Programming Languages: Concepts

(Lectures on High-performance Computing for Economists IV)

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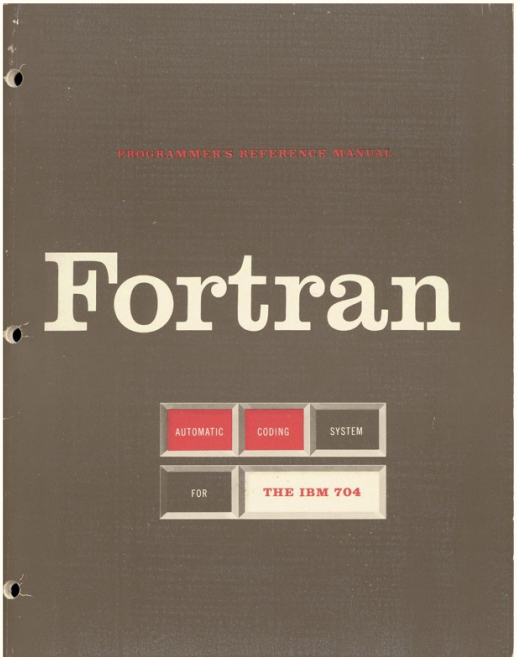
Introduction

Motivation

- Since the invention of `Fortran` in 1954-1957 to substitute assembly language, hundreds of programming languages have appeared.
- Some more successful than others, some more useful than others.
- Moreover, languages evolve over time (different version of `Fortran`).
- Different languages are oriented toward certain goals and have different approaches.
- Our thinking about what is a good programming language has also changed as we accumulate more experience with computers.


PROGRAMMER'S REFERENCE MANUAL
Fortran
AUTOMATIC
CODING
SYSTEM
FOR
THE IBM 704

Some references

- *Programming Language Pragmatics (4th Edition)*, by Michael L. Scott.
- *Essentials of Programming Languages (3rd Edition)*, by Daniel P. Friedman and Mitchell Wand.
- *Concepts of Programming Languages (11th Edition)*, by Robert W. Sebesta.
- `http://hyperpolyglot.org/`

The basic questions

- Which programming language to learn?
- Which programming language to use in *this* project?
- Do I need to learn a *new* language?

Which programming language? I

- Likely to be a large investment.
- Also, you will probably want to be familiar at least with a couple of them (good mental flexibility) plus LaTeX.

Alan Perlis

A language that doesn't affect the way you think about programming is not worth knowing.

- There is a good chance you will need to recycle yourself over your career.

Which programming language? II

- Typical problems in economics can be:
  1. CPU-intensive.
  2. Memory-intensive.
- Imply different emphasis.
- Because of time constraints, we will not discuss memory-intensive tools such as `Kubernetes` and `Spark`.

Classification

Classification

- There is no “best” solution.
- But there are some good tips.
- We can classify programming languages according to different criteria.
- We will pick several criteria that are relevant for economists:
  1. Level.
  2. Domain.
  3. Execution.
  4. Type.
  5. Paradigm.

Level

- Levels:
  1. `machine code`.
  2. Low level: `assembly language` like `NASM` (`http://www.nasm.us/`), `GAS`, or `HLA` (*The Art of 64-Bit Assembly*, by Randall Hyde).
  3. High level: like `C/C++`, `Julia`, ...
- You can actually mix different levels (`C`).
- Portability.
- You are unlikely to see low level programming unless you get into the absolute frontier of performance (for instance, with extremely aggressive parallelization).

Fibonacci number

Machine code:

```
8B542408 83FA0077 06B80000 0000C383 FA027706 B8010000 00C353BB
01000000 B9010000 008D0419 83FA0376 078BD98B C84AEBF1 5BC3
```

Assembler:

```
ib: mov edx, [esp+8] cmp edx, 0 ja @f mov eax, 0 ret @@: cmp edx, 2 ja @f
mov eax, 1 ret @@: push ebx mov ebx, 1 mov ecx, 1 @@: lea eax, 3 jbe @f mov
ebx, ecx  [ebx+ecx]  cmp edx, mov ecx, eax dec edx jmp @b  @@: pop ebx  ret
```

C++:

```
int fibonacci(const int x) {
        if (x==0) return(0);
        if (x==1) return(1);
        return (fibonacci(x-1))+fibonacci(x-2);}
```

Domain

- Domain:
  1. General-purpose programming languages (GPL), such as `Fortran`, `C/C++`, `Python`, ...
  2. Domain specific language (DSL) such as `Julia`, `R`, `Matlab`, `Mathematica`, ...
- Advantages/disadvantages:
  1. GPL are more powerful, usually faster to run.
  2. DSL are easier to learn, faster to code, built-in functions and procedures.

Execution I

- Three basic modes to run code:
  1. Interpreted: `Python`, `R`, `Mathematica`.
  2. Compiled: `Fortran`, `C/C++`.
  3. JIT (Just-in-Time) compilation: `Julia`, `Matlab`.
- Interpreted languages can we used with:
  1. A command line in a `REPL` (Read–eval–print loop).
  2. A script file.
- Many DSL are interpreted, but this is neither necessary nor sufficient.
- Advantages/disadvantages: similar to GPL versus DSL.
- Interpreted and JIT programs are easier to move across platforms.

