

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

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- it's fairly rare that you get to choose a language, but when you do, it's a big responsibility!
 - lecture goal: give you tools to think about the trade-offs between different languages

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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Programming language paradigms

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Definition: a language *paradigm* is a way to classify programming languages, usually by their style of structuring programs

- 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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 - commands = ?
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 - array that is destructively updated = registers/memory/disk

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) {  
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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

Functional programming: characteristics

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 - **Higher-order, first-class** functions
 - 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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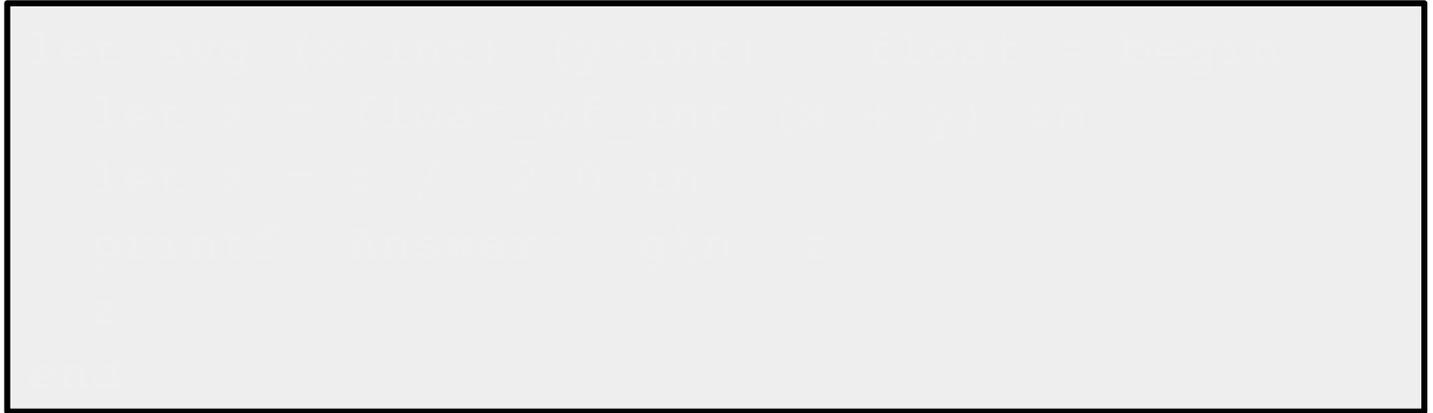
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 - e.g., after executing `*x = y` (in a C program), the memory cell that `x` points to now holds the value `y`. Its old value is gone.
- **Functional** programs yield **new similar states** over time.
 - `let x = y in ...`, however, only changes `x`'s value **within** the scope of the ...

Example: functional vs. imperative

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double avg(int x, int y) {  
    double z = (double)(x + y);  
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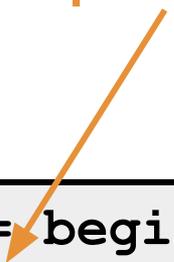
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NOT the same as a semi-colon:
commands vs expressions



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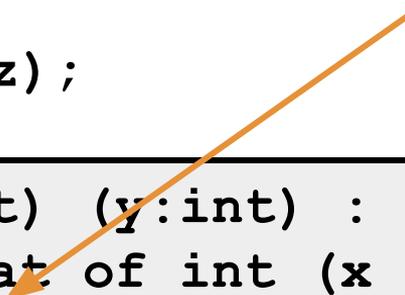
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even the operators are
type-safe (in OCaml)



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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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 - Formulate and prove assertions about code more easily
 - More readable (if you like math)
- *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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 - 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?

- programming paradigm
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 - and, if they do, what kind of type system they have
- library support
 - the standard library is especially important
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- goal of a type system: **prevent errors** at run time due to unexpected values
- **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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 - 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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- Tied to **language popularity**: languages that are more popular have better libraries, so people are more likely to use them
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Library support

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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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- **Examples:** Emacs (C / Lisp), Adobe Lightroom (C++ / Lua), NRAO Telescope (C / Python), Google Android (C / Java), most games (C++ / Lua), etc.
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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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- **Developer expertise** is required in multiple languages
 - Must understand types (etc.) in **all** languages
- 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
 - how easy it'll be to hire other developers who do

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 - Python: easy to write, okay safety, slow
 - C: good performance, easy-ish to write, very unsafe

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 - dynamic type checking: type safety
 - **garbage collection**: memory safety
 - exceptions: segfault safety
- 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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 - requires **static analysis** (= there will be false positives)
 - harder for programmers (trades off against **effort**)
 - the garbage collector in Java/Go/etc. is automatic
 - 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
 - the standard library is especially important
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- **team/process factors**
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 - cf. AWS employs some JVM experts to tune the garbage collector for AWS services that use Java

Team/process factors

- Learning a new programming language takes time
 - **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
 - Becoming an expert takes a long time!
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 - it's **easier to hire** new engineers who already know the language, and therefore can ramp up faster
 - but this impact is relatively small over a typical engineer's tenure at a company
- Implication: if all else is equal, **choose the more popular** language

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 - you're not building new features
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 - why? **Performance problems**.
- This is usually a **risky thing** to do:
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Implication: rewriting is a good idea if you're confident that the benefits of the new language are worthwhile, but be cautious: it can be 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