Programming Languages and Translators

Stephen A. Edwards

Columbia University

Fall 2018

Pieter Bruegel, *The Tower of Babel*, 1563
Sadly, Aho has retired from teaching 4115.

But now, Prof. Baishakhi Rey and Prof. Ronghui Gu also teach 4115.
Instructor

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Email me for appointments
Edwards is the snarkiest, most sarcastic, immature professor you will meet in the CS department. He tells some really great nerdy jokes and his Facebook wall is hilarious since he belittles all his students publicly on it, but I don't recommend taking his class. Don't ever email him with an excuse or stupid question since he will publicly shame you (name removed though) on Facebook.
Objectives

Theory

- Principles of modern programming languages
- Fundamentals of compilers: parsing, type checking, code generation
- Models of computation

Practice: Semester-long Team Project

- Design and implement your own language and compiler
- Code it in the OCaml functional language
- Manage the project and your teammates; communicate
Recommended Text

Alfred V. Aho, Monica S. Lam, Ravi Sethi, and Jeffrey D. Ullman.

*Compilers: Principles, Techniques, and Tools.*


Bug Al about all bugs.

You can get away with the first edition.
Assignments and Grading

40%  Team Programming Project
20%  Midterm Exam
30%  Final Exam (cumulative)
10%  Three individual homework assignments
0%   Effort*

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

*Do or do not; there is no try —Yoda
Schedule

**Lectures:** Mondays and Wednesdays, 4:10 – 5:25 PM
451 Computer Science Building
September 5 – December 10

**Midterm Exam**
October 17

**Final Exam**
December 10

**Presentations**
December 19*

**Final Team project reports**
December 19

* You can present before December 19. All team members must present.
Prerequisites

COMS W3157 Advanced Programming
- How to work on a large software system in a team
- Makefiles, version control, test suites
- Testing will be as important as coding

COMS W3261 Computer Science Theory
- Regular languages and expressions
- Context-free grammars
- Finite automata (NFAs and DFAs)
Collaboration

Read the CS Department’s Academic Honesty Policy: https://www.cs.columbia.edu/education/honesty/

Collaborate with your team on the project.

Do your homework by yourself.

- **OK**: Discussing lecture content, OCaml features
- **Not OK**: Solving a homework problem with classmates
- **Not OK**: Posting any homework questions or solutions

Don’t be a cheater (e.g., copy from each other):
  - If you’re dumb enough to cheat,
    - I’m smart enough to catch you.

Nearly every term I’ve caught cheaters and sent them to the dean. Please try to break my streak.
The Team Project
The Team Project

Design and implement your own little language.

Six deliverables:

1. A proposal describing your language
2. A language reference manual defining it formally
3. An intermediate milestone: compiling “Hello World.”
4. A compiler for it, written in OCaml; generating LLVM
5. A final project report
6. A final project presentation
Teams

Immediately start forming four-person teams
Each team will develop its own language
Each teach member should participate in design, coding, testing, and documentation

Choose one team member to head specific tasks:

<table>
<thead>
<tr>
<th>Role</th>
<th>Responsibilities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manager</td>
<td>Timely completion of deliverables</td>
</tr>
<tr>
<td>Language Guru</td>
<td>Language design</td>
</tr>
<tr>
<td>System Architect</td>
<td>Compiler architecture, development environment</td>
</tr>
<tr>
<td>Tester</td>
<td>Test plan, test suites</td>
</tr>
</tbody>
</table>
QA ENGINEER
WALKS INTO A BAR
ORDERS A BEER
ORDERS NULL BEERS
ORDERS 1.33 BEERS
ORDERS A LIZARD
ORDERS -1 BEERS
ORDERS ☺ BEERS
Cover for flaky teammates. They will thank you later by completely reforming their behavior, making up for all the times you did their work for them.

Assign the least qualified team member to each task.

Avoid leadership; include every feature and make all decisions by arguing.

Don’t let other members speak; they don’t want to.

Ignore other members’ opinions: you’re always right; they’re always wrong.

Never let anybody take responsibility for anything. Write software communally so nobody is ever at fault.

Never tell the instructor or a TA that something is wrong with your group. It will only lower your grade.
RED
FLAGS
“START EARLY, and really be selective in picking your team. A bad team will ruin the semester for you.”

