Programming Languages and Translators

COMS W4115

Pieter Bruegel, *The Tower of Babel*, 1563

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Fall 2004
Columbia University
Department of Computer Science

Instructor

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Schedule

Tuesdays and Thursdays, 11:00 AM to 12:15 PM

Room 535, Seeley W. Mudd

Lectures: September 7 to December 9

Midterm: November 9

Final: December 9

Final project report: December 21

Holidays: November 2 (Election day), November 25 (Thanksgiving)

Objectives

Theory of language design

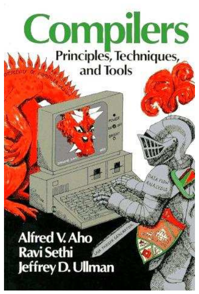
- Finer points of languages
- Different languages and paradigms

Practice of Compiler Construction

- Overall structure of a compiler
- Automated tools and their use
- Lexical analysis to assembly generation

Required Text

Alfred V. Aho, Ravi Sethi, and Jeffrey D. Ullman.
Compilers: Principles, Techniques, and Tools.
Addison-Wesley, 1985.



Assignments and Grading

40% Programming Project

20% Midterm (near middle of term)

30% Final (at end of term)

10% Individual homework

Project is most important, but most students do well on it. Grades for tests often vary more.

Prerequisite: Java Fluency

You and your group will write perhaps 5000 lines of Java; you will not have time to learn it.

We will be using a tool that generates fairly complicated Java and it will be necessary to understand the output.

Prerequisite: COMS W3157 Advanced Programming

Teams will build a large software system

Makefiles, version control, test suites

Testing will be as important as development

Prerequisite: COMS W3261 Computability and Models of Computation

You need to understand grammars

We will be working with regular and context-free languages

Class Website

Off my home page,
http://www1.cs.columbia.edu/˜sedwards/

Contains syllabus, lecture notes, and assignments.

Schedule will be continually updated during the semester.

Collaboration

Collaborate with your team on the project.

Exception: CVN students do the project by themselves.

Homework is to be done by yourself.

Tests: Will be closed book with a one-page “cheat sheet” of your own devising.

The Project

The Project

Design and implement your own little language.

Five deliverables:

1. A white paper describing and motivating your language
2. A language reference manual defining it formally
3. A compiler or interpreter for your language running on some sample programs
4. A final project report
5. A final project presentation

Teams

Immediately start forming four-person teams to work on this project.

Each team will develop its own langauge.

Suggested division of labor: Front-end, back-end, testing, documentation.

All members of the team should be familiar with the whole project.

Exception: CVN students do the project by themselves.

First Three Tasks

1. Decide who you will work with

   You’ll be stuck with them for the term; choose wisely.

2. Elect a team leader

   Languages come out better from dictatorships, not democracies. Besides, you’ll have someone to blame.

3. Select a weekly meeting time

   Harder than you might think. Might want to discuss with a TA you’d like to have so it is convenient for him/her as well.

White Paper

Follow the style of the Java white paper (see the class website for a link), but tone down the marketing hype.

4–8 pages.

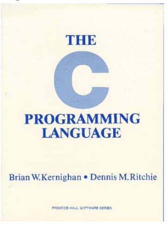
Answer the question, “why another language?” with a description of what problem your language solves and how it should be used.

Small snippets of code to show syntax is enough.

Language Reference Manual

A careful definition of the syntax and semantics of your language.

Follow the style of the C language reference manual (Appendix A of Kernighan and Ritchie, *The C Programming Langauge*; see the class website).



Final Report Sections

1. Introduction: the white paper
2. Language Tutorial
3. Language Reference Manual
4. Project Plan
5. Architectural Design
6. Test Plan
7. Lessons Learned
8. Complete listing

Due Dates

White Paper	September 28 *soon*
Reference Manual	October 21
Final Report	December 21

Design a language?

A small, domain-specific language.

Think of awk or php, not Java or C++.

