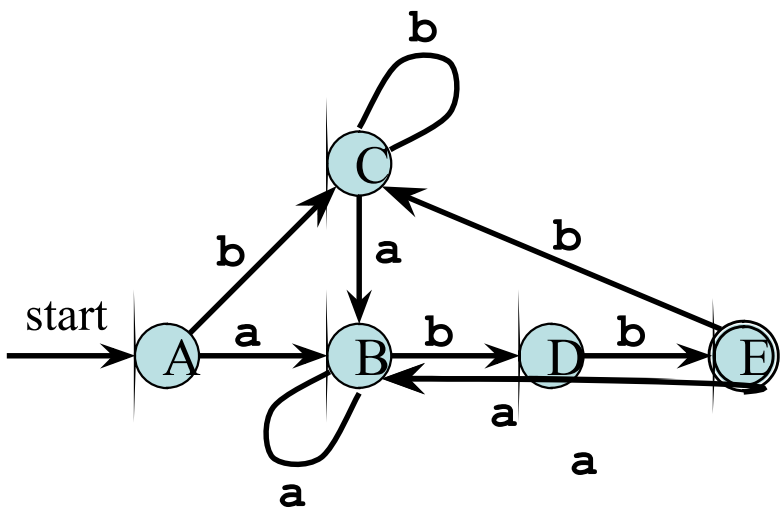
$S$ := ε-*closure*($\{s_0\}$)
$S_{prev}$ := $\varnothing$
$a$ := *nextchar*()
**while** $S \neq \varnothing$ **do**
    $S_{prev}$ := $S$
    $S$ := ε-*closure*(*move*($S$,$a$))
    $a$ := *nextchar*()
**end do**
**if** $S_{prev} \cap F \neq \varnothing$ **then**
    **execute** *action in* $S_{prev}$
    **return** "yes"
**else**  **return** "no"

# The Subset Construction Algorithm

Initially, ε-*closure*($s_0$) is the only state in *Dstates* and it is unmarked
**while** there is an unmarked state *T* in *Dstates* **do**
    mark *T*
    **for** each input symbol $a \in \Sigma$ **do**
        *U* := ε-*closure*(*move*(*T,a*))
        **if** *U* is not in *Dstates* **then**
            add *U* as an unmarked state to *Dstates*
        **end if**
        *Dtran*[*T*,*a*] := *U*
    **end do**
**end do**

