Experiment in Compiler Construction

Scanner design

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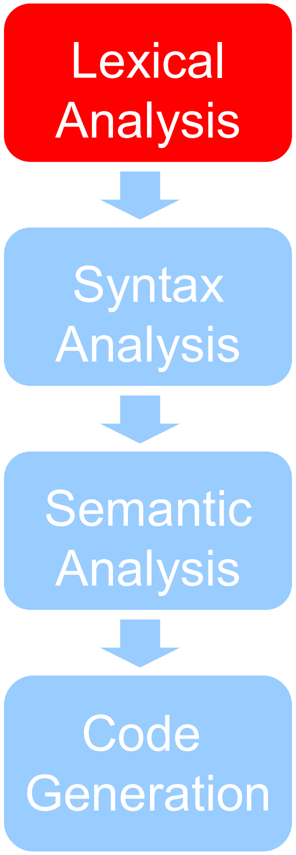
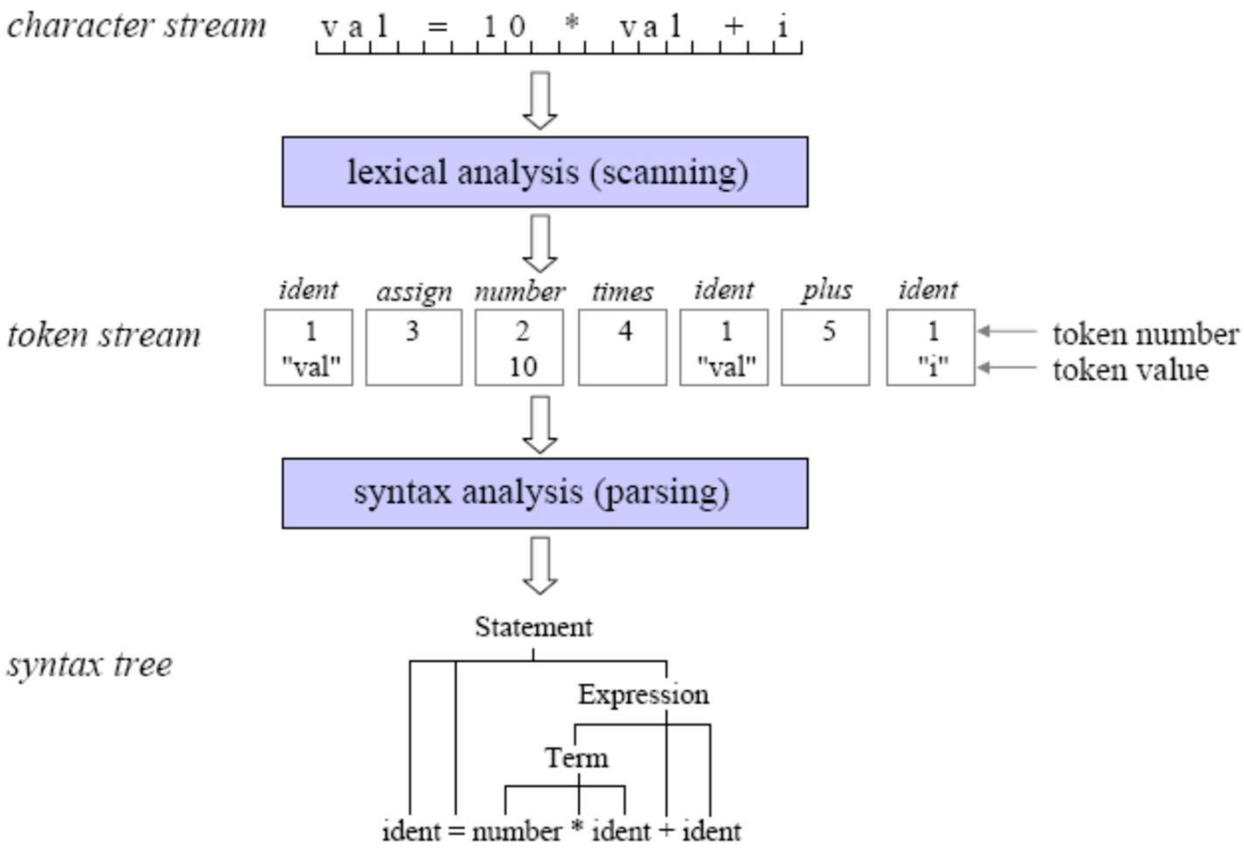
What is a scanner?



