A Comparative Study of Programming Languages for Next-Generation Astrodynamics Systems

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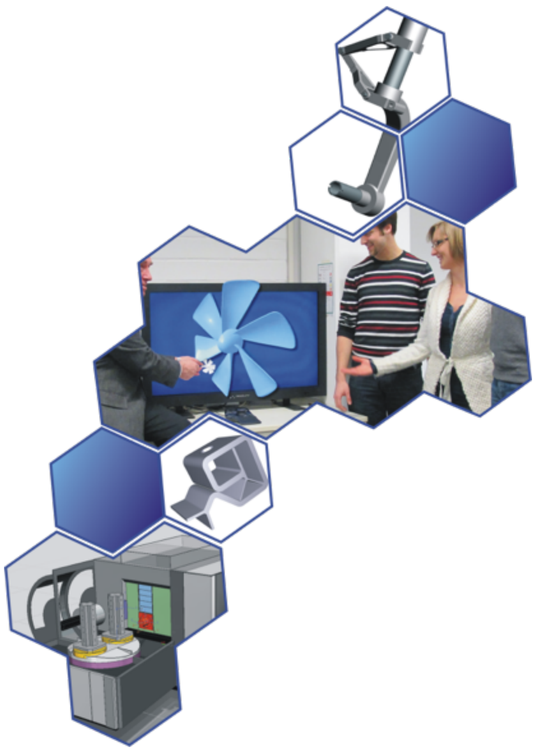
Prof Dr.-Ing. Reiner Anderl



Speed/Usability Dichotomy

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Computing costs
are the limiting factor

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Efficiency is most
important

Speed/Usability Dichotomy

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2016
Personnel costs
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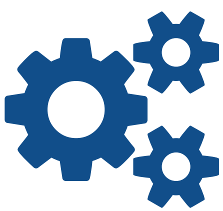

Efficiency is most important

Speed/Usability Dichotomy

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Efficiency is most important

Usability should be most important

Speed/Usability Dichotomy

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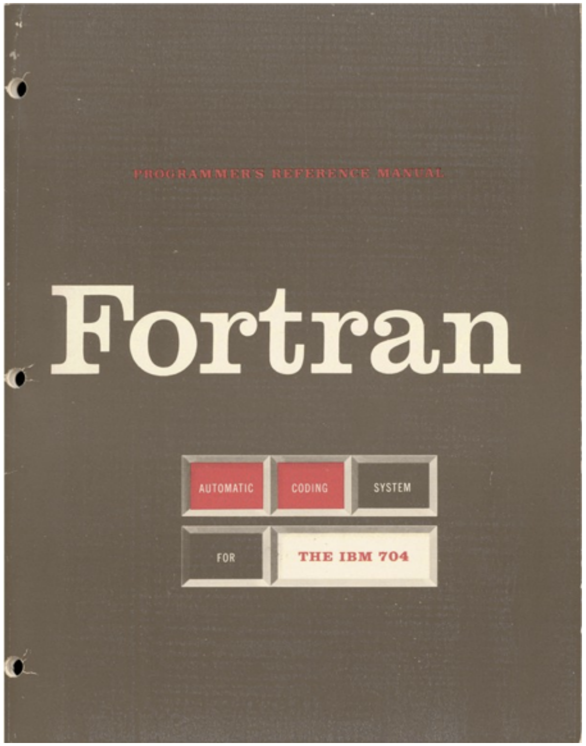
Efficiency is most
important

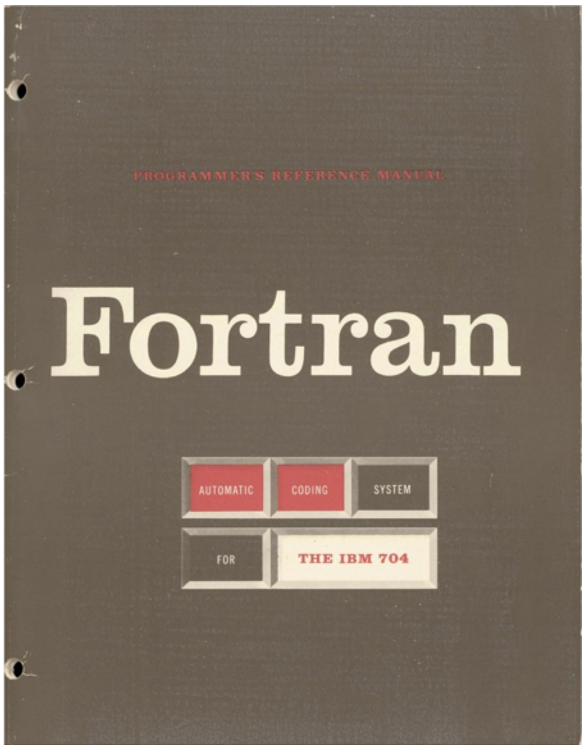
Cannot have both?

