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A Performance and Usability Study of the Rust Programming Language

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Motivation

Current state

NCAR models contain code that is unable to utilize modern computing tools.

+

Better practices

Prioritize developability and usability when choosing a programming language.

+

Maintain performance

Match or exceed the performance of current implementations.

Which programming languages are well-suited for NCAR's community models?

Explanation of Problem

Goal: benchmark the performance and usability of a simple fluid model between programming languages on Derecho

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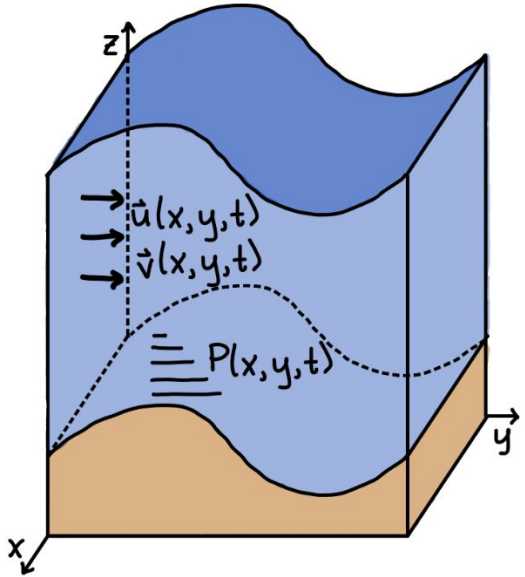
Choice of Model: 2D Shallow Water Equations

- Models velocity and pressure of an incompressible fluid
- Fluid is “shallow”, i.e. the vertical scale is much smaller than the horizontal scale
- Examples: propagation of a tsunami, storm surge

Numerical method: time-filtered leapfrog scheme with second-order central finite differences



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Goal: benchmark the performance and usability of a simple fluid model between programming languages on Derecho

Programming Languages

- Rust
- C
- Python
- Fortran

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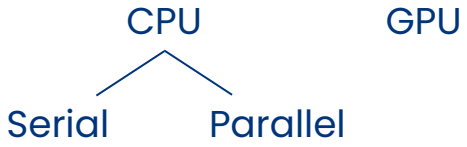
Implementations



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- **Rust**
- **C**
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Implementations

CPU GPU

Serial Parallel

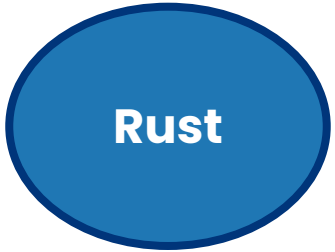
Performance Criteria

- Runtime
- Strong Scaling
- **Usability**

*Icons made by Freepik from www.flaticon.com

What is Rust?

NCAR
OPERATED BY UCAR



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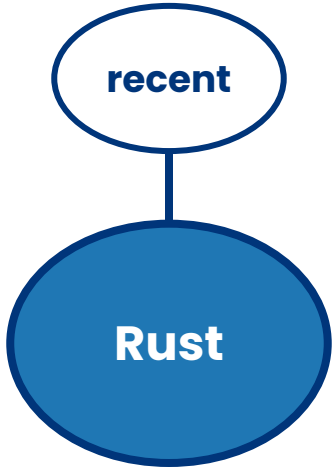

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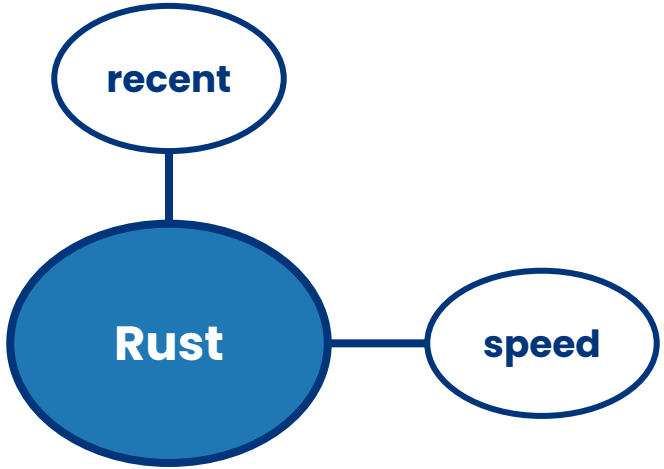

