Introduction to Compiler

What is a Compiler?

- Compilers translate from a source language (typically a high level language such as C, C++) to a functionally equivalent target language (typically the machine code of a particular machine or a machine-independent virtual machine).

- Compilers for high level programming languages are among the larger and more complex pieces of software.

Why Should We Study Compiler Design?

Compilers are everywhere!

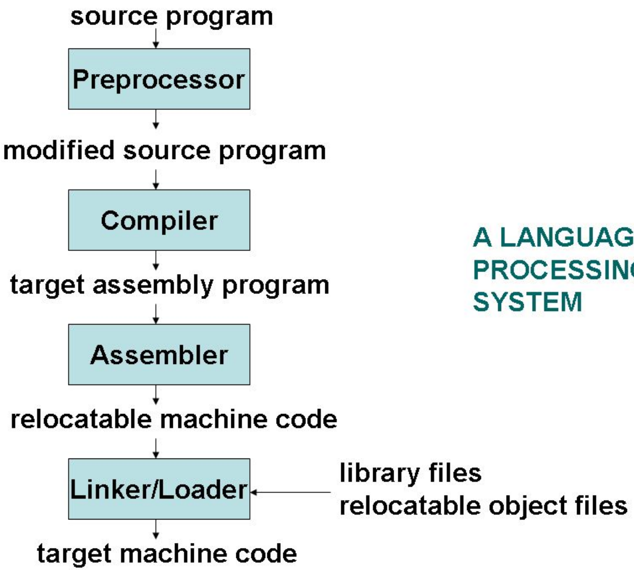
Many applications for compiler technology

- Parsers for HTML in web browser
- Interpreters for javascript/flash
- Machine code generation for high level languages
- Software testing
- Program optimization
- Malicious code detection
- Design of new computer architectures

About the Complexity of Compiler Technology

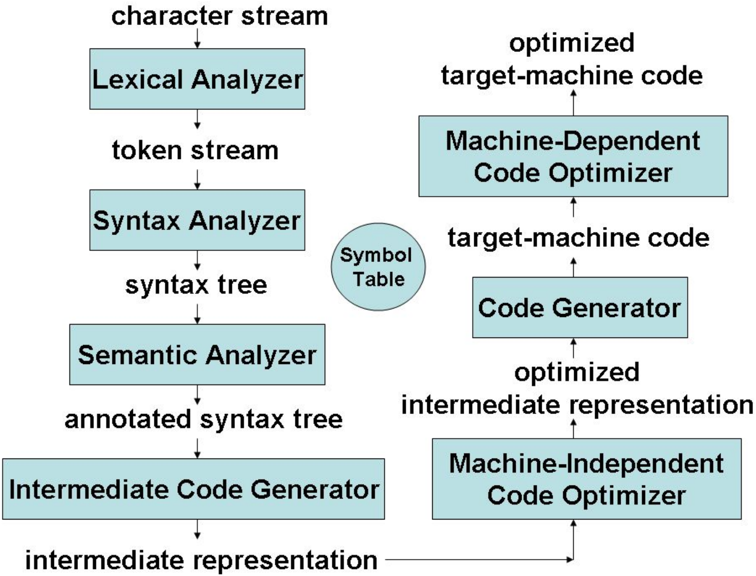
- A compiler is possibly the most complex system software and writing it is a substantial exercise in software engineering
- The complexity arises from the fact that it is required to map a programmer's requirements (in a HLL program) to architectural details
- It uses algorithms and techniques from a very large number of areas in computer science
- Translates complex theory into practice - enables tool building

Language Processing System



A LANGUAGE PROCESSING SYSTEM

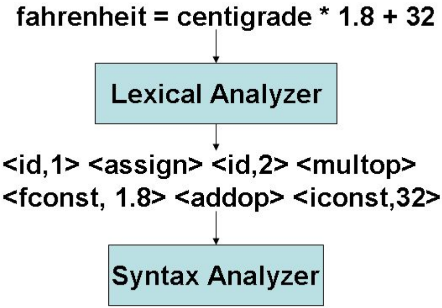
Compiler Overview



Compilers and Interpreters

- Compilers generate machine code, whereas interpreters interpret intermediate code
- Interpreters are easier to write and can provide better error messages (symbol table is still available)
- Interpreters are at least 5 times slower than machine code generated by compilers
- Interpreters also require much more memory than machine code generated by compilers

Translation Overview - Lexical Analysis

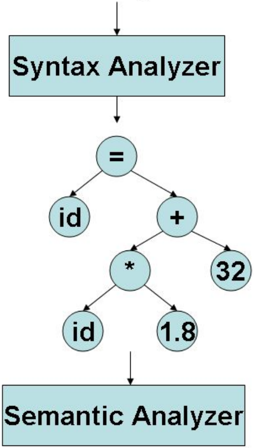


Lexical Analysis

- LA can be generated automatically from regular expression specifications
  - LEX and Flex are two such tools
- LA is a deterministic finite state automaton

Translation Overview - Syntax Analysis

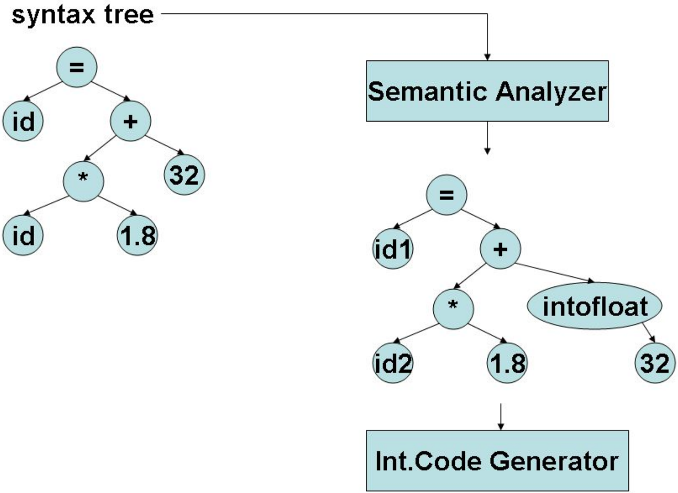
<id,1> <assign> <id,2> <multop>
<fconst, 1.8> <addop> <iconst,32>



