ĐẠI HỌC BÁCH KHOA HÀ NỘI
VIỆN CÔNG NGHỆ THÔNG TIN VÀ TRUYỀN THÔNG

Experiment in Compiler Construction

Introduction to compilers

School of Infomation and Communication Technology

Hanoi University of Science and Technology

Introduction to compiler

- Compiler vs interpreter
- Phases of a compiler

Compiler vs interpreter

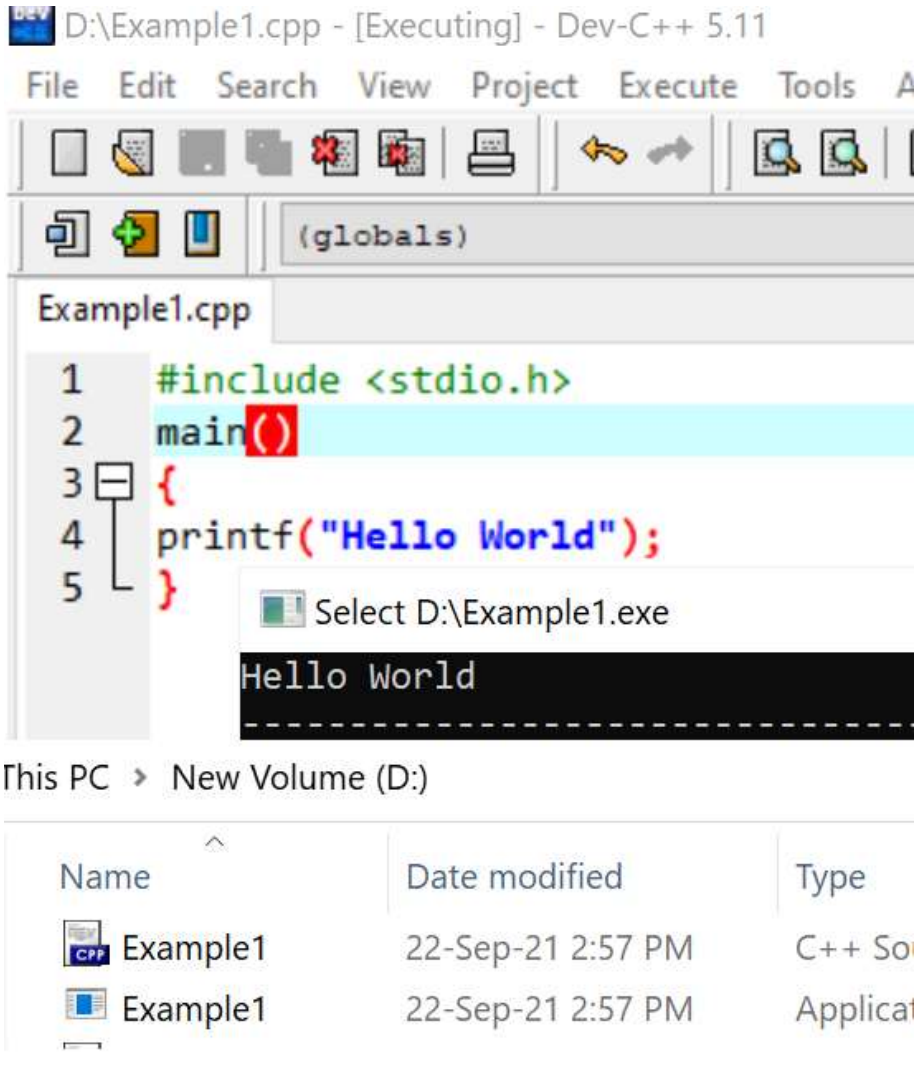
- Carry out the same purpose: translating high level language instructions into the binary form that is understandable by the computer.
- Interpreter: reads a statement (instruction), translates and then executes it, then take another
- Compiler: translates the entire program in one go and executes it (through .exe file)

