Lexical Analysis

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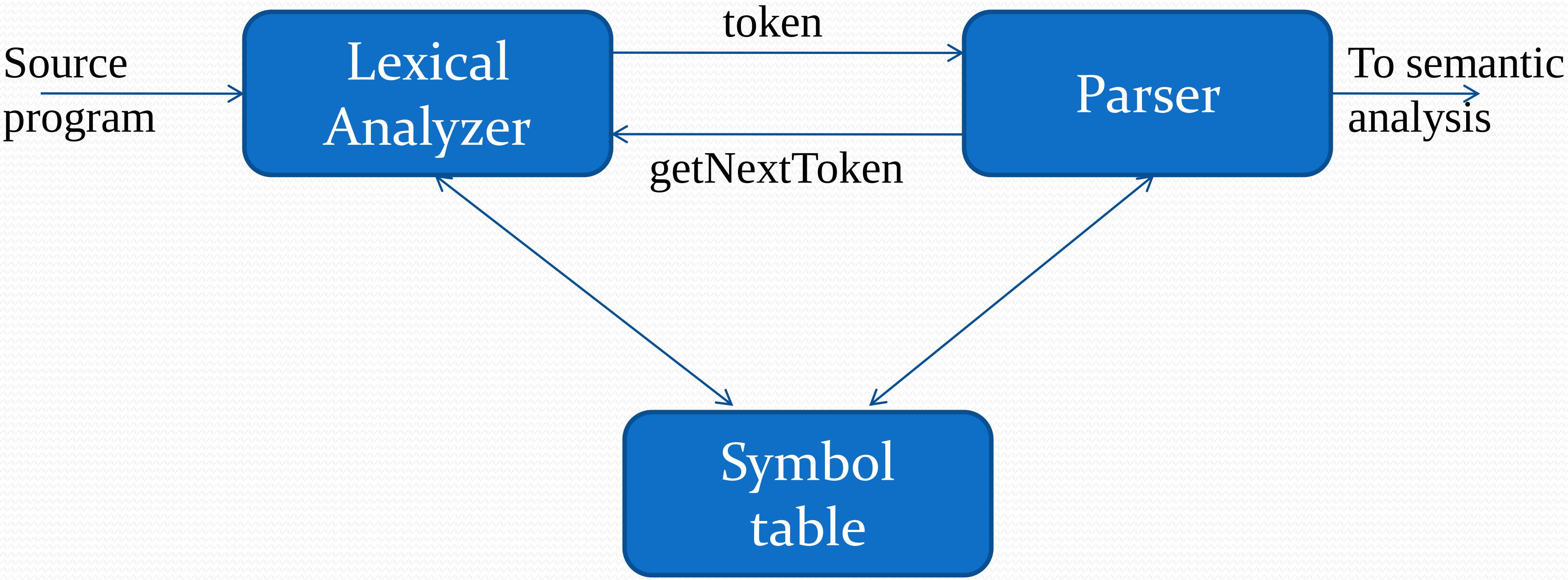
Outline

- Role of lexical analyzer
- Input Buffering
- Specification of tokens
- Recognition of tokens
- Lexical analyzer generator
- Finite automata
- Design of lexical analyzer generator

The role of lexical analyzer



Why to separate Lexical analysis and parsing

1. Simplicity of design
2. Improving compiler efficiency
3. Enhancing compiler portability

Tokens, Patterns and Lexemes

- A token is a pair a token name and an optional token value
- A pattern is a description of the form that the lexemes of a token may take
- A lexeme is a sequence of characters in the source program that matches the pattern for a token

Example

Token	Informal description	Sample lexemes
if	Characters i, f	if
else	Characters e, l, s, e	else
comparison	< or > or <= or >= or == or !=	<=, !=
id	Letter followed by letter and digits	pi, score, D2
number	Any numeric constant	3.14159, 0, 6.02e23
literal	Anything but " sorrounded by "	"core dumped"

printf("total = %d\n", score);

