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

Experiment in Compiler Construction

School of Infomation and Communication Technology

Hanoi University of Science and Technology

What is the course about

- Knowledge about compiler is introduced in 2 courses :
  - IT3322 – Compiler construction: Theory course
  - IT4182 - Experiment in compiler construction
- The course will require students to build a simple compiler for a tiny programming language
- Through the course, students will understand how each phase of the compiler works.
- The operation of the compiler will illustrate and clarify the knowledge presented in the theory course
- At each lesson, an **incompleted project** is provided to students. In the project, some functions or code paragraphs are left blank
- Students only need to complete the sections marked todo

Projects

- Lexical analyzer (scanner)
- Syntax analyzer (parser)
- Symbol Table
- Semantic analyzer
- Code generator
- Interpreter

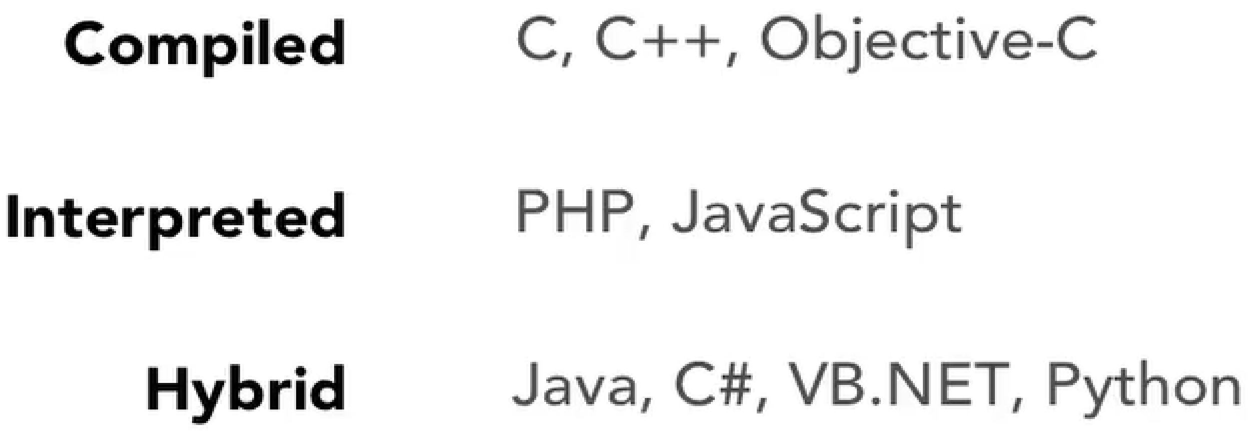
Introduction to compiler

- 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)