“Start early and be sure to pester the TAs for help. Also, half of your team will be slackers and you will lose all faith in humanity.”

“We didn’t bring this up earlier since we imagined that when it became crunch time everyone in the group would take the project seriously, but that hasn’t been the case.”
EVEN GROUP PROJECT

DOES 99% OF THE WORK
SAYS HE'S GOING TO HELP BUT HE'S NOT
HAS NO IDEA WHAT'S GOING ON THE WHOLE TIME
DISAPPEAR AT THE VERY BEGINNING AND DOESN'T SHOW UP AGAIN TIL THE VERY END

IN SCHOOL YOU HAVE EVER DONE
When I die I want my group project members to lower me into my grave so they can let me down one last time.
How Do You Work In a Team?

If I knew, I’d use the knowledge to take over the world

- Address problems sooner rather than later
  If you think your teammate’s a flake, you’re right

- Complain to me or your TA as early as possible
  Alerting me a day before the project is due isn’t helpful

- Not every member of a team will get the same grade
  Remind your slacking teammates of this early and often

- I have forcibly split and dissolved teams
  If someone is really underperforming, dump his ass
What Google Learned From Its Quest to Build the Perfect Team

Things that did not matter

❌ Members’ intelligence
❌ Members’ experience
❌ Mix of personality types
❌ Whether the members were close friends
❌ Strong organization
❌ Gender balance


https://hunterwalk.com/2016/09/03/google-finds-that-successful-teams-are-about-norms-not-just-smarts/
What Google Learned From Its Quest to Build the Perfect Team

Things that \textit{did} matter

Team “norms.” Unwritten rules of team interaction.

✓ That every team member spoke in the same proportion
✓ That team members had “social sensitivity”
  Empathy for fellow team members: the ability to read others’ feelings through void, expressions, etc.
First Three Tasks

1. Decide who you will work with
   *You’ll be stuck with them for the term; choose wisely.*

2. Assign a role to each member
   *Languages come out better from dictatorships, not democracies.*

3. Select a weekly meeting time
   *Harder than you might think.*
Describe the language that you plan to implement.

Explain what sorts of programs are meant to be written in your language

Explain the parts of your language and what they do

Include the source code for an interesting program in your language

2–4 pages
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 Language*; see the class website).
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<th>Section</th>
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<td>Full Code Listing</td>
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</table>
Project Due Dates

Proposal September 19 soon

Language Reference Manual and parser October 15

Hello World Demo November 14

Final Report December 19
A domain-specific language: awk or PHP, not Java or C++.

Examples from earlier terms:
Matlab-like array manipulation language
Geometric figure drawing language
Music manipulation language
Mathematical function manipulator
Simple scripting language (à là Tcl)
Two Common Mistakes to Avoid

Configuration File Syndrome

- Your language should have more than just nouns
- Must be able to express *algorithms*, not just data

Standard Library Syndrome

- Good languages enable you to *build* abstractions, not just *provide* them
- Write your standard library in your language
- Aim for Legos, not Microsoft Word
What I’m Looking For

Your language must be able to express different algorithms

- Avoid Configuration File Syndrome. Most languages should be able to express, e.g., the GCD algorithm.

Your language should consist of pieces that can mix freely

- Avoid Standard Library Syndrome. For anything you provide in the language, ask yourself whether you can express it using other primitives in your language.

Your compiler must generate LLVM code

- Compilers should lower the level of abstraction; LLVM provides a machine-independent, low-level IR.
- Robust, widespread “collection of modular and reusable compiler and toolchain technologies.”
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.

```java
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:

```
expr → expr + expr
| expr − expr
| expr * expr
| expr / expr
| ( expr )
| digits
```
Components of a language: Semantics
What a well-formed program “means.”

The semantics of C says this computes the $n$th 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;
}
```

‘When I use a word,’ Humpty Dumpty said in rather a scornful tone, ‘it means just what I choose it to mean—neither more nor less.’

