TDDD55 Compilers and interpreters
TDDB44 Compiler Construction

Lexical Analysis Scanners

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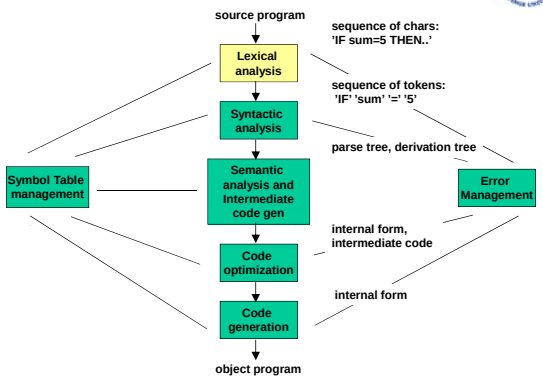
Lexical Analysis in the Compiler



Lexical Analysis, Scanners

- **Function**

1. Read the input stream (sequence of characters), group the characters into primitives (tokens).
   Returns token as <*type, value*>.
2. Throw out certain sequences of characters (blanks, comments, etc.).
3. Build the symbol table, string table, constant table, etc.
4. Generate error messages.
5. Convert, for example, string → integer.

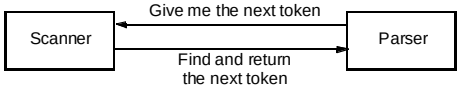
- Tokens are described using regular expressions

  Note: See Lecture 3 on Formal Languages to refresh you knowledge of regular expressions, DFAs, NFAs.

Construction of a Scanner

- **Tools:** state automata and transition diagrams.
- Regular expressions enable the automatic construction of scanners.
- **Scanner generator** (e.g. *Lex*):
  In: Regular expressions.
  Out: Scanner.

- **Environment:**



How is a Scanner Programmed?

- Describe tokens with regular expressions.
- Draw transition diagrams.
- Code the diagram as table/program.

Example Scanner

- **Example. Write a scanner for the following tokens.**

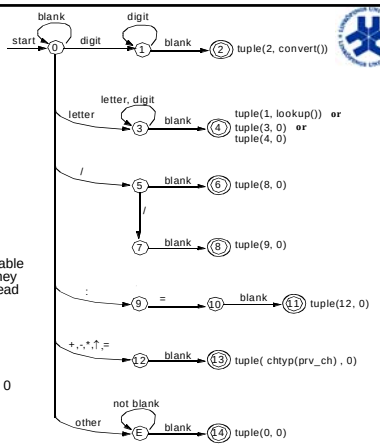
  Several categories of tokens:
  - keyword = **BEGIN | END**
  - id = letter (letter | digit)*
  - integer = digit+
  - op = **+ | - | * | / | // | ↑ | = | :=**

- Simplification:
  - Assume that there is a blank character after each token.
  - This simplification can easily be removed!

The Scanner Represents Tokens as Tuples

Tuple type	< Typecode, value >
undef.	< 0,0 >
id	< 1, table-pointer >
integer	< 2, value >
BEGIN	< 3,0 >
END	< 4,0 >
+	< 5,0 >
-	< 6,0 >
*	< 7,0 >
/	< 8,0 >
//	< 9,0 >
^	< 10,0 >
=	< 11,0 >
:=	< 12,0 >

1. Draw the Transition Diagram



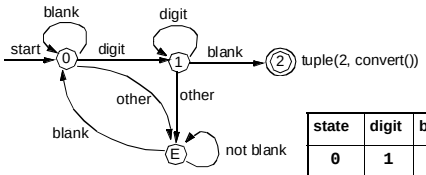
Comments:

- **convert()** converts text to integers.
- **lookup()** returns index to symbol table.
- **BEGIN**, **END** dealt with by putting them in the symbol table from the beginning. When they are found, return 3 or 4 instead of 1.
- **ch** always contains the next character
- **prv_ch** always contains the next to the last character.
- Automatic transition to state 0 after each recognized token (even after state 14).

2. Translating the Transition Diagram

Translate the diagram to a transition table, perform simple interpretation of the table.