Examples from earlier terms:

Quantum computing language

Geometric figure drawing language

Projectile motion simulation langauge

Matlab-like array manipulation language

Screenplay animation language

Other language ideas

Simple animation language

Model train simulation language

Escher-like pattern generator

Music manipulation language (harmony)

Web surfing language

Mathematical function manipulator

Simple scripting language (à lá Tcl)

Petri net simulation language

What's in a Language?

Components of a language: Syntax

How characters combine to form words, sentences, paragraphs.

`The quick brown fox jumps over the lazy dog.`

is syntactically correct English, but isn't a Java program.

```
class Foo {
  public int j;
  public int foo(int k) { return j + k; }
}
```

Is syntactically correct Java, but isn't C.

Specifying Syntax

Usually done with a context-free grammar.

Typical syntax for algebraic expressions:

$$
\begin{array}{rcl}
\textit{expr} & \rightarrow & \textit{expr} + \textit{expr} \\
& | & \textit{expr} - \textit{expr} \\
& | & \textit{expr} * \textit{expr} \\
& | & \textit{expr} / \textit{expr} \\
& | & \textbf{digit} \\
& | & (\textit{expr})
\end{array}
$$

Components of a language: Semantics

What a well-formed program "means."

The semantics of C says this computes the nth Fibonacci number.

```
int fib(int n)
{
  int a = 0, b = 1;
  int i;
  for (i = 1 ; i < n ; i++)
    int c = a + b;
    a = b;
    b = c;
  }
  return b;
}
```

Semantics

Something may be syntactically correct but semantically nonsensical.

> The rock jumped through the hairy planet.

Or ambiguous

> The chickens are ready for eating.

Semantics

Nonsensical in Java:

```
class Foo {
  int bar(int x) { return Foo; }
}
```

Ambiguous in Java:

```
class Bar {
  public float foo() { return 0; }
  public int foo() { return 0; }
}
```

Specifying Semantics

Doing it formally beyond the scope of this class, but basically two ways:

- Operational semantics

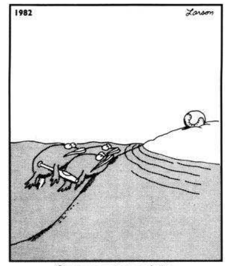
  Define a virtual machine and how executing the program evolves the state of the virtual machine

- Denotational semantics

  Shows how to build the function representing the behavior of the program (i.e., a transformation of inputs to outputs) from statements in the language.

Most language definitions use an informal operational semantics written in English.

Great Moments in Programming Language Evolution



Great moments in evolution

Assembly

```
Before: numbers     After: Symbols
55                  gcd: pushl %ebp
89E5                     movl  %esp, %ebp
8B4508                   movl  8(%ebp), %eax
8B550C                   movl  12(%ebp), %edx
39D0                     cmpl  %edx, %eax
740D                     je    .L9
39D0                .L7: cmpl  %edx, %eax
7E08                     jle   .L5
29D0                     subl  %edx, %eax
39D0                .L2: cmpl  %edx, %eax
75F6                     jne   .L7
C9                  .L9: leave
C3                       ret
29C2                .L5: subl  %eax, %edx
EBF6                     jmp   .L2
```

FORTRAN

```
Before                          After: Expressions, control-flow
gcd: pushl %ebp                  10    if (a .EQ. b) goto 20
     movl  %esp, %ebp                  if (a .LT. b) then
     movl  8(%ebp), %eax                  a = a - b
     movl  12(%ebp), %edx              else
     cmpl  %edx, %eax                     b = b - a
     je    .L9                         endif
.L7: cmpl  %edx, %eax                  goto 10
     jle   .L5                   20    end
     subl  %edx, %eax
.L2: cmpl  %edx, %eax
     jne   .L7
.L9: leave
     ret
.L5: subl  %eax, %edx
     jmp   .L2
```

COBOL

Added type declarations, record types, file manipulation

```
data division.
file section.
*   describe the input file
fd  employee-file-in
            label records standard
            block contains 5 records
            record contains 31 characters
            data record is employee-record-in.
01  employee-record-in.
    02  employee-name-in      pic x(20).
    02  employee-rate-in      pic 9(3)v99.
    02  employee-hours-in     pic 9(3)v99.
    02  line-feed-in          pic x(1).
```