Source: Lewis Carroll, Through the Looking Glass, 1872.
Semantics

Something may be syntactically correct but semantically nonsensical

*The rock jumped through the hairy planet.*

Or ambiguous

*The chickens are ready to eat.*
Semantics

Nonsensical in Java:
```java
class Foo {
    int bar(int x) { return Foo; }
}
```

Ambiguous in Java:
```java
class Bar {
    public float foo() { return 0; }
    public int foo() { return 0; }
}
```
Great Moments in Evolution
Before: numbers
55
89E5
8B4508
8B550C
39D0
740D
39D0
7E08
29D0
39D0
75F6
C9
C3
29C2
EBF6

After: Symbols

```assembly
gcd:
pushl %ebp
movl %esp, %ebp
movl 8(%ebp), %eax
movl 12(%ebp), %edx
cmpl %edx, %eax
je .L9
.L7:
cmpl %edx, %eax
jle .L5
subl %edx, %eax
.L2:
cmpl %edx, %eax
jne .L7
.L9:
leave
ret
.L5:
subl %eax, %edx
jmp .L2
```
FORTRAN

Before

gcd: pushl %ebp
    movl %esp, %ebp
    movl 8(%ebp), %eax
    movl 12(%ebp), %edx
    cmpl %edx, %eax
    je .L9
    .L7: cmpl %edx, %eax
        jle .L5
        subl %edx, %eax
    .L2: cmpl %edx, %eax
        jne .L7
    .L9: leave
        ret
    .L5: subl %eax, %edx
        jmp .L2

After: Expressions, control-flow

10    if (a .EQ. b) goto 20

if (a .LT. b) then
    a = a - b
else
    b = b - a
endif

20    end
Before:

```fortran
FORTRAN

Before: gcd

pushl %ebp
movl %esp, %ebp
movl 8(%ebp), %eax
movl 12(%ebp), %edx
cmpl %edx, %eax
je .L9
.L7: cmpl %edx, %eax
jle .L5
subl %edx, %eax
.L2: cmpl %edx, %eax
jne .L7
.L9: leave
ret
.L5: subl %eax, %edx
jmp .L2
```

Backus, IBM, 1956

Imperative language for science and engineering

First compiled language

Fixed format punch cards

Arithmetic expressions, If, Do, and Goto statements

Scalar and array types

Limited string support

Still common in high-performance computing

Inspired most modern languages, especially BASIC

After:

**Expressions, control-flow**

```fortran
10 if (a .EQ. b) goto 20
if (a .LT. b) then
a = a - b
else
b = b - a
endif
goto 10
20 end
```
**COBOL**

Added type declarations, record types, file manipulation

```cobol
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).
```

English-like syntax: 300 reserved words
Grace Hopper et al.
LISP, Scheme, Common LISP

Functional, high-level languages

(defun append (l1 l2)
  (if (null l1)
      l2
      (cons (first l1) (append (rest l1) l2)))))
LISP, Scheme, Common LISP

Functional, high-level languages

```lisp
(defun append (l1 l2)
  (if (null l1)
      l2
      (cons (first l1) (append (rest l1) l2))))
```

McCarthy, MIT, 1958

Functional: recursive, list-focused functions

Semantics from Church’s Lambda Calculus

Simple, heavily parenthesized S-expression syntax

Dynamically typed

Automatic garbage collection

Originally for AI applications

Dialects: Scheme and Common Lisp
APL

Powerful operators, interactive, custom character set

```
[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.
[4] \(\)
[5] \(\) \(\) Z+1.0
[6] \(\) M+\(\)1+2\(\)31 \(\) largest integer
[7] \(\) L1:Q+N−ρZ \(\) 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)ρM \(\) random points in −1 to 1 square
[11] \(\) R++/P×P \(\) a distance from origin squared
[12] \(\) B+(R≠0)∧R<1
[13] \(\) R−B/R \(\) P→B≠P \(\) points within unit circle
[14] \(\) F+−2×(ΦR)÷R)\(\)★.5
[16] \(\) →L1
[17] \(\) L2:Z+N+Z
[18] \(\) ArchDate: 12/16/1997 16:20:23.170
```

“Emoticons for Mathematicians”