Language examples

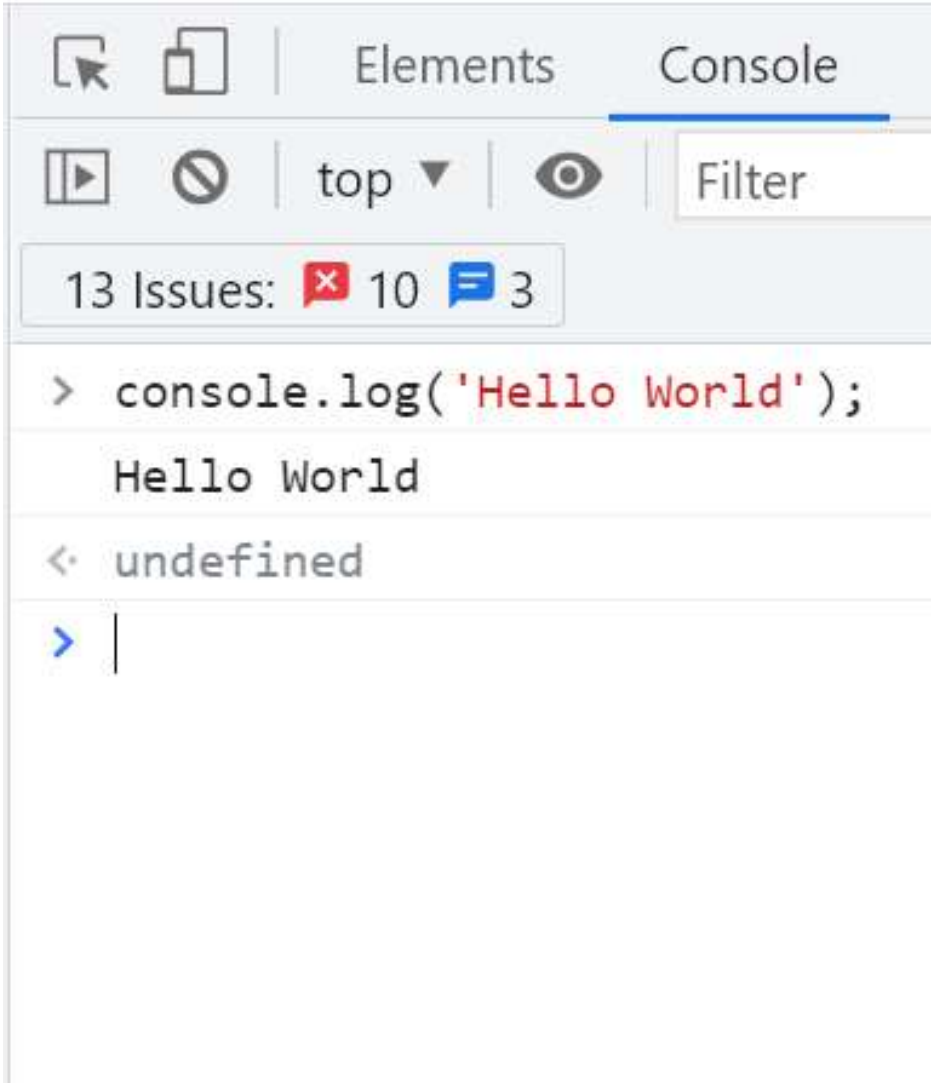
Compiled	C, C++, Objective-C
Interpreted	PHP, JavaScript
Hybrid	Java, C#, VB.NET, Python

