CS421 Lecture 5 - Lexical Analysis

- Today's class
  - Lexing
  - Finite-State Machine as Lexer

Compiler Outline

- Front-End
  - Takes Input Source Code
  - Returns Abstract Syntax Tree + symbol table
- Back-End
  - Takes Abstract Syntax Tree + symbol table
  - Returns machine executable binary code, or virtual machine code, or just interprets program

Front-end structure

- Lexer (aka scanner, tokenizer)
  - Transforms program to list of tokens
  - Produces name table (usually hash table)
- Parser
  - Transforms list of tokens to AST
- Symbol table construction
  - Fills in name table with information about names in program - type, location, etc.

Manual and automatic methods

- We will study how to write lexers and parsers. For each, we will give a manual technique and an automatic one:
- Lexing:
    - Manual: Finite-state machines
    - Automatic: Regular expressions - ocamllex
- Parsing
    - Manual: Top-down (recursive descent) parsing
    - Automatic: Bottom-up (LR(1)) - ocamlyacc

Lexer

- Divide input into “tokens”
- Tokens are smallest units that are useful for parsing. E.g. parser needs to know if “while” keyword appears; doesn’t need to know that it is made up of characters w, h, etc.
- Why? Efficiency
  - Simpler to specify grammatical structure, and implement parser, in terms of tokens

Lexer Input & Output

- Lexer Input
  - Character stream in the form of
    - Input Stream, or
    - String
- Lexer Output
  - Stream of tokens, or
  - List of tokens

Tokens

```
type token =
  EOF | BOOLEAN | BREAK | CASE | CHAR | CLASS | CONST | CONTINUE
 | DO | DOUBLE | ELSE | EXTENDS | FINAL | FINALLY | FLOAT | FOR
 | DEFAULT | IMPLEMENTS | IMPORT | INT | NEW | IF | PUBLIC
 | SWITCH | RETURN | VOID | STATIC | WHILE | THIS
 | NULL_LITERAL | LPAREN | RPAREN | LBRACE | RBRACE | LBRACK | RBRACK
 | SEMICOLON | COMMA | DOT | EQ | GT | LT | NOT | COMP
 | QUESTION | COLON | EQEQ | LTEQ | GTEQ | NOTEQ | ANDAND | OROR
 | PLUSPLUS | MINUSMINUS | PLUS | MINUS | MULT | DIV | AND
 | OR | XOR | MOD | LSHIFT | RSHIFT | URSHIFT | PLUSEQ | MINUSEQ |
   MULTEQ
 | DIVEQ | ANDEQ | OREQ | XOREQ | MODEQ | LSHIFTEQ | RSHIFTEQ
 | URSHIFTEQ
 | BOOLEAN_LITERAL of bool
 | INTEGER_LITERAL of int
 | FLOAT_LITERAL of float
 | IDENTIFIER of string
 | STRING_LITERAL of string
```

Example

- Input

  “class MP1 { public static void main (……”

- Output – list of tokens

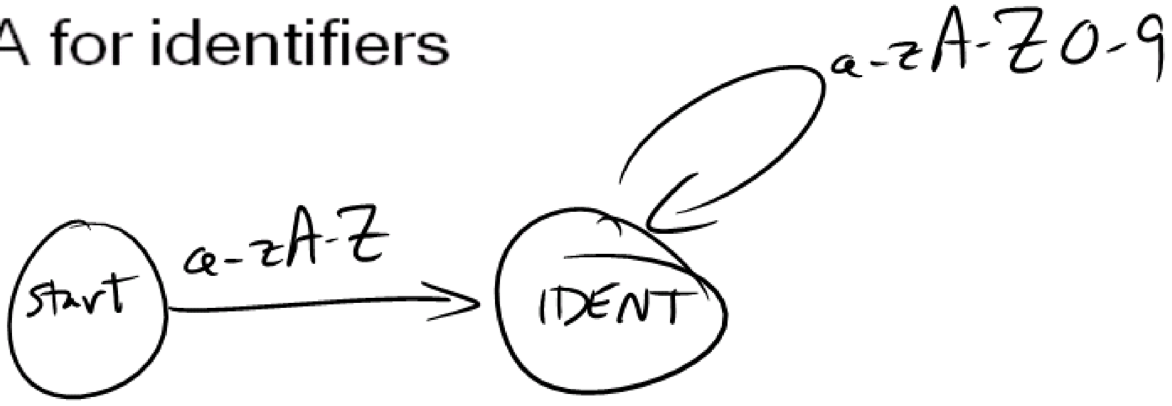
  [CLASS; IDENTIFIER “MP1”; LBRACE; PUBLIC; STATIC; VOID;
  IDENTIFIER “main”; LPAREN; ……]

Lexing with ~~FSM~~ DFA

- Words recognized by corresponding finite state automaton
- Deterministic Finite Automaton (DFA)
  - A directed graph whose *vertices* are labeled from a set Tokens U {Error, Discard} and whose *edges* are labeled with sets of characters. Also, if the outgoing edges from vertex v are $\{e_1, \ldots, e_n\}$, then the sets $\text{label}(e_1), \ldots, \text{label}(e_n)$ are disjoint. Also, a vertex is specified as the start vertex.

