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Programming Languages
1. Introduction

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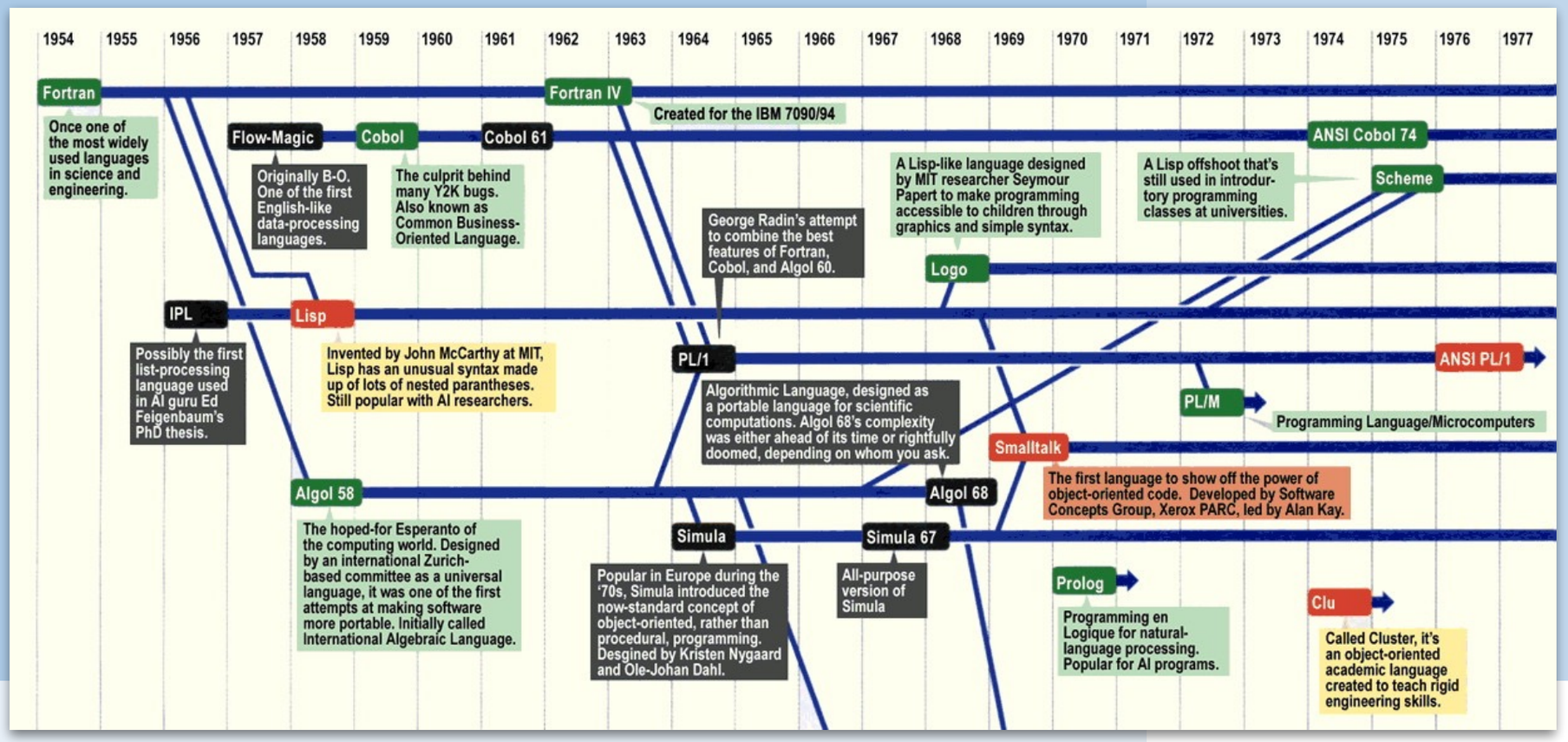

Roadmap

- Course Schedule
- Programming Paradigms
- A Quick Tour of Programming Language History

Programming Languages

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NB: Please register on both Academia and Ilias for this course

Roadmap

- **Course Schedule**
- Programming Paradigms
- A Quick Tour of Programming Language History

Sources

- **Text:**
  - Kenneth C. Louden, Programming Languages: Principles and Practice, PWS Publishing (Boston), 1993.

- **Other Sources:**
  - Paul Hudak, “Conception, Evolution, and Application of Functional Programming Languages,” ACM Computing Surveys 21/3, 1989, pp 359-411.
  - Clocksin and Mellish, Programming in Prolog, Springer Verlag, 1987.