# Subset Construction Example 1




*Dstates*

A = {0,1,2,4,7}

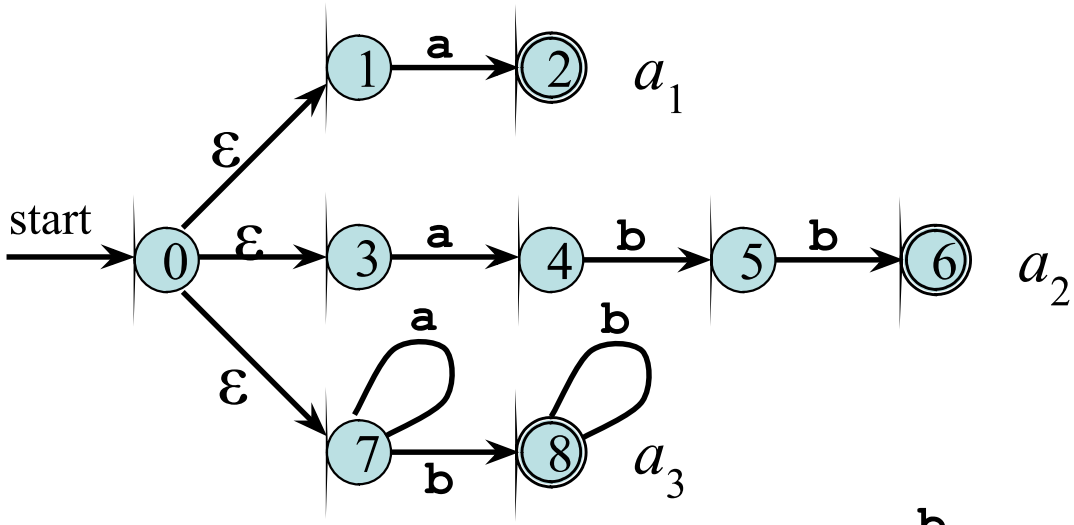
B = {1,2,3,4,6,7,8}

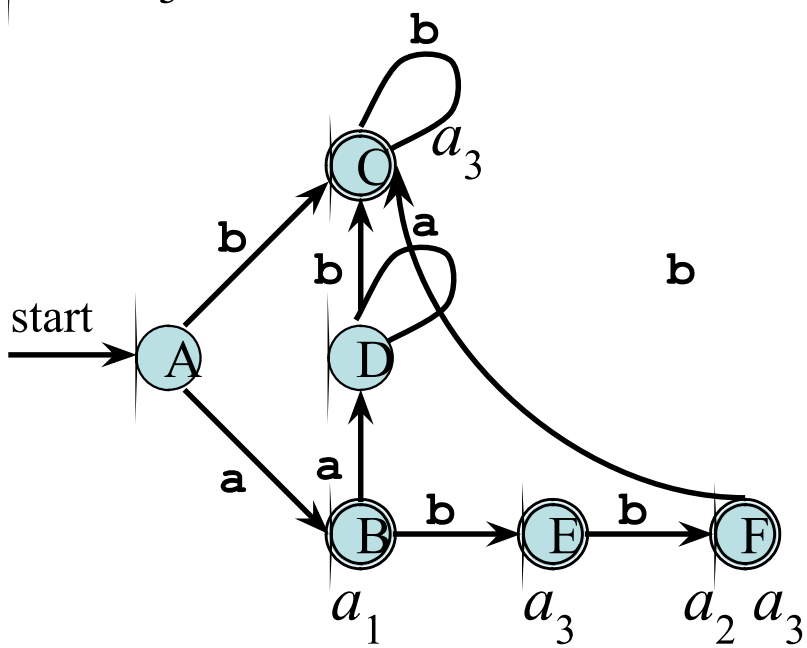
C = {1,2,4,5,6,7}

D = {1,2,4,5,6,7,9}

E = {1,2,4,5,6,7,10}

# Subset Construction Example 2




*Dstates*