Examples of Hello World program

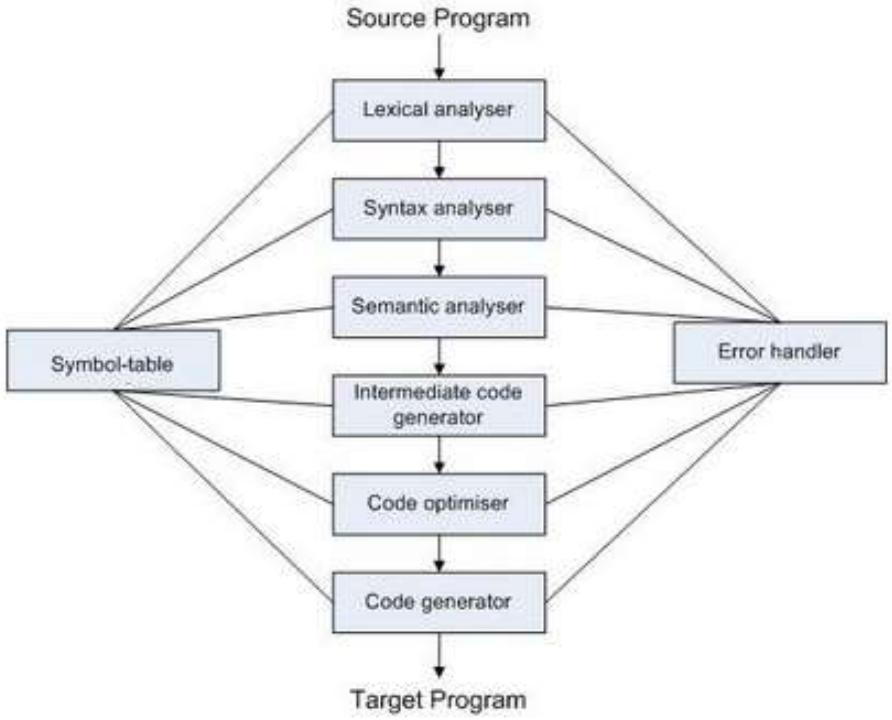
C language



Javascript



Phases of a compiler

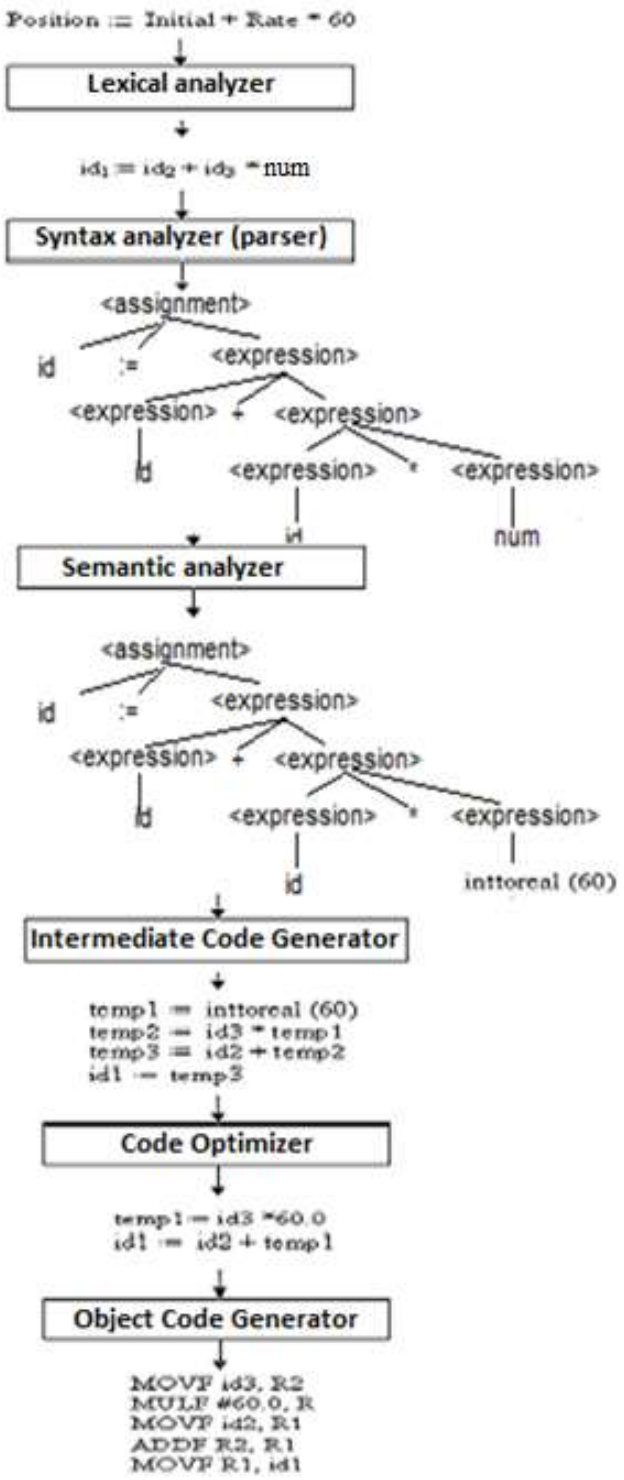


2 major phases

Analysis: Lexical analysis, syntax analysis, semantic analysis

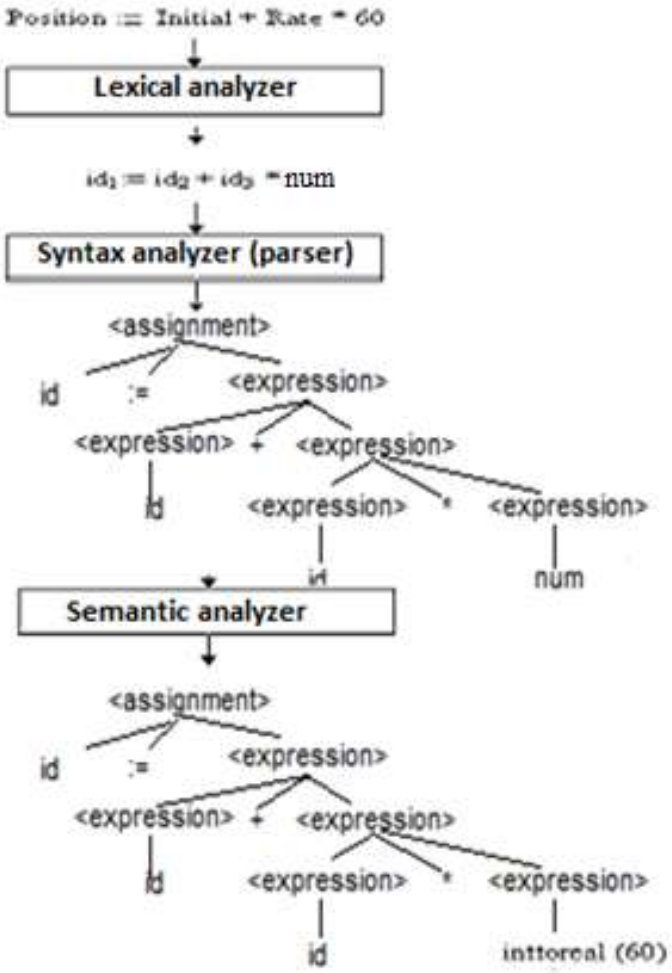
Synthesis: Intermediate code generation, code optimization, code generation

Translation of a statement



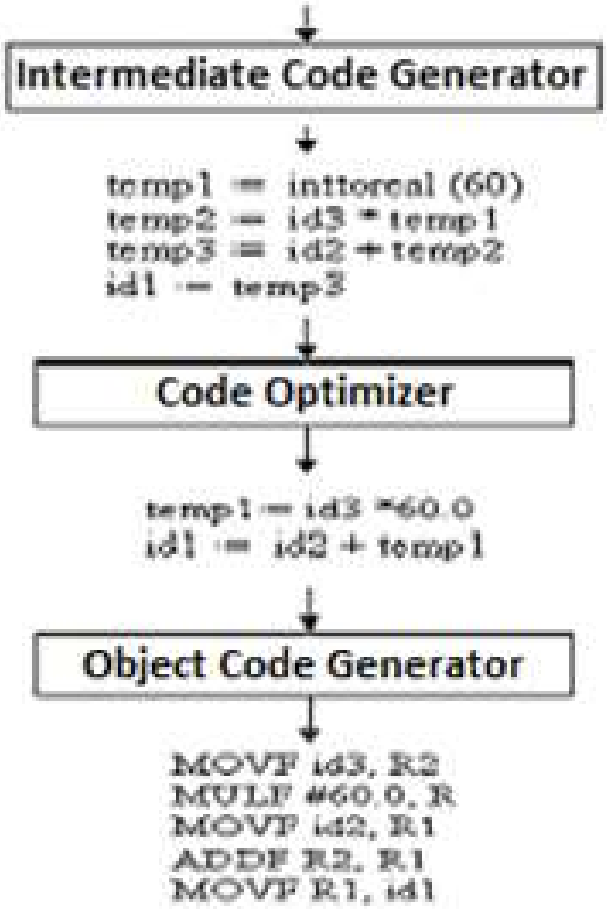
Analysis phase

Syntax rules (grammar)
<assignment> → id := <expression>
<expression> → <expression> + <expression>
<expression> → <expression> * <expression>
<expression> → id
<expression> → num



Symbol table	
Name	Attributes
Position	…
Initial	…
Rate	…

Synthesis phase



KPL programming language

- A tiny programming language used in writing a simple compiler
- Issued by University of Kyoto
- A subset of Pascal language

```
Program Example2; (* Factorial *)

Var n : Integer;

Function F(n : Integer) : Integer;
  Begin
    If n = 0 Then F := 1 Else F := N
* F (N - 1);
  End;

Begin
  For n := 1 To 7 Do
    Begin
      Call WriteLn;
      Call WriteI(F(i));
    End;
End. (* Factorial *)
```