Schedule

1	26-Feb-21	Introduction
2	05-Mar-21	Stack-based Programming
3	12-Mar-21	Functional Programming
4	19-Mar-21	Types and Polymorphism
5	26-Mar-21	Lambda Calculus
-	*02-Apr-21*	*Good Friday*
-	*09-Apr-21*	*Easter vacation*
6	16-Apr-21	Fixed Points
7	23-Apr-21	Programming Language Semantics
8	30-Apr-21	Objects and Prototypes
9	07-May-21	Objects, Types and Classes
10	14-May-21	Logic Programming
11	21-May-21	Applications of Logic Programming
12	28-May-21	Visual Programming
-	*04-Jun-21*	*Final Exam*

This is a note (a hidden slide). You will find some of these scattered around the PDF versions of the slides.

Roadmap

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- **Programming Paradigms**
- A Quick Tour of Programming Language History

What is a Programming Language?

- A formal language for describing computation?
- A "user interface" to a computer?
- Syntax + semantics?
- Compiler, or interpreter, or translator?
- A tool to support a programming paradigm?

> A programming language is a notational system for describing computation in a machine-readable and human-readable form.
>
> — Louden

What is a Programming Language? (II)

The thesis of this course:

> A programming language is a tool for developing executable models for a class of problem domains.

Themes Addressed in this Course

Paradigms
How do different language paradigms support problem-solving?

Foundations
What are the foundations of programming languages?

Semantics
How can we understand the semantics of programming languages?

Generations of Programming Languages

1GL: machine codes
2GL: symbolic assemblers
3GL: (machine-independent) imperative languages
4GL: domain specific application generators
5GL: AI languages …

Each generation is at a higher level of abstraction

How do Programming Languages Differ?

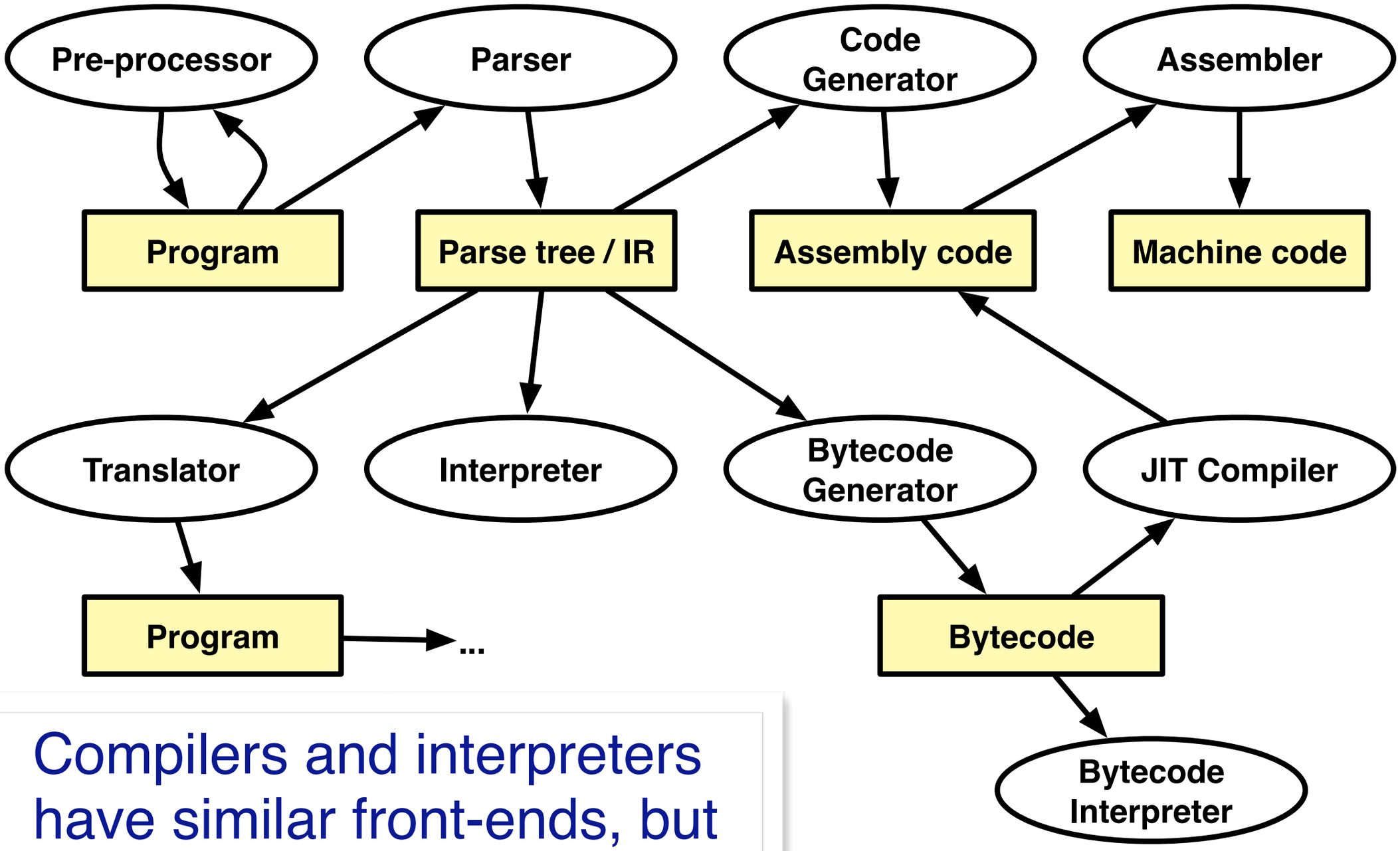
- **Common Constructs:**
  - basic data types (numbers, etc.); variables; expressions; statements; keywords; control constructs; procedures; comments; errors ...