Usability should
be most important

Fortran

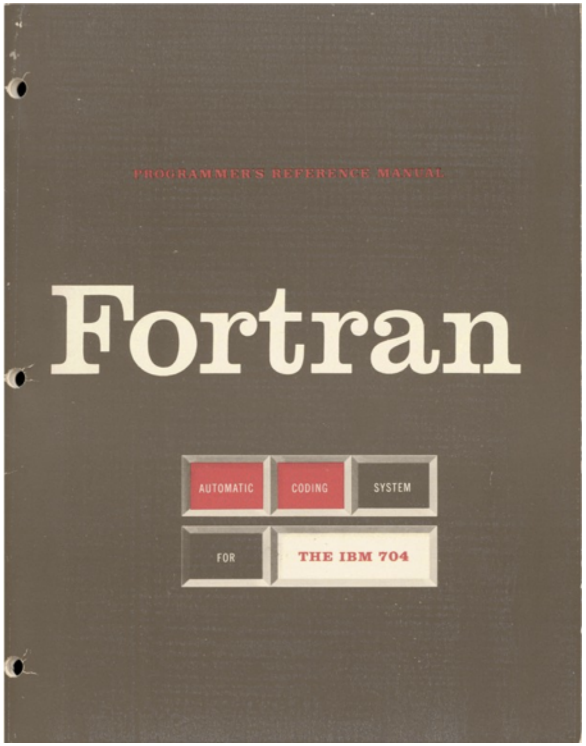

PROGRAMMER'S REFERENCE MANUAL
Fortran
AUTOMATIC
CODING
SYSTEM
FOR
THE IBM 704

Fortran



- Tried and tested

Fortran



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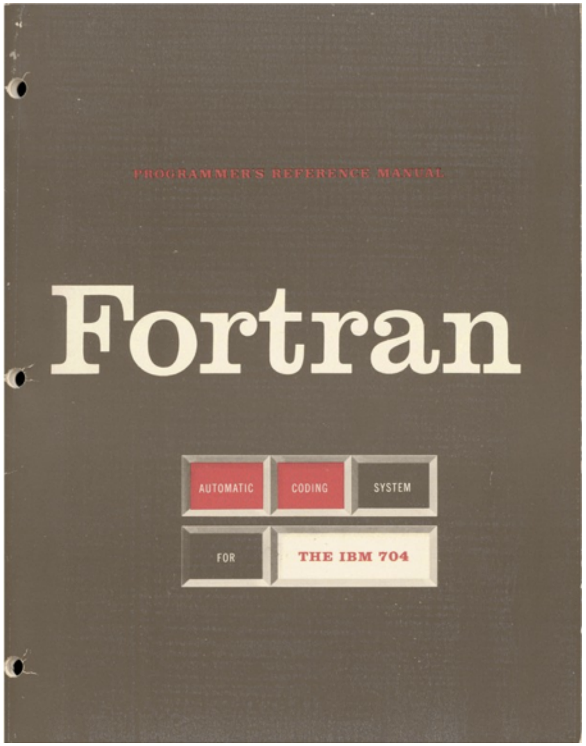
Fortran



