CSE401: Introduction to Compiler Construction

David Notkin
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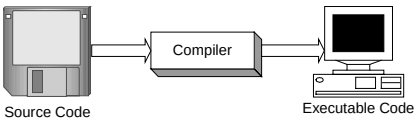
Today's objectives

- Defining compilers and why we study them
- Defining the high-level structure of compilers
- Associating specific tasks, theories, and technologies with achieving the different structural elements of a compiler
  - And building some initial intuition about why these are needed

What is a compiler?



- A software tool that translates
  - a program in source code form to
  - an equivalent program in an executable (target) form
- Converts from a form good for people to a form good for computers

Examples

- Source languages
  - Java
  - C
  - ML
  - COBOL
  - …
- Target architectures
  - MIPS
  - x86
  - SPARC
  - Alpha
  - …

Why study compilers?

- In groups (of 3-5 people), list as many reasons as you can in one minute

- I'm going to try to do a significant amount of active learning in this course
- We'll all need to practice, but the benefits should be real

CSE401's project-oriented approach

- Start with a compiler for PL/0, written in C++
- We define additional language features
  - Such as comments, arrays, call-by-reference parameters, result-returning procedures, for loops, etc.
- You modify the compiler to translate the extended PL/0 language
  - Project completed in well-defined stages

More on the project

- Strongly recommended that you work in two-person teams for the quarter
- Grading based on
  - correctness
  - clarity of design and implementation
  - quality of testing
- Provides experience with object-oriented design and with C++
- Provides experience with working on a team

Break into groups

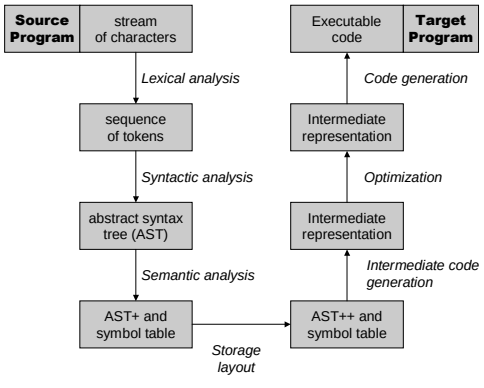
- I will present a small program to you, character by character
- In 5 minutes, each group will identify problems that you can see that you will encounter in compiling this program
- Here's an example problem
  - When we see a character `'1'` followed by a character `'7'`, we have to convert it to the integer 17.


```
1.  i      11. 1      21. i
2.  n      12. 7      22. *
3.  t      13. □      23. i
4.  □      14. ;      24. )
5.  i      15. p      25. ;
6.  ;      16. r
7.  □      17. i
8.  i      18. n
9.  :      19. t
10. =      20. (
```

- □ is the space character
- This is not a PL/0 program!

Structure of compilation

- A common compiler structure has been defined
  - Years and years of deep, difficult research intermixed with building of thousands of compilers
- Actual compilers often differ from this prototypical model
  - The primary differences are the ordering and the clarity with which the pieces are actually separated
  - But the model is still extremely useful
- You will see the structure — to a large degree — in the PL/0 compiler



Front- and back-end

- These parts of the compiler structure are often split into two categories
- The front-end
  - Focuses on (repeated) analysis
  - Determines what the program is
- The back-end
  - Focuses on synthesis
  - Produces the target program that is equivalent to the source program

An example compilation

```
module main;
  var x:int, result: int;
  procedure square(n:int);
  begin
    result := n*n;
  end square;
begin
  x := input;
  while x <> 0 do
    square(x);
    output := result;
    x := input;
  end;
end main.
```

- A real PL/0 program
- We'll step through
  - Lexical analysis
  - Syntactic analysis
  - Semantic analysis
  - Storage layout
  - Code generation

Lexical analysis

(AKA scanning and tokenizing)

- Read in characters and clump them into **tokens**
  - Also strip out white space and comments
- Use regular expressions to specify tokens
- Use finite state machines to scan
- Remember the connection between regular expressions and finite state machines

```
Ident    ::= Letter AlphaNum*
Integer  ::= Digit+
AlphaNum ::= Letter | Digit
Letter   ::= 'a'|…|'z'|…|
             'A'|…|'Z'
Digit    ::= '0'|…|'9'
```


Syntactic analysis

(AKA parsing)

- Turn token stream into tree based on the program's syntactic structure
- Define syntax using context free grammar (CFG)
  - EBNF is a common notation for defining *concrete syntax*
    - Cares about semi-colons and such
  - Parser usually constructs AST representing *abstract syntax*
    - Cares about statement structures and such

```
Stmt   ::= Astmt | IfStmt | …
Astmt  ::= Lvalue := Expr ;
Lvalue ::= Id
IfStmt ::= if Test then Stmt
           [else Stmt] ;
Test   ::= Expr = Expr |
           Expr < Expr | …
Expr   ::= Term + Term |
           Term – Term | Term
Term   ::= Factor * Factor |
           … | Factor
Factor ::= - Factor | Id |
           Int | ( Expr )
```


Semantic analysis

(Name resolution and type checking)

- Given AST
  - figure out what declaration each name refers to
  - perform static consistency checks
- Key data structure: *symbol table*
  - maps names to information about name derived from declaration
- Semantic analysis steps
  - Process each scope, top down
  - Process declarations in each scope into symbol table for scope
  - Process body of each scope in context of symbol table

Storage layout

- Given symbol table, determine how and where variables will be stored at runtime
- What representation is used for each kind of data?
- How much space does each variable require?
- In what kind of memory should it be placed?
  - static, global memory
  - stack memory
  - heap memory
- Where in memory should it be placed?
  - e.g., what stack offset?

Code generation

- Given annotated AST and symbol table, produce target code
- Often done as three steps
  - Produce machine-independent low-level representation of the program (*intermediate representation* or *IR*)
  - Perform machine-independent optimizations (optional)
  - Translate IR into machine-specific target instructions
    - Instruction selection
    - Register allocation

Compilers vs. interpreters

- Compilers implement languages by translation
- Interpreters implement languages directly
- Note: the line is not always crystal-clear
- Compilers and interpreters have tradeoffs
  - Execution speed of program
  - Start-up overhead, turn-around time
  - Ease of implementation
  - Programming environment facilities
  - Conceptual clarity

Engineering issues in compiling

- Portability
  - Ideal is multiple front-ends and multiple back-ends with a shared intermediate language
- Sequencing phases of compilation
  - Stream-based vs. syntax-directed
- Multiple, separate passes vs. fewer, integrated passes
- How to avoid compiler bugs?

Objectives: next lecture

- Define overall theory and practical structure of lexical analysis
- Briefly recap regular expressions, finite state machines, and their relationship
  - Even briefer recap of the language hierarchy
- Show how to define tokens with regular expressions
- Show how to leverage this style of token definition in implementing a lexer