CS 430
Spring 2021

Mike Lam, Professor

Grace Hopper (1906-1992)

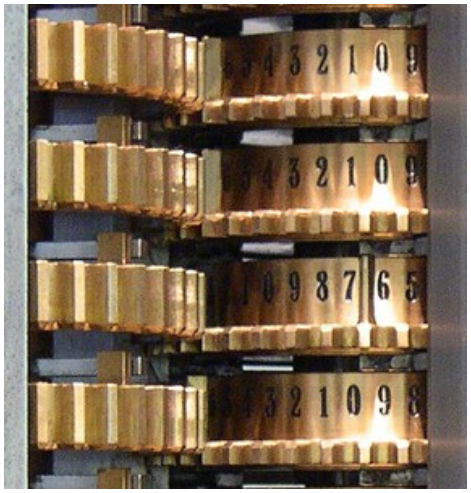
Dennis Ritchie (1941-2011)

History of Programming Languages

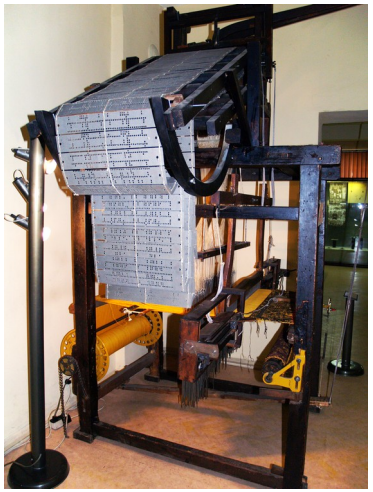
All media taken from Sebesta or Wikipedia unless stated otherwise

Mechanical Computers

- Difference engine
  - Designed by Charles Babbage, an English mathematician
  - Ada Lovelace (one of his collaborators) is often credited as the first computer programmer
  - https://www.youtube.com/watch?v=BlbQsKpq3Ak
- Jacquard machines
  - https://www.youtube.com/watch?v=K6NgMNvK52A
- Fire control computers
  - https://www.youtube.com/watch?v=s1i-dnAH9Y4



Difference engine

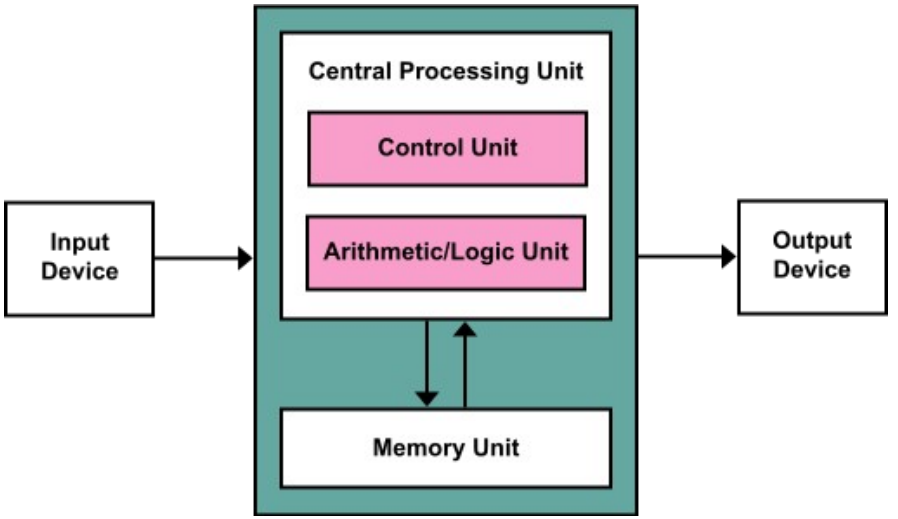


Jacquard machine

Fire control computer

von Neumann Architecture

- Fetch-Decode-Execute cycle
- Primary hardware architecture
- Heavily influenced early programming languages
- Most programming languages are procedural because this is the easiest to translate into machine code for von Neumann architectures



Konrad Zuse's Plankalkül (1945)

- "Program Calculus" or "Plan Calculus"
- Designed for Zuse's electromechanical Z4 machine
- Many innovative concepts
  - Data types and arrays
  - Iteration and control flow
- Verbose written style
  - Originally 2-dimensional
- Not widely known at the time
  - World War II obscured parallel development efforts in Germany, Great Britain, and the U.S.

```
   | X + 1 => X
V  | 1       1
S  | 1.n     1.n
```

```
X = X+1
```

```
   | A + 1 => A
V  | 4       5
S  | 1.n     1.n
```

```
A[5] = A[4]+1
```