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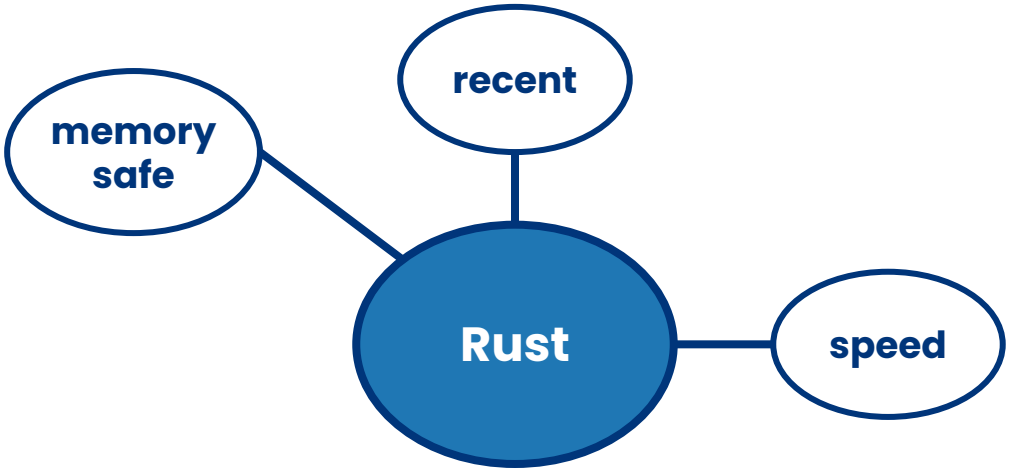

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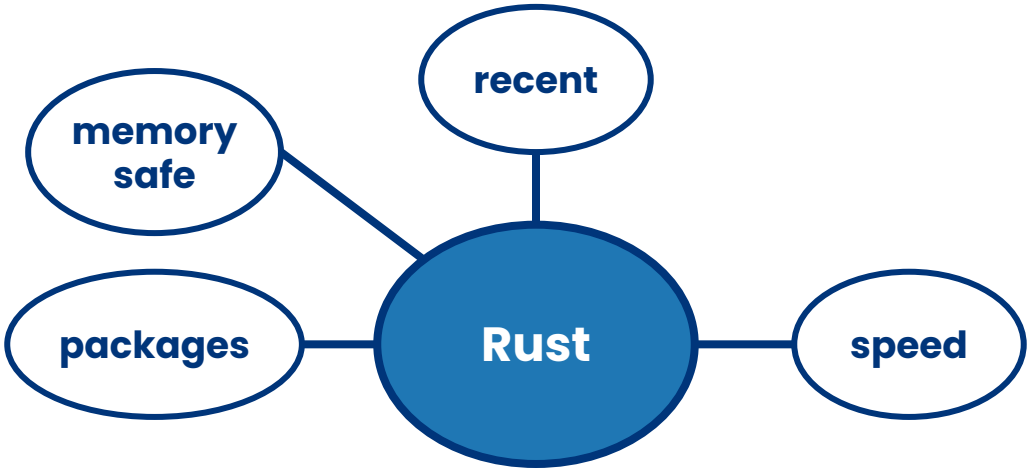

