TDDD16 Compilers and interpreters

TDDB44 Compiler Construction

Lexical Analysis
Scanners

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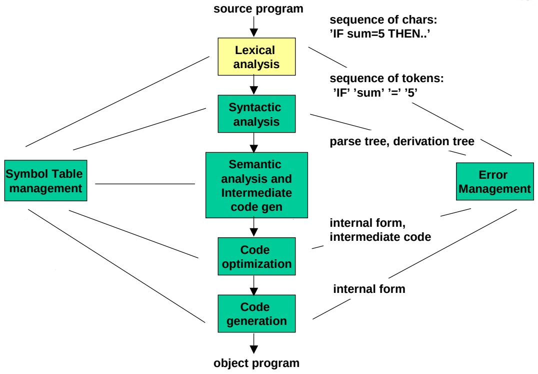
Lexical Analysis in the Compiler


source program
Lexical analysis
Syntactic analysis
Semantic analysis and Intermediate code gen
Code optimization
Code generation
object program
Symbol Table management
Error Management
sequence of chars: 'IF sum=5 THEN..'
sequence of tokens: 'IF' 'sum' '=' '5'
parse tree, derivation tree
internal form, intermediate code
internal form

Lexical Analysis, Scanners

- **Function**

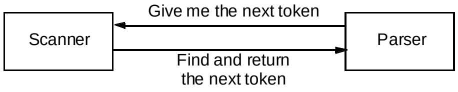
1. Read the input stream (sequence of characters), group the characters into primitives (tokens).
   Returns token as <*type, value*>.
2. Throw out certain sequences of characters (blanks, comments, etc.).
3. Build the symbol table, string table, constant table, etc.
4. Generate error messages.
5. Convert,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

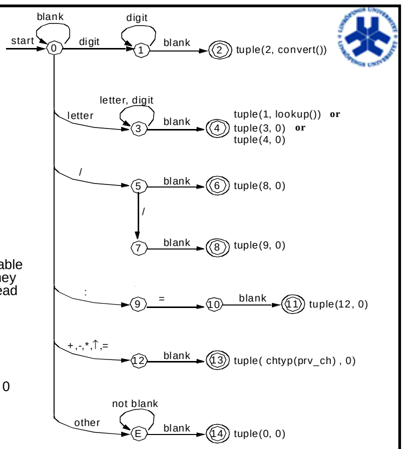
- **Example. Write a scanner for the following tokens.**

  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



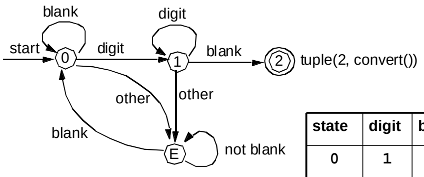
Comments:

- **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

```
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;
   }
```

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

table

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:
...
```

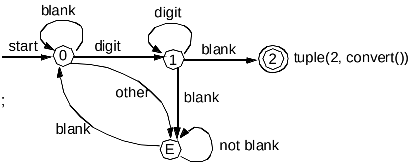
c) using a Switch statement

```
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
- **Initialization:**
  - initialize **chtyp** according to the previous description;
  - initialize the symbol table with reserved words;
- **Functions:**
  - getc;
  - skip_blanks;
  - symtab_lookup(id);
  - is_letter(ch);
  - is_digit(ch);



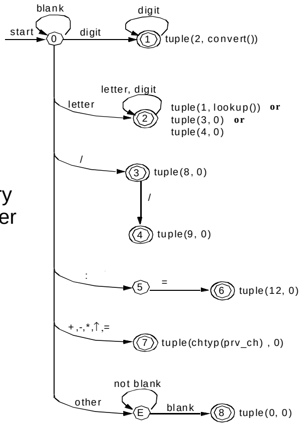
5. Scanner Fragment with Direct Coding Continued

```
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**