Parsing or Syntax Analysis

- Syntax analyzers (parsers) can be generated automatically from several variants of context-free grammar specifications
  - LL(1), and LALR(1) are the most popular ones
  - ANTLR (for LL(1)), YACC and Bison (for LALR(1)) are such tools
- Parsers are deterministic ***push down automata***
- Parsers cannot handle context-sensitive features of programming languages; e.g.,
  - Variables are declared before use
  - Types match on both sides of assignments
  - Parameter types and number match in declaration and use

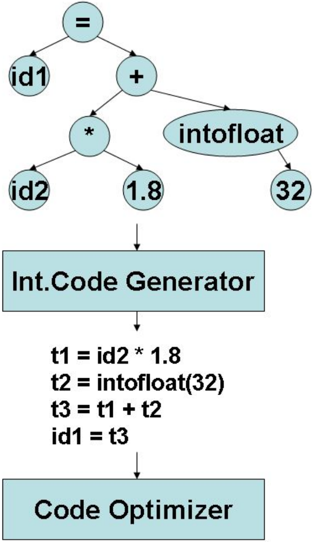
Translation Overview - Semantic Analysis



Semantic Analysis

- Semantic consistency that cannot be handled at the parsing stage is handled here
- Type checking of various programming language constructs is one of the most important tasks
- Stores type information in the symbol table or the syntax tree
  - Types of variables, function parameters, array dimensions, etc.
  - Used not only for semantic validation but also for subsequent phases of compilation
- Static semantics of programming languages can be specified using attribute grammars

Translation Overview - Intermediate Code Generation



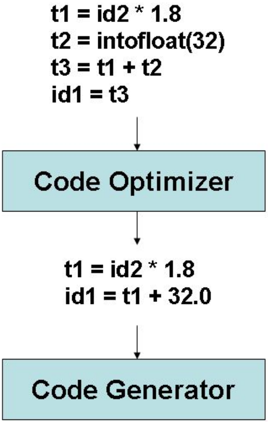
Intermediate Code Generation

- While generating machine code directly from source code is possible, it entails two problems
  - With m languages and n target machines, we need to write $m \times n$ compilers
  - The code optimizer which is one of the largest and very-difficult-to-write components of any compiler cannot be reused
- By converting source code to an intermediate code, a machine-independent code optimizer may be written
- Intermediate code must be easy to produce and easy to translate to machine code
  - A sort of universal assembly language
  - Should not contain any machine-specific parameters (registers, addresses, etc.)

Different Types of Intermediate Code

- The type of intermediate code deployed is based on the application
- Quadruples, triples, indirect triples, abstract syntax trees are the classical forms used for machine-independent optimizations and machine code generation
- Static Single Assignment form (SSA) is a recent form and enables more effective optimizations
  - Conditional constant propagation and global value numbering are more effective on SSA
- Program Dependence Graph (PDG) is useful in automatic parallelization, instruction scheduling, and software pipelining

Translation Overview - Code Optimization



Machine-independent Code Optimization

- Intermediate code generation process introduces many inefficiencies
  - Extra copies of variables, using variables instead of constants, repeated evaluation of expressions, etc.
- Code optimization removes such inefficiencies and improves code
- Improvement may be time, space, or power consumption
- It changes the structure of programs, sometimes of beyond recognition
  - Inlines functions, unrolls loops, eliminates some programmer-defined variables, etc.
- Code optimization consists of a bunch of heuristics and percentage of improvement depends on programs (may be zero also)

Examples of Machine-Independant Optimizations

- Common sub-expression elimination
- Copy propagation
- Loop invariant code motion
- Partial redundancy elimination
- Induction variable elimination and strength reduction
- Code optimization needs information about the program
  - which expressions are being recomputed in a function?
  - which definitions reach a point?
- All such information is gathered through data-flow analysis

Translation Overview - Code Generation

```
t1 = id2 * 1.8
id1 = t1 + 32.0
```

↓

Code Generator

↓

```
LDF R2, id2
MULF R2, R2, 1.8
ADDF R2, R2, 32.0
STF id1, R2
```

Code Generation

- Converts intermediate code to machine code
- Each intermediate code instruction may result in many machine instructions or vice-versa
- Must handle all aspects of machine architecture
  - Registers, pipelining, cache, multiple function units, etc.
- Generating efficient code is an NP-complete problem
  - Tree pattern matching-based strategies are among the best
  - Needs tree intermediate code
- Storage allocation decisions are made here
  - Register allocation and assignment are the most important problems

Machine Dependent Code Optimization

- Peephole optimizations
  - Analyze sequence of instructions in a small window (peephole) and using preset patterns, replace them with a more efficient sequence
  - Redundant instruction elimination

    e.g., replace the sequence [LD A,R1][ST R1,A] by [LD A,R1]
  - Eliminate “jump to jump” instructions
- Use machine idioms (use INC instead of LD and ADD)
- Instruction scheduling (reordering) to eliminate pipeline interlocks and to increase parallelism
- Trace scheduling to increase the size of basic blocks and increase parallelism
- Software pipelining to increase parallelism in loops