CS 153: Concepts of Compiler Design

October 17 Class Meeting

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Fall 2017
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Midterm Solutions: Question 1

- Briefly explain why it is appropriate to use stacks for the following:

  a. At compile time for symbol tables (symbol table stack).

     - As the compiler parses a Pascal source program from top to bottom, it enters and leaves nested scopes, and therefore it needs to push and pop symbol tables on and off the stack to enable the parser to access local and nonlocal variables.

Midterm Solutions: Question 1, *cont'd*

- Briefly explain why it is appropriate to use stacks for the following:

  a. At run time for activation records (runtime stack).

     - As calls and returns are made to and from procedures and functions, activation records need to be pushed and popped to enable access to the values of local and nonlocal variables.

Midterm Solutions: Question 2

- How does the parser look up a variable name while it is parsing variable declarations, and for what purpose.
  - The parser searches the local symbol table (the one at the top of the symbol table stack) to check that the name is not already declared in the local scope

Midterm Solutions: Question 2, *cont'd*

- How does the parser look up a variable name while it is parsing the boolean expression of an IF statement, and for what purpose.
  - The parser searches the entire <u>symbol table stack</u> to find where that name is <u>already declared</u>, either in the local scope or an enclosing scope.

Midterm Solutions: Question 2, *cont'd*

- How does the executor look up a variable while it is executing the boolean expression of an IF statement, and for what purpose.
  - The executor uses the nesting level of the variable and the runtime display to access the appropriate activation record on the runtime stack and get the variable's value.

Midterm Solutions: Question 3

- Three-operand conditional expression:

  <expression-1> **?** <expression-2> **:** <expression-3>

- Examples:

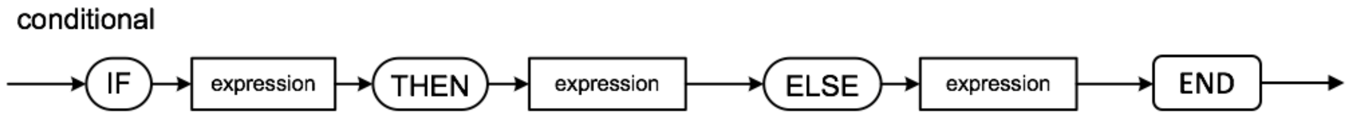
```
float value = 3.14*(x > y ? x : y)/2;
string name = text != null ? "The name is " + text : "Anonymous"
```

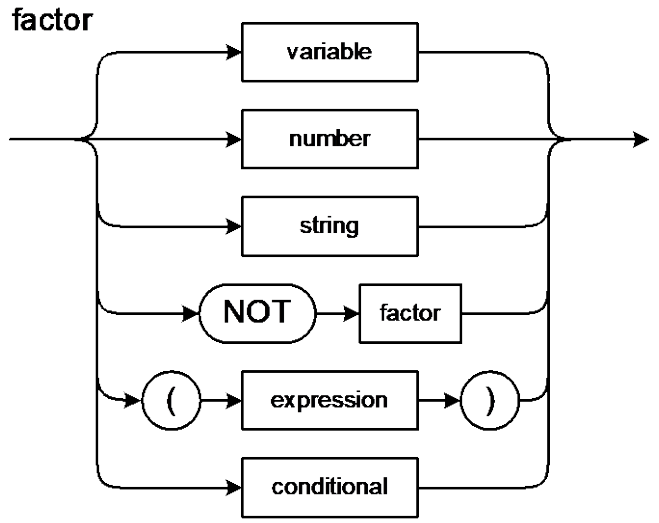
- Pascal implementation:

```
VAR
    i, j, k, m, n : integer;

BEGIN
    i := IF j > k THEN j ELSE k END;
    k := i - j*IF m-n = 0 THEN m*n ELSE m+n END;
...
```

Midterm Solutions: Question 3, *cont'd*





The result at run time of evaluating the conditional operator is a **single value**, the result of evaluating either *<expression-2>* or *<expression-3>*.

Therefore, a conditional expression must be a **factor**.