- **Uncommon Constructs:**
  - type declarations; special types (strings, arrays, matrices, ...); sequential execution; concurrency constructs; packages/modules; objects; general functions; generics; modifiable state; ...

Programming Paradigms

A programming language is a problem-solving tool.	
Imperative style:	program = algorithms + data *good for decomposition*
Functional style:	program = functions ∘ functions *good for reasoning*
Logic programming style:	program = facts + rules *good for searching*
Object-oriented style:	program = objects + messages *good for modeling(!)*
Other styles and paradigms: blackboard, pipes and filters, constraints, lists, ...	

Compilers and Interpreters



Compilers and interpreters have similar front-ends, but have different back-ends.

In this course we will focus on programming language paradigms and semantics of PLs, not so much on compiler technology. However we will see how to implement some simple interpreters based on the formal semantics of a language.

Roadmap

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- **A Quick Tour of Programming Language History**

A Brief Chronology

Early 1950s		“order codes” (primitive assemblers)
1957	FORTRAN	the first high-level programming language
1958	ALGOL	the first modern, imperative language
1960	LISP, COBOL	Interactive programming; business programming
1962	APL, SIMULA	the birth of OOP (SIMULA)
1964	BASIC, PL/I	
1966	ISWIM	first modern functional language (a proposal)
1970	Prolog	logic programming is born
1972	C	the systems programming language
1975	Pascal, Scheme	two teaching languages
1978	CSP	Concurrency matures
1978	FP	Backus’ proposal
1983	Smalltalk-80, Ada	OOP is reinvented
1984	Standard ML	FP becomes mainstream (?)
1986	C++, Eiffel	OOP is reinvented (again)
1988	CLOS, Oberon, Mathematica	
1990	Haskell	FP is reinvented
1990s	Perl, Python, Ruby, JavaScript	Scripting languages become mainstream
1995	Java	OOP is reinvented for the internet
2000	C#	

So, nothing has happened in the last twenty years? Well, there have been quite some innovations in the area of advanced type systems for programming languages. Scala, Rust, Swift, and other languages have leveraged advances in type systems to help programmers catch bugs statically. We'll see more about that in the Types lecture.

Fortran

History

- John Backus (1953) sought to write programs in conventional mathematical notation, and generate code comparable to good assembly programs.
- No language design effort (made it up as they went along)
- Most effort spent on code generation and optimization
- FORTRAN I released April 1957; working by April 1958
- The current standard is FORTRAN 2008 (FORTRAN 2015 is work in progress)

Fortran …

Innovations

- Symbolic notation for subroutines and functions
- Assignments to variables of complex expressions
- DO loops
- Comments
- Input/output formats
- Machine-independence

Successes

- Easy to learn; high level
- Promoted by IBM; addressed large user base
- (scientific computing)

“Hello World” in FORTRAN

```
      PROGRAM HELLO
      DO 10, I=1,10
      PRINT *,'Hello World'
10    CONTINUE
      STOP
      END
```

All examples from the ACM "Hello World" project:

www2.latech.edu/~acm/HelloWorld.shtml

ALGOL 60

History

- Committee of PL experts formed in 1955 to design universal, machine-independent, algorithmic language
- First version (ALGOL 58) never implemented; criticisms led to ALGOL 60

Innovations

- BNF (Backus-Naur Form) introduced to define syntax (led to syntax-directed compilers)
- First block-structured language; variables with local scope
- Structured control statements
- Recursive procedures
- Variable size arrays

Successes

- Highly influenced design of other PLs but never displaced FORTRAN

ALGOL introduced both recursion and Backus-Naur form to describe the syntax of the language. Neither of these features existed when FORTRAN was originally designed.