A = {0,1,3,7}

B = {2,4,7}

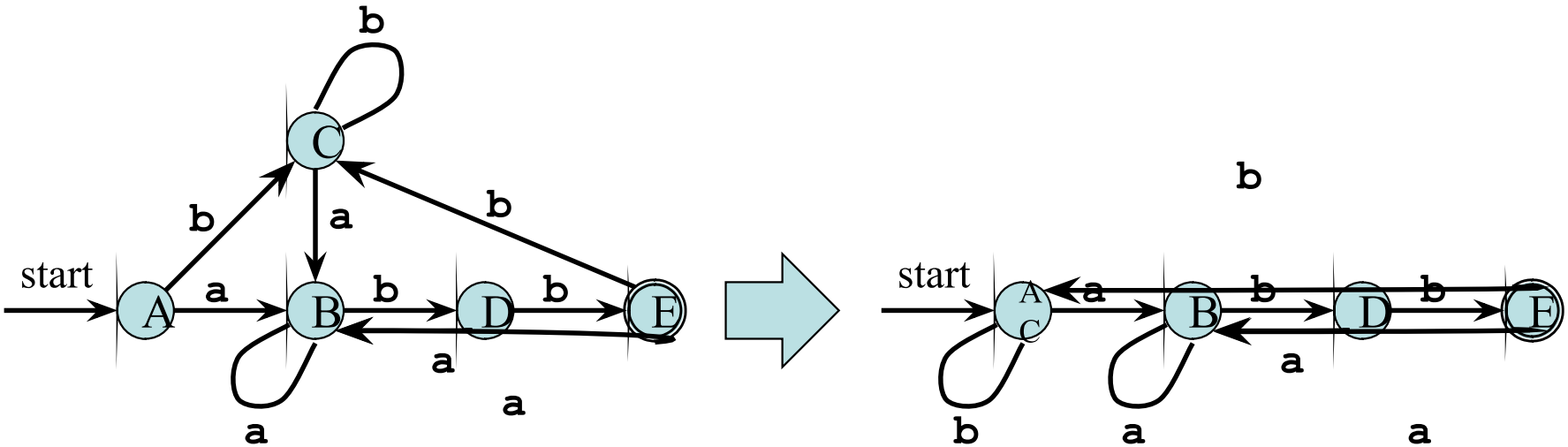
C = {8}

D = {7}

E = {5,8}

F = {6,8}

# Minimizing the Number of States of a DFA



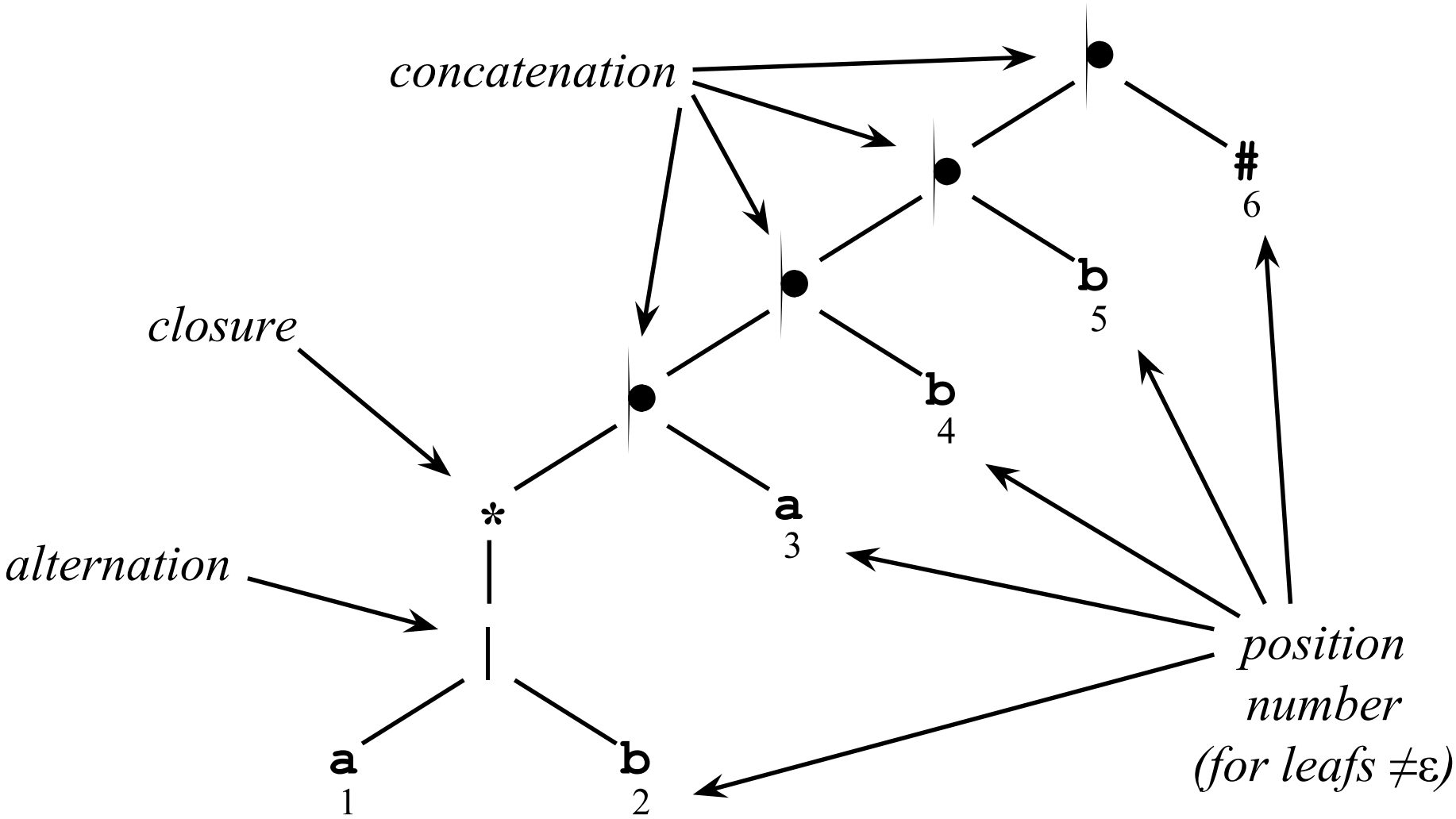
# From Regular Expression to DFA Directly

