Translation Strategy

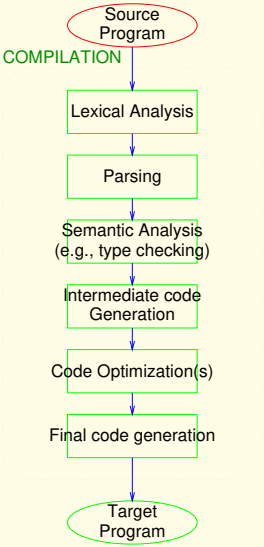
Classic Software Engineering Problem

- **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

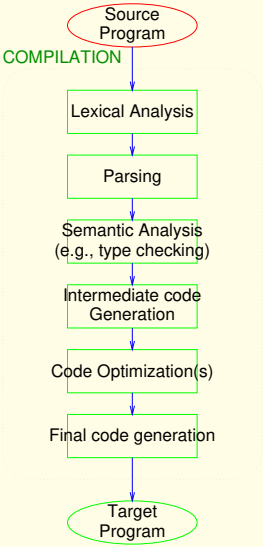
Semantic Analysis Phase: Infers information about the program using the *semantics* of the language

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.

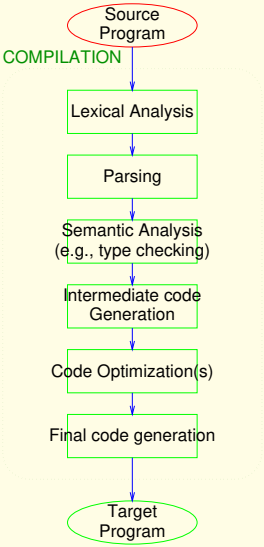
Final Code Generation Phase: Translates the abstract intermediate code into specific machine instructions.

Translation Steps: Lexical Analysis (Scanning 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 "++".

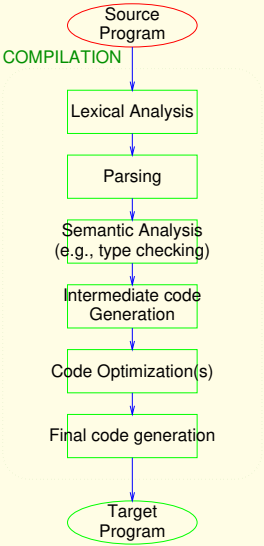
Translation Steps: Parsing (Syntax Analysis Phase)



- 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.

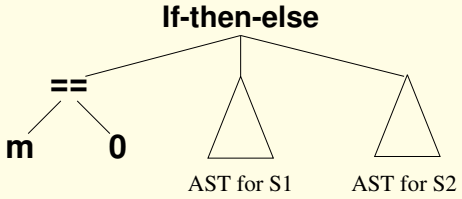
Translation Steps: Abstract Syntax Tree (AST)



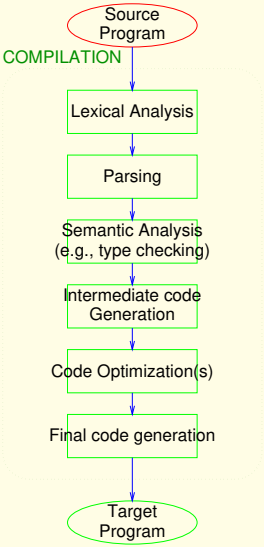
- Represents the syntactic structure of the program, hiding a few details that are irrelevent to later phases of compilation.
- For instance, consider a statement of the form:

```
if (m == 0) S1 else S2
```

where `S1` and `S2` stand for some block of statements. A possible AST for this statement is:

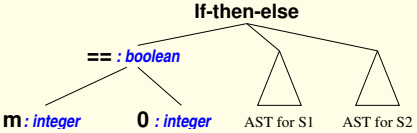


Translation Steps: Type Checking (Semantic Analysis)

