Topic #11: Compilers

CSE 413, Autumn 2004

Programming Languages

http://www.cs.washington.edu/education/courses/413/04au/

1

Credits

- Much of the material in the following lectures is
  - » derived from Doug Johnson, CSE 413…
  - » derived from Hal Perkins, CSE 413 and CSE 582…
  - » derived from…
    - Cornell CS 412-3 (Teitelbaum, Perkins)
    - Rice CS 412 (Cooper, Kennedy, Torczon)
    - UW CSE 401 (Chambers, Ruzzo, et al)

2

References

- Primary Reference
  - » Sebesta text, Chapters 3 and 4
  - » READ 3-3.3. SKIM 3.4-3.5
  - » READ Chapter 4
- Other references
  - » *Engineering a Compiler* by Keith Cooper & Linda Torczon
  - » *Modern Compiler Implementation in Java*, by Appel

3

Why are we doing this?

- Execute this ...

```
int nPos = 0;
int k = 0;
while (k < length) {
   if (a[k] > 0) {
      nPos++;
   }
}
```

- How?

4

Interpreters & Compilers

- Interpreter
- Compiler

5

Common Issues

- Compilers and interpreters both must read the input – a stream of characters – and “understand” it; *analysis*

```
w h i l e ( k < l e n g t h ) { <nl> <tab> i f ( a [ k
] > 0 ) <nl> <tab> <tab>{ n P o s + + ; } <nl> <tab> }
```

6

Interpreter

- Interpreter
  - » Execution engine
  - » Program execution interleaved with analysis

```
running = true;
while (running) {
    analyze next statement;
    execute that statement;
}
```

7

Compiler

- Read and analyze entire program
- Translate to semantically equivalent program in another language
  - » Presumably easier to execute or more efficient
  - » Should "improve" the program in some fashion
- Offline process

8

Typical Implementations

- Compilers
  - » FORTRAN, C, C++, Java, C#, COBOL, etc. etc.
- Interpreters
  - » PERL, Python, awk, sed, sh, csh, postscript printer, Java VM
  - » Functional languages like Scheme and Smalltalk where the environment is dynamic

9

Hybrid approaches

- Well-known example: Java
  - » Compile Java source to byte codes – Java Virtual Machine language (.class files)
  - » Execution

10

Why Study Compilers? *Programmer*

- Become a better programmer
  - » Insight into interaction between languages, compilers, and hardware
  - » Understanding of implementation techniques
  - » What is all that stuff in the debugger anyway?
  - » Better intuition about what your code does
- You might even write a compiler some day!

11

Why Study Compilers? *Designer*

- Compiler techniques are everywhere
  - » Parsing (little languages, interpreters)
  - » Database engines
  - » AI: domain-specific languages
  - » Text processing
    - Tex/LaTex -> dvi -> Postscript -> pdf
  - » Hardware: VHDL; model-checking tools

12

Why Study Compilers? *Theoretician*

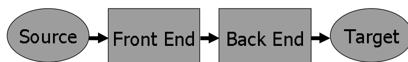
- Fascinating blend of theory and engineering
  - » Direct applications of theory to practice
  - » Some very difficult problems (NP-hard or worse)

Why Study Compilers? *Education*

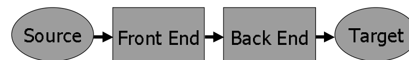
- Ideas from many parts of CSE
  - » AI: Greedy algorithms, heuristic search
  - » Algorithms: graph algorithms, dynamic programming, approximation algorithms
  - » Theory: Grammars DFAs and PDAs, pattern matching, fixed-point algorithms
  - » Systems: Allocation & naming, synchronization, locality
  - » Architecture: pipelines & hierarchy management, instruction set use
- Application to many other problem domains

Structure of a Compiler

- First approximation
  - » Front end:
    - Read source program and understand structure/meaning
  - » Back end:
    - Generate equivalent target language program



Implications



Intermediate Representation (IR)

Front End

- Split into two parts

- Both can be generated automatically or by hand
  - » Source language specified by a formal grammar
  - » Tools read the grammar and generate scanner & parser (either table-driven or hard coded)

Tokens

- Token stream: Each significant lexical chunk of the program is represented by a token
  - » Operators & Punctuation: {}[]!+-=*;: …
  - » Keywords: if while return goto
  - » Identifiers:
    (variables, procedure names…)
  - » Constants:
    (int, floating-point character, string, …)

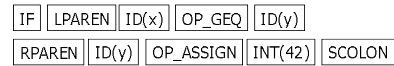
19

Scanner Example

- Input text

```
// this line is a simple comment
if (x >= y) y = 42;
```

- Token Stream



20

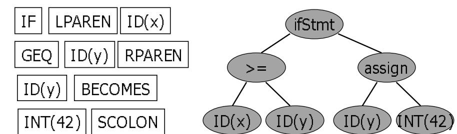
Parser Output (IR)

- Many different forms
- Common output from a parser is an abstract syntax tree
  - » Essential meaning of the program without the syntactic noise

21

Parser Example

- Token Stream Input
- Abstract Syntax Tree



22

Static Semantic Analysis

- During or (more common) after parsing
  - » Type checking
  - » Check for language requirements
  - » Preliminary resource allocation
  - » Collect other information needed by back end analysis and code generation

23

Back End

- Responsibilities
  - » Translate IR into target machine code
  - » Should produce fast, compact code
  - » Should use machine resources effectively
    - Registers
    - Instructions
    - Memory hierarchy

24

Back End Structure

- Typically split into two major parts with sub phases
  - » "Optimization" – code improvements
  - » Code generation

25

The Result

```
if (x >= y)
  y = 42;
```

x86 assembly language

```
mov   eax,[ebp+16]
cmp   eax,[ebp-8]
jl        L17
mov    [ebp-8],42
L17:
```

Java bytecode

```
4:   iload_1
5:   iload_2
6:   if_icmplt 12
9:   bipush  42
11:  istore_2
12:
```

Postscript

```
x y ge
{/y 42 def}
if
```

26

Some Ancient History

- 1950's. Existence proof
  - » FORTRAN I (1954) – competitive with hand-optimized code
- 1960's
  - » New languages: ALGOL, LISP, COBOL
  - » Formal notations for syntax
  - » Fundamental implementation techniques
    - Stack frames, recursive procedures, etc.

27

Some Later History

- 1970's
  - » Syntax: formal methods for producing compiler front-ends; many theorems
- 1980's
  - » New languages (functional; Smalltalk & object-oriented)
  - » New architectures (RISC machines, parallel machines, memory hierarchy issues)
  - » More attention to back-end issues

28

Some Recent History

- 1990's – now
  - » Compilation techniques appearing in many new places
    - Just-in-time compilers (JITs)
    - Whole program analysis
  - » Phased compilation – blurring the lines between "compile time" and "runtime"
  - » Compiler technology critical to effective use of new hardware (RISC, Itanium, complex memories)

29