- The compiler's component/module that perform the job of lexical analysis (scanning) is called *scanner*.
- Compiler's first phase

What is a scanner?



character stream v a l = 1 0 * v a l + i

lexical analysis (scanning)

token stream

ident	*assign*	*number*	*times*	*ident*	*plus*	*ident*	
1	3	2	4	1	5	1	token number
"val"		10		"val"		"i"	token value

syntax analysis (parsing)

syntax tree

Statement

Expression

Term

ident = number * ident + ident

Tasks of a scanner

- Skip meaningless characters: blank, tab, new line character, comment.
- Recognize illegal character and return error message
- Recognize different types of token
  - identifier
  - keyword
  - number
  - special character
  - ...

Tasks of a scanner

- Recognize tokens of different types
  - identifier
  - keyword
  - number
  - special character
  - ...
- Pass recognized tokens to the *parser* (the module that perform the job of syntatic analysis)

KPL’s alphabet

- Letter: a b c … x y z
  A B C … X Y Z
- Digit: 0 1 2 … 8 9
- Special character:
  - + - * /
  - > < ! =
  - [space] ,(comma) . : ; ‘ _
  - ( )

KPL’s tokens

- Keywords

  PROGRAM, CONST, TYPE, VAR, PROCEDURE, FUNCTION, BEGIN, END, ARRAY, OF, INTEGER, CHAR, CALL, IF, THEN, ELSE, WHILE, DO, FOR, TO
- Operators

  := (assign)

  + (addition), - (subtraction), * (multiplication), / (division)

  = (comparison of equality), != (comparison of difference), > (comparison of greaterness), < (comparison of lessness), >= (comparison of greaterness or equality), <= (comparison of lessness or equality)

KPL’s tokens

- Special characters

  ; (semicolon), . (period), : (colon), , (comma), ((left parenthesis),) (right parenthesis), ‘ (singlequote)