- The "*important states*" of an NFA are those without an ε-transition, that is if $move(\{s\},a) \neq \varnothing$ for some $a$ then $s$ is an important state
- The subset construction algorithm uses only the important states when it determines $\varepsilon\text{-}closure(move(T,a))$

# From Regular Expression to DFA Directly (Algorithm)

- Augment the regular expression *r* with a special end symbol # to make accepting states important: the new expression is *r*#
- Construct a syntax tree for *r*#
- Traverse the tree to construct functions *nullable*, *firstpos*, *lastpos*, and *followpos*

# From Regular Expression to DFA Directly: Syntax Tree of (a|b)*abb#



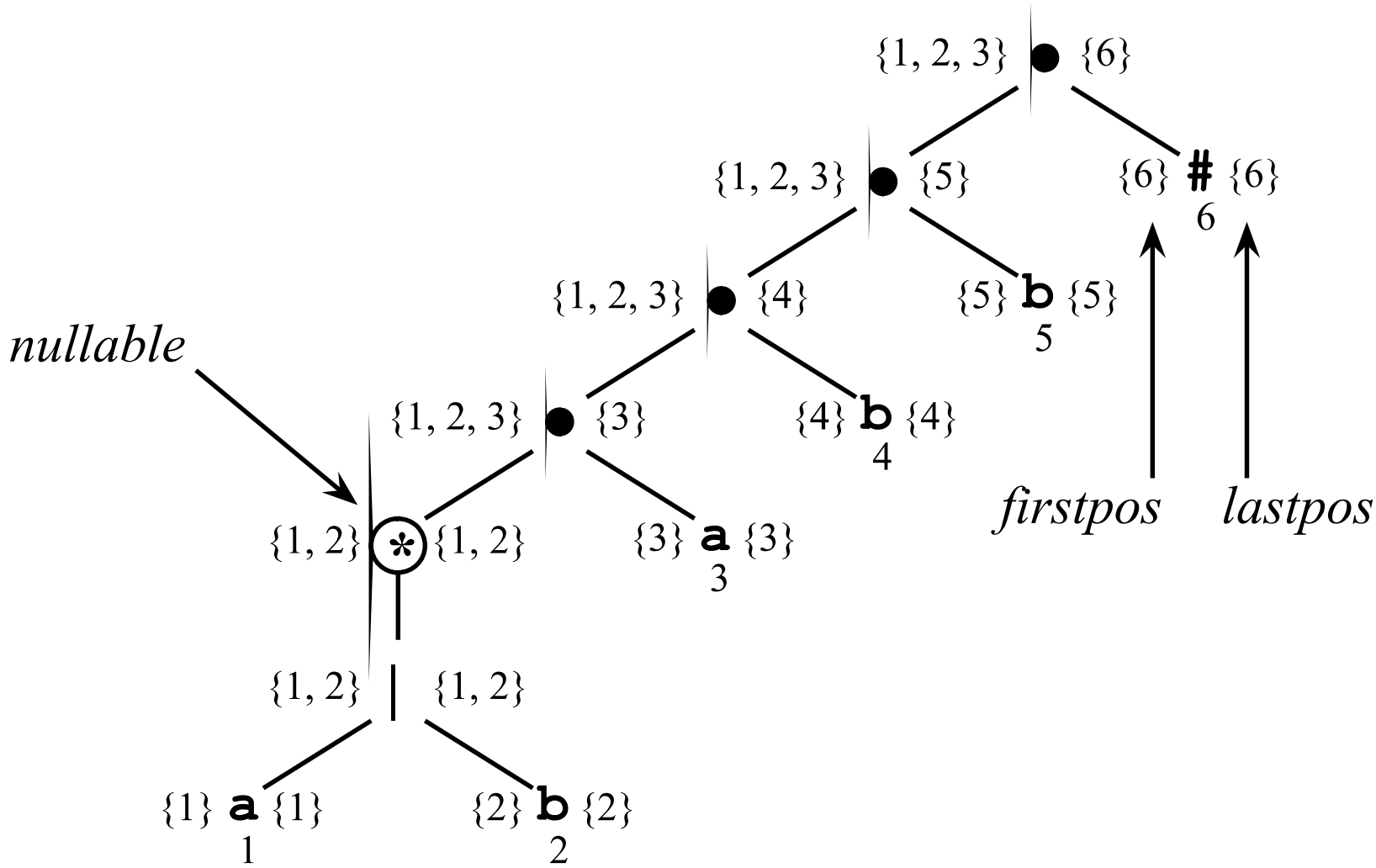
# From Regular Expression to DFA Directly: Annotating the Tree