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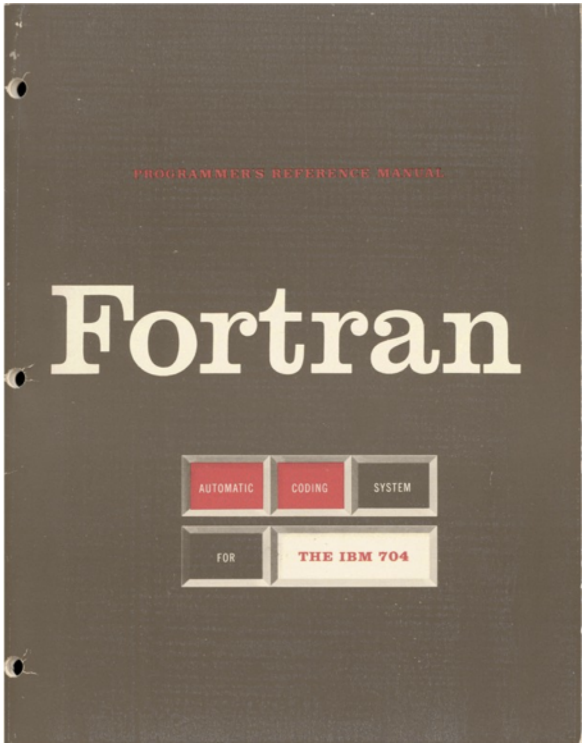
- Fast
- Fortran 90+ offers great improvements…

Fortran



- Tried and tested
- Fast
- Fortran 90+ offers great improvements…
- …but also increases complexity.

C++

C++

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- Powerful and versatile

- Powerful and versatile
- Fast

C++

- Powerful and versatile
- Fast
- Complex and difficult to master

C++

- Powerful and versatile
- Fast
- Complex and difficult to master
- No training wheels

Java

Java

- Mature toolchain

Java

- Mature toolchain
- Large community and ecosystem

Java

- Mature toolchain
- Large community and ecosystem
- Language of Big Data

Java

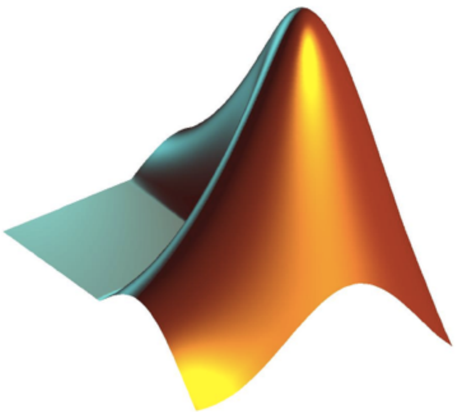
- Mature toolchain
- Large community and ecosystem
- Language of Big Data
- Class-based OOP is not a panacea

Matlab

Matlab

- Easy to learn

Matlab



- Easy to learn
- Powerful environment

Matlab

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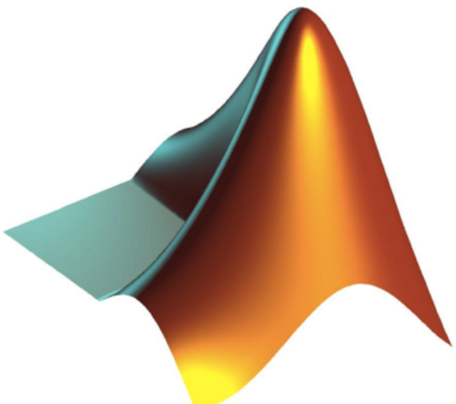
Matlab