At right: Datamedia APL Keyboard
APL

Powerful operators, interactive, custom character set

```
[0] Z+GAUSSRAND N;B;F;M;P;Q;R
[1] * Returns ω random numbers
[2] * (with mean 0 and variance 1)
[3] * See Numerical Recipes in ...
[4] *
[5] Z+0
[6] M−1+2×31   * largest integer
[7] L1:Q+N−ρZ   * how many
[8] →(Q≤0)/L2   * quit if
[9] Q+1.3×Q÷2   * approximate
[10] P+−1+(2÷M−1)×−1+?(Q,2)pM   * E.g., perform an operation on each element of a vector
[12] B+(R≠0)∧R<1   *
[14] F+(-2-(ΦR)/R)×.5   *
[15] Z+Z, P×F,[1.5]F   *
[16] →L1   *
[17] L2:Z+N+Z   *
[18] * ArchDate: 12/16/1997 18:58:10
```

Iverson, IBM, 1960

Imperative, matrix-centric

E.g., perform an operation on each element of a vector

Uses own specialized character set

Concise, effectively cryptic

Primarily symbols instead of words

Dynamically typed

Odd left-to-right evaluation policy

Useful for statistics, other matrix-oriented applications

“Emoticons for Mathematicians”


At right: Datamedia APL Keyboard
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
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
Programming for the masses

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

Invented at Dartmouth by John George Kemeny and Thomas Eugene Kurtz. Started the whole Bill Gates/Microsoft thing.
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 coordinates -;
  integer procedure getX;
    getX := x;
  integer procedure getY;
    getY := y;

  comment - set the x & y coordinates -;
  integer procedure setX(newx); integer newx;
    x := newx;
  integer procedure setY(newy); integer newy;
    y := newy;
end Shape;
class Bottles {
    public static void main(String args[]) {
        String s = "s";
        for (int beers=99; beers>-1;) {
            System.out.print(beers+" bottle"+s+" of beer on the wall, ");
            System.out.println(beers + " bottle" + s + " of beer, ");
            if (beers==0) {
                System.out.print("Go to the store, buy some more, ");
                System.out.println("99 bottles of beer on the wall.\n");
                System.exit(0);
            } else
                System.out.print("Take one down, pass it around, ");
                s = (--beers == 1)?"":"s";
                System.out.println(beers+" bottle"+s+" of beer on the wall.\n");
        }
    }
}

Sean Russell,
class Bottles {
    public static void main(String[] args) {
        String s = "s";
        for (int beers=99; beers>-1;) {
            System.out.print(beers + " bottle" + s + " of beer on the wall, ");
            System.out.println(beers + " bottle" + s + " of beer, ");
            if (beers==0) {
                System.out.print("Go to the store, buy some more, ");
                System.out.println("99 bottles of beer on the wall.
");
                System.exit(0);
            } else
                System.out.print("Take one down, pass it around, ");
            s = (--beers == 1)?"":"s";
            System.out.println(beers + " bottle" + s + " of beer on the wall.
");
        }
    }
}

Gosling et al., Sun, 1991
Imperative, object-oriented, threaded
Based on C++, C, Algol, etc.
Statically typed
Automatic garbage collection
Architecturally neutral
Defined on a virtual machine (Java Bytecode)

Sean Russell,
Efficiency for systems programming

```c
int gcd(int a, int b) {
    while (a != b) {
        if (a > b) a -= b;
        else b -= a;
    }
    return a;
}
```
Efficiency for systems programming

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

Dennis Ritchie, Bell Labs, 1969

Procedural, imperative

Based on Algol, BCPL

Statically typed; liberal conversion policies

Harmonizes with processor architecture

For systems programming: unsafe by design

Remains language of choice for operating systems
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
99 Bottles of Beer in Haskell

```haskell
bottles :: Int -> String
bottles n
    | n == 0 = "no more bottles"
    | n == 1 = "1 bottle"
    | n > 1 = show n ++ " bottles"

verse :: Int -> String
verse n
    | n == 0 = "No more bottles of beer on the wall, "
        ++ "no more bottles of beer.\n"
        ++ "Go to the store and buy some more, "
        ++ "99 bottles of beer on the wall."
    | n > 0 = bottles n ++ " of beer on the wall, "
        ++ bottles n
        ++ " of beer.\n"
        ++ "Take one down and pass it around, "
        ++ bottles (n-1) ++ " of beer on the wall.\n"

main = mapM (putStrLn . verse) [99,98..0]
```