- *nullable*($n$): the subtree at node $n$ generates languages including the empty string
- *firstpos*($n$): set of positions that can match the first symbol of a string generated by the subtree at node $n$
- *lastpos*($n$): the set of positions that can match the last symbol of a string generated be the subtree at node $n$
- *followpos*($i$): the set of positions that can follow position $i$ in the tree

# From Regular Expression to DFA Directly: Annotating the Tree

| Node $n$ | *nullable*($n$) | *firstpos*($n$) | *lastpos*($n$) |
|---|---|---|---|
| Leaf ε | true | ∅ | ∅ |
| Leaf $i$ | false | $\{i\}$ | $\{i\}$ |
| | | | |
| | | | |
| | | | |

# From Regular Expression to DFA Directly: Syntax Tree of (a|b)*abb#



# From Regular Expression to DFA Directly: *followpos*

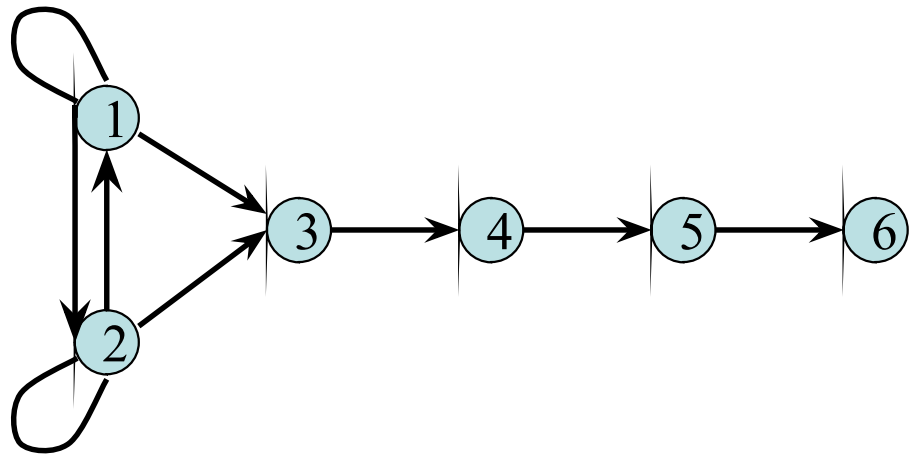
**for** each node $n$ in the tree **do**
    **if** $n$ is a cat-node with left child $c_1$ and right child $c_2$ **then**
        **for** each $i$ in $lastpos(c_1)$ **do**
            $followpos(i) := followpos(i) \cup firstpos(c_2)$
        **end do**
    **else if** $n$ is a star-node
        **for** each $i$ in $lastpos(n)$ **do**
            $followpos(i) := followpos(i) \cup firstpos(n)$
        **end do**
    **end if**
**end do**

