Languages

Martin Kellogg

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Today's agenda:

- Reading Quiz
- how do programming languages differ?

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Reading quiz: languages

Q1: what problem with Go inspired the author's team to rewrite their service in Rust?

A. Go lacks generics
B. Go is owned by Google, but Rust is open-source
C. they wanted to use the new "tokio" async library, which is only available in Rust
D. Go's garbage collector was causing performance problems

Q2: **TRUE** or **FALSE**: Discord used an unstable version of a Rust async library, even though they knew that it carried risks

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Why discuss programming languages at all?

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  - lecture goal: give you tools to **evaluate the trade-offs** between different languages

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  - lecture goal: give you tool
    between different languag

Advice before we go further: when you inherit a code base, **don't try to rewrite** it right away in a "better" language: it's usually not worth it

How can programming languages differ?

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- programming paradigm
- whether they have a type system
  - and, if they do, what kind of type system they have
- library support
  - the standard library is especially important
- performance
- team/process factors
  - how well do you know the language
  - how easy it'll be to hire other developers who do

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- usually based on some kind of mathematical foundation
- common, important paradigms we'll discuss today:
    - imperative
    - functional
    - object-oriented

Imperative programming

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Imperative programming: examples

Languages with imperative programming (non-exhaustive list):

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Languages with imperative programming (non-exhaustive list):

- FORTRAN
- C
- C++
- Python
- Java
- JavaScript/TypeScript
- many, many others!

Imperative programming: examples

Consider the following C program:

```
double avg(int x, int y) {
  double z = (double)(x + y);
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semicolons separate commands, program is a list of commands

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destructive updates of memory cells

Functional programming

Definition: in the ***functional*** paradigm, programs are compositions of mathematical expressions (especially functions)

- key mathematical formalism: **lambda calculus**
  - in the lambda calculus, **everything is a function**
  - lambda calculus is **as powerful** as Turing machines
    - "as powerful" = anything you can compute with a Turing machine can also be computed with the lambda calculus
- functional programming **models math** well
  - it is easier to formally reason about functional programs

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  - Closures and **recursion**
  - **Lists** and list processing

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Let's look at how imperative and functional languages **manage state** in a bit more detail

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- **Functional** programs yield **new similar states** over time.
  - `let x = y in …` , however, only changes `x`'s value **within** the scope of the …

Example: functional vs. imperative

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NOT the same as a semi-colon: commands vs expressions

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even the operators are type-safe (in OCaml)

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commands still exist, but limited to inherently "imperative" operations (I/O, saving to disk, etc.)

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no "return" statement, because everything is an expression

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15.27. Lambda Expressions

Here are some examples of lambda expressions:

```
() -> {}                // No parameters; result is void
() -> 42                // No parameters, expression body
() -> null              // No parameters, expression body
() -> { return 42; }    // No parameters, block body with return
() -> { System.gc(); }  // No parameters, void block body
```

Functional advantages

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- ***Referential transparency***
  - Replace any expression by its value without changing the result
- "No" side-effects
  - Fewer errors

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17 small benchmarks

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- Compiler implementation
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  - New programming style
- Not appropriate for every program
  - Some programs are inherently stateful

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- **extraordinarily common**
- models **the real world** well
  - objects are good abstractions for real-world entities and concepts

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Which of the two does Java use? What about JavaScript?

Object-oriented programming languages

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- Smalltalk
- Java
- C++
- C#
- Python
- JavaScript/TypeScript
- Swift
- R
- etc.

How can programming languages differ?

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  - and, if they do, what kind of type system they have
- library support
  - the standard library is especially important
- performance
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- **type theory** is the discipline of math (yes!) that studies the formal properties of type systems
- most programming languages include some kind of type system
  - exceptions: assembly, Lisp, a few others

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- **Insight**: typechecking is just another program analysis

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    - early detection of errors, types are documentation
  - Benefits of dynamic typing:
    - faster prototyping, no false positives

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  - e.g., Kotlin **guarantees no null-pointer dereferences**, but Java doesn't (both compile to Java bytecode)
  - stronger types can be added to a language (**ask me more**)
    - "pluggable types"

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Remember: **Don’t Repeat Yourself**
If someone else has already built what you need, don’t build it again

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  - positive feedback loop!
- Common situation: you need library A and library B, but A is written in language L and B is written in language M
  - What to do?

Multi-language projects

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Multi-language projects are common!
Developer quote: ““My last 4 jobs have been apps that called: Java from C#, and C# from F#; Java from Ruby; Python from Tcl, C++ from Python, and C from Tcl; Java from Python, and Java from Scheme (And that's not even counting SQL, JS, OQL, etc.)””

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For example, concurrency might be better handled in F#/OCaml (immutable functional) or Ruby (designed to hide such details), while low-level OS or hardware access is much easier in C or C++, while rapid prototyping is much easier in Python or Lua, etc.

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C/C++ is a lingua franca

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- Examples:
  - .NET framework (Microsoft)
    - C++, C#, J#, F#, Visual Basic, etc.
  - Java bytecode + Java virtual machine
    - Java, Scala, Kotlin, Closure, etc.
  - LLVM bytecode
  - etc.

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- Most **tools are language specific**: testing frameworks (+ generation, coverage, etc.), static analysis, build systems, debuggers, etc.

How can programming languages differ?

- programming paradigm
- whether they have a type system
  - and, if they do, what kind of type system they have
- library support
  - the standard library is especially important
- **performance**
- team/process factors
  - how well do you know the language
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  - Rust: good performance and safety, hard to write
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  - C: good performance, easy-ish to write, very unsafe

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- Also relevant: **optimizations**
  - **interpreted** languages almost always slower: no optimizing compiler
  - JITs (***just-in-time compilers***) can produce surprisingly fast code
    - e.g., Java Virtual Machine

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    - but writing Rust code requires follows its (complex) type discipline
  - bottom line: statically safe languages **can be faster**, but are **generally harder to program in**

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- library support
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- **team/process factors**
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Implication: if you're going to need an expert, make sure you have one! This often seriously limits your choice of languages in practice :(

program

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- Implication: if all else is equal, **choose the more popular** language

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  - you're not building new features
  - integration problems
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  - why? **Performance problems**.
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  - integration problems
  - will the benefits be worth it?

Implication: rewriting is a good idea if you're confident that the benefits of the new language are worthwhile, but be cautious: it can expensive!

Takeaways

- there is a wider world of languages than just imperative and object-oriented (but those are the most popular)
  - learning to write functional code can make you a better programmer
- different programming languages have different trade-offs
  - performance vs safety vs ease of use vs …
- when starting a new project, think carefully about the requirements before choosing a language
- rewrite a project in a new language only after careful consideration