Simon Johansson,
99 Bottles of Beer in Haskell

```haskell
bottles :: Int -> String
bottles n
    | n == 0 = "no more bottles"
    | n == 1 = "1 bottle"
    | n > 1 = show n ++ " bottles"

verse :: Int -> String
verse n
    | n == 0 = "No more bottles of beer on the wall, 
               + "no more bottles of beer.
               + "Go to the store and buy some more, 
               + "99 bottles of beer on the wall."
    | n > 0 = bottles n ++ " of beer on the wall, 
               + " bottles of beer.
               + "Take one down and pass it around, 
               + " bottles (n-1) of beer on the wall.

main = mapM (putStrLn . verse) [99,98..0]
```

Peyton Jones et al., 1990

Functional

Pure: no side-effects

Lazy: computation only on demand; infinite data structures

Statically typed; types inferred

Algebraic data types, pattern matching, lists, strings

Great for compilers, domain-specific languages, type system research

Related to ML, OCaml

Simon Johansson,
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
}
BEGIN {
    for(i = 99; i >= 0; i--) {
        print ubottle(i), "on the wall," , lbottle(i) "."
        print action(i), lbottle(inext(i)), "on the wall."
    }
}

function ubottle(n) {
    return sprintf("%s bottle%s of beer", n?n:"No more", n-1?"s":"")
}

function lbottle(n) {
    return sprintf("%s bottle%s of beer", n?n:"no more", n-1?"s":"")
}

function action(n) {
    return sprintf("%s", n ? "Take one down and pass it around," : "Go to the store and buy some more," )
}

function inext(n) {
    return n ? n - 1 : 99
}

OsamuAoki,
99 Bottles of Beer in AWK

BEGIN {
    for (i = 99; i >= 0; i--) {
        print ubottle(i), "on the wall,", lbottle(i) "."
        print action(i), lbottle(inext(i)), "on the wall."
        print
    }
}

function ubottle(n) {
    return sprintf("%s bottle%s of beer", n ? n : "No more", n - 1 ? "s" : "")
}

function lbottle(n) {
    return sprintf("%s bottle%s of beer", n ? n : "no more", n - 1 ? "s" : "")
}

function action(n) {
    return sprintf("%s", n ? "Take one down and pass it around," : "Go to the store and buy some more,")
}

function inext(n) {
    return n ? n - 1 : 99
}

Aho, Weinberger, and Kernighan, Bell Labs, 1977

Interpreted domain-specific scripting language for text processing

Pattern-action statements matched against input lines

C-inspired syntax

Automatic garbage collection

OsamuAoki,
BEGIN{
    split( "no mo"
          "rexxN"
          "o mor"
          "exsxx"
          "Take "
          "one dow"
          "n and pas"
          "s it around"
          "Go to the "
          "store and buy s"
          "ome more, x bot"
          "lex of beerx o"
          "n the wall" , s,
          "x" );
    for( i=99 ;
          i>=0; i--){ s[0]=\ s[2] = i ; print \ s[2 + !(i) ] s[8]\ s[4+ !(i-1)] s[9]\ s[10]" , " s[!(i)]\ s[8] s[4+ !(i-1)]\ s[9]".; i?s[0]--:\ s[0] = 99; print \ s[6+i]s[!(s[0])]\ s[8] s[4+ !(i-2)]\ s[9]s[10] ".\n";}}
for quant in range(99, 0, -1):
    if quant > 1:
        print quant, "bottles of beer on the wall," , \
                quant, "bottles of beer."
    if quant > 2:
        suffix = str(quant - 1) + " bottles of beer on the wall."
    else:
        suffix = "1 bottle of beer on the wall."
    elif quant == 1:
        print "1 bottle of beer on the wall, 1 bottle of beer."
        suffix = "no more beer on the wall!"
    print "Take one down, pass it around," , suffix
    print ""

Gerold Penz,
for quant in range(99, 0, -1):
    if quant > 1:
        print quant, "bottles of beer on the wall,",
        quant, "bottles of beer."
    if quant > 2:
        suffix = str(quant - 1) + " bottles of beer on the wall."
    else:
        suffix = "1 bottle of beer on the wall."
    if quant == 1:
        print "1 bottle of beer on the wall, 1 bottle of beer."
        suffix = "no more beer on the wall!"
    print "Take one down, pass it around,"
    print suffix
    print ""
99 Bottles of Beer in FORTH