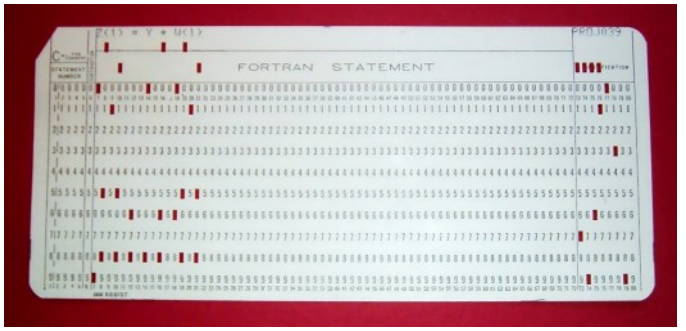
Early Digital Computing ('40s-'50s)

- Every machine had a different set of binary instructions and data addressing modes
  - Low readability and writability; programming was HARD!
  - Programs were very rigid because of explicit memory addresses
  - Very little portability between machines
  - No hardware support for floating-point arithmetic
- Interpreted “pseudocodes” helped address these issues
  - Sometimes called “automatic programming”
  - Short Code (BINAC-1949) by John Mauchly
  - Speedcoding (IBM 701-1954) by John Backus
  - UNIVAC compiling systems A-0, A-1, and A-2 (1953)
    - Development team lead by Grace Hopper
    - Pseudocode expanded into machine code via macros
    - Precursor to assembly language

Grace Hopper

Fortran (1957)

- “FORmula TRANslation”
- Primary goal: execution speed
- Designed by John Backus at IBM
  - Practical alternative to assembly language
  - First widely-accepted compiled high-level language
- Original hardware: IBM 704 mainframe
  - Hardware floating-point implementation
- Very restrictive by today's standards
  - No block structure
  - One loop structure (DO)
  - Punchcard-restricted formatting
  - Implicit data types based on variable names



Punch card

IBM 704

Fortran (1957)

- Goal: half the efficiency of hand-written machine code
  - Largely successful!
  - All modern high-performance compiler groups (Intel, Portland Group, etc.) maintain excellent Fortran support
- Highlights importance of a language's available compilers
  - Fortran remains the dominant language in high-performance computing, originally because of excellent compilers; more recently it is also because of the amount of existing legacy code
- Significant versions:
  - FORTRAN IV (1962): platform-independent
  - FORTRAN 77: block structures; broke backwards compatibility
  - Fortran 90: relaxed formatting guidelines
  - Fortran 2003: object-oriented support
  - Fortran 2008 / 2018: more parallel/concurrency features

ALGOL (1960)

- “ALGOrithmic Language”
- Primary goal: independent general-purpose language
- Joint-effort design: ACM in the U.S. and GAMM in Germany
  - Generalization of Fortran features w/ several new contributions
  - First language syntax definition written in Backus-Naur Form
- Became widely used to describe algorithms in papers and publications
  - Influenced **many** languages over the subsequent decades
  - ALGOL 68 introduced user-defined data types built from primitives
- Never widely used in practice
  - Early BNF was difficult to understand
  - Hard to implement; too many confusing and overly-flexible constructs
  - No support from IBM (ALGOL was a competitor to Fortran)
- Question for the ages: what if ALGOL had "won?"

COBOL (1960)

- “COmmon Business-Oriented Language”
  - U.S. Department of Defense effort
  - Descendant of FLOW-MATIC data-processing language
    - Also developed by Grace Hopper
- Primary goal: easy for non-programmers to use
  - Resembled natural English and was very verbose
  - Used decimal arithmetic
  - Poor support for structured programming
  - First true implementation of records
- Gained tremendous momentum
- Lots of legacy code
  - Estimated 200 billion lines in 1997!
- No major influence on subsequent PL design

```
OPEN INPUT sales, OUTPUT report-out
INITIATE sales-report

PERFORM UNTIL 1 <> 1
    READ sales
        AT END
            EXIT PERFORM
    END-READ

    VALIDATE sales-record
    IF valid-record
        GENERATE sales-on-day
    ELSE
        GENERATE invalid-sales
    END-IF
END-PERFORM

TERMINATE sales-report
CLOSE sales, report-out
```