Execution II

- In reality, things are somewhat messier.
- Some languages are explicitly designed with an interpreter and a compiler (`Haskell`, `Scala`, `F#`).
- Compiled programs can be extended with third-party interpreters (`CINT` and `Cling` for C/C++).
- Often, interpreted programs can be compiled with an auxiliary tool (`Matlab`, `Mathematica`,...).
- Interpreted programs can also be compiled into byte code (`R`, languages that run on the `JVM` -by design or by a third party compiler).
- We can mix interpretation/compilation with libraries.

Types I

- Type strength:
  1. Strong: type enforced.
  2. Weak: type is tried to be adapted.
- Type expression:
  1. Manifest: explicit type.
  2. Inferred: implicit.
- Type checking:
  1. Static: type checking is performed during compile-time.
  2. Dynamic: type checking is performed during run-time.
- Type safety:
  1. Safe: error message.
  2. Unsafe: no error.

Types II

- Advantages of strong/manifest/static/safe type:
  1. Easier to find programming mistakes⇒`ADA`, for critical real-time applications, is strongly typed.
  2. Easier to read.
  3. Easier to optimize for compilers.
  4. Faster runtime not all values need to carry a dynamic type.
- Disadvantages:
  1. Harder to code.
  2. Harder to learn.
  3. Harder to prototype.

Types III

- You implement strong/manifest/static/safe typing in dynamically typed languages.
- You can define variables explicitly. For example, in `Julia`

```
a = 10::Int
```

- It often improve performance speed and safety.
- You can introduce checks:

```
a = "This is a string"
if typeof(a) == String
    println(a)
else
    println("Error")
end
```

Jan 2022	Jan 2021	Change	Programming Language	Ratings	Change
1	3	↑	Python	13.58%	+1.86%
2	1	↓	C	12.44%	-4.94%
3	2	↓	Java	10.66%	-1.30%
4	4		C++	8.29%	+0.73%
5	5		C#	5.68%	+1.73%
6	6		Visual Basic	4.74%	+0.90%
7	7		JavaScript	2.09%	-0.11%
8	11	↑	Assembly language	1.85%	+0.21%
9	12	↑	SQL	1.80%	+0.19%
10	13	↑	Swift	1.41%	-0.02%
11	8	↓	PHP	1.40%	-0.60%
12	9	↓	R	1.25%	-0.65%
13	14	↑	Go	1.04%	-0.37%
14	19	⇈	Delphi/Object Pascal	0.99%	+0.20%
15	20	⇈	Classic Visual Basic	0.98%	+0.19%
16	16		MATLAB	0.96%	-0.19%
17	10	⇊	Groovy	0.94%	-0.90%
18	15	↓	Ruby	0.88%	-0.43%
19	30	⇈	Fortran	0.77%	+0.31%
20	17	↓	Perl	0.71%	-0.31%

Programming Language	2022	2017	2012	2007	2002	1997	1992	1987
C	1	2	2	2	1	1	1	1
Python	2	5	8	8	18	28	-	-
Java	3	1	1	1	2	18	-	-
C++	4	3	3	3	3	2	2	4
C#	5	4	4	7	12	-	-	-
Visual Basic	6	14	-	-	-	-	-	-
JavaScript	7	7	10	9	9	21	-	-
Assembly language	8	10	-	-	-	-	-	-
PHP	9	6	5	5	8	-	-	-
SQL	10	-	-	-	35	-	-	-
Prolog	24	33	45	28	29	15	10	3
Ada	28	30	17	17	17	11	3	14
Lisp	32	28	13	13	11	8	12	2
(Visual) Basic	-	-	7	4	4	3	7	5

Language popularity I

- C family (a subset of the ALGOL family), also known as "curly-brackets languages":
  1. C, C++, C#: 26.41%: 3 out of top 5.
  2. C, Java, C++, C#, JavaScript: 39.16%: 5 out of top 10.
- Python: position 1, 13.58%.
- R: position 12, 1.25%.
- Matlab: position 16, 0.96%.
- Fortran: position 19, 0.77%.
- Julia: position 28, 0.39%.

Language popularity II

- High-performance and scientific computing is a small area within the programming community.
- Thus, you need to read the previous numbers carefully.
- For example:
  1. You will most likely never use `JavaScript` or `PHP` (at least while wearing with your "economist" hat) or deal with an embedded system.
  2. `C#` and `Swift` are cousins of C focused on industry applications not very relevant for you.
  3. `Java` (usually) pays a speed penalty.
  4. `Fortran` is still used in some circles in high-performance programming, but most programmers will never bump into anyone who uses `Fortran`.

Multiprogramming

- Attractive approach in many situations.
- Best `IDEs` can easily link files from different languages.
- Easier examples:
  1. `ccall` and `PyCall` in `Julia`.
  2. `Rcpp`.
  3. `Mex` files in `Matlab`.