- Also

  (. and .) to mark the index of an array element

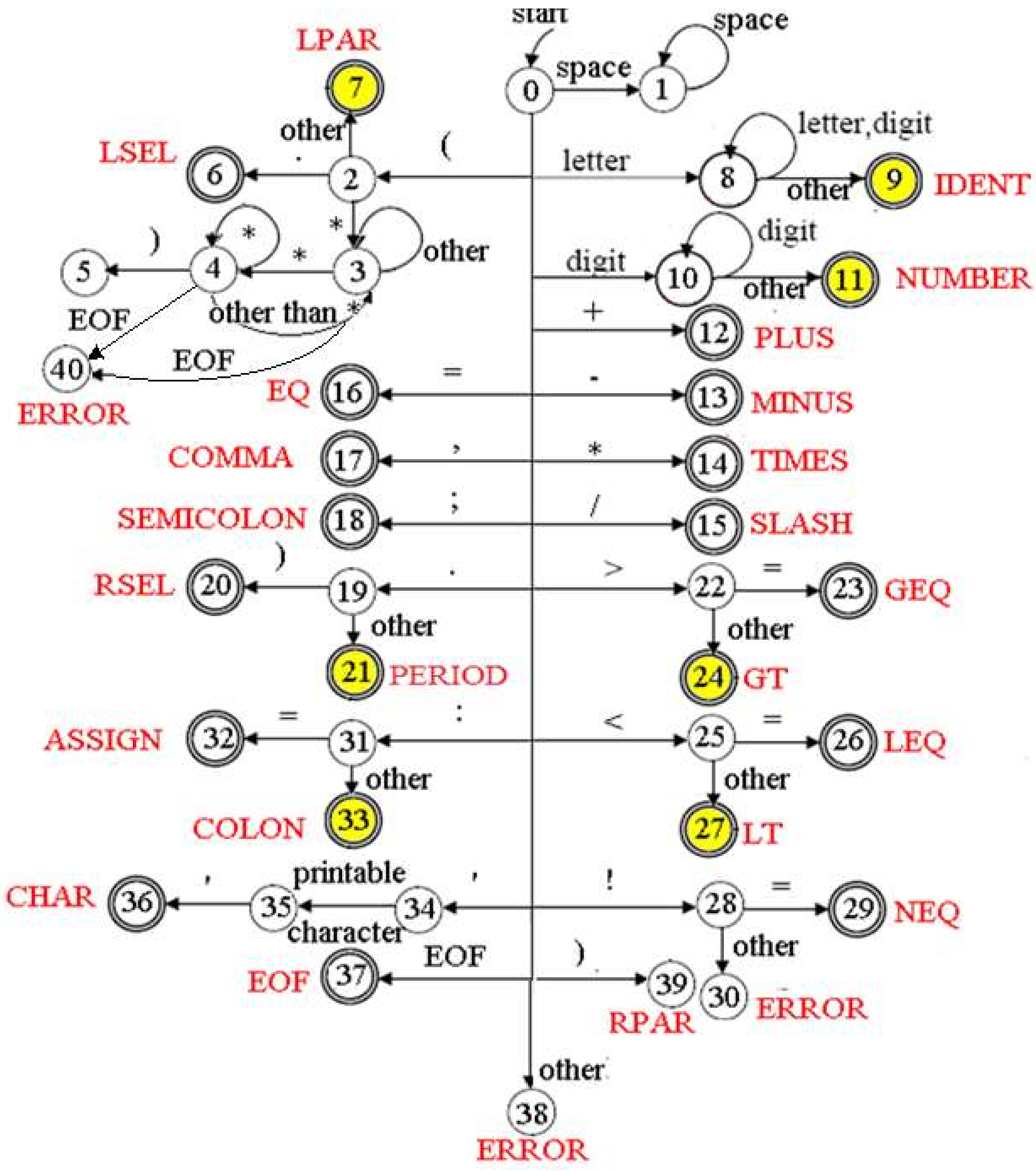
  (* and *) to mark the comment

- Others

  identifier, number, illegal charater

Recognizing KPL’s tokens

- All KPL’s tokens make up a regular language.
- They can be described with regular grammar
- They can be recognized by a Deterministic Finite Automaton (DFA)
- The scanner is a big DFA



Recognizing KPL's tokens

- After every token is recognized, the scanner starts in state 0 again
- If an illegal character is met, the scanner would change to the state -1 which tell the scanner to stop scanning and return error messages.

KPL scanner - organization

#	Filename	Task
1	Makefile	Project
2	scanner.c	Main
3	reader.h, reader.c	Read the source code
4	charcode.h, charcode.c	Classify character
5	token.h, token.c	Classify and recognize token, keywords
6	error.h, error.c	Manage error types and messages

KPL scanner – reader

```
// Read a character from input stream
int readChar(void);

// Open input stream
int openInputStream(char *fileName);

// Close input stream
void closeInputStream(void);

// Current line number and column number
int lineNo, colNo;

// Current character
int currentChar;
```

KPL scanner – charcode

```
typedef enum {
  CHAR_SPACE,            // space
  CHAR_LETTER,           // character
  CHAR_DIGIT,            // digit
  CHAR_PLUS,             // ‘+’
  CHAR_MINUS,            // ‘-’
  CHAR_TIMES,            // ‘*’
  CHAR_SLASH,            // ‘/’
  CHAR_LT,               // ‘<‘
  CHAR_GT,               // ‘>‘
  CHAR_EXCLAIMATION,     // ‘!’
  CHAR_EQ,               // ‘=‘
  CHAR_COMMA,            // ‘,’
  CHAR_PERIOD,           // ‘.’
  CHAR_COLON,            // ‘:’
  CHAR_SEMICOLON,        // ‘;’
  CHAR_SINGLEQUOTE,      // ‘\’’
  CHAR_LPAR,             // ‘(‘
  CHAR_RPAR,             // ‘)’
  CHAR_UNKNOWN           // invalid character
} CharCode;
```

KPL scanner – charcode

- In *charcode.c*, we define *charCodes* array that associates every ASCII character with an unique predifined *CharCode*.
- *getc*() function may return EOF (or -1) which is not an ASCII character.

KPL scanner – token

```
typedef enum {
  TK_NONE,      // Invalid token - Error
  TK_IDENT,     // Identifier token
  TK_NUMBER,    // Number token
  TK_CHAR,      // Character constant token
  TK_EOF,       // End of program token
  // keywords
  KW_PROGRAM, KW_CONST, KW_TYPE, KW_VAR,
  KW_INTEGER, KW_CHAR, KW_ARRAY, KW_OF,
  KW_FUNCTION, KW_PROCEDURE,
  KW_BEGIN, KW_END, KW_CALL,
  KW_IF, KW_THEN, KW_ELSE,
  KW_WHILE, KW_DO, KW_FOR, KW_TO,
  // Special character
  SB_SEMICOLON, SB_COLON, SB_PERIOD, SB_COMMA,
  SB_ASSIGN, SB_EQ, SB_NEQ, SB_LT, SB_LE, SB_GT, SB_GE,
  SB_PLUS, SB_MINUS, SB_TIMES, SB_SLASH,
  SB_LPAR, SB_RPAR, SB_LSEL, SB_RSEL
} TokenType;
```