- Easy to learn
- Powerful environment
- Expensive
- Core language is limited

Python

Python

- Easy to learn

Python

- Easy to learn
- Batteries included

Python

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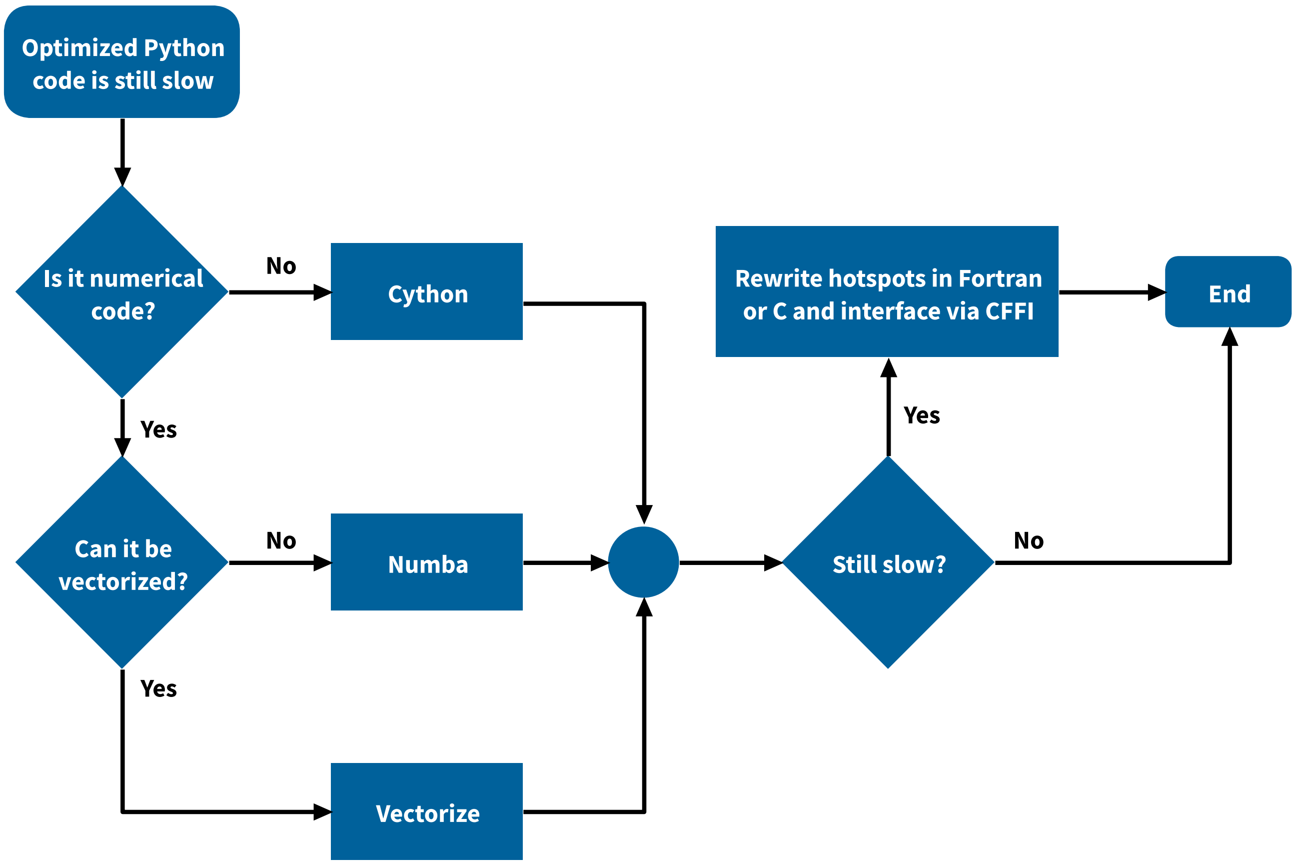
- Large scientific computing ecosystem

Python

- Easy to learn
- Batteries included
- Large scientific computing ecosystem
- (Too) many optimization options