LISP, Scheme, Common LISP

Functional, high-level languages

```
(defun gnome-doc-insert ()
  "Add a documentation header to the current function.
Only C/C++ function types are properly supported currently."
  (interactive)
  (let (c-insert-here (point))
    (save-excursion
      (beginning-of-defun)
      (let (c-arglist
            c-funcname
            (c-point (point))
            c-comment-point
            c-isvoid
            c-doinsert)
        (search-backward "(")
        (forward-line -2)
        (while (or (looking-at "^$")
                   (looking-at "^ *}")
                   (looking-at "^ \\*")
                   (looking-at "^#"))
          (forward-line 1))
```

APL

Powerful operators, interactive language

```
[0]   Z←GAUSSRAND N;B;F;M;P;Q;R
[1]   ⍝Returns ⍵ random numbers having a Gaussian normal distribution
[2]   ⍝ (with mean 0 and variance 1)  Uses the Box-Muller method.
[3]   ⍝ See Numerical Recipes in C, pg. 289.
[4]   ⍝
[5]   Z←⍳0
[6]   M←¯1+2⋆31          ⍝ largest integer
[7]  L1:Q←N-⍴Z           ⍝ how many more we need
[8]   →(Q≤0)/L2          ⍝ quit if none
[9]   Q←⌈1.3×Q÷2         ⍝ approx num points needed
[10]  P←¯1+(2÷M-1)×¯1+?(Q,2)⍴M  ⍝ random points in -1 to 1 square
[11]  R←+/P×P            ⍝ distance from origin squared
[12]  B←(R≠0)∧R<1
[13]  R←B/R ⋄ P←B⌿P      ⍝ points within unit circle
[14]  F←(¯2×(⍟R)÷R)⋆.5
[15]  Z←Z,,P×F,[1.5]F
[16]  →L1
[17] L2:Z←N↑Z
[18]  ⍝ ArchDate: 12/16/1997 16:20:23.170
```

Source: Jim Weigang, http://www.chilton.com/˜ jimw/gsrand.html

Algol, Pascal, Clu, Modula, Ada

Imperative, block-structured language, formal syntax definition, structured programming

```
PROC insert = (INT e, REF TREE t)VOID:
   # NB inserts in t as a side effect #
   IF TREE(t) IS NIL THEN t := HEAP NODE := (e, TREE(NIL), TREE(NIL))
   ELIF e < e OF t THEN insert(e, l OF t)
   ELIF e > e OF t THEN insert(e, r OF t)
   FI;

 PROC trav = (INT switch, TREE t, SCANNER continue, alternative)VOID:
   # traverse the root node and right sub-tree of t  only. #
   IF t IS NIL THEN continue(switch, alternative)
   ELIF e OF t  <=  switch THEN
         print(e OF t);
         traverse( switch, r OF t, continue, alternative)
   ELSE  # e OF t > switch #
         PROC defer = (INT sw, SCANNER alt)VOID:
               trav(sw, t, continue, alt);
         alternative(e OF t, defer)
   FI;
```

Algol-68, source http://www.csse.monash.edu.au/˜ lloyd/tildeProgLang/Algol68/treemerge.a68

SNOBOL, Icon

String-processing languages

```
   LETTER  =  'ABCDEFGHIJKLMNOPQRSTUVWXYZ$#@'
   SP.CH   =  "+-,=.*()'/& "
   SCOTA  =  SP.CH
   SCOTA   '&'  =
   Q  =  "'"
   QLIT  =  Q  FENCE  BREAK(Q)  Q
   ELEM  =  QLIT | 'L' Q | ANY(SCOTA) | BREAK(SCOTA) | REM
   F3  =  ARBNO(ELEM FENCE)
   B  =  (SPAN(' ') | RPOS(0))  FENCE
   F1  =  BREAK(' ')  |  REM
   F2  =  F1
   CAOP  =  ('LCL'  |  'SET')  ANY('ABC')  |
+  'AIF'  |  'AGO'  |  'ACTR'  |  'ANOP'
   ATTR  =  ANY('TLSIKN')
   ELEMC  =  '(' FENCE *F3C ')'  |  ATTR Q  |  ELEM
   F3C    =  ARBNO(ELEMC  FENCE)
   ASM360  =  F1 . NAME  B
+  ( CAOP . OPERATION  B  F3C . OPERAND  |
+  F2 . OPERATION    B  F3 . OPERAND)
+  B    REM . COMMENT
```

