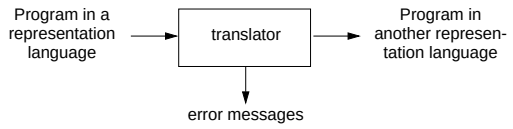
Introduction

Translators



Compiler

High-level language → machine language or assembly language

e.g. Pascal, Ada, Fortran

Three phases of execution:

"Compile time"

1. Source program → object program (compiling)
2. Linking, loading → absolute program

"Run-time"

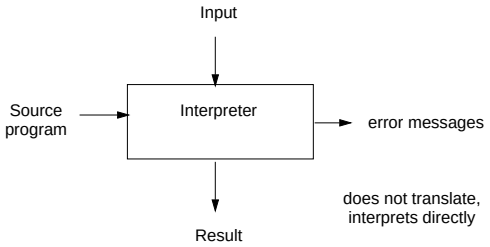
3. Input → output

Interpreters

High-level language → intermediate code – which is *interpreted*

e.g.

- BASIC, LISP, APL
- command languages, e.g. UNIX-shell
- query languages for databases



Assembler

Symbolic machine code → machine code

e.g. `MOVE R1,SUM` → `01..101`

Simulator, Emulator

Machine code *is interpreted* → machine code

e.g. Simulate a processor on an existing processor.

Preprocessor

Extended ("sugared") high-level language → high-level language

- Example1: `IF-THEN-ELSE` in FORTRAN:

  Before preprocessing:

```
IF A < B THEN
                Z=A
ELSE
                Z=B
```

  After preprocessing:

```
        IF (A.LT.B) THEN GOTO 99
        Z=B
        GOTO 100
99      Z=A
100     CONTINUE
```

- Example 2: "File inclusion"

```
#include "fil1.h"
```


Natural language – translators

e.g. Chinese → English

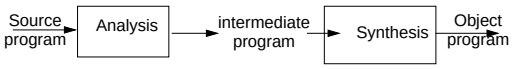
Very difficult problem, especially to include context.

> *Visiting relatives* can be hard work.
> - To *go and visit* relatives . . .
> - Relatives *who are visiting* . . .
>
> I saw a man *with a telescope*

Why high-level languages?

- Understandability (readability)
- Naturalness (languages for different applications)
- Portability (machine-independent)
- Efficient to use (development time) due to
  - separation of data and instructions
  - typing
  - data-structures
  - blocks
  - program-flow primitives
  - subroutines

The structure of the compiler



Logical organisation

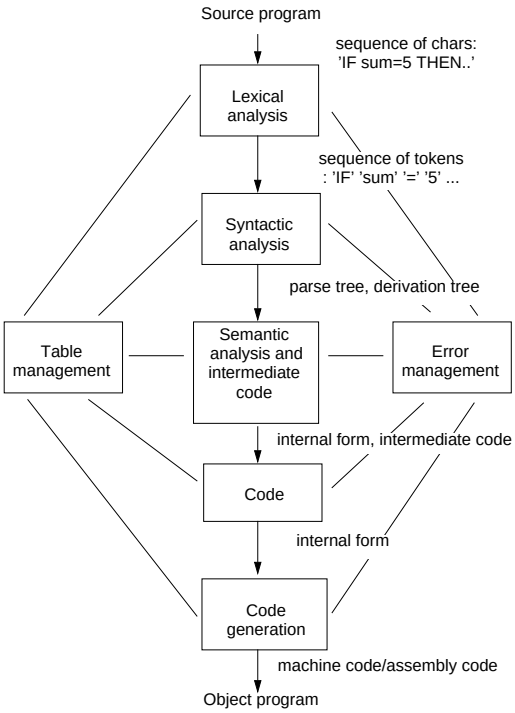
Analysis ("front-end"):

Pull apart the text string (the program) to internal structures, reveal the structure and meaning of the source program.

Synthesis ("back-end"):

Construct an object program using information from the analysis.

The phases of the compiler



Pass:

Physical organisation (phase to phase) dependent on language and compromises.

Available memory space, efficiency (time taken), forward references, portability- and modularity-requirements determine the number of passes.

The number of passes

The number of times the program is written in a file (or is read from a file).

Several phases can be gathered together in one pass.

Lexical analysis (scanner)

Input:

Sequence of characters

Output:

Tokens (basic symbols, groups of successive characters which belong together logically).

1. In the source text isolate and classify the basic elements that form the language:

Token	Example
Identifiers	`SUM, A`
Constants	`556, 1.5E-5`
Strings	`'Provide a number'`
Keywords, reserved words	`WHILE, IF`
Operators	`+ - * /`
Others	`. ; ^ ,`

2. Construct tables (symbol table, constant table, string table etc.).

3. Distinguish homonyms.

Homonyms:
Words that are pronounced and/or are written alike but which have different meanings.

- *feet, feat; spoke (of a wheel), spoke (talked)*
- *coach*: football *coach*, journey by *coach*

Example1: FORTRAN:

```
DO 10 I=1,15      is a loop, but
DO 10 I=1.15      is an assignment.
```

NB! Blanks have no meaning in FORTRAN.