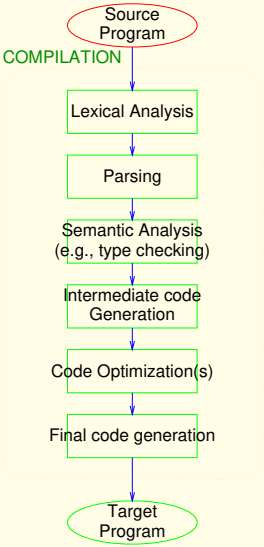


- Decorate the AST with semantic information that is necessary in later phases of translation.
- For instance, the AST

becomes

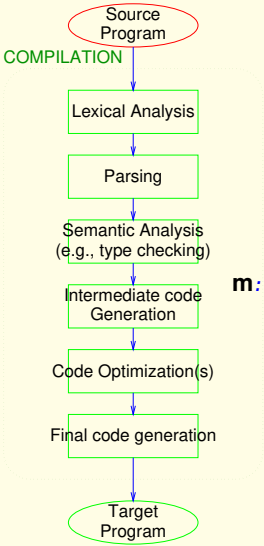


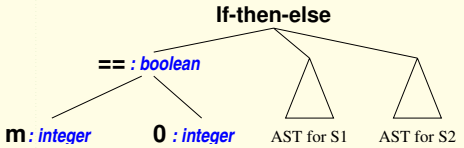
Translation Steps: Intermediate Code Generation



- 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.

Translation Steps: Intermediate Code Generation Example

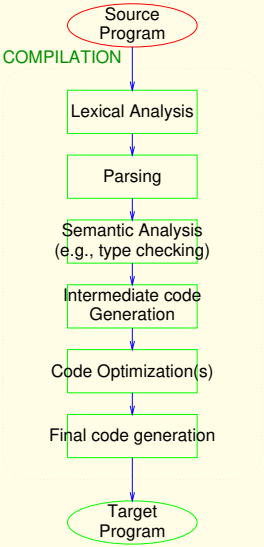




becomes

```
        R1 ← mem(m)
        cmp R1, 0
        jz .L1
        jmp .L2
.L1:
        ....  code for S1
        jmp .L3
.L2:
        ....  code for S2
        jmp .L3
.L3:
```

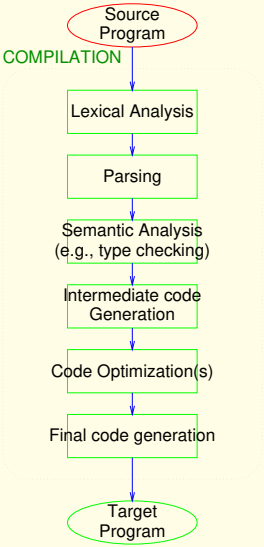
Translation Steps: Code Optimization



Apply a series of transformations to improve the time and space efficiency of the generated code.

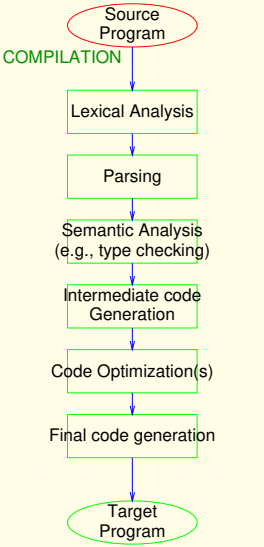
- *Peephole optimizations:* generate new instructions by combining/expanding on a small number of consecutive instructions.
- *Intraprocedural optimizations:* reorder, remove or add instructions to change the structure of generated code *within each function*. Code transformations guided by *static analysis.*
- *Interprocedural optimizations:* Guided by interprocedural static analysis.

Translation Steps: 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.

Translation Steps: Final Code Generation Example




```
    R1 ← mem(m)
    cmp R1, 0
    jz .L1
    jmp .L2
.L1:
    .... code
for S1
    jmp .L3
.L2:
    .... code
for S2
    jmp .L3
.L3:
```

$\Longrightarrow$

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

Broader Applications of Languages

- Command Interpreters: `bash`, ksh, Powershell, ...
- Programming: Java, Python, C++, Rust, Go, Haskell, Scala, OCaml, ...
- Document Structuring: LaTeX, HTML, RTF, `troff`, ...
- Page Definition: PDF, PostScript, ...
- Databases: SQL, ...
- Hardware Design: VHDL, VeriLog, ...
- Domain-Specific Languages (DSL)