Attributes for tokens

- E = M * C ** 2
  - <id, pointer to symbol table entry for E>
  - <assign-op>
  - <id, pointer to symbol table entry for M>
  - <mult-op>
  - <id, pointer to symbol table entry for C>
  - <exp-op>
  - <number, integer value 2>

Lexical errors

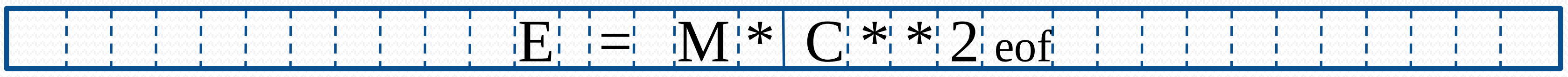
- Some errors are out of power of lexical analyzer to recognize:
  - fi (a == f(x)) …
- However it may be able to recognize errors like:
  - d = 2r
- Such errors are recognized when no pattern for tokens matches a character sequence

Error recovery

- Panic mode: successive characters are ignored until we reach to a well formed token
- Delete one character from the remaining input
- Insert a missing character into the remaining input
- Replace a character by another character
- Transpose two adjacent characters

Input buffering

- Sometimes lexical analyzer needs to look ahead one or more symbols to decide about the current token.
  - In C language: we need to look after -, = or < to decide what token to return
- We need to introduce a two buffer scheme to handle large look-aheads safely



Sentinels


```
Switch (*forward++) {
    case eof:
        if (forward is at end of first buffer) {
                reload second buffer;
                forward = beginning of second buffer;
        }
        else if {forward is at end of second buffer) {
                reload first buffer;\
                forward = beginning of first buffer;
        }
        else /* eof within a buffer marks the end of input */
                terminate lexical analysis;
        break;
    cases for the other characters;
}
```

Specification of tokens

- In theory of compilation regular expressions are used to formalize the specification of tokens
- Regular expressions are means for specifying regular languages
- Example:
  - Letter_(letter_ | digit)*
- Each regular expression is a pattern specifying the form of strings

Regular expressions

- ε is a regular expression, L(ε) = {ε}
- If a is a symbol in Σ then a is a regular expression, L(a) = {a}
- (r) | (s) is a regular expression denoting the language L(r) ∪ L(s)
- (r)(s) is a regular expression denoting the language L(r)L(s)
- (r)* is a regular expression denoting (L9r))*
- (r) is a regular expression denting L(r)

Regular definitions

d1 -> r1

d2 -> r2

…

dn -> rn

- Example:

letter_ -> A | B | … | Z | a | b | … | Z | _

digit -> 0 | 1 | … | 9

id -> letter_ (letter_ | digit)*

Extensions

- One or more instances: (r)+
- Zero of one instances: r?
- Character classes: [abc]

- Example:
  - letter_ -> [A-Za-z_]
  - digit -> [0-9]
  - id -> letter_(letter|digit)*

Recognition of tokens

- The next step is to formalize the patterns:

  digit -> [0-9]

  Digits -> digit+

  number -> digit(.digits)? (E[+-]? Digit)?

  letter -> [A-Za-z_]