Example 1

- DFA for identifiers

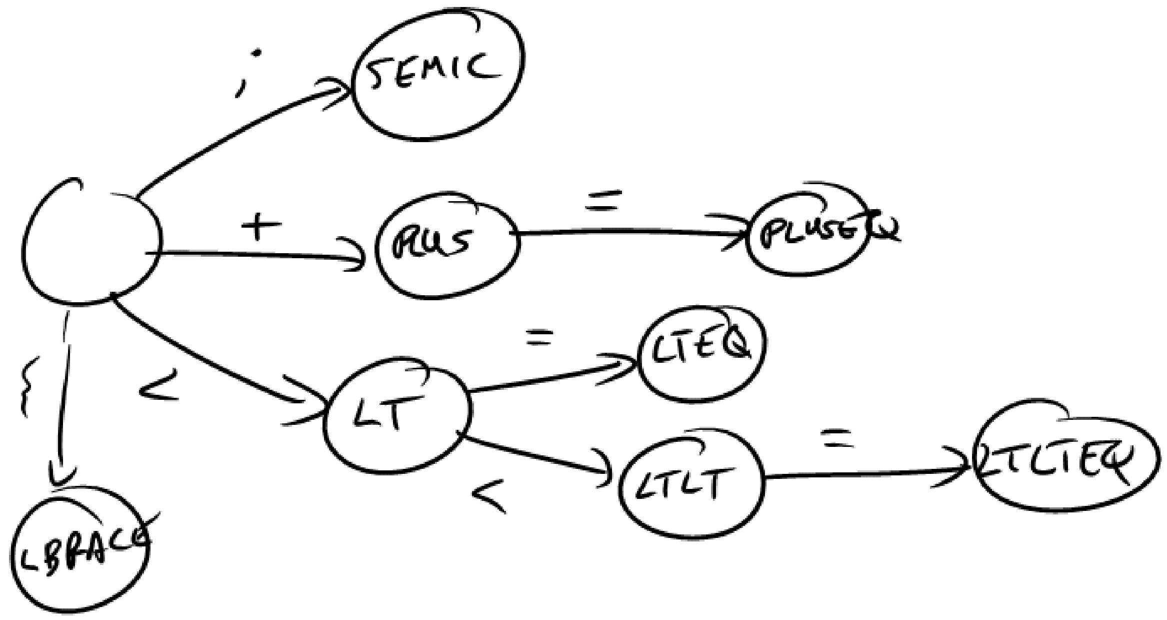


Keywords ?

