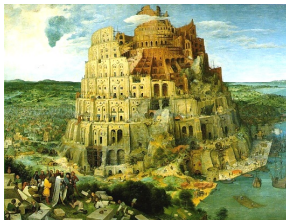


Programming Languages and Translators

Stephen A. Edwards

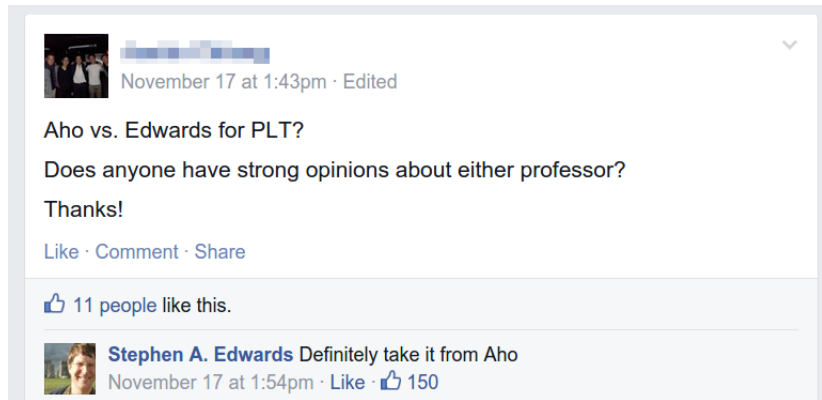
Columbia University



Spring 2017



Pieter Bruegel, *The Tower of Babel*, 1563


Facebook on 4115



A screenshot of a Facebook post. The post is from a user whose profile picture is blurred. The text of the post asks for opinions on whether Aho or Edwards should teach PLT. Below the text are interaction options: Like, Comment, and Share. The post has 11 likes. A comment from Stephen A. Edwards is visible below, stating that the course should be taught by Edwards and that he has 150 likes.

  November 17 at 1:43pm · Edited

Aho vs. Edwards for PLT?
Does anyone have strong opinions about either professor?
Thanks!

[Like](#) · [Comment](#) · [Share](#)

 11 people like this.

 **Stephen A. Edwards** Definitely take it from Aho
November 17 at 1:54pm · [Like](#) ·  150

Sadly, Aho has retired from teaching 4115.

Instructor

Prof. Stephen A. Edwards

sedwards@cs.columbia.edu

<http://www.cs.columbia.edu/~sedwards/>

462 Computer Science Building

Email me for appointments

Culpa on 4115

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

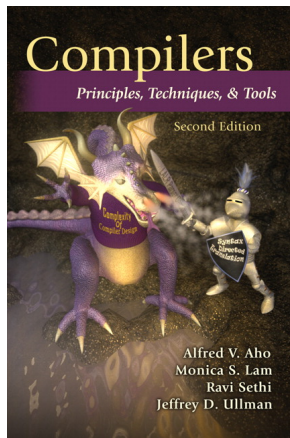
Alfred V. Aho, Monica S. Lam,
Ravi Sethi, and Jeffrey D. Ullman.

*Compilers: Principles, Techniques,
and Tools.*

Addison-Wesley, 2006.
Second Edition.

Bug AI about all bugs.

You can get away with the first
edition.



Assignments and Grading

40% Team Programming Project

20% Exam 1

30% Exam 2 (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, 2:40 – 3:55

207 Mathematics

January 18 – May 1

Exam 1: March 8

Exam 2: May 1

Presentations: May 10*

Final Team project reports: May 10

* You can present before May 10. 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

Collaborate with your team on the project.

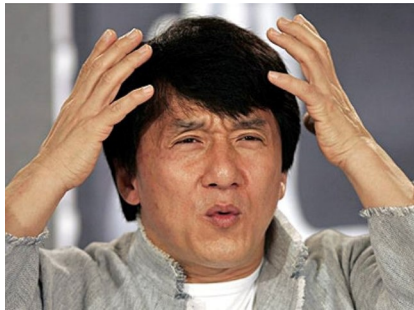
Do your homework by yourself.