  id -> letter (letter|digit)*

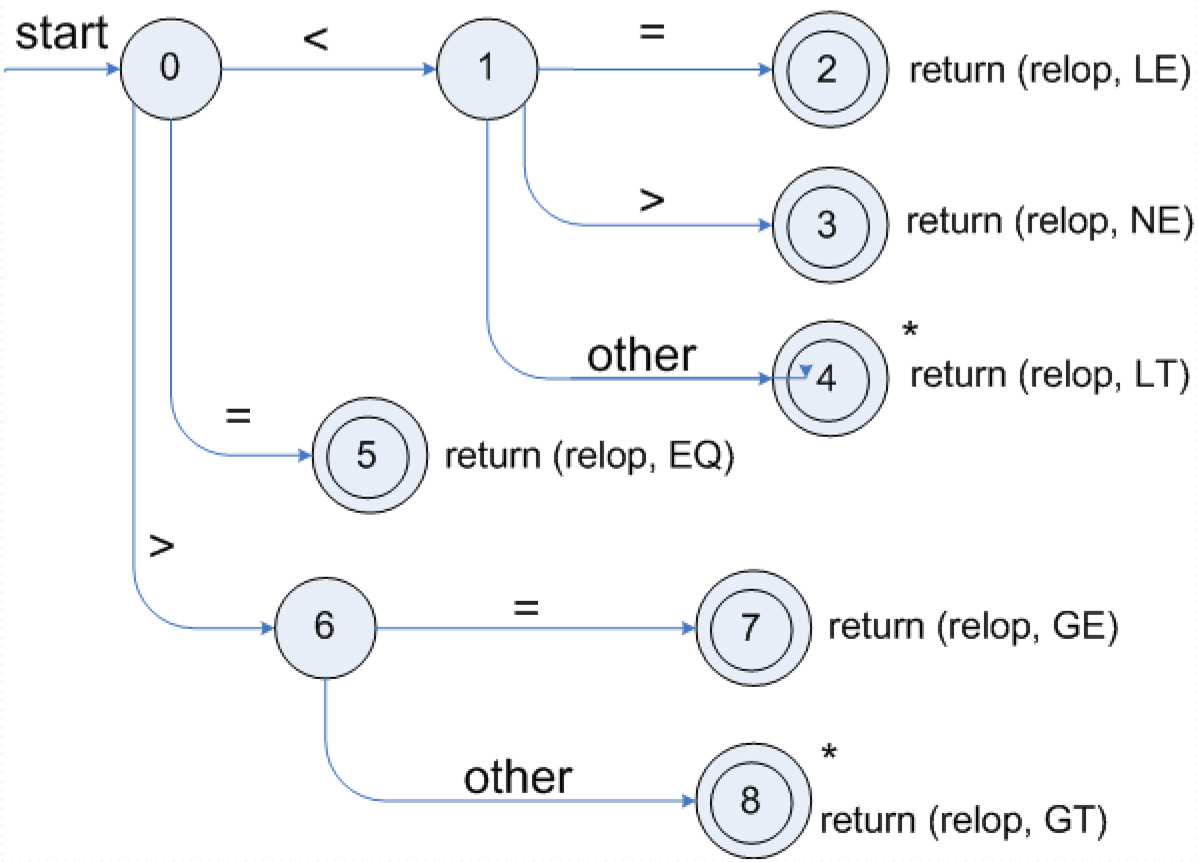
  Relop -> < | > | <= | >= | = | <>

- We also need to handle whitespaces:

  ws -> (blank | tab | newline)+

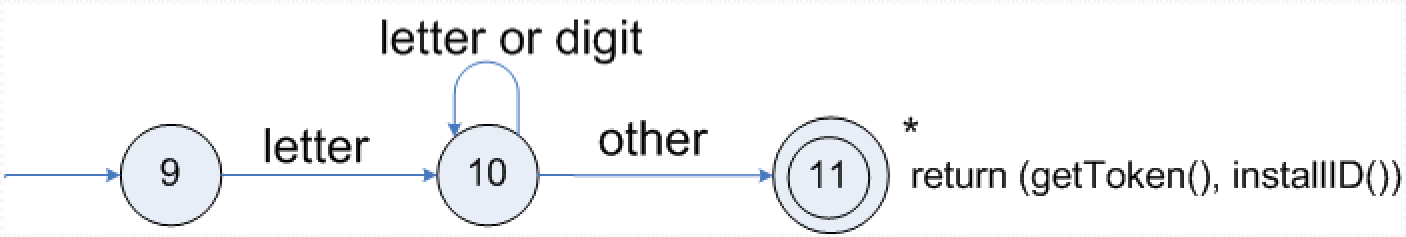
Transition diagrams

- Transition diagram for relop



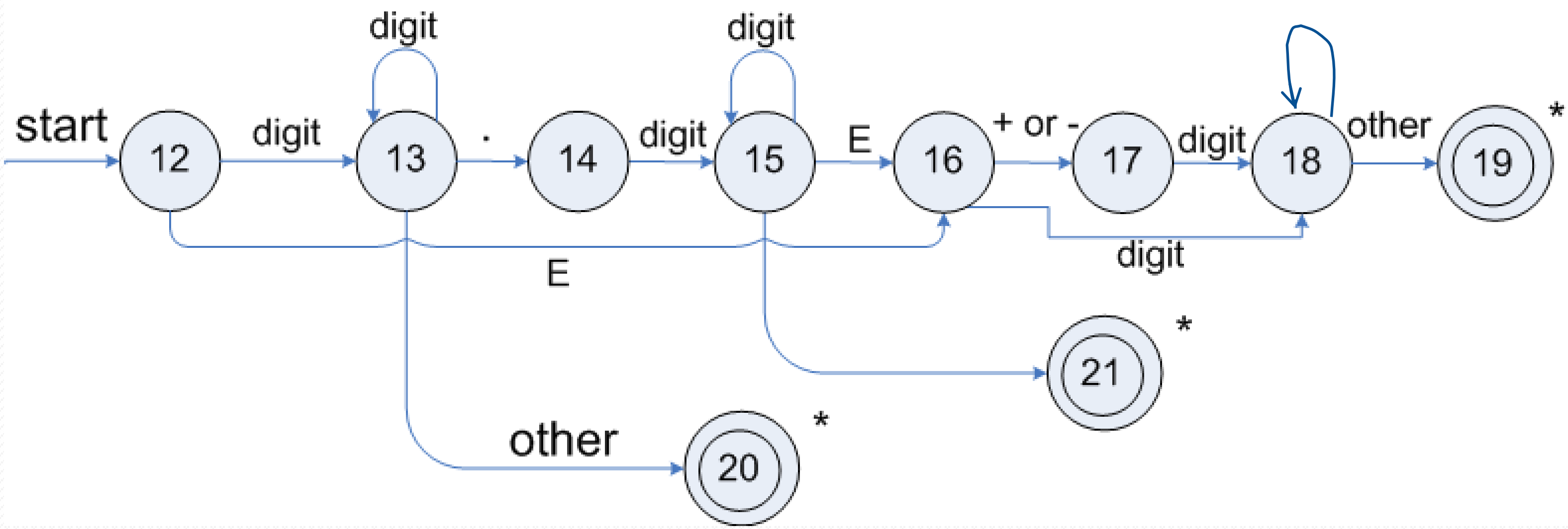
Transition diagrams

- Transition diagram for reserved words and identifiers



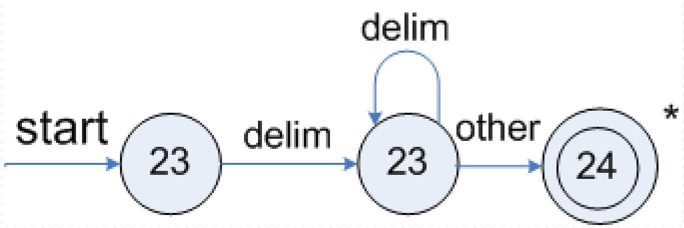
Transition diagrams

- Transition diagram for unsigned numbers



Transition diagrams

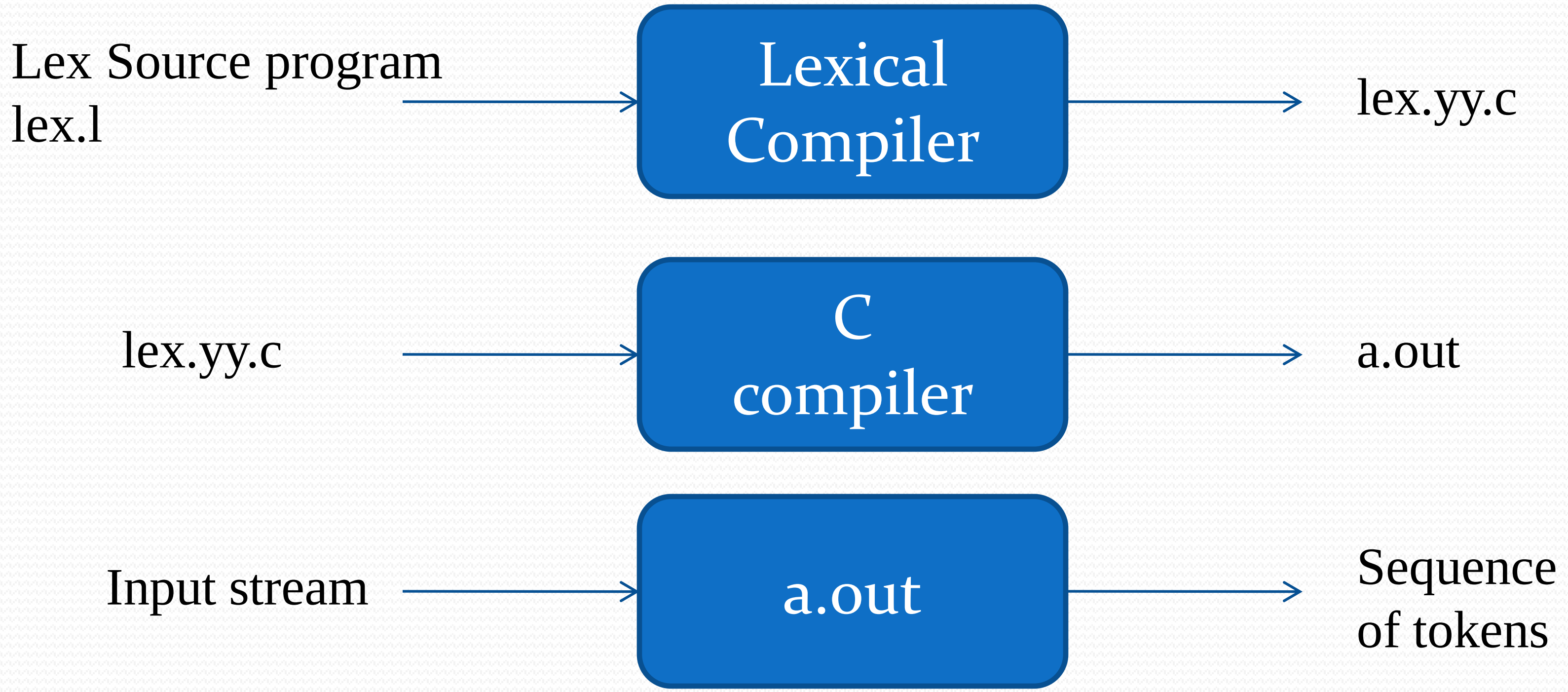
- Transition diagram for whitespace



Architecture of a transition-diagram-based lexical analyzer

```
TOKEN getRelop()
{
    TOKEN retToken = new (RELOP)
    while (1) {           /* repeat character processing until a
                             return or failure occurs  */
    switch(state) {
        case 0: c= nextchar();
                if (c == ‘<‘) state = 1;
                else if (c == ‘=‘) state = 5;
                else if (c == ‘>’) state = 6;
                else fail();  /* lexeme is not a relop */
                break;
        case 1: …
        …
        case 8: retract();
               retToken.attribute = GT;
               return(retToken);
    }
```

Lexical Analyzer Generator - Lex



Structure of Lex programs

Declarations
%%
Translation rules → Pattern {Action}
%%
Auxiliary functions

Example

```
%{
    /* definitions of manifest constants
    LT, LE, EQ, NE, GT, GE,
    IF, THEN, ELSE, ID, NUMBER, RELOP */
%}

/* regular definitions
delim       [ \t\n]
ws          {delim}+
letter      [A-Za-z]
digit       [0-9]
id          {letter}({letter}|{digit})*
number      {digit}+(\.{digit}+)?(E[+-]?{digit}+)?

%%
{ws}        {/* no action and no return */}
if          {return(IF);}
then        {return(THEN);}
else        {return(ELSE);}
{id}        {yylval = (int) installID(); return(ID); }
{number}    {yylval = (int) installNum(); return(NUMBER);}
…
```

```
Int installID() {/* funtion to install the
    lexeme, whose first character is
    pointed to by yytext, and whose
    length is yyleng, into the symbol
    table and return a pointer thereto
    */
}

Int installNum() { /* similar to
    installID, but puts numerical
    constants into a separate table */
}
```