Example: Transition-diagram and transition-table for integers:



state	digit	blank	Other	Accept
0	1	0	E	false
1	1	2	E	false
2	-	-	-	true
E	E	0	E	false

3. Interpreting the Table

state	digit	blank	other	accept
0	1	0	E	0
1	1	2	E	0
2	-	-	-	1
E	E	0	E	0

table

```
Token t = new_Token();
int state = 0;
while ( 1 ) {
  char ch = getc ( inputfile );
  int oldstate = state;
  state = table [ state ][ ch ];   // transition
  // update t->tokenval with ch as appropriate:
  accumulate ( ch, state, t );
  if (is_error_state( state ))
     error_handler( oldstate, ch, … );
  else if (is_accepting_state( state )) {
     t->tokentype = tokentype( state );
     return t;
  }
```


Generic Scanner, Interpreting the Table Using Global Data Structures

state	digit	blank	other	accept
0	1	0	E	0
1	1	2	E	0
2	-	-	-	1
E	E	0	E	0

```
// global data structures:
int table [ Nstates ][ Nchars ]
              = … (read in or initialize)
typedef struct {
    int tokentype;
    union {
      int ival; float fval; double dval; …
      symboltable *stptr;
    } tokenval;
} *Token;
```

```
// scanner routine, called from parser:
Token getNextToken( void )
{
  Token t = new_Token();
  int state = 0;
  while ( 1 ) {
     char ch = getc ( inputfile );
     int oldstate = state;
     state = table [ state ][ ch ];   // transition
     // update t->tokenval with ch as appropriate:
     accumulate ( ch, state, t );
     if (is_error_state( state ))
        error_handler( oldstate, ch, … );
     else if (is_accepting_state( state )) {
        t->tokentype = tokentype( state );
        return t;
     }
  }
}
```


4. Goto-Representation of the Table

b) Direct Jumps

```
state0:
       ch = getc;
if ch >= '0' && ch <= '9' goto state1;
if ch == " " goto state0;
goto stateE;    /* in other cases */

state1:
...
```

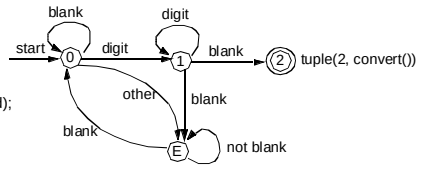
c) using a Switch statement

```
switch (state)  {
  case 0:
    switch (ch) {
      case '0': state = 1; break;
      ...
      case '9': state = 1; break;
      case ' ': state = 0; break;
      default:  state = E; }
      break;
  case 1:     ...
```

state	digit	blank	other	accept
0	1	0	E	0
1	1	2	E	0
2	-	-	-	1
E	E	0	E	0

5. Direct Coding of Diagrams (not via a table) Data Structures and Functions

- **Variables:**
  - t->tokentype = current symbol class
  - value = value
  - ch = current character
  - chtyp = vector for 1-character tokens
  - symtab = symbol table
- **Functions:**
  - getc;
  - skip_blanks;
  - symtab_lookup(id);
  - is_letter(ch);
  - is_digit(ch);
- **Initialization:**
  - initialize **chtyp** according to the previous description;
  - initialize the symbol table with reserved words;

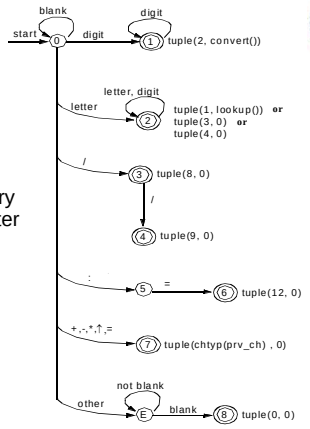


5. Scanner Fragment with Direct Coding Continued

```
Token getNextToken( void )
{
  char ch = getc( inputfile );
  char idstr [ … ];  // lexeme buffer for identifiers
  t = new_Token();
  while (is_blank(ch))
      ch = getc ( inputfile );  // eat whitespace
  if (is_letter(ch)) {   // identifier:
      while (is_letter(ch) || is_digit(ch) ) {
          append( ch, idstr );
          ch = getc( inputfile );
      }
      if (is_blank(ch))
          t->tokenval.stptr =
                          symtab_lookup( idstr );
      else error( … );
  }
  …
```

```
  …
  else if (is_digit(ch))  { // int-constant:
       int ivalue = ch – '0';
       ch = getc( inputfile );
       while (is_digit(ch)) {
            ivalue *= 10;
            ivalue += ch – '0';
            ch = getc( inputfile );
       }
       if (is_blank(ch))
            t->tokenval.ival = ivalue;
       else error( … );
  }
  …
  else {
     // others  (single-char. symbols):
     t->tokentype = chtyp[ ch ];
     if (t->tokentype == 0)
          error( … );
  }
  return t;
}
```


Diagram with simplification removed



Removed simplification:

- Space is not necessary as concluding character

Scanner Lookahead Problems

- **Lookahead** is sometimes needed to determine symbol type.
- ´Example: in FORTRAN
  - **DO 10 I = 1.25** is an assignment, but
  - **DO 10 I = 1,25** is a for-statement.

  It is '**.**' or '**,**' which determines whether the scanner returns **DO10I** or **DO**
- Another Example: in Pascal.

  Two character lookahead needed
  - **715..816**