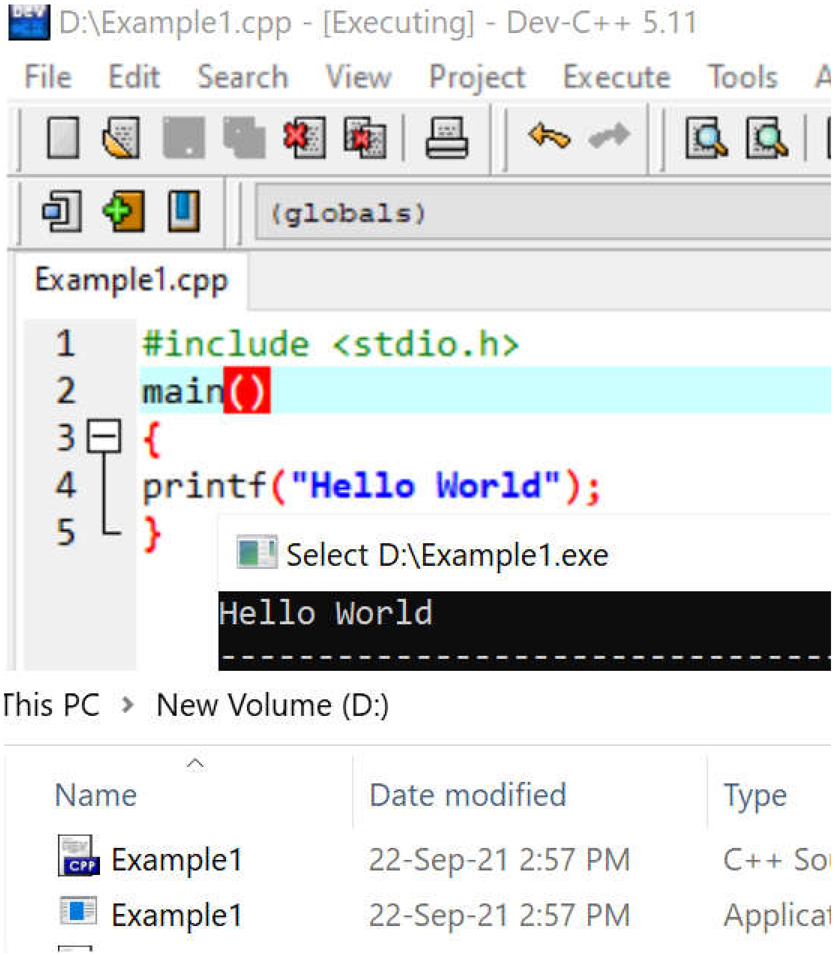
Language examples



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

Examples of Hello World program

C language



```
#include <stdio.h>
main()
{
printf("Hello World");
}
```

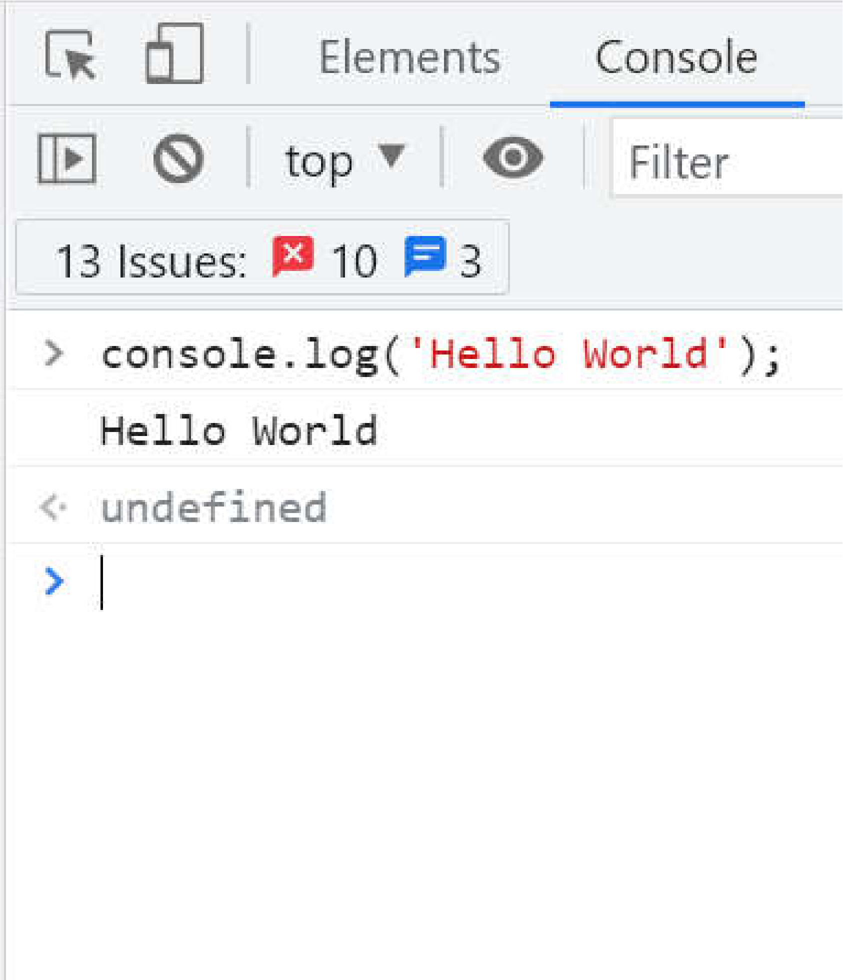
Select D:\Example1.exe

```
Hello World
--------------------------------
```