Finite Automata

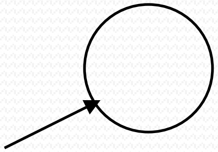
- Regular expressions = specification
- Finite automata = implementation

- A finite automaton consists of
  - An input alphabet Σ
  - A set of states S
  - A start state n
  - A set of accepting states $F \subseteq S$
  - A set of transitions state $\rightarrow^{input}$ state

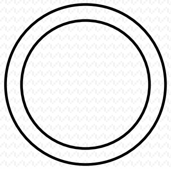
Finite Automata State Graphs

- A state

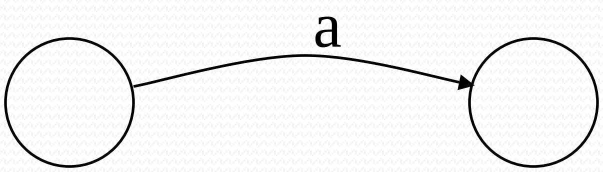
- The start state



- An accepting state

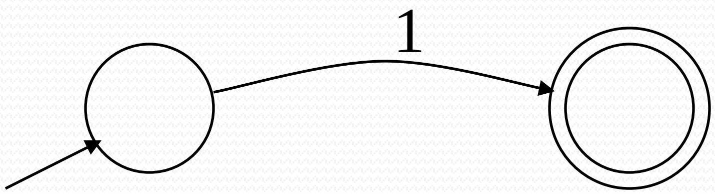


- A transition



A Simple Example

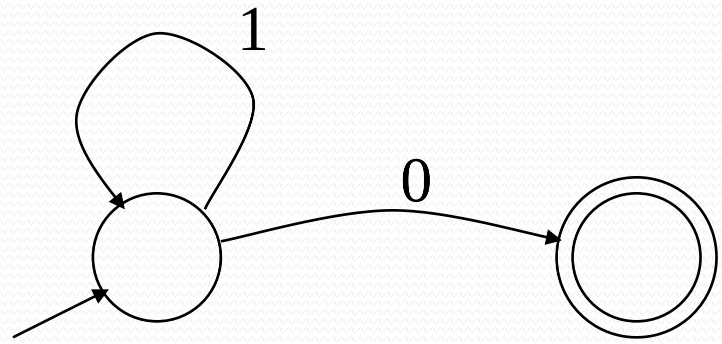
- A finite automaton that accepts only “1”



- A finite automaton accepts a string if we can follow transitions labeled with the characters in the string from the start to some accepting state

Another Simple Example

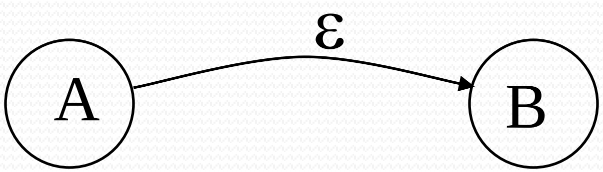
- A finite automaton accepting any number of 1's followed by a single 0
- Alphabet: {0,1}