Midterm Solutions: Question 3, *cont'd*

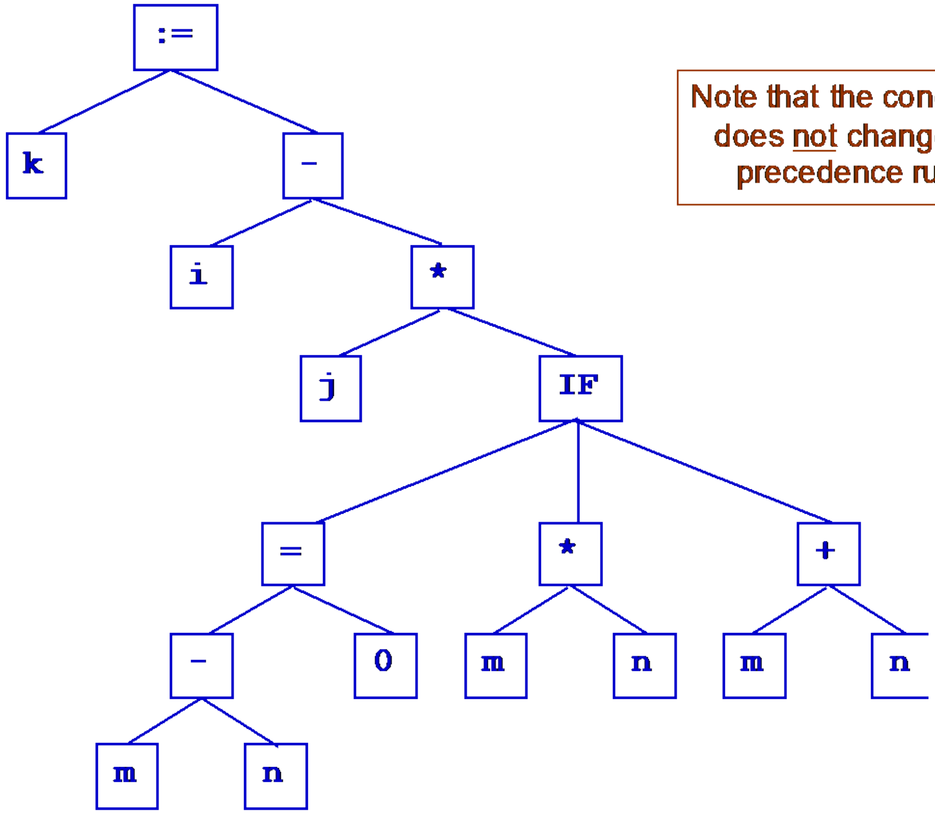
- Why is the final **END** necessary for the ternary operator? Give an example of a problematic Pascal statement that a parser would face if the final **END** were not in the grammar.
  - The **END** is required to enable the parser to know that it is done parsing the <*expression-3*>. Without the **END**, a statement such as

    ```
    k := i - IF m-n = 0 THEN m*n ELSE m+n *j
    ```

    would be ambiguous. Is **`*j`** part of <*expression-3*> or does **`j`** multiply the value of the conditional?

Midterm Solutions: Question 3, *cont'd*

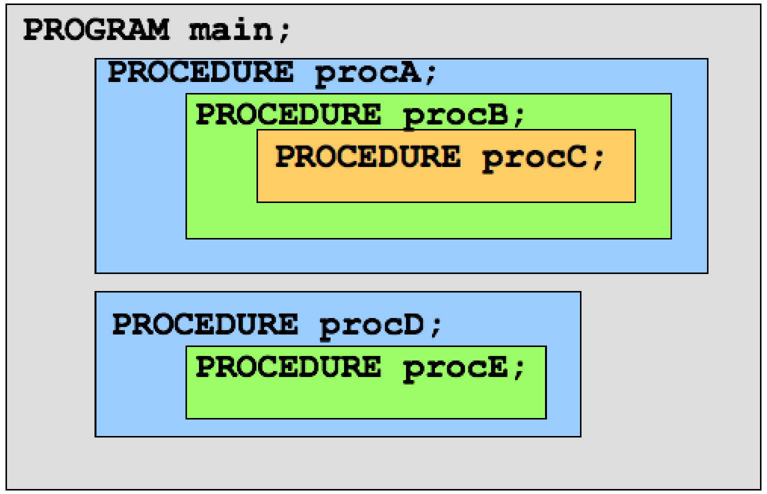
- Parse tree for `k := i - j*IF m-n = 0 THEN m*n ELSE m+n END`



Note that the conditional does not change any precedence rules.