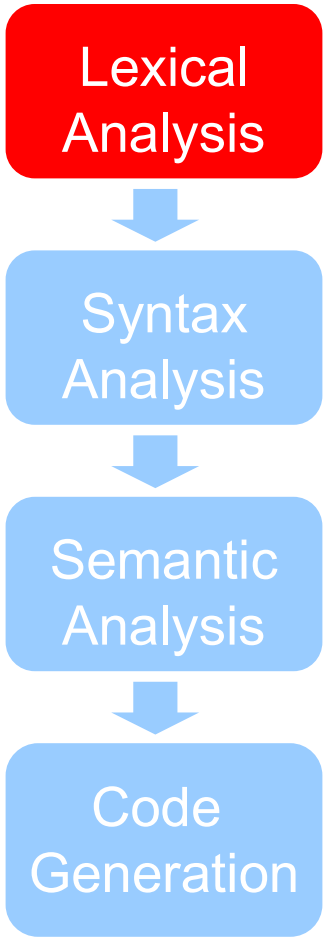
Experiment in Compiler Construction

Scanner design

School of Infomation and Communication Technology

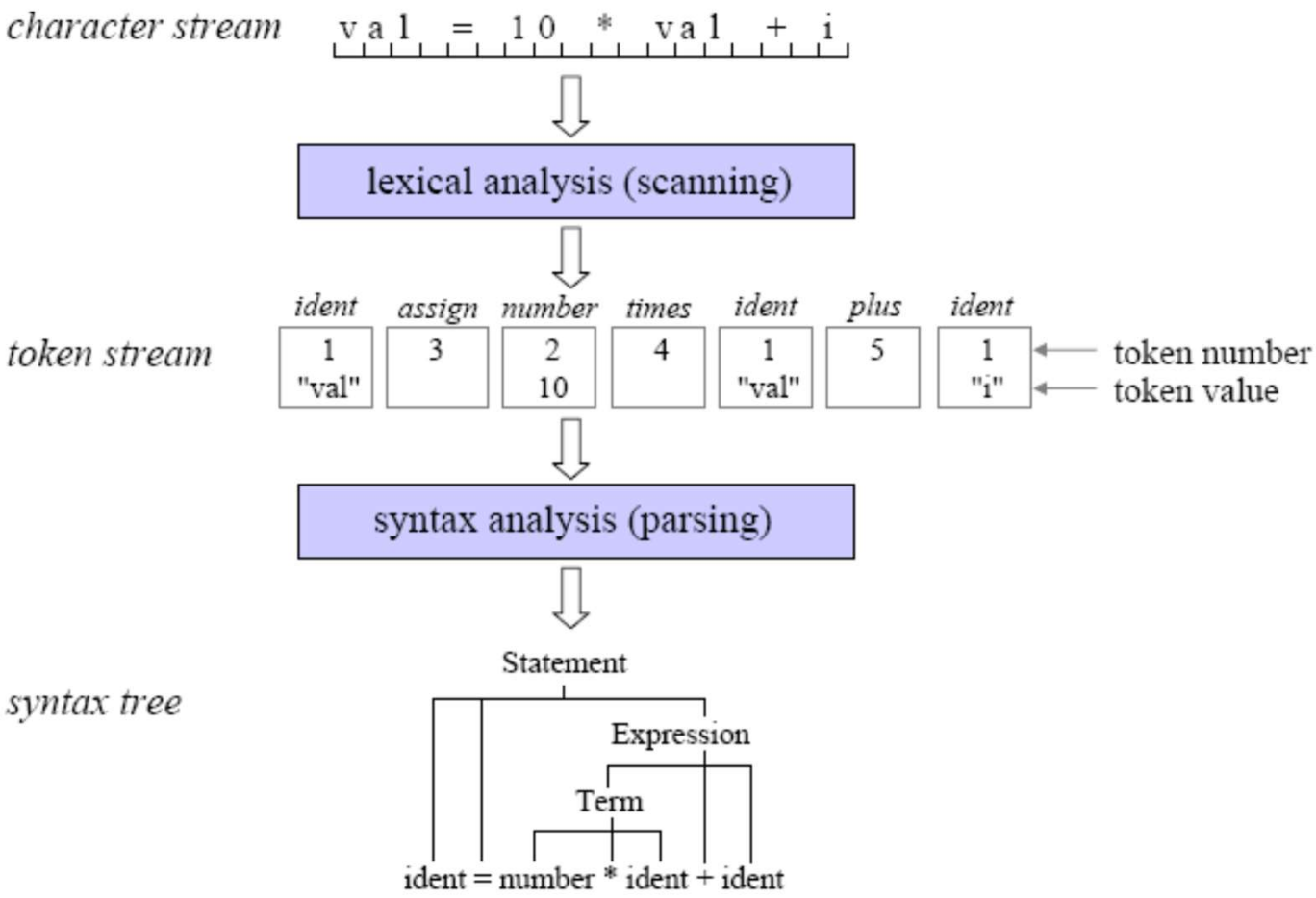
Hanoi University of Science and Technology