- Check that "1110" is accepted but "110…" is not

Epsilon Moves

- Another kind of transition: ε-moves



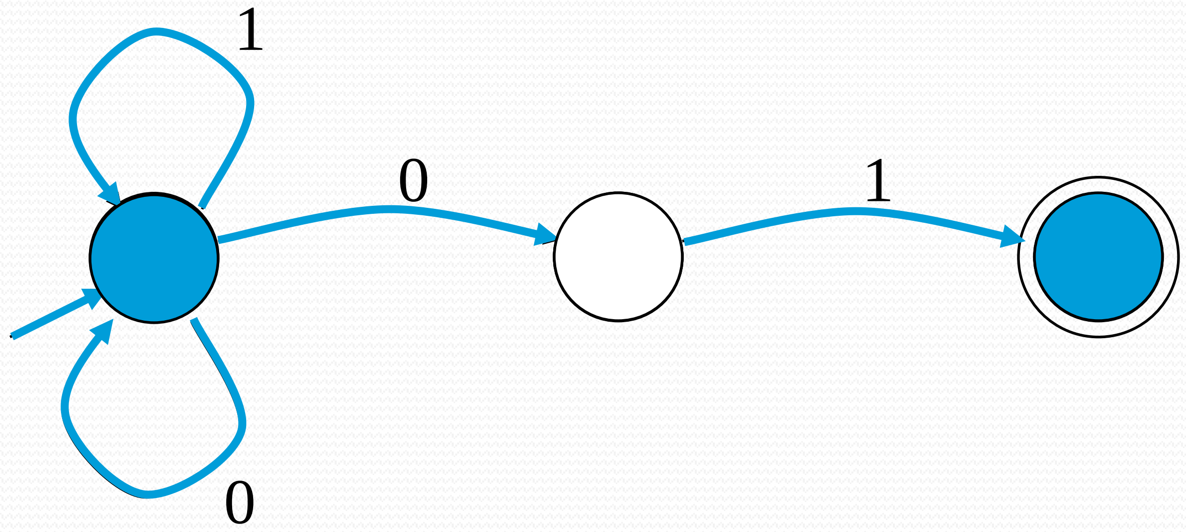
- Machine can move from state A to state B without reading input

Execution of Finite Automata

- A DFA can take only one path through the state graph
  - Completely determined by input
- NFAs can choose
  - Whether to make ε-moves
  - Which of multiple transitions for a single input to take

Acceptance of NFAs

- An NFA can get into multiple states



- Input: 1 0 1
- Rule: NFA accepts if it <u>can</u> get in a final state

NFA vs. DFA (1)

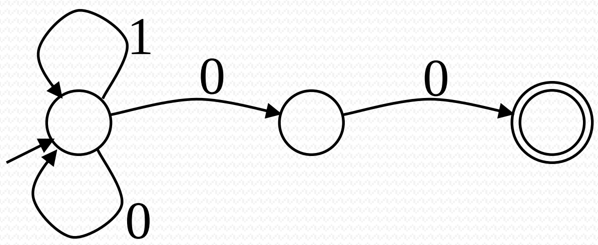
- NFAs and DFAs recognize the same set of languages (regular languages)

- DFAs are easier to implement
  - There are no choices to consider

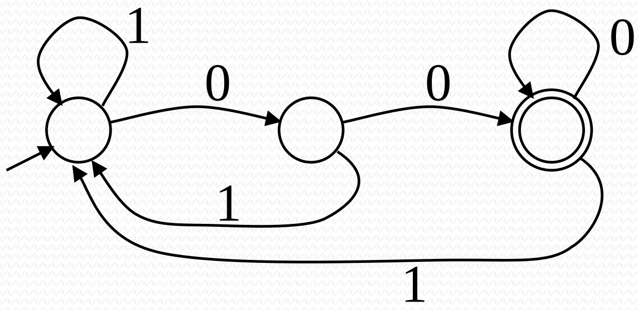
NFA vs. DFA (2)

- For a given language the NFA can be simpler than the DFA

NFA



DFA



- DFA can be exponentially larger than NFA

Implementation

- A DFA can be implemented by a 2D table T
  - One dimension is "states"
  - Other dimension is "input symbols"
  - For every transition $S_i \rightarrow^a S_k$ define T[i,a] = k
- DFA "execution"
  - If in state S_i and input a, read T[i,a] = k and skip to state S_k
  - Very efficient