Translation Strategy

Classic Software Engineering Problem

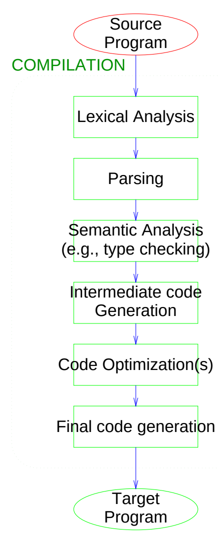
- **Objective:** Translate a program in a high level language into *efficient* executable code.
- **Strategy:** Divide translation process into a series of phases.
  Each phase manages some particular aspect of translation.

Interfaces between phases governed by specific intermediate forms.

Translation Steps

- Syntax Analysis Phase: Recognizes "sentences" in the program using the *syntax* of the language
- Semantic Analysis Phase: Infers information about the program using the *semantics* of the language
- Intermediate Code Generation Phase: Generates "abstract" code based on the syntactic structure of the program and the semantic information from Phase 2.
- Optimization Phase: Refines the generated code using a series of *optimizing* transformations.
- Final Code Generation Phase: Translates the abstract intermediate code into specific machine instructions.

Translation Process



Steps of Translation

1. **Lexical Analysis:** (Syntax Analysis Phase)
   - Convert the *stream of characters representing input program* into a sequence of *tokens*.
   - Tokens are the "words" of the programming language.
   - For instance, the sequence of characters "`static int`" is recognized as two tokens, representing the two words "static" and "int".
   - The sequence of characters "`*x++`" is recognized as three tokens, representing "*", "x" and "++".

Phases of Translation

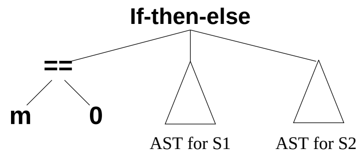
- Uncover the *structure* of a sentence in the program from a stream of *tokens*.
- For instance, the phrase "`x = +y`", which is recognized as four tokens, representing "x", "=" and "+" and "y", has the structure **=(x, +(y))**, i.e., an assignment expression, that operates on "x" and the expression "+(y)".
- Build a *tree* called a *parse tree* that reflects the structure of the input sentence.

Typically, compilers build an *abstract syntax tree* directly, skipping the construction of parse trees.

Abstract Syntax Tree (AST)

- Represents the syntactic structure of the program, hiding a few details that are irrelevent to later phases of compilation.
- For instance, consider a statement of the form: "`if (m == 0) S1 else S2`" where S1 and S2 stand for some block of statements.

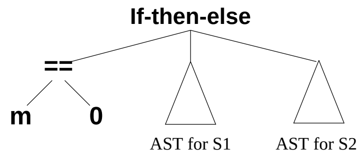
  A possible AST for this statement is:



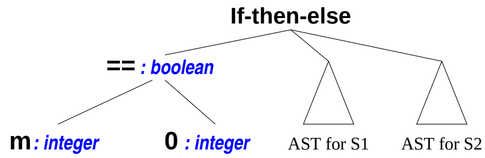
Phases of Translation

3. Type Checking: (Semantic Analysis)

- Decorate the AST with semantic information that is necessary in later phases of translation.
- For instance, the AST



is transformed into

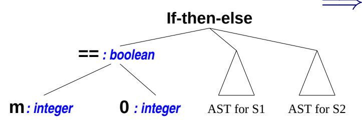


Phases of Translation

4. Intermediate Code Generation:

- Translate each sub-tree of the decorated AST into *intermediate code*.
- Intermediate code hides many machine-level details, but has instruction-level mapping to many assembly languages.
- Main motivation: portability.

Intermediate Code Generation, an Example



⟹

```
    loadint m
    loadimmed 0
    intequal
    jmpz  .L1
    jmp .L2
.L1:
        .... code for S1
    jmp .L3
.L2:
        .... code for S2
    jmp .L3
.L3:
```

Phases of Translation

5. Code Optimization

- Apply a series of transformations to improve the time and space efficiency of the generated code.
- *Peephole optimizations*: generate new instructions by combining/expanding on a small number of consecutive instructions.
- *Global optimizations*: reorder, remove or add instructions to change the structure of generated code.

Code Optimization, an Example

```
    loadint m                  ⟹      loadint m
    loadimmed 0                       jmpnz  .L2
    intequal                      .L1:
    jmpz  .L1                             .... code for S1
    jmp .L2                           jmp .L3
.L1:                              .L2:
        .... code for S1                  .... code for S2
    jmp .L3                       .L3:
.L2:
        .... code for S2
    jmp .L3
.L3:
```

Phases of Translation

6. Final Code Generation

- Map instructions in the intermediate code to specific machine instructions.
- Supports standard object file formats.
- Generates sufficient information to enable symbolic debugging.

Final Code Generation, an Example

```
    loadint m                  ⟹      movl  8(%ebp), %esi
    jmpnz  .L2                        testl %esi, %esi
.L1:                                  jne  .L2
        .... code for S1          .L1:
    jmp .L3                               .... code for S1
.L2:                                  jmp .L3
        .... code for S2          .L2:
.L3:                                      .... code for S2
                                  .L3:
```

Broader Applications of Languages

- Command Interpreters: `csh`, perl, ...
- Programming: FORTRAN, SmallTalk, ...
- Document Structuring: `troff`, LaTeX, HTML, ...
- Page Definition: PostScript, PCL, ...
- Databases: SQL, ...
- Hardware Design: VHDL, VeriLog, ...
- ... and many many more

Language Processing

Flexible control: programmable combination of primitive operations.

- Express input to the system in a well defined *language*.
- Translate the input into the sequence of primitive operations.
  - ▷ Direct execution
  - ▷ Byte code emulation
  - ▷ Object code compilation

Language processing techniques have evolved over the last 30 years.
In almost every domain, at least three steps can be identified: *lexical analysis, parsing, and syntax-directed translation.*