KPL scanner – token

```
// Structure of a token
typedef struct {
  char string[MAX_IDENT_LEN + 1];
  int lineNo, colNo;
  TokenType tokenType;
  int value;
} Token;

// Check whether a string is a keyword or not
TokenType checkKeyword(char *string);

// Create new token, provided type of token and location
Token* makeToken(TokenType tokenType, int lineNo, int
colNo);
```

KPL scanner – error management

```
// List of error may occur in lexical analysis
typedef enum {
  ERR_ENDOFCOMMENT,
  ERR_IDENTTOOLONG,
  ERR_INVALIDCHARCONSTANT,
  ERR_INVALIDSYMBOL
} ErrorCode;

// Error message
#define ERM_ENDOFCOMMENT "End of comment expected!"
#define ERM_IDENTTOOLONG "Identification too long!"
#define ERM_INVALIDCHARCONSTANT "Invalid const char!"
#define ERM_INVALIDSYMBOL "Invalid symbol!"

// Return error message
void error(ErrorCode err, int lineNo, int colNo);
```

KPL scanner – scanner

```
// Get next token
Token* getToken(void) {
  Token *token;
  int ln, cn;

  if (currentChar == EOF)
    return makeToken(TK_EOF, lineNo, colNo);

  switch (charCodes[currentChar]) {
  case CHAR_SPACE:     skipBlank(); return getToken();
  case CHAR_LETTER:    return readIdentKeyword();
  case CHAR_DIGIT:     return readNumber();
  case CHAR_PLUS:
    token = makeToken(SB_PLUS, lineNo, colNo);
    readChar();
    return token;
  case … // more cases
  }
}
```

Assignment

- Complete following function in `scanner.c`
  - **`void skipBlank();`**
  - **`void skipComment();`**
  - **`Token* readIdentKeyword(void);`**
  - **`Token* readNumber(void);`**
  - **`Token* readConstChar(void);`**
  - **`Token* getToken(void);`**

getToken()   (1)

- **Program ⇒ getToken() ⇒ TokenType: token**

```
|- digit                    readNumber()
|- letter                   readIdentKeyword()
|- blank                    skipBlank()
|                           getToken();
|- (   |-   .               SB_LSEL
       |-   *               skipComment()
       |                    getToken();
       |-   other           SB_LPAR
|- ‘                        readConstChar()
|- <  |-   =                SB_LE
      |-   other            SB_LT
```

getToken()   (2)

- **Program ⇒ getToken() ⇒ TokenType: token**

```
|- >  |-  =            SB_GE
      |-  other        SB_GT
|- !  |-  =            SB_NEQ
      |-  other        error: INVALIDSYMBOL
|- .  |-  )            SB_RPAR
      |-  other        SB_PERIOD
|- :  |-  =            SB_ASSIGN
      |-  other        SB_SEMICOLON
|- + - * / = , ; )     SB_...
|- other               error: INVALIDSYMBOL
```

readNumber()

- **readNumber()⇒ TokenType: token**

```
readChar()
|- digit                 readChar()
|- other                 TK_NUMBER
```

- Use **atoi()** function to convert a string to an integer.

readIdentKeyword()

- **readIdentKeyword() ⇒ TokenType: token**

```
readChar()
|- digit, letter                readChar()
|                               count ++
|- other
    |- count > MAX_IDENT_LENT
    |                           error: IDEN_TOO_LONG
    |- count ≤ MAX_IDENT_LENT
        |- ≡ keywords           KW_...
        |- ≠ keywords           TK_IDENT
```

skipBlank()

```
skipBlank()
    |- blank                 readChar()
    |- other                 return
```

skipComment()

- **skipComment()**

```
inside_comment    |- *     |- )      return
                           |- other  inside_comment
                           |- EOF    error: END_OF_COMMENT
                  |- other           inside_comment
                  |- EOF             error: END_OF_COMMENT
```

readConstChar()

- **readConstChar()⇒ TokenType: token**

```
|- character
        |- ‘              TK_CHAR
        |- other          error: INVALID_CONST_CHAR
|- EOF                    error: INVALID_CONST_CHAR
```

```
case CHAR_COLON:
    ln = lineNo;
    cn = colNo;
    readChar();
    if ((currentChar != EOF) &&
(charCodes[currentChar] == CHAR_EQ)) {
      readChar();
      return makeToken(SB_ASSIGN, ln, cn);
    } else return makeToken(SB_COLON, ln,
cn);
```