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

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, running sample programs
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 team member should participate in design, coding, testing, and documentation

Choose one team member to head specific tasks:

Role	Responsibilities
Manager	Timely completion of deliverables
Language Guru	Language design
System Architect	Compiler architecture, development environment
Tester	Test plan, test suites



Culpa Suggestion

START EARLY, and really be selective in picking your team. A bad team will ruin the semester for you.

EVERY GROUP PROJECT



DOES 99%
OF THE WORK

HAS NO
IDEA WHAT'S
GOING ON THE
WHOLE TIME

SAYS HE'S
GOING TO
HELP BUT
HE'S NOT

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

[http://mobile.nytimes.com/2016/02/28/magazine/
what-google-learned-from-its-quest-to-build-the-perfect-team.html](http://mobile.nytimes.com/2016/02/28/magazine/what-google-learned-from-its-quest-to-build-the-perfect-team.html)

[https://hunterwalk.com/2016/09/03/
google-finds-that-successful-teams-are-about-norms-not-just-smarts/](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 *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.

Project Proposal

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

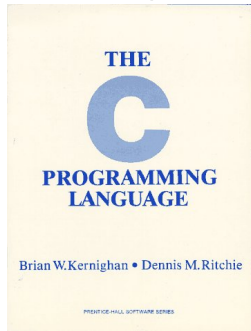
Include the source code for an interesting program in your language

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).



Final Report Sections

Section	Author
Introduction	Team
Tutorial	Team
Reference Manual	Team
Project Plan	Manager
Language Evolution	Language Guru
Translator Architecture	System Architect
Test plan and scripts	Tester
Conclusions	Team
Full Code Listing	Team

Project Due Dates

Proposal	February 8 soon
Language Reference Manual	February 22
Hello World Demo	March 27
Final Report	May 10



Design a language?

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 lá Tcl)

Three Common Mistakes to Avoid

Configuration File Syndrome

- ▶ Must be able to express *algorithms*, not just data
- ▶ E.g., a program like “a bird and a turtle and a pond and grass and a rock,” is just data, not an algorithm

Standard Library Syndrome

- ▶ Good languages express lots by a combining few things
- ▶ Write a standard library in your language
- ▶ Aim for Legos, not Microsoft Word

Java-to-Java Translator Syndrome

- ▶ A compiler mostly adds implementation details to code
- ▶ Your compiler's output should not look like its input
- ▶ Try your best not to re-invent Java

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 lower the level of abstraction

- ▶ Don't write a Java-to-Java translator. Make sure your compiler adds details to the output such as registers, evaluation order of expressions, stack management instructions, etc.

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:

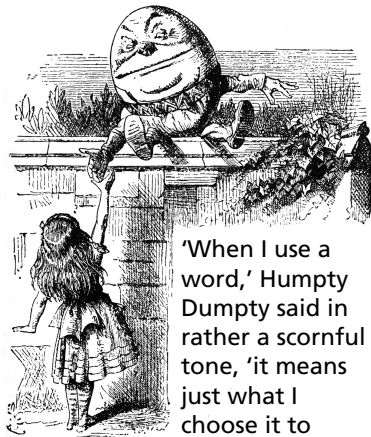
$$\begin{aligned} \text{expr} &\rightarrow \text{expr} + \text{expr} \\ &| \text{expr} - \text{expr} \\ &| \text{expr} * \text{expr} \\ &| \text{expr} / \text{expr} \\ &| \mathbf{\text{digit}} \\ &| (\text{expr}) \end{aligned}$$

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.’

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

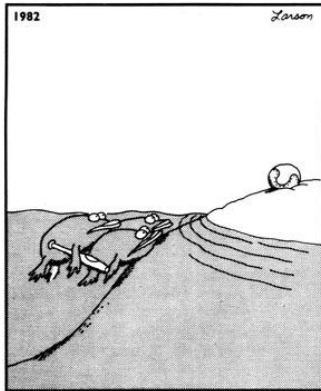
Nonsensical in Java:

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

Ambiguous in Java:

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

Great Moments in Evolution



Great moments in evolution

Assembly Language

Before: numbers

```
55
89E5
8B4508
8B550C
39D0
740D
39D0
7E08
29D0
39D0
75F6
C9
C3
29C2
EBF6
```