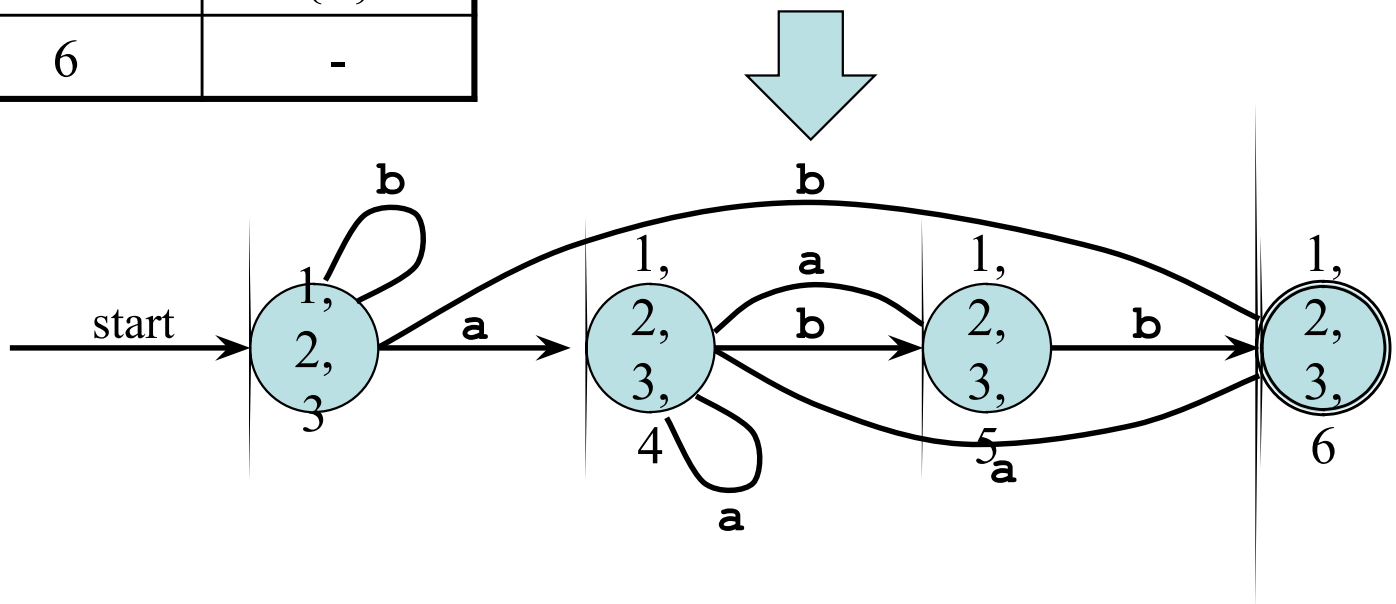
# From Regular Expression to DFA Directly: Algorithm

$s_0$ := *firstpos*(*root*) where *root* is the root of the syntax tree
*Dstates* := $\{s_0\}$ and is unmarked
**while** there is an unmarked state *T* in *Dstates* **do**
    mark *T*
    **for** each input symbol $a \in \Sigma$ **do**
        let *U* be the set of positions that are in *followpos*(*p*)
            for some position *p* in *T*,
            such that the symbol at position *p* is *a*
        **if** *U* is not empty and not in *Dstates* **then**
            add *U* as an unmarked state to *Dstates*
        **end if**
        *Dtran*[*T,a*] := *U*
    **end do**
**end do**

# From Regular Expression to DFA Directly: Example

| Node | *followpos* |
|---|---|
| 1 | {1, 2, 3} |
| 2 | {1, 2, 3} |
| 3 | {4} |
| 4 | {5} |
| 5 | {6} |
| 6 | - |



# Time-Space Tradeoffs

| *Automaton* | *Space (worst case)* | *Time (worst case)* |
|---|---|---|
| NFA | $O(\|r\|)$ | $O(\|r\| \times \|x\|)$ |
| DFA | $O(2^{\|r\|})$ | $O(\|x\|)$ |