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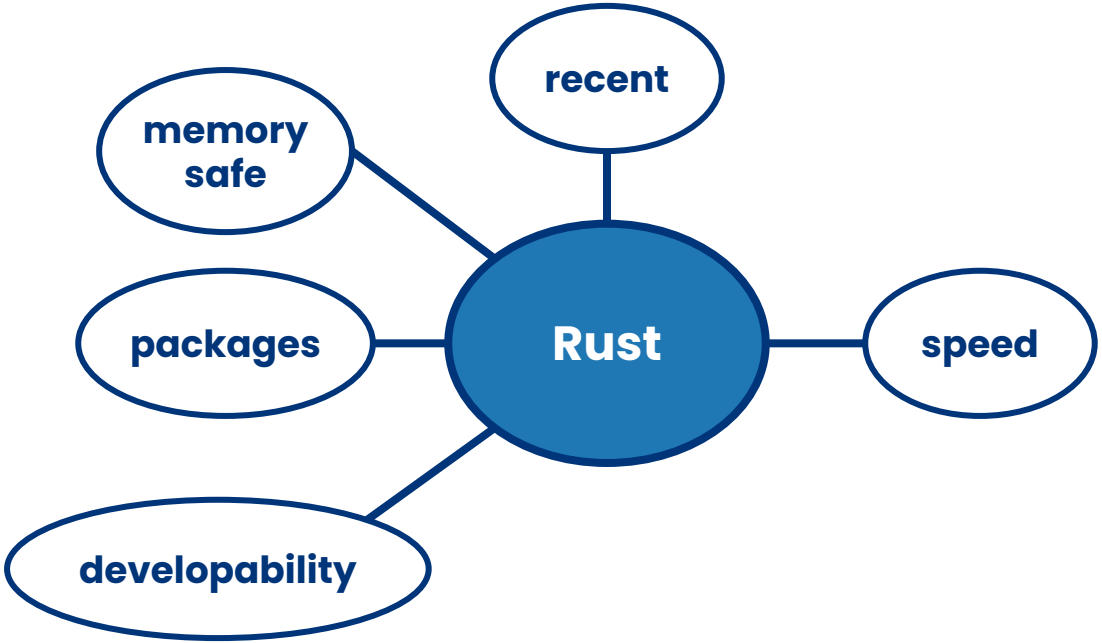

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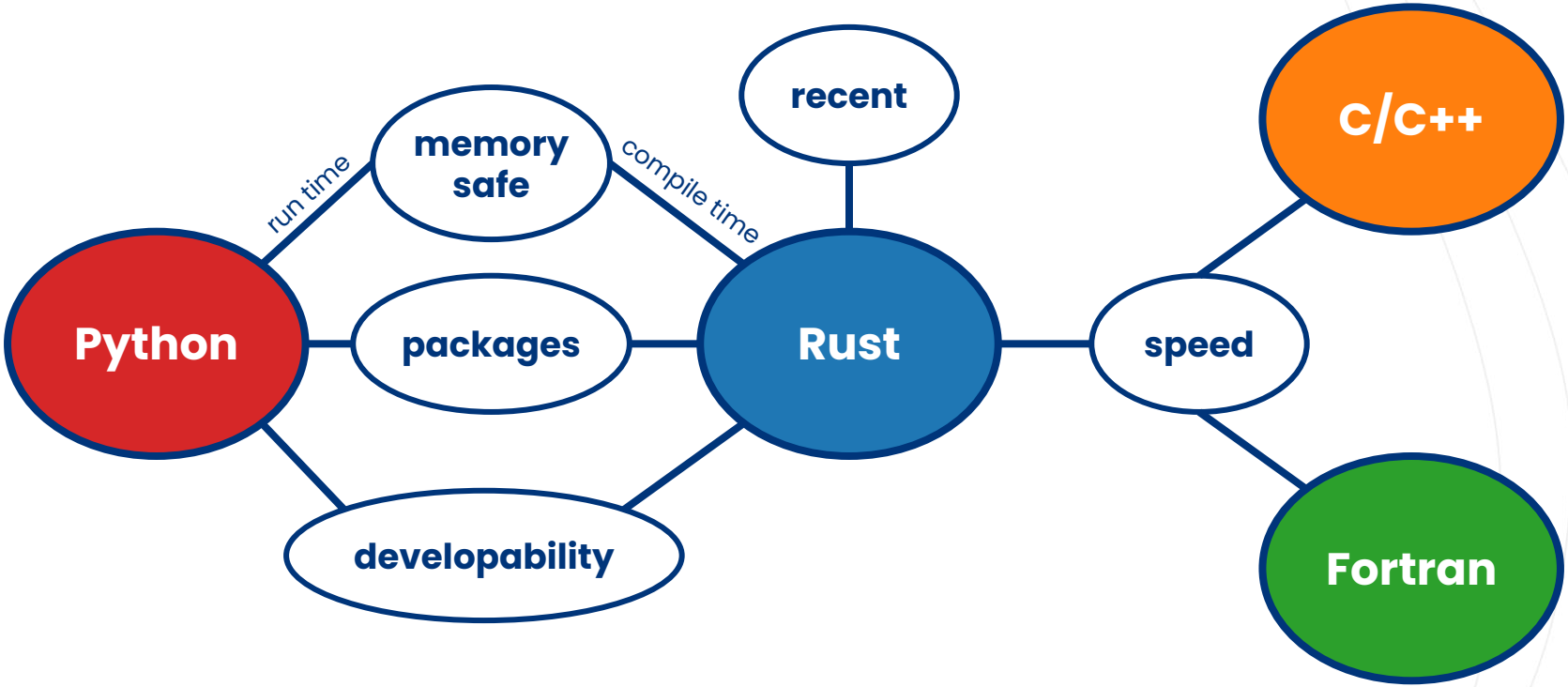
recent
memory safe
run time
compile time
C/C++
Python
packages
Rust
speed
developability
Fortran