After: Symbols

```
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
      goto 10
20  end
```

99 Bottles of Beer in FORTRAN

```
program ninety-nine-bottles
integer bottles
bottles = 99
1  format (I2, A)
2  format (A)
3  format (I2, A, /)
4  format (A, /)
10 write (*,1) bottles, ' bottles of beer on the wall,'
   write (*,1) bottles, ' bottles of beer.'
   write (*,2) 'Take one down, pass it around...'
   if (bottles - 1 .gt. 1) then
       write (*,3) bottles - 1, ' bottles of beer on the wall.'
   else
       write (*,3) bottles - 1, ' bottle of beer on the wall.'
   end if
   bottles = bottles - 1
   if (bottles - 1) 30, 20, 10
*   Last verse
20 write (*,1) bottles, ' bottle of beer on the wall,'
   write (*,1) bottles, ' bottle of beer.'
   write (*,2) 'Take one down, pass it around...'
   write (*,4) 'No bottles of beer on the wall.'
30  stop
   end
```

99 Bottles of Beer in FORTRAN

```
program ninety-ninebott  
integer bottles  
bottles = 99  
1  format (I2, A)  
2  format (A)  
3  format (I2, A, /)  
4  format (A, /)  
10 write (*,1) bottles, '  
   write (*,1) bottles, '  
   write (*,2) 'Take one  
   if (bottles - 1 .gt. 1  
       write (*,3) bottles  
   else  
       write (*,3) bottles  
   end if  
   bottles = bottles - 1  
   if (bottles - 1) 30, 2  
*   Last verse  
20 write (*,1) bottles, '  
   write (*,1) bottles, '  
   write (*,2) 'Take one  
   write (*,4) 'No bottle  
30 stop  
end
```

Backus, IBM, 1956

Imperative language for science and engineering

First compiled language

Fixed format lines (for punch cards)

Arithmetic expressions, If, Do, and Goto statements

Scalar (number) and array types

Limited string support

Still common in high-performance computing

Inspired most modern languages, especially BASIC

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).
```

Grace Hopper et al.



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-doinstert)
        (search-backward "(")
        (forward-line -2)
        (while (or (looking-at "^$")
                     (looking-at "^ *}")
                     (looking-at "^ \\\\*")
                     (looking-at "^#"))
          (forward-line 1))
```

99 Bottles of Beer in LISP

```
(defun bottles-of-bier (n)
  (case 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.))
    (1
      '(1 bottle of beer on the wall 1 bottle of beer.
        Take one down and pass it around no more bottles of beer on the wall.
        ,@(bottles-of-bier 0)))
    (2
      '(2 bottles of beer on the wall 2 bottles of beer.
        Take one down and pass it around 1 bottle of beer on the wall.
        ,@(bottles-of-bier 1)))
    (t
      '(,n bottles of beer on the wall ,n bottles of beer.
        Take one down and pass it around
        ,(1- n) bottles of beer on the wall.
        ,@(bottles-of-bier (1- n))))))
```

99 Bottles of Beer in LISP

```
(defun bottles-of-bier (n)
  (case n
    (0
      '(No more bottles of beer on the wall
        Go to the store and buy some more))
    (1
      '(1 bottle of beer on the wall
        Take one down and pass it around
        ,@(bottles-of-bier 0))
      )
    (2
      '(2 bottles of beer on the wall
        Take one down and pass it around
        ,@(bottles-of-bier 1))
      )
    (t
      '(,n bottles of beer on the wall
        Take one down and pass it around
        ,(1- n) bottles of beer on the wall
        ,@(bottles-of-bier (1- n))))))
```

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 language, 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.
[3] ⍝ See Numerical Recipes in C, pg. 289.
[4] ⍝
[5] Z←⊖0
[6] M←⌈1+2★31 ⍝ A largest integer
[7] L1:Q←N-ρZ ⍝ A how many more we need
[8] →(Q≤0)/L2 ⍝ A quit if none
[9] Q←⌈1.3×Q÷2 ⍝ A approx num points needed
[10] P←⌈1+(2÷M-1)×⌈1+?(Q,2)ρM ⍝ A 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 ⍝ A 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
```

“Emoticons for Mathematicians”

Source: Jim Weigang, <http://www.chilton.com/~jimw/gstrand.html>

At right: Datamedia APL Keyboard



99 Bottles of Beer in APL

⊙ APL (A Programming Language)

⊙ Program written by JT. Taylor, www.jttaylor.net