Example 2

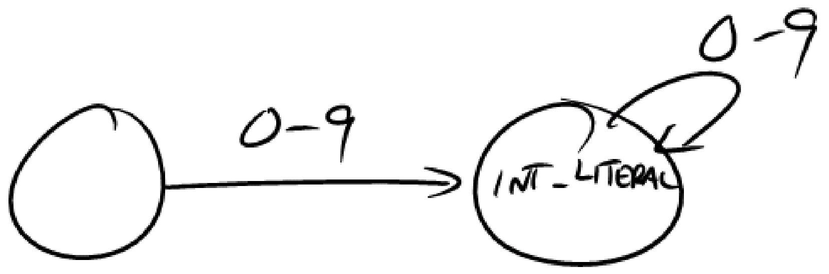
- DFA for Operators

  ;   {   +   +=   <   <=   <<   <<=



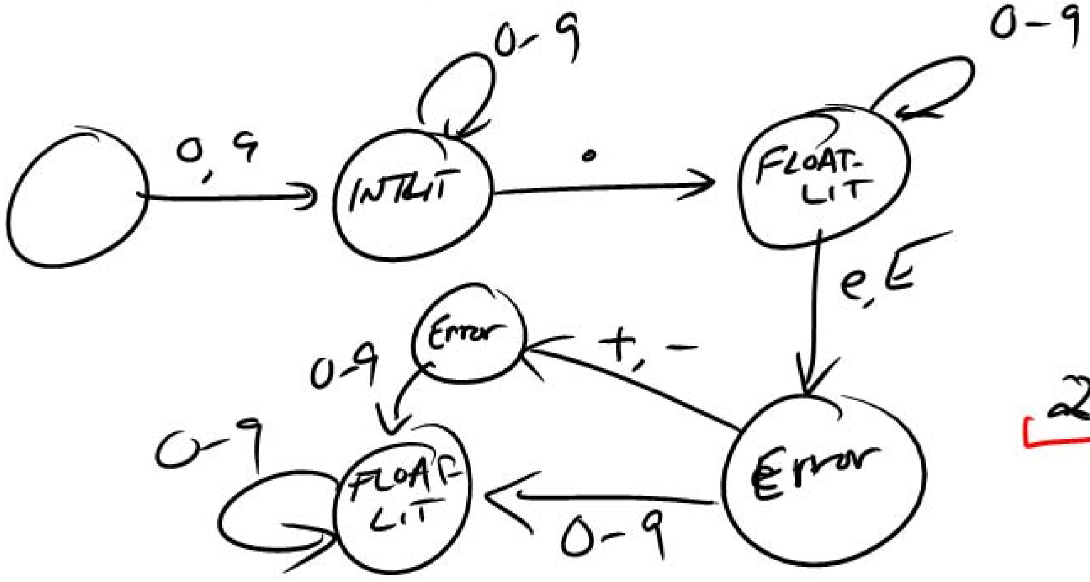
Example 3

- DFA for integer constants



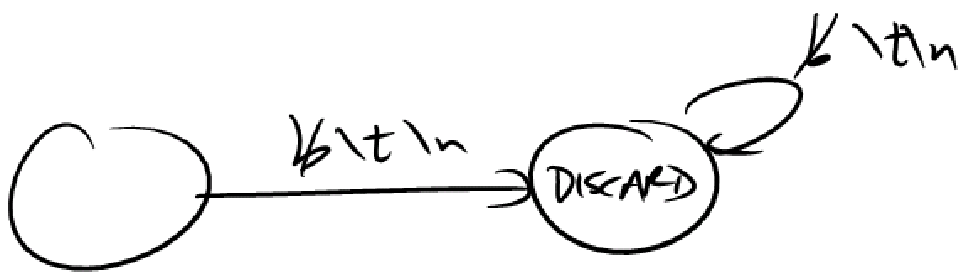
Example 4

- DFA for integers and floats



$\underbrace{23.}\underbrace{.}$

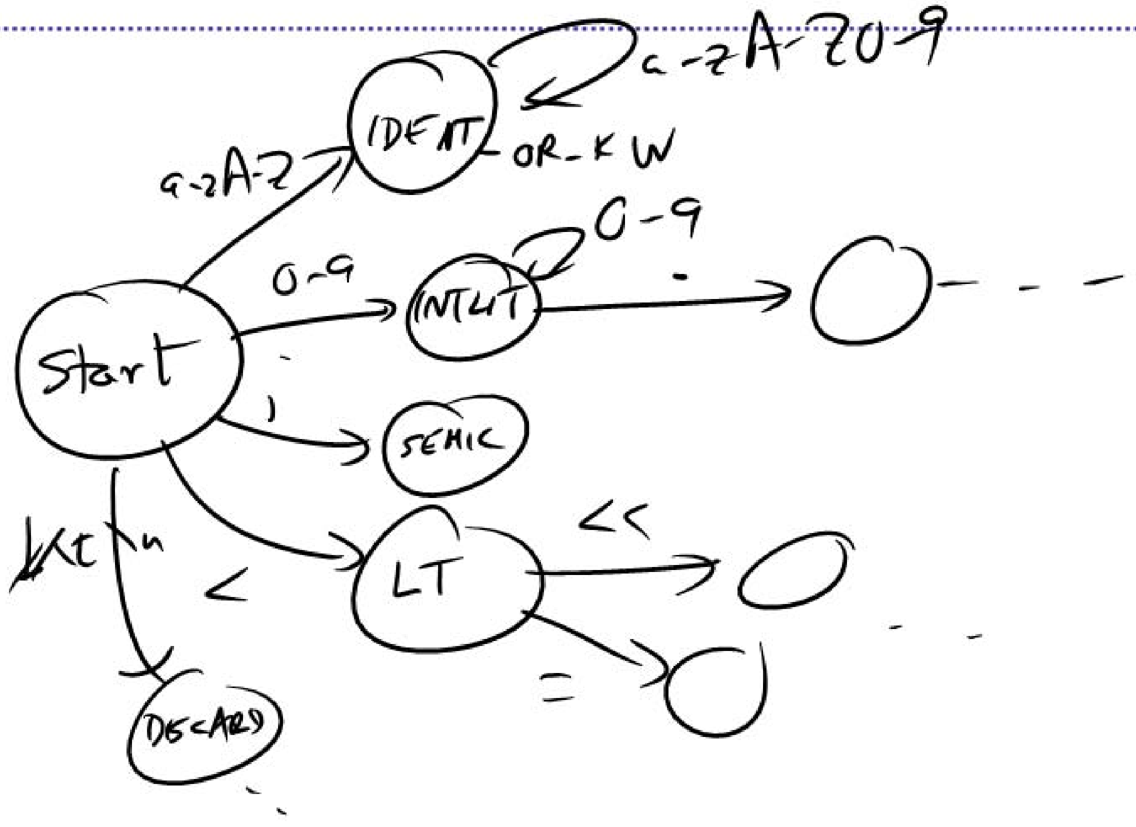
DFA for whitespace



Completing the DFA

- Need to create a single DFA for all tokens – recall that all outgoing edges must have disjoint label sets.
- For keyword:
  - Use DFA for identifiers, but look in table when token is complete to check if it is a keyword.

Completing the DFA



Implementing lexing with a DFA

- Define a transition function. Give each state a number. ✓
  - transition: state x character -> state ∪ {-1}
- Label
  - state -> token ∪ {discard, error} ✓ ∪ {ident_or_kw}
- Assume start state = 0

Implementing lexing with a DFA

Function to get a single token:

```
(state × string) getnexttoken() {
    s = 0;   tokenchars = "";
    while (true) {