: .bottles ( n -- n-1 )
    dup 1 = IF ." One bottle of beer on the wall," CR
    ." One bottle of beer," CR
    ." Take it down,
    ELSE dup ." bottles of beer on the wall," CR
    dup ." bottles of beer," CR
    ." Take one down,
    THEN
    CR
    ." Pass it around," CR
    1-
    ?dup IF dup 1 = IF ." One bottle of beer on the wall;"
        ELSE dup ." bottles of beer on the wall;"
        THEN
        ELSE ." No more bottles of beer on the wall."
        THEN
    CR
;
: nbottles ( n -- )
    BEGIN .bottles ?dup NOT UNTIL ;

99 nbottles

Dan Reish,
99 Bottles of Beer in FORTH

: .bottles ( n -- n-1 )
  dup 1 = IF ." One bottle of beer on the wall,
  ." One bottle of beer,
  ." Take it down,
  ELSE dup ." bottles of beer on the wall,
  dup ." bottles of beer,
  ." Take one down,
  THEN
  CR
  ." Pass it around," CR
  1-
  ?dup IF dup 1 = IF ." No more bottles of beer on the wall;
  ELSE dup ." bottles of beer on the wall;
  THEN
  ELSE ." No more bottles of beer on the wall.
  THEN
  CR
  ;

: nbottles ( n -- )
BEGIN .bottles ?dup NOT
END

99 nbottles

Moore, NRAO, 1973

Stack-based imperative language

Trivial, RPN-inspired grammar

Easily becomes cryptic

Untyped

Low-level, very lightweight

Highly extensible: easy to make programs compile themselves

Used in some firmware boot systems (Apple, IBM, Sun)

Inspired the PostScript language for laser printers

Dan Reish,
The Whitespace Language

Edwin Brady and Chris Morris, April 1st, 2003

Imperative, stack-based language

Space, Tab, and Line Feed characters only

Number literals in binary: Space=0, Tab=1, LF=end

Less-than-programmer-friendly syntax; reduces toner consumption

Andrew Kemp, http://compsoc.dur.ac.uk/whitespace/
VisiCalc, Lotus 1-2-3, Excel

The spreadsheet style of programming

Visicalc on the Apple II, c. 1979
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());
CREATE TABLE shirt (  
id SMALLINT UNSIGNED NOT NULL,  
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());

Chamberlin and Boyce, IBM, 1974
Declarative language for databases
Semantics based on the relational model
Queries on tables: select with predicates, joining, aggregating
Database query optimization: declaration to procedure
> SELECT * FROM users WHERE clue > 0
0 rows returned

From thinkgeek.com
Prolog

Logic Language

\[
\begin{align*}
\text{witch}(X) & \iff \text{burns}(X), \text{female}(X). \\
\text{burns}(X) & \iff \text{wooden}(X). \\
\text{wooden}(X) & \iff \text{floats}(X). \\
\text{floats}(X) & \iff \text{sameweight}(\text{duck}, X). \\
\text{female}(\text{girl}). & \quad \{\text{by observation}\} \\
\text{sameweight}(\text{duck}, \text{girl}). & \quad \{\text{by experiment}\}
\end{align*}
\]

? \text{witch(}\text{girl})\).
Prolog

Logic Language

\[
\begin{align*}
\text{witch}(X) & \Leftarrow \text{burns}(X), \text{female}(X). \\
\text{burns}(X) & \Leftarrow \text{wooden}(X). \\
\text{wooden}(X) & \Leftarrow \text{floats}(X). \\
\text{floats}(X) & \Leftarrow \text{sameweight}(\text{duck}, X). \\
\text{female}(\text{girl}). & \quad \{\text{by observation}\} \\
\text{sameweight}(\text{duck}, \text{girl}). & \quad \{\text{by experiment}\} \\
? \text{witch}(\text{girl}). &
\end{align*}
\]

Alain Colmerauer et al., 1972

Logic programming language

Programs are relations: facts and rules

Program execution consists of trying to satisfy queries

Designed for natural language processing, expert systems, and theorem proving