Python Optimization



Julia

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- Multiple dispatch

Julia

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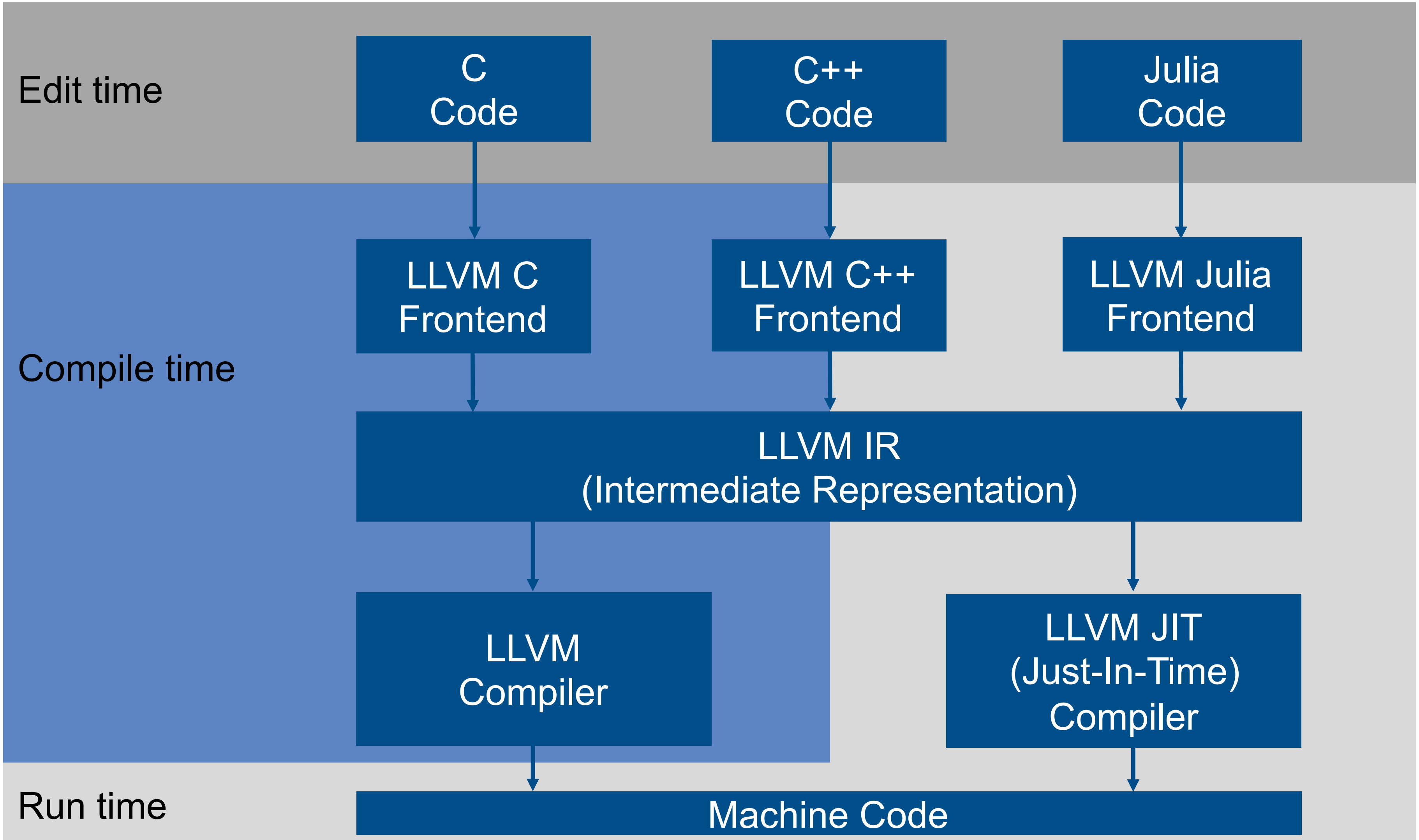
- Matlab-like syntax
- Fast
- Multiple dispatch
- Immature

LLVM


Edit time
C Code
C++ Code
Julia Code
Compile time
LLVM C Frontend
LLVM C++ Frontend
LLVM Julia Frontend
LLVM IR
(Intermediate Representation)
LLVM Compiler
LLVM JIT
(Just-In-Time)
Compiler
Run time
Machine Code

Test Cases

1. Calculating the Keplerian orbital elements

Test Cases

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1. Calculating the Keplerian orbital elements

2. Solving Kepler's equation

Test Cases

1. Calculating the Keplerian orbital elements

2. Solving Kepler's equation

3. Solving Lambert's problem

Test Cases

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1. Calculating the Keplerian orbital elements
2. Solving Kepler's equation
3. Solving Lambert's problem
4. Calling the DOP853 Fortran 77 code

Test 1: Keplerian Elements

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How well can vector expressions be expressed?

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Julia

```
e = ((v_mag^2 - μ/r_mag)*r - (r⋅v)*v)/μ
```

Test 1: Keplerian Elements

How well can vector expressions be expressed?

Julia

```
e = ((v_mag^2 - μ/r_mag)*r - (r⋅v)*v)/μ
```

Java

```
e = new Vector3D(v_mag*v_mag / mu -
1/r_mag, r, -r.dotProduct(v) / mu, v);
```

Test 2: Kepler’s Equation

Can functions be created ad-hoc (higher-order functions) and do they have access to their enclosing scope (closures)?