```
T1←98↑[1]001 99ρι99
```

```
T4←001 98ρι98
```

```
T1,(98 30ρ' BOTTLES OF BEER ON THE WALL, '),T1,  
(98 47ρ'BOTTLES OF BEER, TAKE ONE DOWN, PASS IT  
AROUND, '),T4,(98 28ρ'BOTTLES OF BEER ON THE  
WALL ,')
```

```
'1 BOTTLE OF BEER ON THE WALL, 1 BOTTLE OF BEER,  
TAKE IT DOWN, PASS IT AROUND, NO BOTTLES OF BEER  
ON THE WALL.'
```

<http://www.99-bottles-of-beer.net/language-apl-715.html>

99 Bottles of Beer in APL

⊙ APL (A Programming Language)

⊙ Program written by Iverson

```
T1←98↑[1]⊖1 99ρ⌈99
```

```
T4←⊖1 98ρ⌈98
```

```
T1,(98 30ρ' BOTTLES OF BEER,  
(98 47ρ'BOTTLES OF BEER,  
AROUND, '),T4,(98 28ρ'BOTTLES OF BEER  
ON THE WALL ,')
```

```
'1 BOTTLE OF BEER ON THE WALL,  
TAKE IT DOWN, PASS IT AROUND,  
ON THE WALL.'
```

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

<http://www.99-bottles-of-beer.net/language-apl-715.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;
  FI;
```

SNOBOL, Icon

String-processing languages

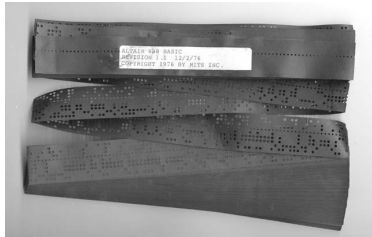
```
LETTER = 'ABCDEFGHIJKLMNOPQRSTUVWXYZ$#@'  
SP.CH  = "+-,=.*()' /& "  
SCOTA  = SP.CH  
SCOTA  '&' =  
Q      = ""  
QLIT   = Q FENCE BREAK(Q) Q  
ELEM   = QLIT | 'L' Q | ANY(SCOTA) | BREAK(SCOTA) | REM  
F3     = ARBNO(ELEM FENCE)  
B      = (SPAN(' ') | RPOS(0)) FENCE  
F1     = BREAK(' ') | REM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


BASIC

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;
```

99 Bottles of Beer in Java

```
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,

<http://www.99-bottles-of-beer.net/language-java-4.html>

99 Bottles of Beer in Java

```
class Bottles {  
    public static void main(St  
        String s = "s";  
        for (int beers=99; beers  
            System.out.print(beers  
            System.out.println(bee  
            if (beers==0) {  
                System.out.print("Go  
                System.out.println(""  
                System.exit(0);  
            } else  
                System.out.print("Ta  
                s = (--beers == 1)?"":  
                System.out.println(bee  
        }  
    }  
}
```

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,

<http://www.99-bottles-of-beer.net/language-java-4.html>

Efficiency for systems programming

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

99 Bottles of Beer in C

```
#define MAXBEER 99
void chug(int beers);

int main()
{
    int beers;
    for(beers = MAXBEER; beers; chug(beers--)) ;
    puts("\nTime to buy more beer!\n");
    return 0;
}

void chug(int beers)
{
    char howmany[8], *s;
    s = beers != 1 ? "s" : "";
    printf("%d bottle%s of beer on the wall,\n", beers, s);
    printf("%d bottle%s of beeeer . . . ,\n", beers, s);
    printf("Take one down, pass it around,\n");
    if (--beers) sprintf(howmany, "%d", beers);
    else strcpy(howmany, "No more");
    s = beers != 1 ? "s" : "";
    printf("%s bottle%s of beer on the wall.\n", howmany, s);
}
```

99 Bottles of Beer in C

