

Modern Computational Economics and Policy Applications

A workshop for the IMF's Institute for Capacity Development

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Topics

These introductory slides provide background on modern scientific computing.

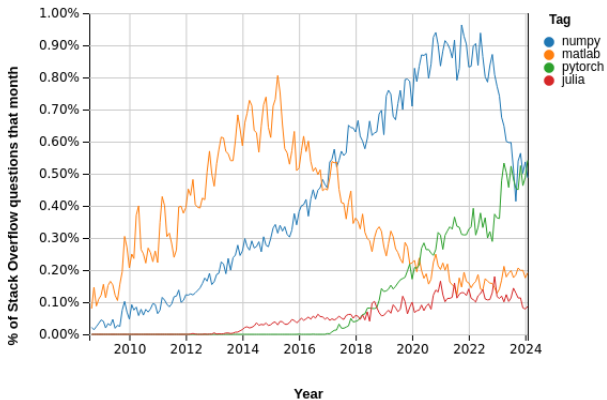
We will discuss

- Traditional compiled languages
- Modern JIT compilers
- AI-driven scientific computing
- Where are we heading?
- Economic applications

Sides, code:

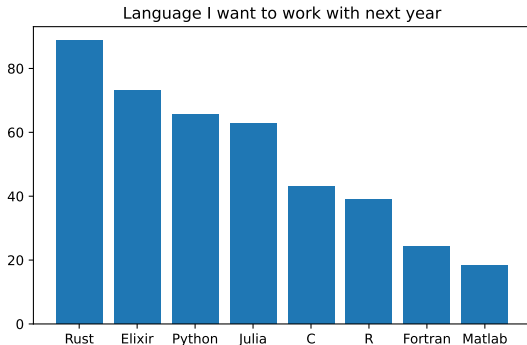
https://github.com/QuantEcon/imf_2024

Some trends:



Source: Stackoverflow Trends

Stack Overflow 2023 Developer Survey (50 languages)



— <https://survey.stackoverflow.co/2023/>

A review of some scientific computing environments

General purpose scientific computing environments:

1. Fortran / C / C++
2. MATLAB (\approx Python + NumPy)
3. Julia (\approx Python + Numba)
4. Python + Google JAX (\approx Python + PyTorch)

Fortran / C / C++ — static types and AOT compilers

Example. Suppose we want to compute the sequence

$$k_{t+1} = sk_t^\alpha + (1 - \delta)k_t$$

from some given k_0

Let's write a function in C that

1. implements the loop
2. returns the last k_t

```
#include <stdio.h>
```

```
#include <math.h>
```

```
int main() {  
    double k = 0.2;  
    double alpha = 0.4;  
    double s = 0.3;  
    double delta = 0.1;  
    int i;  
    int n = 1000;  
    for (i = 0; i < n; i++) {  
        k = s * pow(k, alpha) + (1 - delta) * k;  
    }  
    printf("k = %f\n", k);  
}
```


Pros

- fast

Cons

- time consuming to write
- lack of portability
- hard to debug
- hard to parallelize
- low interactivity

For comparison, the same operation in Python:

```
 $\alpha$  = 0.4  
s = 0.3  
 $\delta$  = 0.1  
n = 1_000  
k = 0.2  
  
for i in range(n-1):  
    k = s * k** $\alpha$  + (1 -  $\delta$ ) * k  
  
print(k)
```

Pros

- easy to write
- high portability
- easy to debug
- high interactivity

Cons

- slow

Why is pure Python slow?

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Why is pure Python slow?

Problem 1: Type checking

Consider the Python code snippets

```
x, y = 1, 2
z = x + y          # z = 3
```

```
x, y = 1.0, 2.0
z = x + y          # z = 3.0
```

```
x, y = 'foo', 'bar'
z = x + y          # z = 'foobar'
```

How does Python know which operation to perform?

Answer: Python checks the type of the objects first

```
>> x = 1
>> type(x)
int
```

```
>> x = 'foo'
>> type(x)
str
```

In a large loop, this type checking generates massive overhead

Problem 2: Memory management

```
>>> import sys
>>> x = [2.56, 3.21]
>>> sys.getsizeof(x) * 8      # number of bits
576                           # whaaaat???
>>> sys.getsizeof(x[0]) * 8   # number of bits
192                           # whaaaat???
```

Also, lists of numbers are pointers to dispersed int/float objects — not contiguous data

So how can we get

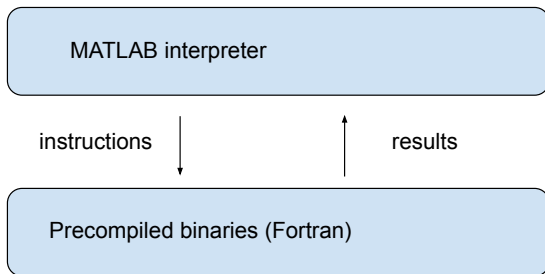
good execution speeds **and** high productivity / interactivity?

MATLAB

```
A = [2.0, -1.0  
     5.0, -0.5];
```

```
b = [0.5, 1.0]';
```

$$x = \text{inv}(A) * b$$



Python + NumPy

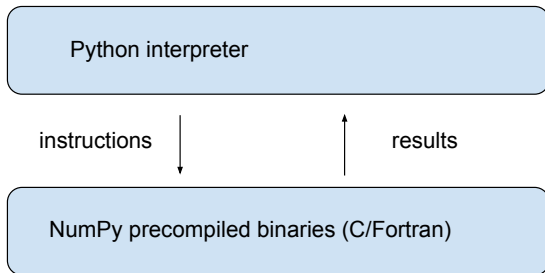
```
import numpy
```

```
A = ((2.0, -1.0),  
      (5.0, -0.5))
```

```
b = (0.5, 1.0)
```

```
A, b = np.array(A), np.array(b)
```

```
x = np.inv(A) @ b
```



But also has fast loops via an efficient JIT compiler

Example. Suppose, again, that we want to compute

$$k_{t+1} = sk_t^\alpha + (1 - \delta)k_t$$

from some given k_0

- Iterative, not easily vectorized

```
function solow(k0, α=0.4, δ=0.1, n=1_000)
    k = k0
    for i in 1:(n-1)
        k = s * k^α + (1 - δ) * k
    end
    return k
end

solow(0.2)
```

Julia accelerates `solow` at runtime via a JIT compiler

Python + Numba copy Julia

```
from numba import jit

@jit(nopython=True)
def solow(k0,  $\alpha=0.4$ ,  $\delta=0.1$ , n=1_000):
    k = k0
    for i in range(n-1):
        k = s * k** $\alpha$  + (1 -  $\delta$ ) * k
    return k

solow(0.2)
```

Runs at same speed as Julia / C / Fortran

Parallelization

For tasks that can be divided across multiple “workers,”

$$\text{execution time} = \text{time per worker} / \text{number of workers}$$

So far we have been discussing time per worker

- running code fast along a single thread

The other option for speed gains is

- divide up the execution task
- spread across multiple threads / processes

Parallelization is the big game changer powering the AI revolution

Market Summary > NVIDIA Corp

879.44 USD

✓ Following

+440.44 (100.33%) ↑ past 6 months

Closed: 14 Mar, 7:59 pm GMT-4 • Disclaimer

After hours 872.98 -6.46 (0.73%)

1D | 5D | 1M | **6M** | YTD | 1Y | 5Y | Max



What economists need: software that will parallelize **for us**

- automated intelligent parallelization
- JIT compiled
- portable
- seamlessly supports most CPUs / GPUs / hardware accelerators