“Hello World” in BEALGOL

```
BEGIN
FILE F (KIND=REMOTE);
EBCDIC ARRAY E [0:11];
REPLACE E BY "HELLO WORLD!";
WHILE TRUE DO
        BEGIN
        WRITE (F, *, E);
        END;
END.
```

COBOL

History

- Designed by committee of US computer manufacturers
- Targeted business applications
- Intended to be readable by managers (!)

Innovations

- Separate descriptions of environment, data, and processes

Successes

- Adopted as de facto standard by US DOD
- Stable standard for 25 years
- *Still the most widely used PL for business applications (!)*

“Hello World” in COBOL

```
000100 IDENTIFICATION DIVISION.
000200 PROGRAM-ID.     HELLOWORLD.
000300 DATE-WRITTEN.   02/05/96        21:04.
000400* AUTHOR BRIAN COLLINS
000500 ENVIRONMENT DIVISION.
000600 CONFIGURATION SECTION.
000700 SOURCE-COMPUTER. RM-COBOL.
000800 OBJECT-COMPUTER. RM-COBOL.
001000 DATA DIVISION.
001100 FILE SECTION.
100000 PROCEDURE DIVISION.
100200 MAIN-LOGIC SECTION.
100300 BEGIN.
100400                 DISPLAY " " LINE 1 POSITION 1 ERASE EOS.
100500                 DISPLAY "HELLO, WORLD." LINE 15 POSITION 10.
100600                 STOP RUN.
100700 MAIN-LOGIC-EXIT.
100800                 EXIT.
```

PL/1

History

- Designed by committee of IBM and users (early 1960s)
- Intended as (large) general-purpose language for broad classes of applications

Innovations

- Support for concurrency (but not synchronization)
- Exception-handling on conditions

Successes

- Achieved both run-time efficiency and flexibility (at expense of complexity)
- First “complete” general purpose language

“Hello World” in PL/1

```
HELLO:    PROCEDURE OPTIONS (MAIN);
       /* A PROGRAM TO OUTPUT HELLO WORLD */
       FLAG = 0;

LOOP:  DO WHILE (FLAG = 0);
                PUT SKIP DATA('HELLO WORLD!');
       END LOOP;

END HELLO;
```

Functional Languages

- ISWIM (If you See What I Mean)
  - Peter Landin (1966) — paper proposal
- FP
  - John Backus (1978) — Turing award lecture
- ML
  - Edinburgh
  - initially designed as meta-language for theorem proving
  - Hindley-Milner *type inference*
  - “non-pure” functional language (with assignments/side effects)
- Miranda, Haskell
  - “pure” functional languages with *“lazy evaluation”*

We will look at functional languages in some detail, and their relation to lambda calculus and type systems. Although the functional paradigm differs fundamentally from the object-oriented paradigm, the two paradigms complement each other nicely, and there have been many interesting integrations of the two in modern languages (see both Python and Scala, for example).

“Hello World” in Functional Languages

SML

```
print("hello world!\n");
```

Haskell

```
hello() = print "Hello World"
```

Prolog

History

- Originated at U. Marseilles (early 1970s), and compilers developed at Marseilles and Edinburgh (mid to late 1970s)

Innovations

- Theorem proving paradigm
- Programs as sets of clauses: facts, rules and questions
- Computation by “unification”

Successes

- Prototypical logic programming language
- Used in Japanese Fifth Generation Initiative

Prolog and other logic-based languages differ radically from other paradigms, even though they are Turing-complete and can be used as general-purpose languages. They have traditionally been more popular in niche domains, such as expert systems.