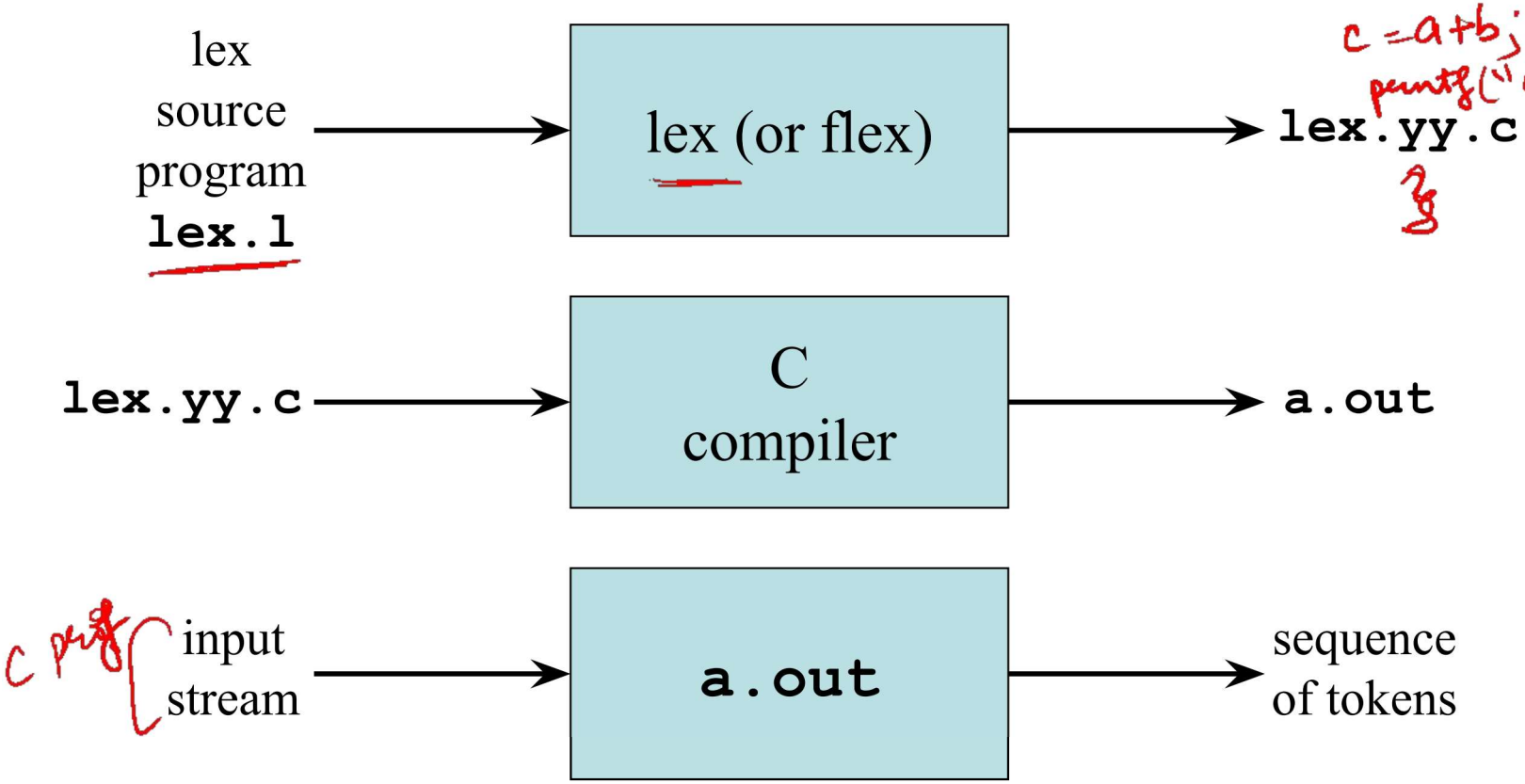
UNIX Windows freeavailable

# The Lex and Flex Scanner Generators

- *Lex* and its newer cousin *flex* are *scanner generators*
- Scanner generators systematically translate regular definitions into C source code for efficient scanning
- Generated code is easy to integrate in C applications