Sample COBOL Program

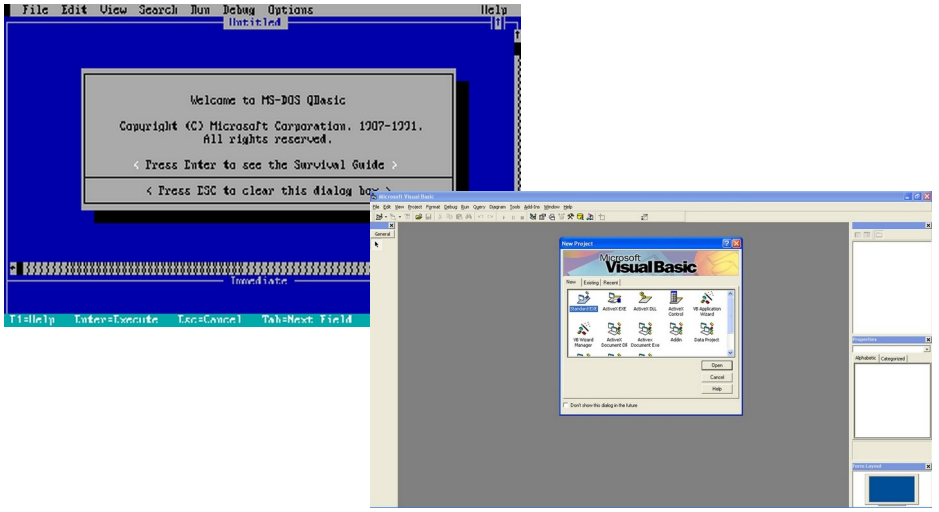
PL/I (1964)

- Programming Language One
- Primary goal: "Jack of all trades"
  - Combined best pieces of ALGOL, FORTRAN, and COBOL
  - Intended to replace them as well as Lisp and assembly
- Not widely used today
- However, it pioneered several lasting features:
  - Concurrent subprograms
  - Exception handling
  - Optional recursive subprograms
  - Pointers
  - Cross-sections (slices) of arrays

BASIC (1964)

- “Beginner's All-purpose Symbolic Instruction Code”
- Primary goal: simple and easy to learn
- Designed for non-science students
  - Emphasis on development time, rather than execution time
  - Prophetic, although not recognized as such at the time
- Descendants: QuickBasic and Visual Basic

```
REM SAY HELLO
10 PRINT "HELLO WORLD!"
20 GOTO 10
```



APL (1964)

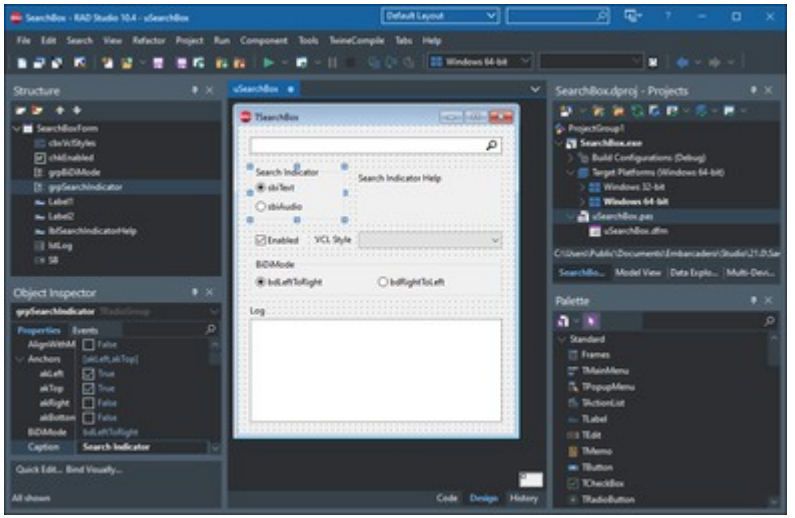
- "A Programming Language"
- Early dynamic language designed by Kenneth Iverson
- Originally designed to describe computer architectures
- Large number of operators
  - Specialized keyboard
  - Very concise code
  - Very unreadable code!
- Game of life:
  - `life←{↑1 ωv.∧3 4=+/,¯1 0 1∘.⊖¯1 0 1∘.⌽⊂ω}`

Early Object-Oriented Languages

- SIMULA (1967)
  - Primary goal: system simulation
  - Required restartable subprograms (coroutines)
  - Introduced a "class" construct for coroutine implementation
  - Precursor to object-oriented languages
- Smalltalk (1972)
  - Based on SIMULA
  - First major successful object-oriented language
  - Objects w/ state send messages to each other
  - Large influence on history of graphical user interfaces (GUIs)