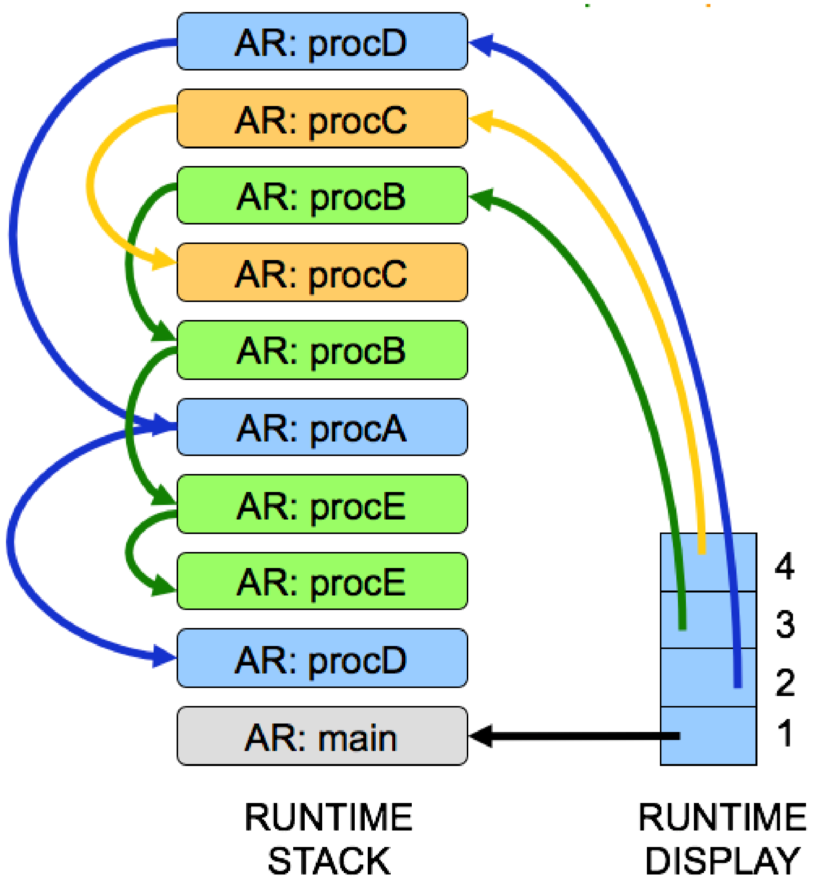
Midterm Solutions: Question 4

`main → procD → procE → procE → procA → procB → procC → procB → procC → procD`



```
PROGRAM main;
    PROCEDURE procA;
        PROCEDURE procB;
            PROCEDURE procC;

    PROCEDURE procD;
        PROCEDURE procE;
```



Midterm Solutions: Question 5

- When it is done parsing the source program and there were no errors, the front end hands over control to the back end. The back end obtains the <u>symbol table entry of the main program name</u> and the <u>root of the main program's parse tree</u>.

  Briefly explain, how does the back end subsequently get access to all the symbol tables and parse trees of the program's procedures and functions?

Midterm Solutions: Question 5, *cont'd*

- Everything is linked together in the symbol table. Once the backend has the symbol table entry of the name of the program, it can obtain the symbol table entries of the names of any top-level procedures and functions, and from there, the symbol table entries of the names of any nested procedures and functions.

  The symbol table entry of the name of the program, procedure, or function each has a link to the root of the corresponding parse tree.

Minimum Acceptable Compiler Project

- At least two data types with type checking.
- Basic arithmetic operations with operator precedence.
- Assignment statements.
- At least one conditional control statement (e.g., IF).
- At least one looping control statement.
- Procedures or functions with calls and returns.
- Parameters passed by value or by reference.
- Basic error recovery (skip to semicolon or end of line).
- "Nontrivial" sample programs written in the source language.
- Generate Jasmin code that can be assembled.
- Execute the resulting **`.class`** file standalone (preferred)
  or with a test harness.
- No crashes (e.g., null pointer exceptions).

70 points/100

Ideas for Programming Languages

- A language that works with a database such as MySQL
  - Combines Pascal and SQL for writing database applications.
  - Compiled code hides JDBC calls from the programmer.
  - Not PL/SQL – use the language to write client programs.
- A language that can access web pages
  - Statements that "scrape" pages to extract information.
- A language for generating business reports
  - A Pascal-like language with features that make it easy to generate reports.