        c = peek at next char
        if (move(s,c) == -1)
            return (s, tokenchars)
        move c from input to tokenchars
        s = move(s,c)
    }
```

Implementing lexing with a DFA

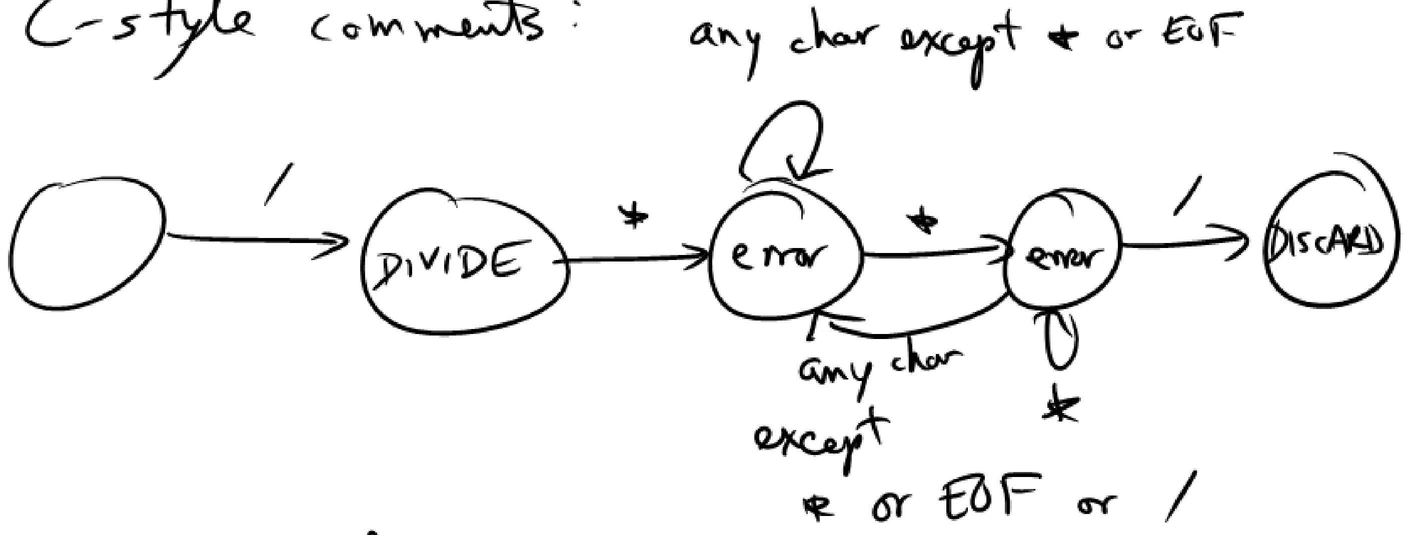
```
token list gettokens() {
    tokenlis = []
    while (true) {
        c = peek at next char
        if (c == eofchar) {
            tokenlis = tokenlis @ [EOF]
            break
        }
        (s, tokenchars) = getnexttoken()
        perform action based on s and tokenchars
    }                                  label (s)
    return tokenlis
}
```

Typical lexer actions

- Recall that a state's label is token, error, or discard. Action depends on that label, e.g.:
  - Error: Represents an erroneous input; abort.
    Report error message
  - LTLT:
    Put LTLT on token list
  - IDENT_OR_KW: Check for keyword, emit keyword or (identifier + tokenchars)
  - ~~COMMENT~~
  - DISCARD: do nothing

More DFAs

C-style comments:



OCaml-style comments?

More DFAs