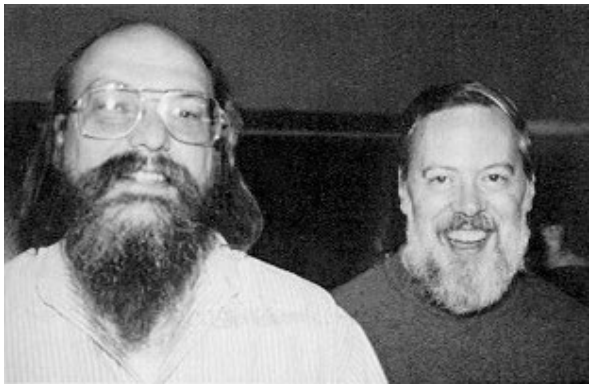
Pascal (1970)

- Based on ALGOL 60
- Designed by Niklaus Wirth
- Primary goal: simplicity and safety
- Widely used as an educational language
- Many extended dialects
  - Turbo Pascal
  - Object Pascal (Delphi)
  - Free Pascal



The Godfather: C (1972)

- Designed for systems programming
  - Influenced by ALGOL 68
  - Designed by Dennis Ritchie and others at Bell Labs
  - Based on a very similar (but untyped) language called B
- Tightly coupled with UNIX operating system
  - Close to the hardware
  - Simple but powerful constructs
  - Minimal type checking (both good and bad!)
  - Lack of true object-oriented capabilities
- Standards
  - Kernighan and Ritchie book (1978)
  - ANSI/ISO: C89/C90 (1989), C99 (1999), C11 (2011), C18 (2018)



Ken Thompson and Dennis Ritchie

Ada (1980)

- Originally designed for embedded systems
  - Another Department of Defense effort
  - Monolithic design process (1974-1980)
  - Named after Ada Lovelace
- Primary goal: good PL principles
  - Enforce software engineering best practices
  - Largely succeeded
- Large, complex, and hard to implement
  - Design published in 1980 and standardized in 1983
  - The first useful compiler was not finished until 1985
- Could not compete with C
  - Many people conjecture that software today would be much safer in general if Ada (and its principles) had gained more widespread support

Augusta Ada Lovelace

C++ (1985)

- Extended C with object-oriented features
  - Bjarne Stroustrup at Bell Labs
- Primary goal: speed and flexibility w/ low-cost abstractions
  - Originally "C with classes" preprocessor
  - Adds objects, templates, exceptions, and **lots** more
  - Few programmers use every feature of C++
- Became tremendously popular as OOP flourished
  - ANSI standardized in 1998
  - “Right place, right time”
  - Even influenced post-1989 versions of C
  - Major revision in 2011 (C++11)
  - Later revisions in 2014, 2017, and 2020

Bjarne Stroustrup

Java (1995)

- Originally designed for embedded applications
- Primary goal: reliability and portability
- Based on C++ but features were simplified and reduced
  - Eliminated pointers and added automatic garbage collection
  - Cleaned up templates (now "generics") and exceptions
  - Much stronger type checking
  - Often used for CS education
- Programs run on the Java Virtual Machine
  - Core runtime system that must be implemented for every new architecture
  - Source code is compiled to "byte code," which is interpreted by the JVM
  - Individual programs are very portable

.NET Languages (starting 2002)

- Common Language Infrastructure (CLI)
  - Language-neutral runtime platform
  - Common Intermediate Language (CIL) and Portable Executable (PE) format
- C# is a descendant of C++ and Java
  - Based on Java
  - Re-introduced some C++ features (but not multiple inheritance!)
- VB.NET is a descendant of BASIC (via Visual Basic)
  - Emphasis on writability and business applications
- J# and JScript.NET are transitional languages for Java/Javascript users
- F# is a multi-paradigm (including functional) language
- ASP.NET for server-side web apps, Q# for quantum computing
- If you're in the Windows world, .NET is great
  - Includes excellent developer support via the Visual Studio suite

Other Notable C/C++ Descendants

- Objective C (1983)
  - Descendant of C and Smalltalk; primarily used today by Apple
- D (2006)
- Go (2009)
  - Developed at Google by Ken Thompson and others
- Rust (2012)
  - Multi-paradigm client/server and systems language from Mozilla
- Common theme: a “modern” redesign of C/C++
  - Without the major problems and headaches
  - Added features for greater safety, concurrency, etc.
  - None have yet succeeded in displacing C/C++