This PC › New Volume (D:)

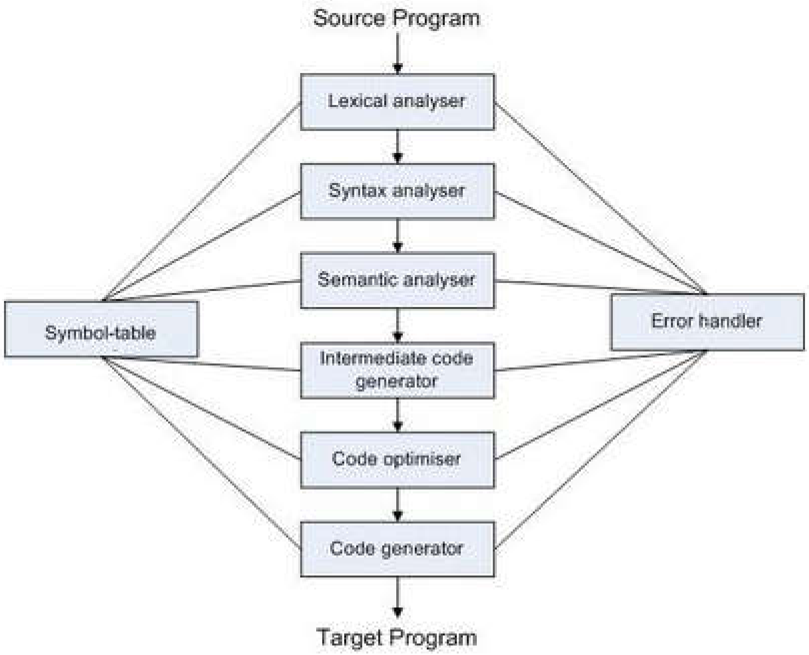
Name	Date modified	Type
Example1	22-Sep-21 2:57 PM	C++ So
Example1	22-Sep-21 2:57 PM	Applicat