```
#define MAXBEER 99
void chug(int beers);

int main()
{
    int beers;
    for(beers = MAXBEER; beers > 0; beers--)
        puts("\nTime to buy more beer!\n");
    return 0;
}

void chug(int beers)
{
    char howmany[8], *s;
    s = beers != 1 ? "s" : "";
    printf("%d bottle%s of beer\n", beers, s);
    printf("%d bottle%s of beer\n", beers, s);
    printf("Take one down, pass the bottle around,\n");
    if (--beers) sprintf(howmany, "%d", beers);
    else strcpy(howmany, "No more bottles");
    s = beers != 1 ? "s" : "";
    printf("%s bottle%s of beer\n", howmany, s);
}
```

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

ML, Miranda, Haskell

Functional languages with types and syntax

```
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

```
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,

<http://www.99-bottles-of-beer.net/language-haskell-1613.html>

99 Bottles of Beer in Haskell

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

verse :: Int -> String
verse n
  | n == 0 = "No more bottles
            ++ "no more bot
            ++ "Go to the s
            ++ "99 bottles
  | n > 0 = bottles n ++ "
            ++ bottles n
            ++ " of beer.\n"
            ++ "Take one do
            ++ bottles (n-1

main = mapM (putStrLn .
```

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,

<http://www.99-bottles-of-beer.net/language-haskell-1613.html>

sh, awk, perl, tcl, python, php

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  
}
```

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
}
```

OsamuAoki,

<http://www.99-bottles-of-beer.net/language-awk-1623.html>

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", n)
}
function lbottle(n) {
  return sprintf("%s bottle", n)
}
function action(n) {
  return sprintf("%s", n ? "bottle" : "bottles")
}
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,

<http://www.99-bottles-of-beer.net/language-awk-1623.html>

AWK (bottled version)

```
        BEGIN{\n            split(\n                "no mo"\n                "rexxN"\n                "o mor"\n                "exsxx"\n                "Take "\n                "one dow"\n                "n and pas"\n                "s it around"\n                ", xGo to the "\n                "store and buy s"\n                "ome more, x bot"\n                "tlex of beerx o"\n                "n the wall" , s,\n                "x"); for( i=99 ;\n                    i>=0; i--){ s[0]=\n                    s[2] = i ; print \n                    s[2 + !(i) ] s[8]\n                    s[4+ !(i-1)] s[9]\n                    s[10]", " s[!(i)]\n                    s[8] s[4+ !(i-1)]\n                    s[9]". ";i?s[0]--:\n                    s[0] = 99; print \n                    s[6+!i]s[!(s[0])]\n                    s[8] s[4 +!(i-2)]\n                    s[9]s[10] ".\n";}}
```

Wilhelm Weske,

<http://www.99-bottles-of-beer.net/language-awk-1910.html>

99 Bottles of Beer in Python

```
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,

<http://www.99-bottles-of-beer.net/language-python-808.html>

99 Bottles of Beer in Python

```
for quant in range(99, 0, -1):
    if quant > 1:
        print quant, "bottles"
            quant, "bottles"
        if quant > 2:
            suffix = str(quant)
        else:
            suffix = "1 bottle"
    elif quant == 1:
        print "1 bottle of beer"
            suffix = "no more beer"
    print "Take one down, pass the bottle around the neck"
    print ""
```

Guido van Rossum, 1989

Object-oriented, imperative

General-purpose scripting language

Indentation indicates grouping

Dynamically typed

Automatic garbage collection

Gerald Penz,

<http://www.99-bottles-of-beer.net/language-python-808.html>

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,

<http://www.99-bottles-of-beer.net/language-forth-263.html>

99 Bottles of Beer in FORTH

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

<http://www.99-bottles-of-beer.net/language-forth-263.html>

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

VisiCalc, Lotus 1-2-3, Excel

The spreadsheet style of programming

C11 (L) TOTAL				C1
	A	B	C	D
1	ITEM	NO.	UNIT	COST
2	MUCK RAKE	43	12.95	556.85
3	BUZZ CUT	15	6.75	101.25
4	TOE TONER	250	49.95	12487.50
5	EYE SNUFF	2	4.95	9.90
6				
7			SUBTOTAL	13155.50
8			9.75% TAX	1282.66
9			TOTAL	14438.16
10				
11				
12				
13				
14				
15				
16				
17				
18				
19				
20				
21				
22				
23				
24				
25				

Visicalc on the Apple II, c. 1979

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());
```