Example 2: Pascal

```
VAR i: 15..25;
```


The scanner returns values in the form

<type, value>

Example: `IF sum < 15 THEN z := 153`

< 5, 0 >	5 = IF, 0 = lacks value
< 7, 14 >	7 = code for identifier, 14 = entry to symbol table
< 9, 1 >	9 = relational operator, 1 = '<'
< 1, 15>	1 = code for constant, 15 = value
< 2, 0 >	2 = THEN, 0 = lacks value
< 7, 9 >	7 = code for identifier, 9 = entry to symbol table
< 3, 0 >	3 = ':=', 0 = lacks value
< 1, 153 >	1 = code for constant, 153 = value

Index	Symbol table		
9	z		
.			
.			
14	sum		

Regular expressions are used to describe tokens.

Syntax analysis (parsing)

Input:

Sequence of tokens

Output:

Parse tree, error messages

Function:

1. Determine whether the input sequence forms a structure which is legal according to the definition of the language.

Example1: OK.

```
'IF' 'X' '=' '1' 'THEN' 'X' ':=' '1'
```

Example 2: Not OK.

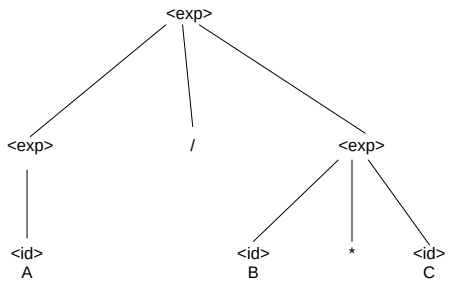
```
'IFF' 'X' '=' '1' 'THEN' 'X' ':=' '1'
```

which produces the sequence of tokens:

```
< 7, 23 >
< 7, 16 >     {Two identifiers in a row → wrong!}
< 9, 0 >
...
```

2. Group tokens into syntactic units and construct parse trees which exhibit the structure.

   Example: `A/B*C`



   represents `A/(B*C)`
   i.e. right-associative (is this desirable?)

   The syntax of a language is described using a context-free grammar.

Semantic analysis and intermediate code generation

Input:

Parse tree + symbol table

Output:

intermediate code + symbol table temp.variables, information on their type …

Function:

1. Semantic analysis checks items which a grammar can not describe:

   - type compatibility `a := i * 1.5`
   - correct number and type of parameters in calls to procedures as specified in the procedure declaration.

2. Generate intermediate code.

   Example: `A + B * C` in the form of a parse tree

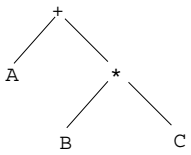
   Produces in reverse Polish notation:

   ```
   A B C * +
   ```

   Or three-address code:

   ```
   T1 := B * C
   T2 := A + T1
   ```


Or abstract syntax tree:



The intermediate form is used because it is:

1. Simpler than the high-level language (fewer and simpler operations).
2. Not profiled for a given machine (portability).
3. Suitable for optimisation.

Syntax-directed translation schemes are used to attach semantic routines (rules) to syntactic constructions.

Code optimisation (more appropriately: "Code improvement")

Input:

Internal form

Output:

Internal form, hopefully improved.

Machine-independent code optimisation:

In some way make the machine code faster or more compact by transforming the internal form.

Example: Eliminating common sub-expressions

Stepwise improvement		

`A:=B+C*I`
`D:=C*I+E`
	`T1:=C*I`
	`T2:=B+T1`
	`A:=T2`
	`T3:=C*I`
	`T4:=T3+E`
	`D:=T4`
		`T1:=C*I`
		`A:=B+T1`
		`D:=T1+E`

Example: Code with no effect!? (two assignments to the same variable)

`A:=B*C*D+4;` ← removed (or error message)
← logical error perhaps?

Code generation

Input:

Internal form

Output:

Machine code/assembly code

Function:

1. Register allocation and machine code generation (or assembly code).
2. Instruction scheduling (specially important for RISC)
3. Machine-dependent code optimisation (so-called “peephole optimisation”).

Example: `Z := A+B*C` is translated to:

```
MOVE  1, B
IMUL  1, C
ADD   1, A
MOVEM 1, Z
```


Table management

Updating and search in tables

- Symbol table (for identifiers)
- String table
- Constant table

Help for other phases during compilation.

Error management

1. Discover an error.
2. Write an error message.
3. Correct the error (or guess, very difficult!)
4. Restart from the error (try to continue).

Examples of error messages:

- Lexical analysis:

  Faulty sequence of characters which does not result in a token, e.g.

  `Ö, 5EL, %K, 'string`
- Syntax analysis:

  Syntax error (e.g. missing semicolon).
- Semantic analysis:

  Type conflict, e.g. `'HEJ'+5`
- Code optimisation:

  Uninitialised variables, anomaly detection.
- Code generation:

  Too large integers, run out of memory.
- Table management:

  Double declaration, table overflow.