# Creating a Lexical Analyzer with Lex and Flex

main()
{ int a = 1;
int b = 2;
c = a+b;
printf("c ");
}



# Lex Specification

- A *lex specification* consists of three parts:
  *regular definitions, C declarations in* `%{ %}`
  `%%`
  *translation rules*
  `%%`
  *user-defined auxiliary procedures*
- The *translation rules* are of the form:
  $p_1$ { $action_1$ }
  $p_2$ { $action_2$ }
  …
  $p_n$ { $action_n$ }

'c' → RE → tokens
words

# Regular Expressions in Lex

**x** match the character **x**

**\.** match the character **.**

"*string*" match contents of string of characters

**.** match any character except newline

**^** match beginning of a line

**$** match the end of a line

**[xyz]** match one character **x**, **y**, or **z** (use **** to escape **-**)

**[^xyz]** match any character except **x**, **y**, and **z**

**[a-z]** match one of **a** to **z**

*r****** closure (match zero or more occurrences)

*r***+** positive closure (match one or more occurrences)

*r***?** optional (match zero or one occurrence)

$r_1 r_2$ match $r_1$ then $r_2$ (concatenation)

$r_1$ **|** $r_2$ match $r_1$ or $r_2$ (union)

**(** *r* **)** grouping

$r_1$ **/** $r_2$ match $r_1$ when followed by $r_2$

**{***d***}** match the regular expression defined by *d*

# Example Lex Specification 1

Translation rules

Contains the matching lexeme

```
%{
#include <stdio.h>
%}
%%
[0-9]+   { printf("%s\n", yytext); }
.|\n     { }
%%
main()
{ yylex();
}
```

Invokes the lexical analyzer

```
lex spec.l
gcc lex.yy.c -ll
./a.out < spec.l
```

# Example Lex Specification 2

Translation rules

Regular definition

```
%{
#include <stdio.h>
int ch = 0, wd = 0, nl = 0;
%}
delim      [ \t]+
%%
\n         { ch++; wd++; nl++; }
^{delim}   { ch+=yyleng; }
{delim}    { ch+=yyleng; wd++; }
.          { ch++; }
%%
main()
{ yylex();
  printf("%8d%8d%8d\n", nl, wd, ch);
}
```

tool → NFA DFA

# Example Lex Specification 3

Lex prog

lex.l → lex.yy.c → C comp → a.out

prog → a.out

a
b
c

token - identifier

Translation rules

Regular definitions

```
%{
#include <stdio.h>
%}
digit       [0-9]
letter      [A-Za-z]
id          {letter}({letter}|{digit})*
%%
{digit}+    { printf("number: %s\n", yytext); }
{id}        { printf("ident: %s\n", yytext); }
.           { printf("other: %s\n", yytext); }
%%
main()
{ yylex();
}
```

```
main()
{ int a = 1;
  int b = 2;
  int c;
  c = a + b;
  printf(c)
}
```

NFA
DFA

# Example Lex Specification 4

```
%{ /* definitions of manifest constants */
#define LT (256)
…
%}
delim      [ \t\n]
ws         {delim}+
letter     [A-Za-z]
digit      [0-9]
id         {letter}({letter}|{digit})*
number     {digit}+(\.{digit}+)?(E[+\-]?{digit}+)?
%%
{ws}       { }
if         {return IF;}
then       {return THEN;}
else       {return ELSE;}
{id}       {yylval = install_id(); return ID;}
{number}   {yylval = install_num(); return NUMBER;}
"<"        {yylval = LT; return RELOP;}
"<="       {yylval = LE; return RELOP;}
"="        {yylval = EQ; return RELOP;}
"<>"       {yylval = NE; return RELOP;}
">"        {yylval = GT; return RELOP;}
">="       {yylval = GE; return RELOP;}
%%
int install_id()
…
```

Return token to parser

Token attribute

Install **`yytext`** as identifier in symbol table