Javascript



```
> console.log('Hello World');
  Hello World
<· undefined
>
```

Phases of a compiler

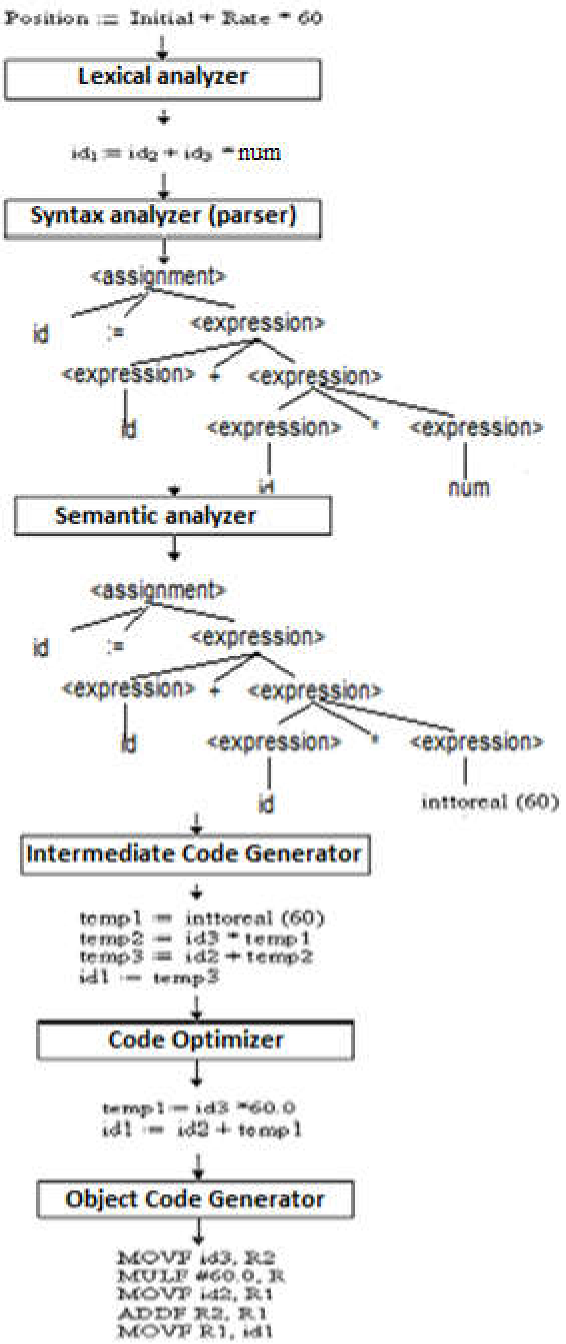


2 major phases

Analysis: Lexical analysis, syntax analysis, semantic analysis

Synthesis: Intermediate code generation, code optimization, code generation

Translation of a statement



```
Position := Initial + Rate * 60
```

```
id1 := id2 + id3 * num
```

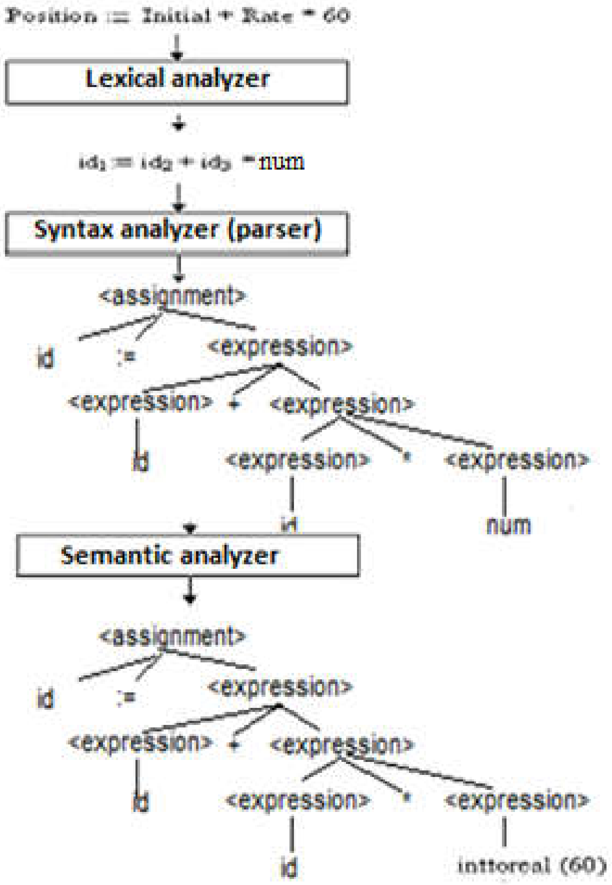
```
temp1 := inttoreal (60)
temp2 := id3 * temp1
temp3 := id2 + temp2
id1 := temp3
```

```
temp1 := id3 *60.0
id1 := id2 + temp1
```

```
MOVF id3, R2
MULF #60.0, R
MOVF id2, R1
ADDF R2, R1
MOVF R1, id1
```

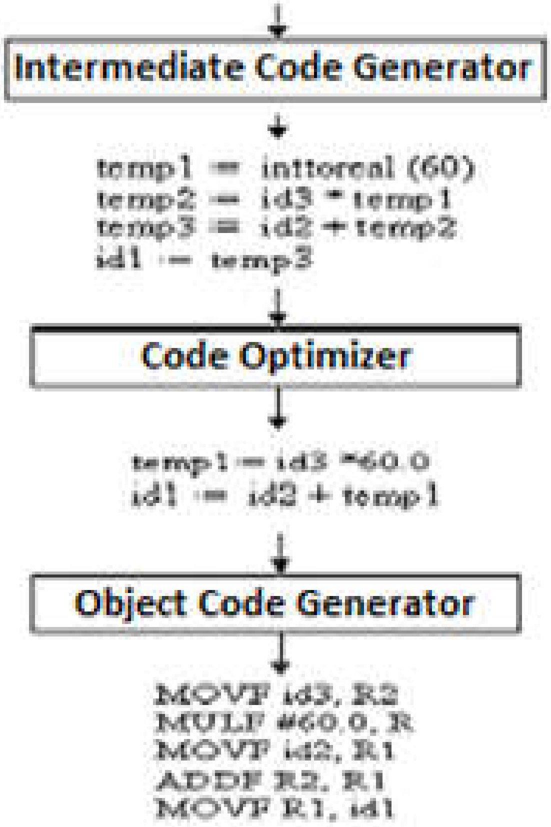
Analysis phase

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



Intermediate Code Generator

```
temp1 = inttoreal (60)
temp2 = id3 * temp1
temp3 = id2 + temp2
id1 = temp3
```