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def mean2ecc(M, ecc):
    def keplereq(E):
        return E - ecc*np.sin(E) - M
    def keplerderiv(E):
        return 1 - ecc*np.cos(E)
    return newton(M, keplereq, keplerderiv)
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Test 3: Lambert's Problem ➤ Performance test

Test 4: Interfacing with Fortran 77

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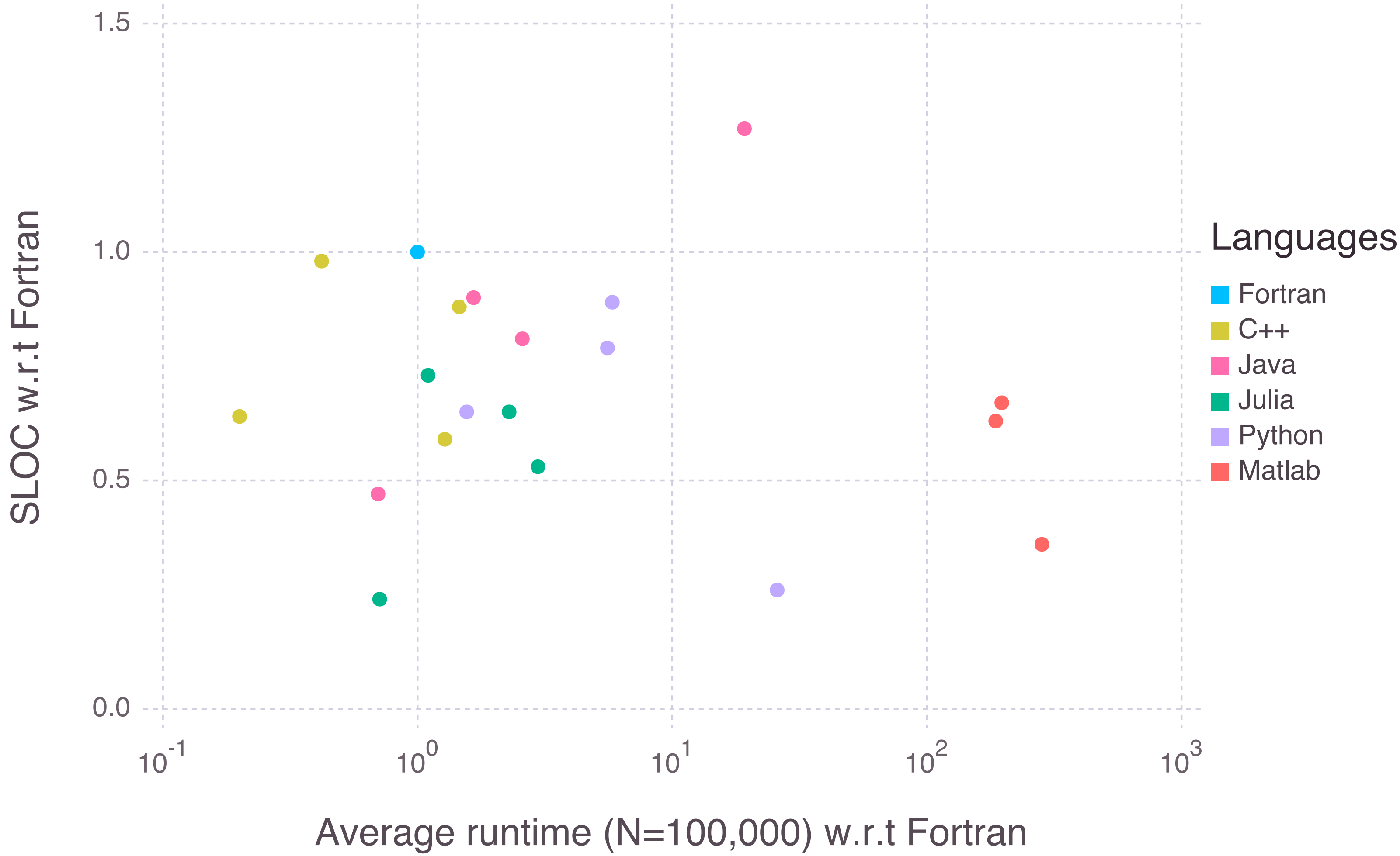
- Fortran2008, C++, Julia: No glue code required. Callbacks are possible.
- Python: Moderate amounts of glue code required. Callbacks are possible.
- Java, Matlab: Larger amounts of glue code required. Callbacks might require changes to the Fortran code.