“Hello World” in Prolog

```
hello :- printstring("HELLO WORLD!!!!").

printstring([]).
printstring([H|T]) :- put(H),
printstring(T).
```

Object-Oriented Languages

History

- *Simula* was developed by Nygaard and Dahl (early 1960s) in Oslo as a language for simulation programming, by adding classes and inheritance to ALGOL 60

```
Begin
   while 1 = 1 do begin
      outtext ("Hello World!");
      outimage;
   end;
End;
```

- *Smalltalk* was developed by Xerox PARC (early 1970s) to drive graphic workstations

```
Transcript show:'Hello World';cr
```

Object-Oriented Languages

Innovations

- *Encapsulation* of data and operations (contrast ADTs)
- *Inheritance* to share behaviour and interfaces

Successes

- Smalltalk project pioneered OO user interfaces
- Large commercial impact since mid 1980s
- Countless new languages: C++, Objective C, Eiffel, Beta, Oberon, Self, Perl 5, Python, Java, Ada 95 ...

Pretty much all industrial programming is done in OO languages, due to their support for modularity and scalability. They have been extremely successful for building long-lived software systems. In recent years, however, there has been much interest in integrations with functional programming, to improve expressiveness and the ability to reason about programs.

Interactive Languages

- Made possible by advent of time-sharing systems (early 1960s through mid 1970s).

BASIC

- Developed at Dartmouth College in mid 1960s
- Minimal; easy to learn
- Incorporated basic O/S commands (NEW, LIST, DELETE, RUN, SAVE)

```
10 print "Hello World!"
20 goto 10
```

- ...

Interactive Languages ...

APL

- Developed by Ken Iverson for concise description of numerical algorithms
- Large, non-standard alphabet (52 characters in addition to alphanumerics)
- Primitive objects are arrays (lists, tables or matrices)
- Operator-driven (power comes from composing array operators)
- No operator precedence (statements parsed right to left)

```
'HELLO WORLD'
```

Special-Purpose Languages

SNOBOL

- First successful string manipulation language
- Influenced design of text editors more than other PLs
- String operations: pattern-matching and substitution
- Arrays and associative arrays (tables)
- Variable-length strings

```
        OUTPUT = 'Hello World!'
END
```

- ...

Symbolic Languages ...

Lisp

- Performs computations on symbolic expressions
- Symbolic expressions are represented as *lists*
- Small set of constructor/selector operations to create and manipulate lists
- Recursive rather than iterative control
- *No distinction between data and programs*
- First PL to implement storage management by garbage collection
- Affinity with lambda calculus

```
(DEFUN HELLO-WORLD ()
  (PRINT (LIST 'HELLO 'WORLD)))
```

4GLs

"Problem-oriented" languages

- PLs for "non-programmers"
- Very High Level (VHL) languages for specific problem domains

Classes of 4GLs (no clear boundaries)

- Report Program Generator (RPG)
- Application generators

Query languages

- Decision-support languages
- Successes
- Highly popular, but generally ad hoc

“Hello World” in RPG

```
H
FSCREEN O F 80 80
                                                    CRT
C
         EXCPT
OSCREEN E 1
O
                                                   12 'HELLO WORLD!'
```

“Hello World” in SQL

```
CREATE TABLE HELLO (HELLO CHAR(12))
UPDATE HELLO
     SET HELLO = 'HELLO WORLD!'
SELECT * FROM HELLO
```

Scripting Languages

History

Countless “shell languages” and “command languages” for operating systems and configurable applications

Unix shell (ca. 1971) developed as user shell and scripting tool

```
echo "Hello, World!"
```

HyperTalk (1987) was developed at Apple to script HyperCard stacks

```
on OpenStack
        show message box
        put "Hello World!" into
message box
end OpenStack
```

TCL (1990) developed as embedding language and scripting language for X windows applications (via Tk)

```
puts "Hello World "
```

Perl (~1990) became de facto web scripting language

```
print "Hello, World!\n";
```

Scripting Languages ...

Innovations

- Pipes and filters (Unix shell)
- Generalized embedding/command languages (TCL)

Successes

- Unix Shell, awk, emacs, HyperTalk, AppleTalk, TCL, Python, Perl, VisualBasic ...

The future? The present?

- Dynamic languages
  - very active
- Domain-specific languages
  - very active
- Visual languages
  - many developments, but still immature
- Modeling languages
  - emerging from UML and MDE …

What you should know!

- What, exactly, is a programming language?
- How do compilers and interpreters differ?
- Why was FORTRAN developed?
- What were the main achievements of ALGOL 60?
- Why do we call C a “Third Generation Language”?
- What is a “Fourth Generation Language”?

Can you answer these questions?

- Why are there so many programming languages?
- Why are FORTRAN and COBOL still important programming languages?
- Which language should you use to implement a spelling checker?
- A filter to translate upper-to-lower case?
- A theorem prover?
- An address database?
- An expert system?
- A game server for initiating chess games on the internet?
- A user interface for a network chess client?