DSL = Domain-Specific Language

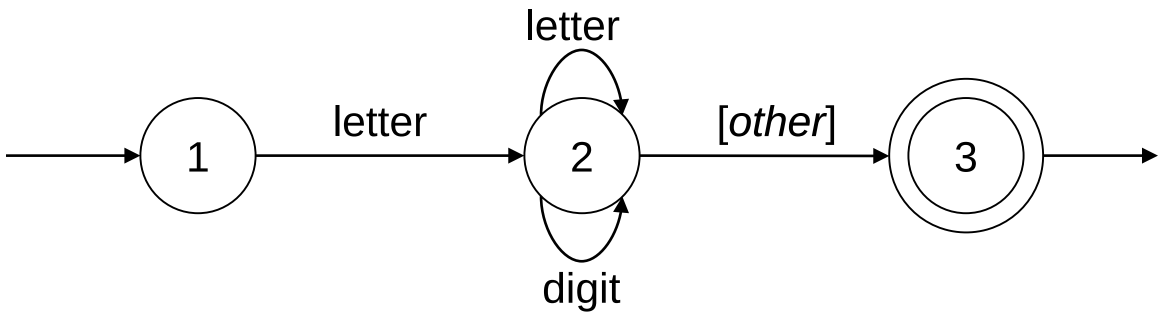
- A string-processing language
  - Combines Pascal and Perl for writing applications that involve pattern matching and string transformations.

Can We Build a Better Scanner?

- Our scanner in the front end is relatively easy to understand and follow.
  - Separate scanner classes for each token type.
- However, it's big and slow.
  - Separate scanner classes for each token type.
  - Creates lots of objects and makes lots of method calls.
- We can write a more compact and faster scanner.
  - However, it may be harder to understand and follow.

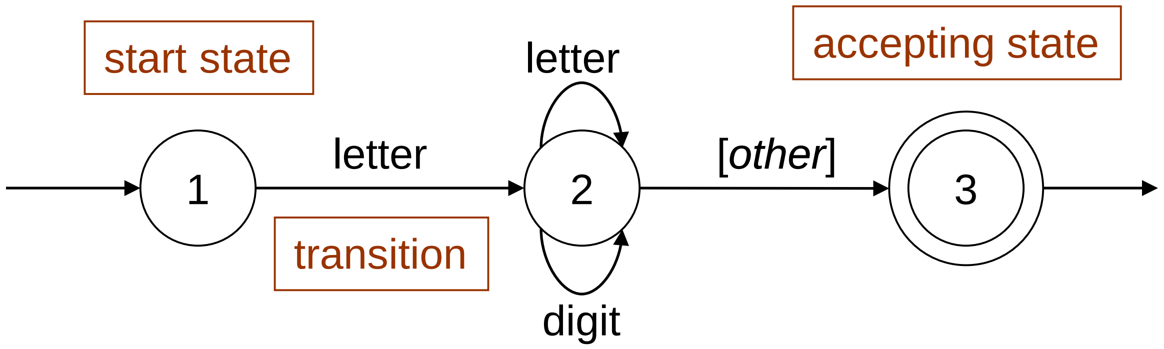
Deterministic Finite Automata (DFA)

- Pascal identifier
  - Regular expression: <letter> (<letter> | <digit>)*
  - Implement the regular expression with a finite automaton (AKA finite state machine):

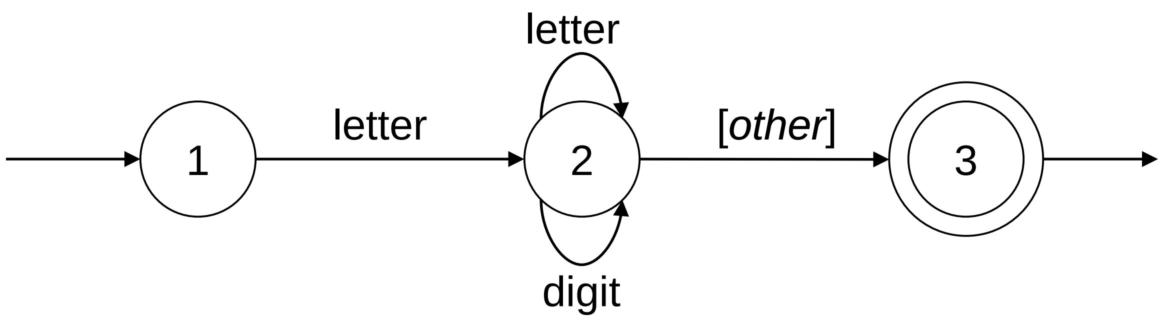


Deterministic Finite Automata (DFA)

- This automaton is a deterministic finite automaton (DFA).
  - At each state, the next input character uniquely determines which transition to take to the next state.