Code Optimizer

```
temp1 = id3 * 60.0
id1 = id2 + temp1
```

Object Code Generator

```
MOVF id3, R2
MULF #60.0, R
MOVF id2, R1
ADDF R2, R1
MOVF R1, id1
```

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 *)
```

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Experiment in Compiler Construction

Scanner design

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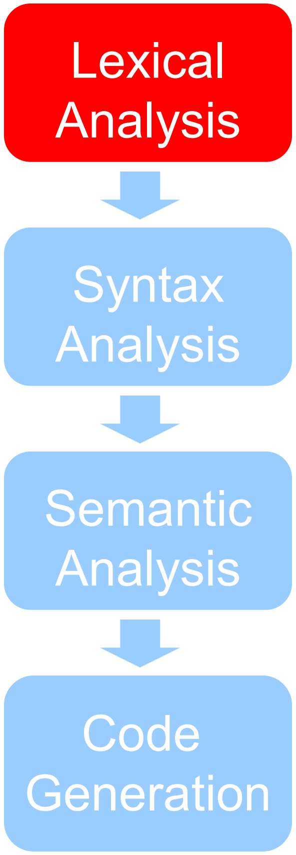
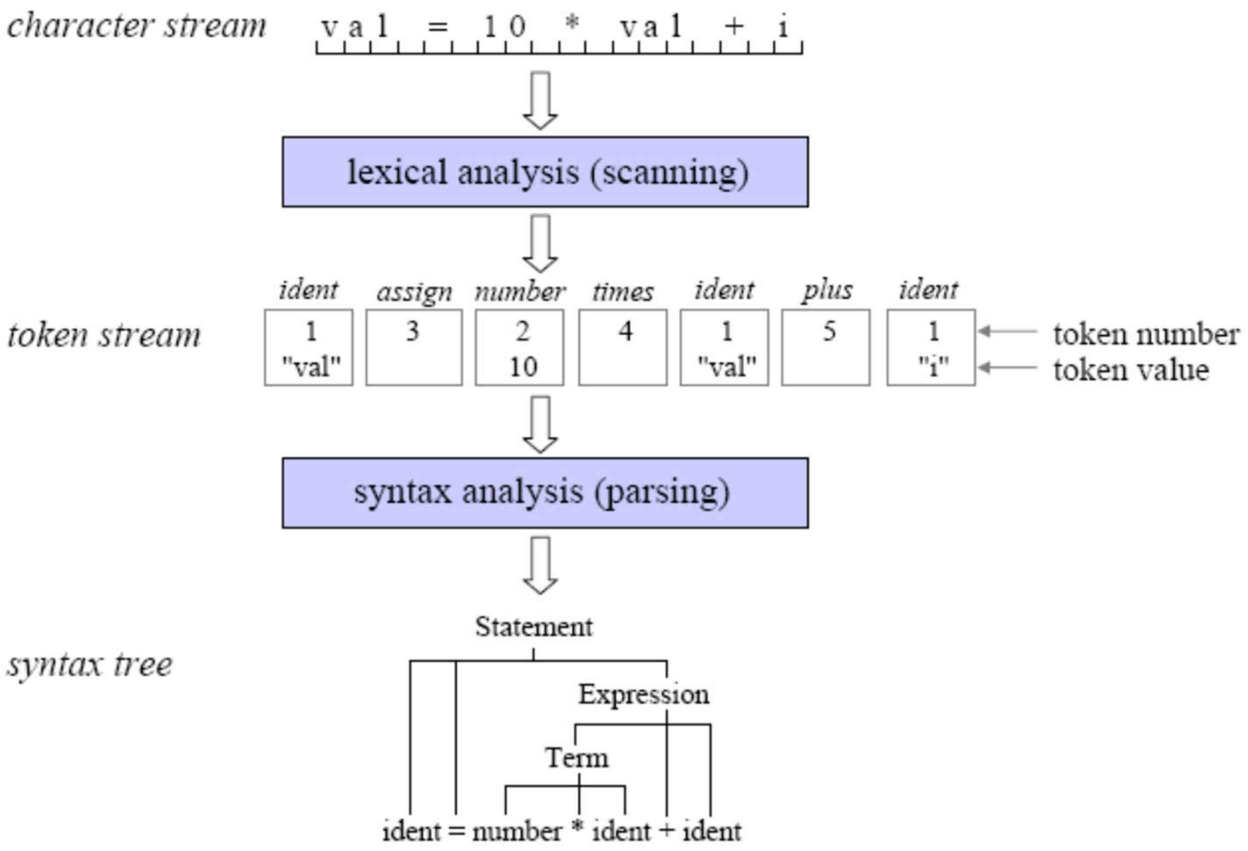
What is a scanner?

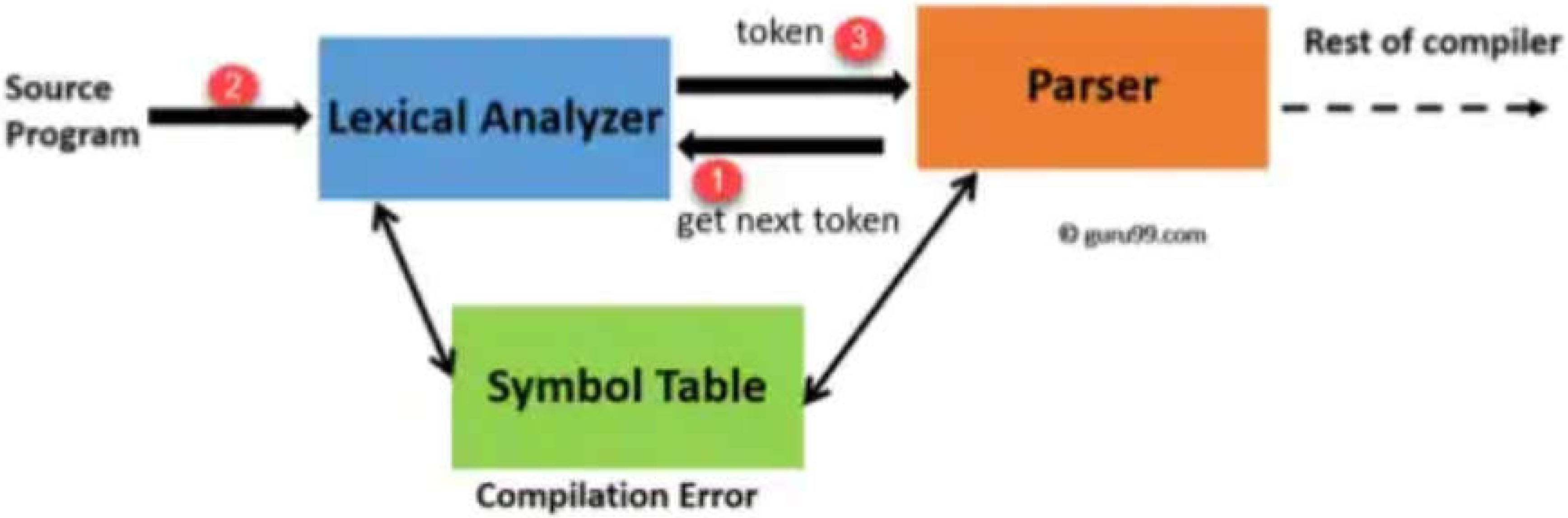


- The compiler's component/module that perform the job of lexical analysis (scanning) is called *scanner*.
- Compiler's first phase

What is a scanner?



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 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)

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.**