From thinkgeek.com

99 Bottles of Beer in SQL

```
SELECT
  CASE (bottlecount)
    WHEN 0 THEN 'No more bottle of beer on the wall, no more bottles of
                'Go to the store and buy some more, 99 bottles of beer
    WHEN 1 THEN '1 bottle of beer on the wall, 1 bottle of beer. ' ||
                'Take one down and pass it around, no more bottles of
    WHEN 2 THEN '2 bottles of beer on the wall, 2 bottles of beer. ' |
                'Take one down and pass it around, 1 bottle of beer on

  ELSE
    rtrim (cast(BottleCount) as char(2)) || ' bottles of beer on t
    rtrim (cast(BottleCount) as char(2)) || ' bottles of beer. ' |
    'Take one down and pass it around, ' ||
    rtrim (cast(BottleCount-1 as char(2))) || ' bottles of beer on

  END
FROM
(
  SELECT avalue * 10 + bvalue as bottlecount
  FROM
    (VALUES (9), (8), (7), (6), (5), (4), (3), (2), (1), (0)) a(avalue)
    (VALUES (9), (8), (7), (6), (5), (4), (3), (2), (1), (0)) b(bvalue)
) as valuelist;
```

Kent Olsen,

<http://www.99-bottles-of-beer.net/language-sql-967.html>

99 Bottles of Beer in SQL

```
SELECT
CASE (bottlecount)
  WHEN 0 THEN 'No more bottle of beer on the wall, no more bottles of
              'Go to the store and buy some more, 99 bottles of beer
  WHEN 1 THEN '1 bottle of beer on the wall, 1 bottle of beer. ' ||
              'Take one down and pass it around, no more bottles of
  WHEN 2 THEN '2 bottles of beer on the wall 2 bottles of beer. ' |
              'Take one do
ELSE
  rtrim (cast(BottleCou
  rtrim (cast(BottleCou
  'Take one down and pas
  rtrim (cast(BottleCou
END
FROM
(
  SELECT avalue * 10 + bvalue
  FROM
    (VALUES (9), (8), (7), (
    (VALUES (9), (8), (7), (
) as valuelist;
```

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

Kent Olsen,

<http://www.99-bottles-of-beer.net/language-sql-967.html>

Prolog

Logic Language

```
witch(X)  <= burns(X) and female(X).  
burns(X) <= wooden(X).  
wooden(X) <= floats(X).  
floats(X) <= sameweight(duck, X).
```

```
female(girl).           {by observation}  
sameweight(duck,girl). {by experiment }
```

```
? witch(girl).
```



99 Bottles of Beer in Prolog

```
bottles :-  
    bottles(99).  
  
bottles(1) :-  
    write('1 bottle of beer on the wall, 1 bottle of beer, '), nl,  
    write('Take one down, and pass it around, '), nl,  
    write('Now they are all gone. '), nl,!.  
bottles(X) :-  
    write(X), write(' bottles of beer on the wall, '), nl,  
    write(X), write(' bottles of beer, '), nl,  
    write('Take one down and pass it around, '), nl,  
    NX is X - 1,  
    write(NX), write(' bottles of beer on the wall. '), nl, nl,  
    bottles(NX).
```

Remko Trocon et al.,

<http://www.99-bottles-of-beer.net/language-prolog-965.html>

99 Bottles of Beer in Prolog

```
bottles :-  
    bottles(99).  
  
bottles(1) :-  
    write('1 bottle of beer  
    write('Take one down, an  
    write('Now they are all  
bottles(X) :-  
    write(X), write(' bottle  
    write(X), write(' bottle  
    write('Take one down and  
    NX is X - 1,  
    write(NX), write(' bottl  
    bottles(NX).
```

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

Remko Trocon et al.,

<http://www.99-bottles-of-beer.net/language-prolog-965.html>