CSE 401: Introduction to Compiler Construction

Text: *Modern Compiler Implementation in Java, Second Edition,* by Appel, with Palsberg

Suggested: *Compilers - Principles, Techniques, and Tools*, by Aho *et al.* (the "Dragon Book")

Goals:

- learn principles & practice of language implementation
  - brings together theory & pragmatics of previous courses
  - understand compile-time vs. run-time processing
- study interactions among:
  - language features
  - implementation efficiency
  - compiler complexity
  - architectural features
- gain more experience with object-oriented design & Java
- gain more experience working on a team

Prerequisites: 322, 326, 341, 378

Sign up on course mailing list!

Course Outline

Compiler front-ends:

- lexical analysis (scanning): characters → tokens
- syntactic analysis (parsing): tokens → abstract syntax trees
- semantic analysis (typechecking): annotate ASTs

Midterm

Compiler back-ends:

- intermediate code generation: ASTs → intermediate code
- target code generation: intermediate code → target code
  - run-time storage layout
  - target instruction selection
  - register allocation
- optimizations

Final

Project

Start with compiler for MiniJava, written in Java

Add:

- comments
- floating-point values
- arrays
- static (class) variables
- for loops
- break statements
- and more

Completed in stages over the quarter

Strongly encourage working in a 2-person team on project

- but only if joint work, not divided work

Grading based on:

- correctness
- clarity of design & implementation
- quality of test cases

Grading

Project: 40% total

Homework: 20% total

Midterm: 15%

Final: 25%

Homework & projects due at the **start of class**

3 free late days, per person, for the whole quarter

- thereafter, 25% off per calendar day late

An example compilation

Sample (extended) MiniJava program: `Factorial.java`

```
// Computes 10! and prints it out
class Factorial {
   public static void main(String[] a) {
      System.out.println(
         new Fac().ComputeFac(10));
     }
}

class Fac {
   // the recursive helper function
   public int ComputeFac(int num) {
      int numAux;
      if (num < 1)
         numAux = 1;
      else
         numAux = num * this.ComputeFac(num-1);
      return numAux;
   }
}
```

First step: lexical analysis

“Scanning”, “tokenizing”

Read in characters, clump into **tokens**

- strip out whitespace & comments in the process

Specifying tokens: regular expressions

Example:

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

Second step: syntactic analysis

“Parsing”

Read in tokens, turn into a tree based on syntactic structure

- report any errors in syntax

Specifying syntax: context-free grammars

EBNF is a popular notation for CFG's

Example:

```
Stmt    ::= if ( Expr ) Stmt [else Stmt]
          | while ( Expr ) Stmt
          | ID = Expr;
          | ...
Expr    ::= Expr + Expr | Expr < Expr | ...
          | ! Expr
          | Expr . ID ( [Expr {, Expr}] )
          | ID
          | Integer | ...
          | (Expr)
          | ...
```

EBNF specifies *concrete syntax* of language

Parser usually constructs tree representing *abstract syntax* of language

Third step: semantic analysis

"Name resolution and typechecking"

Given AST:
- figure out what declaration each name refers to
- perform typechecking and other static consistency checks

Key data structure: symbol table
- maps names to info about name derived from declaration
- tree of symbol tables corresponding to nesting of scopes

Semantic analysis steps:
1. Process each scope, top down
2. Process declarations in each scope into symbol table for scope
3. Process body of each scope in context of symbol table

Fourth step: intermediate code generation

Given annotated AST & symbol tables,
translate into lower-level intermediate code

Intermediate code is a separate language
- Source-language independent
- Target-machine independent

Intermediate code is simple and regular
⇒ good representation for doing optimizations

Might be a reasonable target language itself, e.g. Java bytecode

Example

```
int Fac.ComputeFac(*? this, int num) {
   int T1, numAux, T8, T3, T7, T2, T6, T0;
   T0 := 1;
   T1 := num < T0;
   ifnonzero T1 goto L0;
   T2 := 1;
   T3 := num - T2;
   T6 := Fac.ComputeFac(this, T3);
   T7 := num * T6;
   numAux := T7;
   goto L2;
   label L0;
   T8 := 1;
   numAux := T8;
   label L2;
   return numAux;
}
```

Fifth step: target (machine) code generation

Translate intermediate code into target code

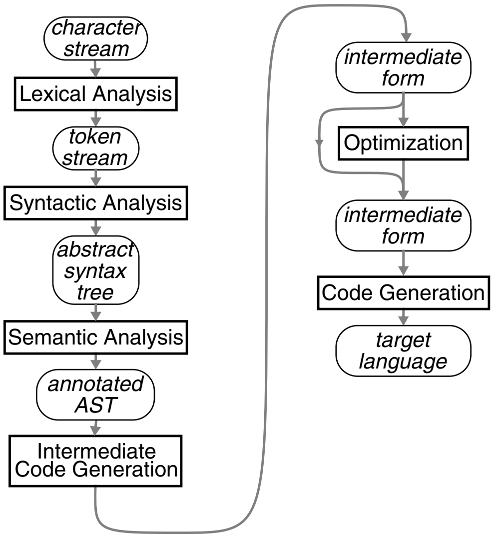
Need to do:

- instruction selection: choose target instructions for (subsequences of) intermediate code instructions
- register allocation: allocate intermediate code variables to machine registers, spilling excess to stack
- compute layout of each procedure's stack frame & other run-time data structures
- emit target code

Summary of compiler phases

Analysis
of input program
(**front-end**)

Synthesis
of output program
(**back-end**)



character stream

Lexical Analysis

token stream

Syntactic Analysis

abstract syntax tree

Semantic Analysis

annotated AST

Intermediate Code Generation

intermediate form

Optimization

intermediate form

Code Generation

target language

Ideal: many front-ends, many back-ends sharing one intermediate language

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Other language processing tools

Compilers translate the input language into a different, usually lower-level, target language

Interpreters directly execute the input language

- same front-end structure as a compiler
- then evaluate the annotated AST, or translate to intermediate code and evaluate that

Software engineering tools can resemble compilers

- same front-end structure as a compiler
- then:
  - pretty-print/reformat/colorize
  - analyze to compute relationships like declarations/uses, calls/callees, etc.
  - analyze to find potential bugs
  - aid in refactoring/restructuring/evolving programs

Engineering issues

Compilers are hard to design so that they are

- fast
- highly optimizing
- extensible & evolvable
- correct

Some parts of compilers can be automatically generated from specifications, e.g., scanners, parsers, & target code generators

- generated parts are fast & correct
- specifications are easily evolvable

(Some of my current research is on generating fast, correct optimizations from specifications.)

Need good management of software complexity