- 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.
- 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

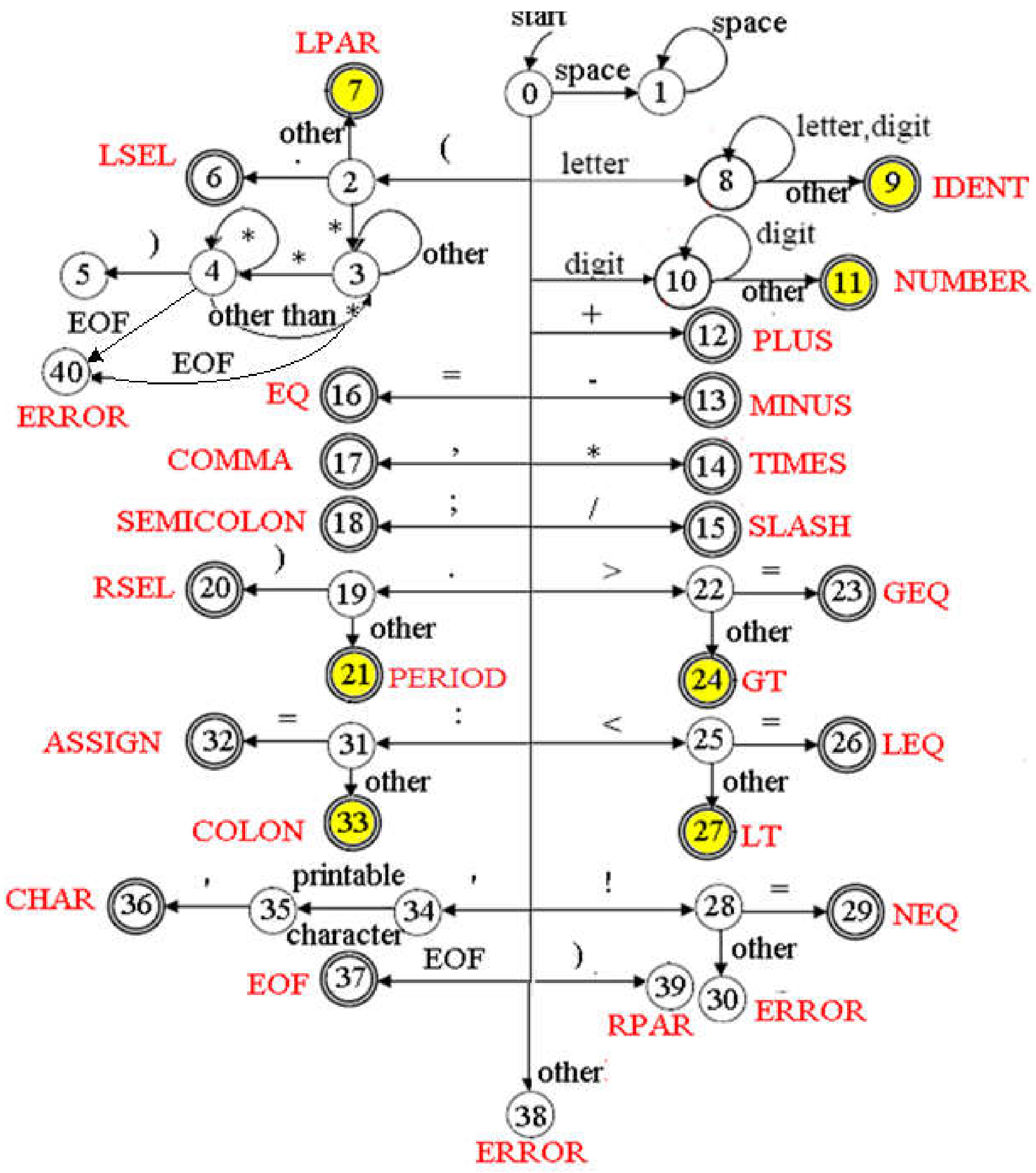
- Others

  identifier, number, illegal charater

Recognizing KPL’s tokens

- All KPL’s tokens make up a regular language.
- They can be described with regular grammar
- 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
```