Dynamic Scripting Languages

- Perl (1987) – Larry Wall
  - Originally designed for text processing
  - Powerful but ugly: the “Swiss Army chainsaw” of PL
  - Widely used across many domains, especially CGI programming
- Python (1991) – Guido van Rossum
  - Strong design philosophies
  - Large standard library
  - Python 3.0 (2008) is backwards-incompatible
- Ruby (1995) – Yukihiro Matsumoto
  - Designed for "productivity and fun"
  - Pure object-oriented multi-paradigm language
  - Strong self-inspection features ("reflection")

Dynamic Scripting Languages

- Javascript (1995) – Brendan Eich at Netscape
  - Embedded web browser and document programming
  - **Not related to Java!**
  - Widely used, but has been a source of many security flaws
  - Many popular extensions: Node.js, JSON, jQuery, etc.
- Others: Bash, TCL, VBScript, PHP, Lua
- General themes of dynamic scripting languages:
  - Interpreted (sometimes compiled for speed)
  - Powerful, expressive, and flexible syntax
  - Dynamic and/or "duck" typing
  - Automatic memory management
  - Anyone who doesn't use your preferred scripting language is clearly ~~wrong~~ ignorant and must be ~~converted~~ educated

Programming Paradigms

- Procedural
  - Includes all previously-discussed languages
  - And probably every language you saw before 430
  - It's definitely here to stay (at least for the foreseeable future)
  - But it's not the only paradigm
- Functional
  - LISP, Scheme, and descendants (including **Haskell**)
- Declarative / Logic
  - **Prolog** and descendants

LISP (1959)

- LISt Processing language
  - John McCarthy at MIT
- Functional language based on mathematics (lambda calculus)
  - No variables or global state
    - No side effects! This makes reasoning about program correctness much simpler and more powerful.
  - All computation involves applying functions to inputs
  - Iteration via recursion
  - Data types: atom and list (atom + list)
  - Symbolic computation
- Used primarily for AI research

```
(defun factorial (n)
  (if (= n 0) 1
      (* n (factorial (- n 1)))))
```

Descendants of LISP

- Common Lisp (1984/94)
  - Consolidation of many LISP variants
  - Multi-paradigm (supports procedural programming as well)
- Scheme (1970s)
  - Designed by Guy Steele and Gerald Sussman
  - Simplification of LISP; often used as a teaching language
- ML - MetaLanguage (1973)
  - Strongly-typed proof language designed by Robin Milner
  - Later extended at INRIA (France) to Caml and OCaml
- Haskell (1990)
  - Named after influential logician Haskell Curry
  - Purely functional language w/ strong typing and lazy evaluation

Prolog (1972)

- Declarative / Logic programming language
- Based on first-order predicate logic
  - Built-in goal-directed inference engine
  - Given facts and implications
  - Uses inference to infer the truth of queries
- Drawbacks
  - Can be difficult to understand
  - Solutions are often inefficient and/or of limited usefulness

```
% read as “sally has mother alice”
mother(sally, alice).

father(sally, tom).
father(erica, tom).
father(tom, mike).

% parent(X, Y) is read as “X has parent Y”
parent(X, Y)  :- father(X, Y).
parent(X, Y)  :- mother(X, Y).
sibling(X, Y) :- parent(X, Z), parent(Y, Z).
```