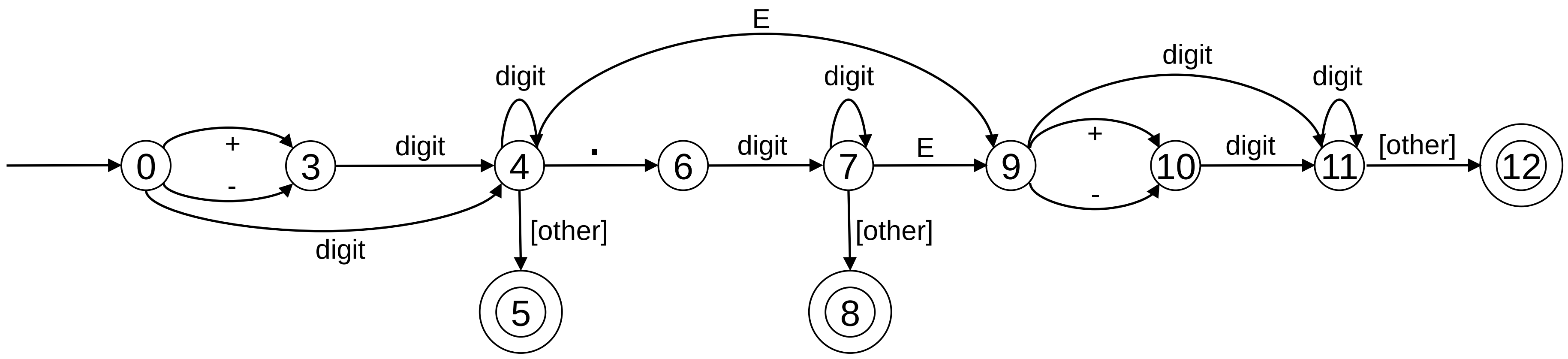
State-Transition Matrix



- Represent the behavior of a DFA by a state-transition matrix:

	Input character		
State	Letter	Digit	other
1	2		
2	2	2	3
3			

DFA for a Pascal Number

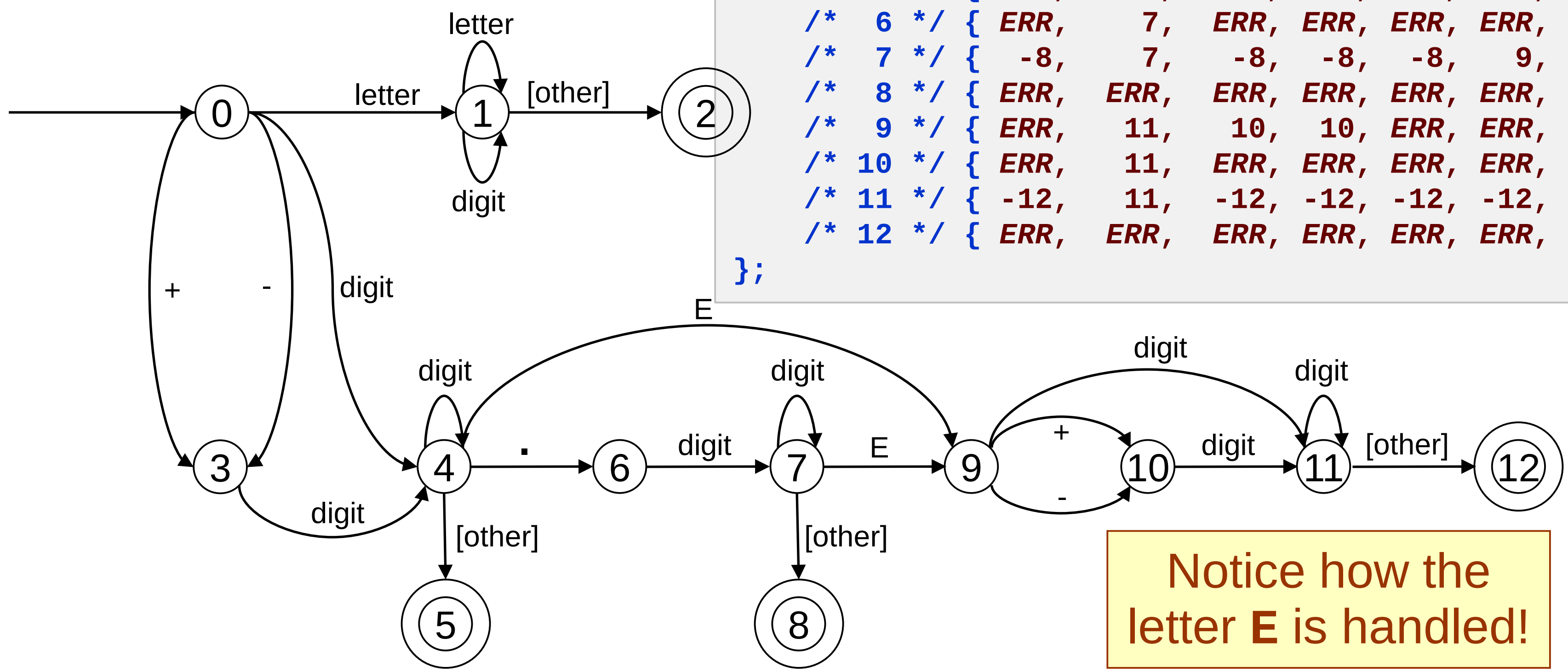


Note that this diagram allows only an upper-case **E** for an exponent.
What changes are required to also allow a lower-case **e**?

DFA for a Pascal Identifier or Number

```
private static final int matrix[][] = {
    /*           letter digit   +    -    .    E other */
    /*  0 */ {    1,    4,    3,   3, ERR,   1, ERR },
    /*  1 */ {    1,    1,   -2,  -2,  -2,   1,  -2 },
    /*  2 */ { ERR,  ERR,  ERR, ERR, ERR, ERR, ERR },
    /*  3 */ { ERR,    4,  ERR, ERR, ERR, ERR, ERR },
    /*  4 */ {  -5,    4,   -5,  -5,   6,   9,  -5 },
    /*  5 */ { ERR,  ERR,  ERR, ERR, ERR, ERR, ERR },
    /*  6 */ { ERR,    7,  ERR, ERR, ERR, ERR, ERR },
    /*  7 */ {  -8,    7,   -8,  -8,  -8,   9,  -8 },
    /*  8 */ { ERR,  ERR,  ERR, ERR, ERR, ERR, ERR },
    /*  9 */ { ERR,   11,   10,  10, ERR, ERR, ERR },
    /* 10 */ { ERR,   11,  ERR, ERR, ERR, ERR, ERR },
    /* 11 */ { -12,   11,  -12, -12, -12, -12, -12 },
    /* 12 */ { ERR,  ERR,  ERR, ERR, ERR, ERR, ERR },
};
```

Negative numbers in the matrix are the <u>accepting states</u>.



Notice how the letter **E** is handled!

A Simple DFA Scanner

```
public class SimpleDFAScanner
{
    // Input characters.
    private static final int LETTER = 0;
    private static final int DIGIT  = 1;
    private static final int PLUS   = 2;
    private static final int MINUS  = 3;
    private static final int DOT    = 4;
    private static final int E      = 5;
    private static final int OTHER  = 6;

    private static final int ERR = -99999;  // error state

    private static final int matrix[][] = { ... };

    private char ch;    // current input character
    private int state;  // current state

    ...
}
```

A Simple DFA Scanner, *cont'd*

```
int typeOf(char ch)
{
    return   (ch == 'E')              ? E
           : Character.isLetter(ch) ? LETTER
           : Character.isDigit(ch)  ? DIGIT
           : (ch == '+')            ? PLUS
           : (ch == '-')            ? MINUS
           : (ch == '.')            ? DOT
           :                          OTHER;
}
```

A Simple DFA Scanner, *cont'd*

```
private String nextToken()
    throws IOException
{
    while (Character.isWhitespace(ch)) nextChar();
    if (ch == 0) return null;  // EOF?

    state = 0;  // start state
    StringBuilder buffer = new StringBuilder();

    while (state >= 0) {   // not accepting state
        state = matrix[state][typeOf(ch)];  // transit

        if ((state >= 0) || (state == ERR)) {
            buffer.append(ch);  // build token string
            nextChar();
        }
    }

    return buffer.toString();
}
```

This is the heart of the scanner.

Table-driven scanners can be very fast!

A Simple DFA Scanner, *cont'd*

```
private void scan()
    throws IOException
{
    nextChar();

    while (ch != 0) {  // EOF?
        String token = nextToken();

        if (token != null) {
            System.out.print("=====> \"" + token + "\" ");
            String tokenType =
                  (state ==  -2) ? "IDENTIFIER"
                : (state ==  -5) ? "INTEGER"
                : (state ==  -8) ? "REAL (fraction only)"
                : (state == -12) ? "REAL"
                :                  "*** ERROR ***";
            System.out.println(tokenType);
        }
    }
}
```

How do we know which token we just got?