Benchmark

https://github.com/helgee/icatt-2016



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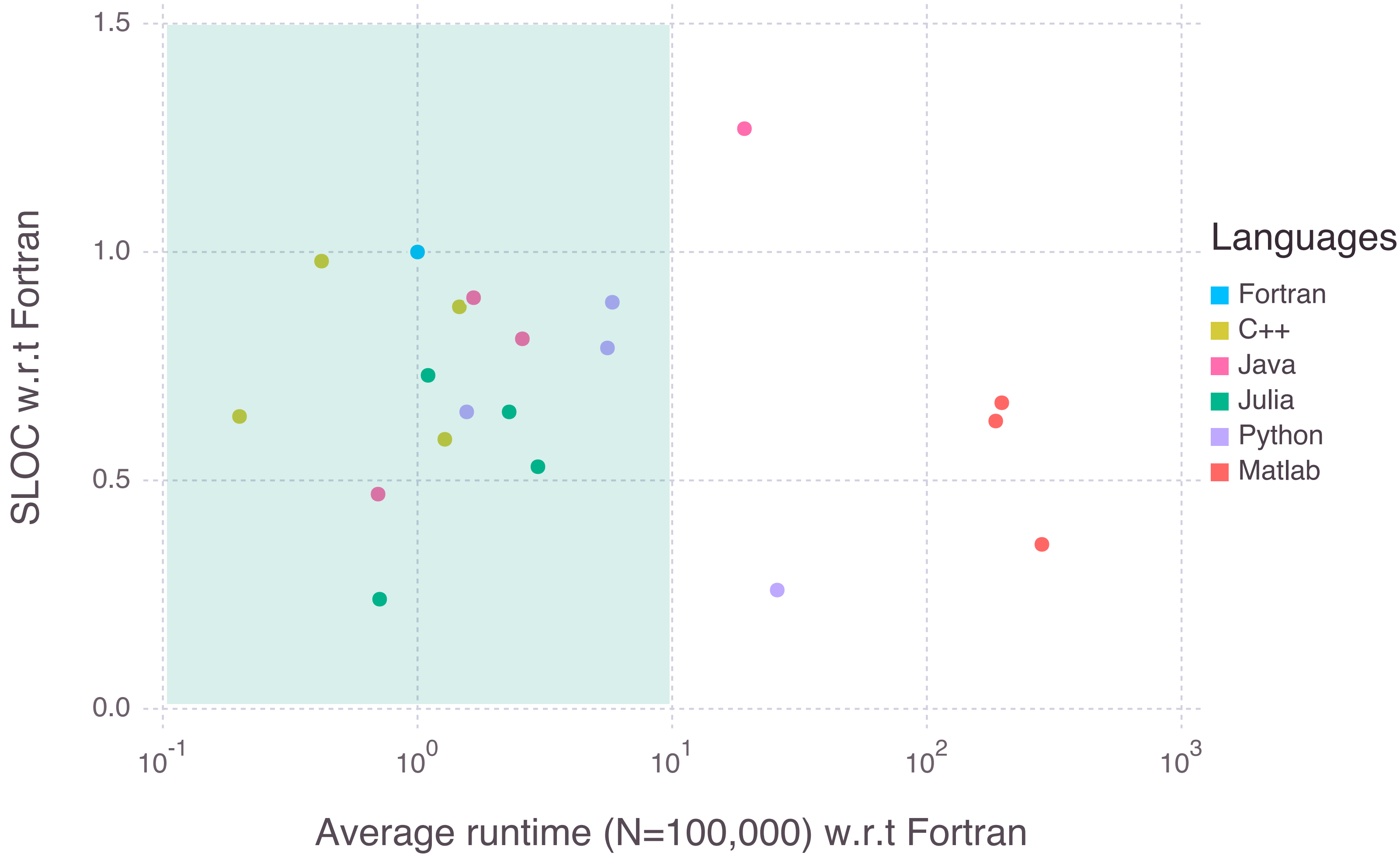