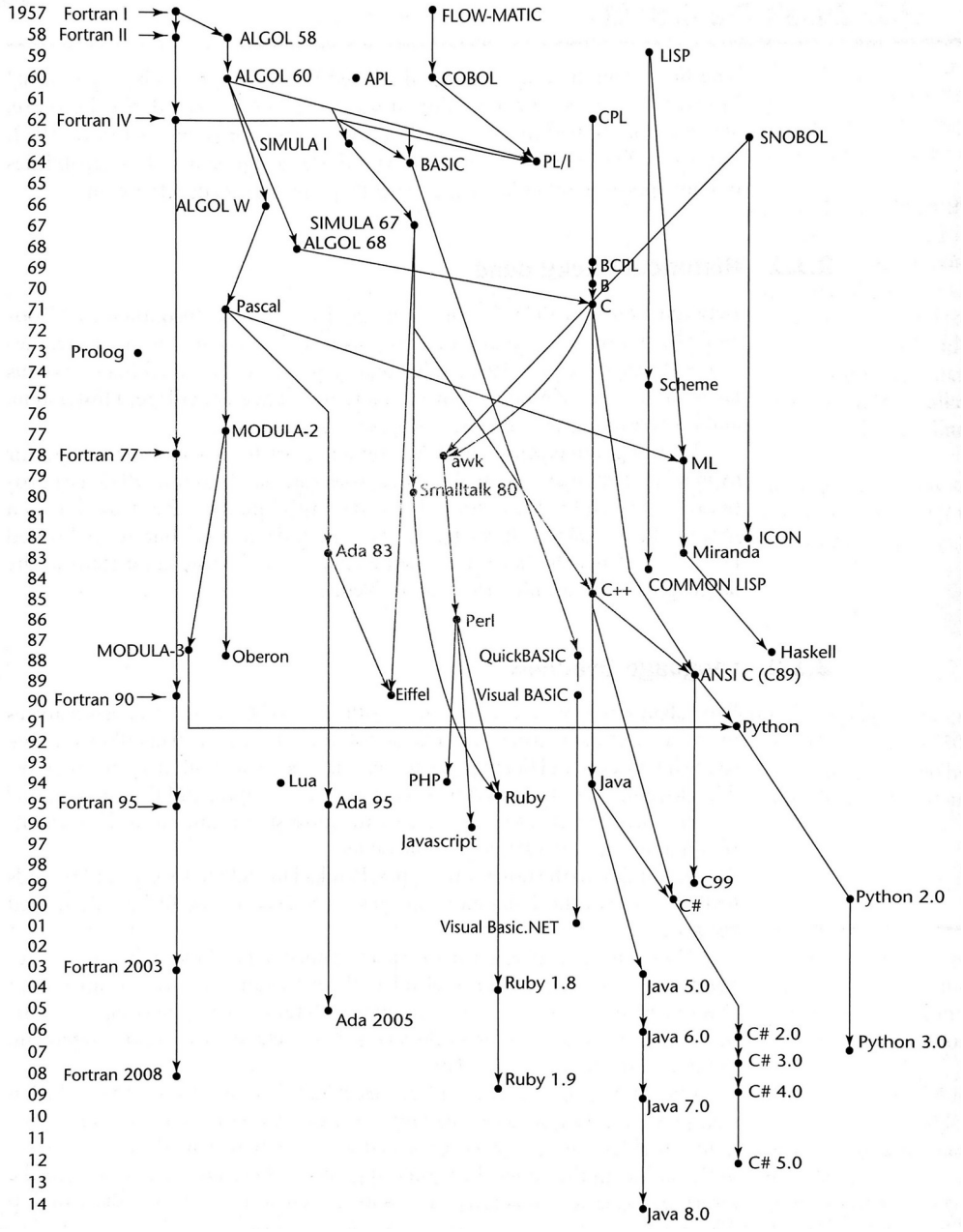
```
?- sibling(sally, erica).
Yes

?- parent(erica, alice).
No
```

Functional and Logic Paradigms

- Functional languages are still a niche
  - Concepts are extremely useful
  - Gaining popularity as software becomes more complex and concurrency becomes more important
  - Many procedural languages are adding functional features (including heavy-hitters like C# and Java)
  - Good tool to know
- Logic languages are an even smaller niche
  - Rarely used in practice
  - Useful for pattern matching w/ rules (e.g., IBM Watson)
  - Curry-Howard isomorphism: “programs are proofs”
  - Good tool to be aware of

Language Family Tree



“History of PL” Conferences

- HOPL-I (1978)
  - Keynote by then-Captain Grace Hopper
  - FORTRAN, ALGOL, LISP, COBOL, SIMULA, BASIC, PL/I, APL, and others
  - https://dl.acm.org/doi/book/10.1145/800025
- HOPL-II (1993)
  - Prolog, Smalltalk, C, Forth, C++, Ada, Pascal, and others
  - https://dl.acm.org/doi/proceedings/10.1145/154766
- HOPL-III (2007)
  - “50 in 50” talk by Guy Steele and Richard Gabriel
  - Lua, C++, Erlang, “Rise and Fall of High Performance Fortran”, ZPL, Haskell, and others
  - https://dl.acm.org/doi/proceedings/10.1145/1238844
- HOPL-IV (June 2021, co-virtual w/ PLDI 2021)
  - APL, **C++**, Fortran, D, Emacs Lisp, F#, Groovy, **Javascript**, LabVIEW, Logo, MATLAB, Objective-C, R, Smalltalk, Standard ML, Verilog, and others
  - https://hopl4.sigplan.org

“There are only two kinds of programming languages; those people always [complain] about and those nobody uses.”

– Bjarne Stroustrup