What is a scanner?

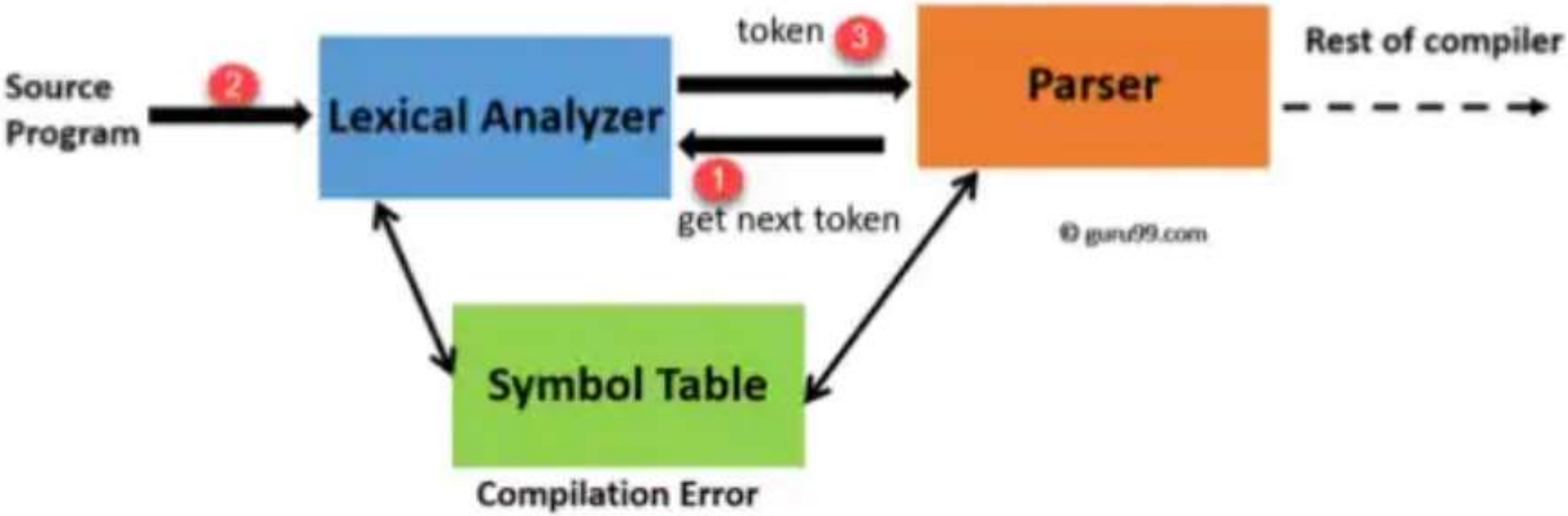


- The compiler's component/module that perform the job of lexical analysis (scanning) is called *scanner*.
- Compiler's first phase

What is a scanner?