SNOBOL: Parse IBM 360 assembly. From Gimpel's book, http://www.snobol4.org/

BASIC

Programming for the masses

```
10 PRINT "GUESS A NUMBER BETWEEN ONE AND TEN"
20 INPUT A$
30 IF A$ = "5" THEN PRINT "GOOD JOB, YOU GUESSED IT"
40 IF A$ = "5" GOTO 100
50 PRINT "YOU ARE WRONG. TRY AGAIN"
60 GOTO 10
100 END
```

Simula, Smalltalk, C++, Java, C#

The object-oriented philosophy

```
class Shape(x, y); integer x; integer y;
virtual: procedure draw;
begin
   comment -- get the x & y components for the object --
   integer procedure getX;
      getX := x;
   integer procedure getY;
      getY := y;

   comment -- set the x & y coordinates for the object -
   integer procedure setX(newx); integer newx;
      x := newx;
   integer procedure setY(newy); integer newy;
      y := newy;
end Shape;
```

C

Efficiency for systems programming

```
int gcd(int a, int b)
{
  while (a != b) {
    if (a > b) a -= b;
    else b -= a;
  }
  return a;
}
```

ML, Miranda, Haskell

Purer functional language

```
structure RevStack = struct
  type  'a stack =  'a list
  exception Empty
  val empty = []
  fun isEmpty (s:'a stack):bool =
    (case s
       of [] => true
        | _ => false)
  fun top (s:'a stack): =
    (case s
       of [] => raise Empty
        | x::xs => x)
  fun pop (s:'a stack):'a stack =
    (case s
        of [] => raise Empty
         | x::xs => xs)
  fun push (s:'a stack,x: 'a):'a stack = x::s
  fun rev (s:'a stack):'a stack = rev (s)
end
```

sh, awk, perl, tcl, python

Scripting languages:glue for binding the universe together

```
class() {
  classname=`echo "$1" | sed -n '1 s/ *:.*$//p'`
  parent=`echo "$1" | sed -n '1 s/^.*: *//p'`
  hppbody=`echo "$1" | sed -n '2,$p'`

  forwarddefs="$forwarddefs
  class $classname;"

  if (echo $hppbody | grep -q "$classname()"); then
    defaultconstructor=
  else
    defaultconstructor="$classname() {}"
  fi
}
```

VisiCalc, Lotus 1-2-3, Excel

The spreadsheet style of programming

	A	B
1	Hours	23
2	Wage per hour	$ 5.36
3		
4	Total Pay	= B1 * B2

SQL

Database queries

```
CREATE TABLE shirt (
    id SMALLINT UNSIGNED NOT NULL AUTO_INCREMENT,
    style ENUM('t-shirt', 'polo', 'dress') NOT NULL,
    color ENUM('red', 'blue', 'white', 'black') NOT NULL
    owner SMALLINT UNSIGNED NOT NULL
          REFERENCES person(id),
    PRIMARY KEY (id)
);

INSERT INTO shirt VALUES
(NULL, 'polo', 'blue', LAST_INSERT_ID()),
(NULL, 'dress', 'white', LAST_INSERT_ID()),
(NULL, 't-shirt', 'blue', LAST_INSERT_ID());
```

Prolog

Logic Language

```
edge(a, b). edge(b, c).
edge(c, d). edge(d, e).
edge(b, e). edge(d, f).
path(X, X).
path(X, Y) :-
    edge(X, Z), path(Z, Y).
```