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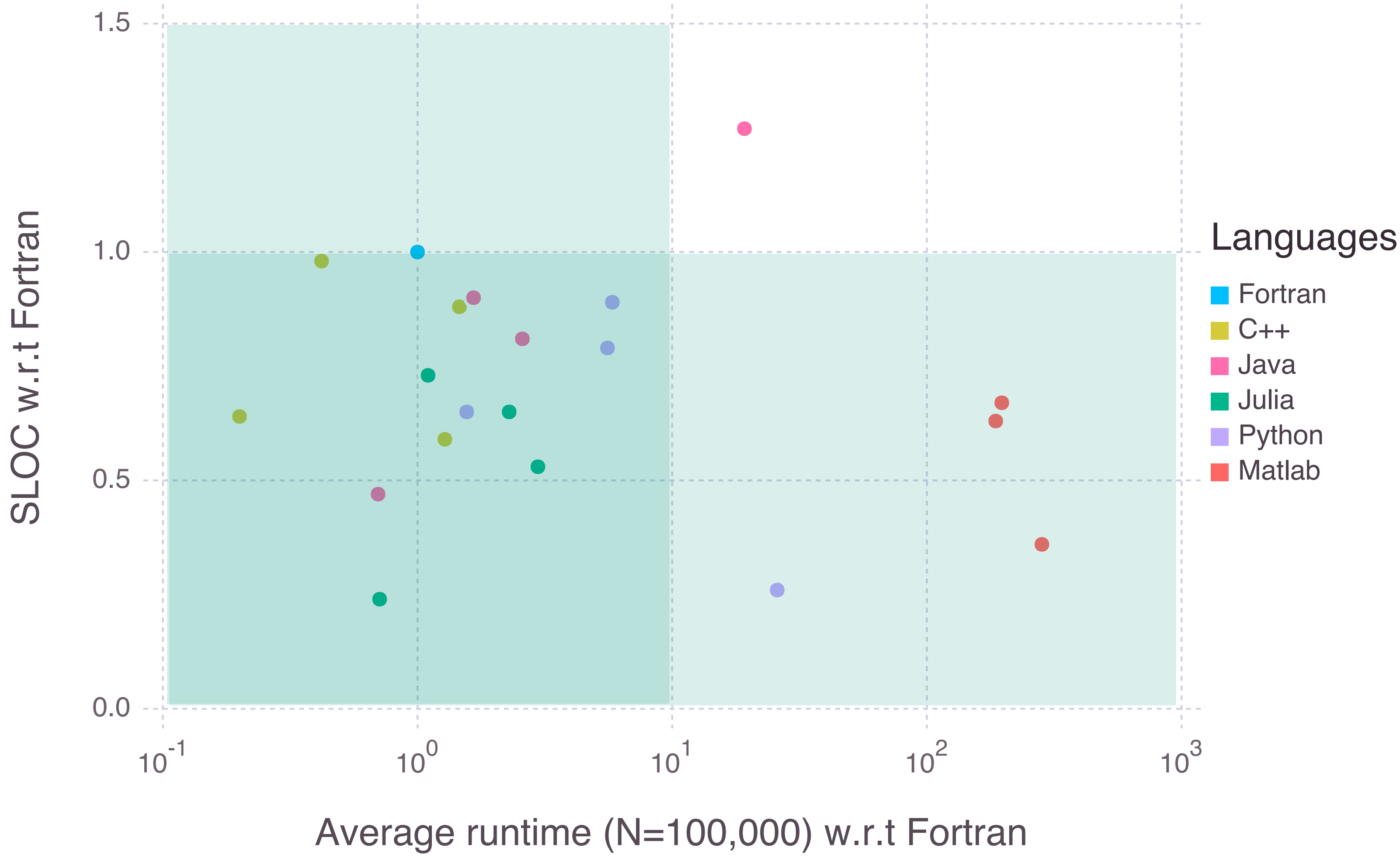

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- Purely interpreted languages remain orders of magnitude slower but JIT-compiled dynamic languages have become competitive.
- Python+Numba and Julia offer an attractive compromise between flexibility and performance.