Scanner – Parser interaction



Tasks of a scanner

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

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)

Lexical rules of KPL

- Only use unsigned integer
- The KPL identifier is made with a combination of **lowercase** or **uppercase letters**, **digits.** An identifier must **start with a letter. The length <=15.**
- Only allows **character constants**. A character constant is enclosed with a pair of single quote marks. ‘’
- The language do not use string constant.
- - is use for subtraction only. The language does not allow unary minus and negative numbers
- The relational operator “not equal to” is represented by !=

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

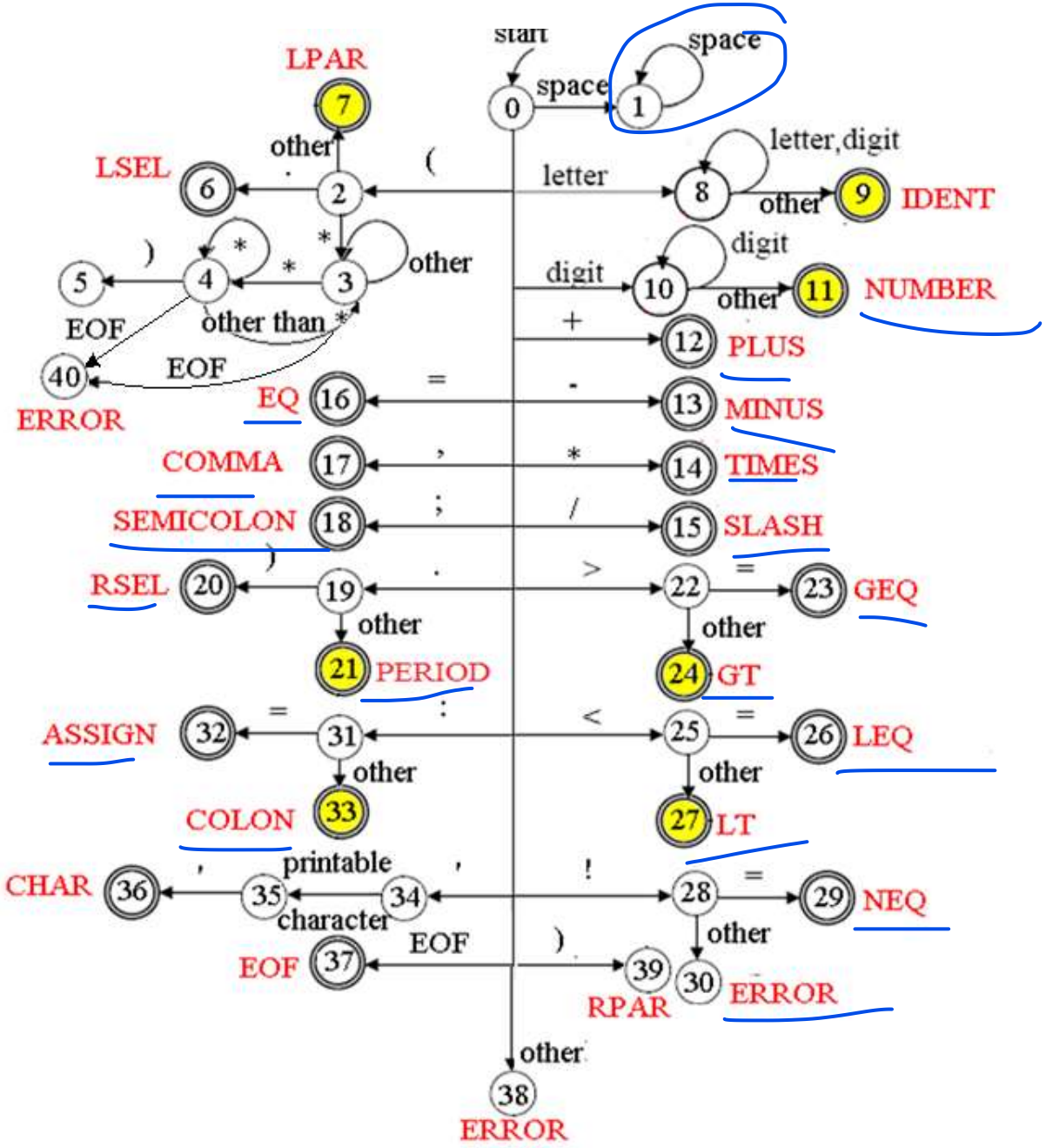
  (* and *) to mark the comment

- 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, regular expression
- They can be recognized by a Deterministic Finite Automaton (DFA)
- The scanner is a big DFA
- The incompleted project does not use DFA. But the diagram is helpful for you to check if your scanner cover all token in KPL or not.
- Use of DFA in function skipComment also useful to process the error of unclosed comments
- I will explain how to use DFA to build a scanner in Unit 5 of the theory course. After learning that unit, you can build a new scanner project with 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

getToken() (3) C code

```
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);//:=
```

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