What is Rust?

NCAR
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C/C++

Python

Rust

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What is Rust?

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Python

Rust

C/C++

```
$ gcc project.c -o project
$ ./project
```

Fortran

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$ gfortran project.f90 -o project
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What is Rust?

Python

Rust

C/C++

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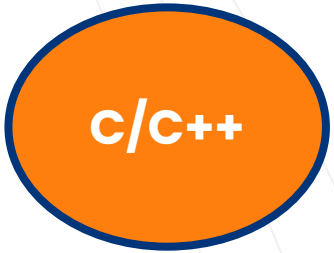


```
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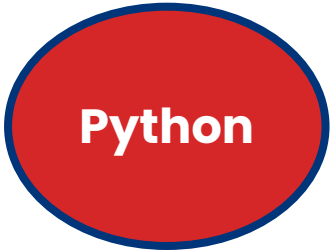
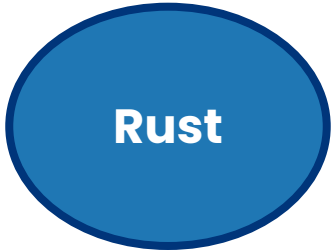



```
$ python project.py
```

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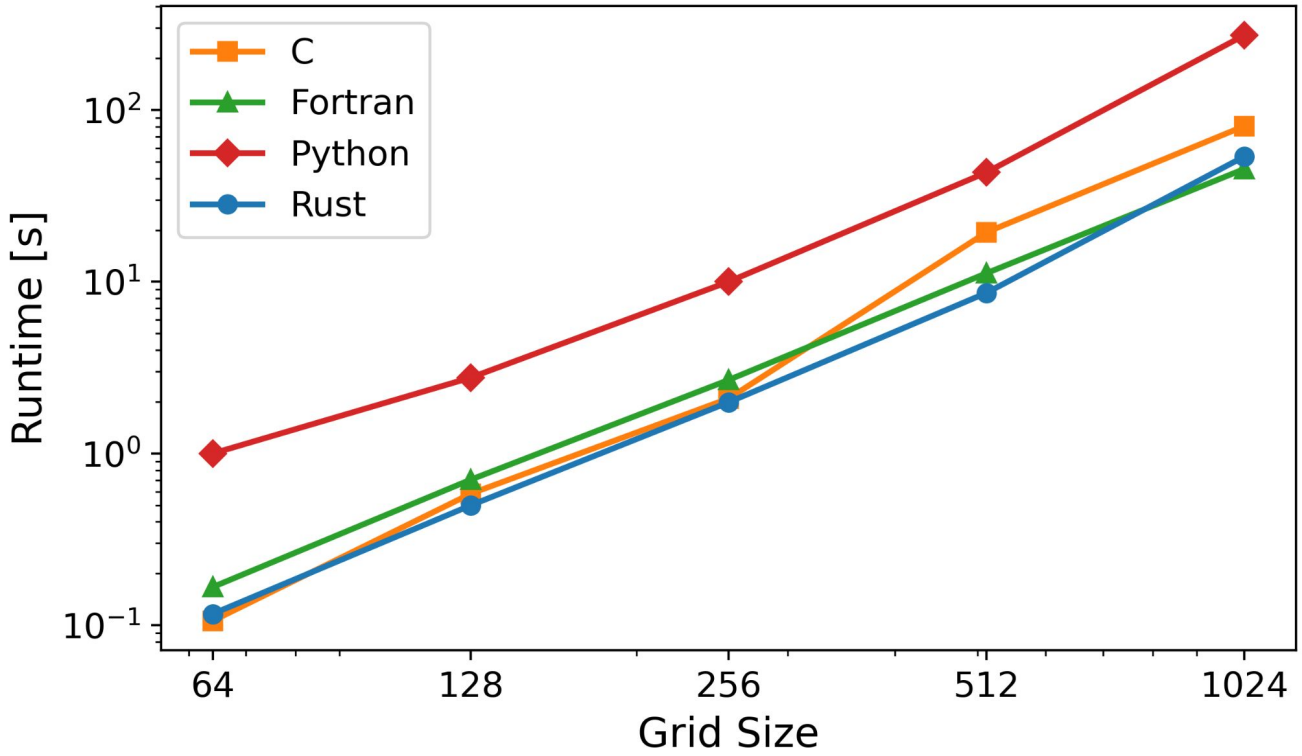
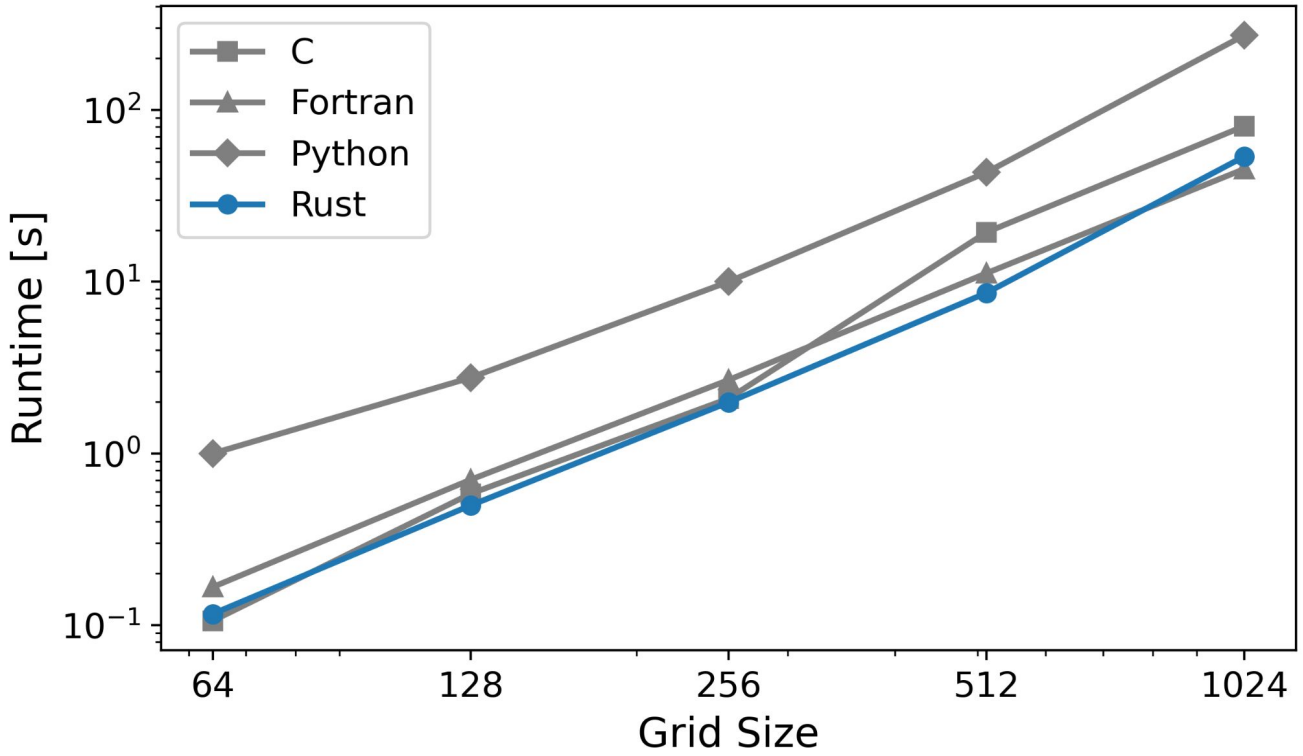
Performance Results

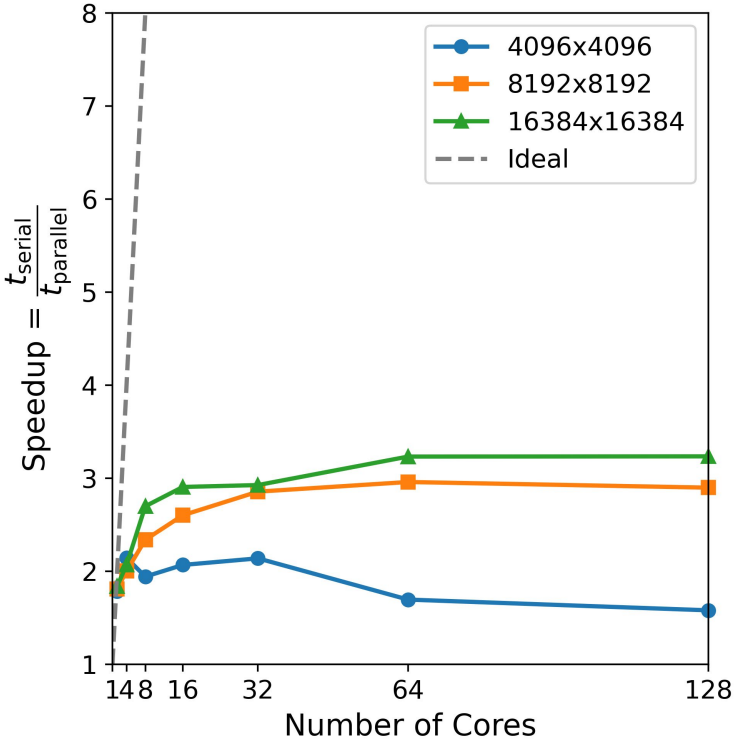
Serial, Single Core CPU

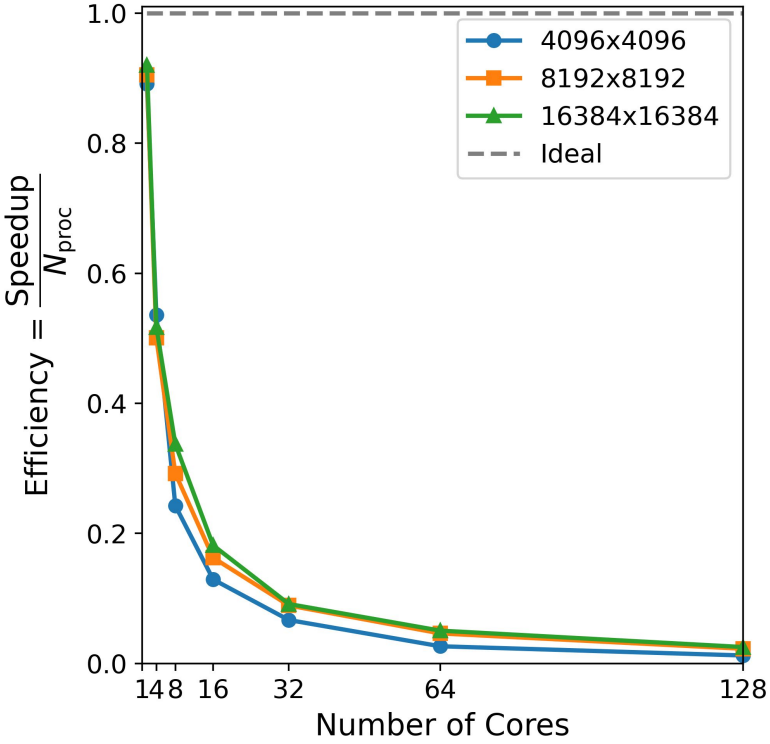


Serial, Single Core CPU



Shared Memory, Single Node CPU





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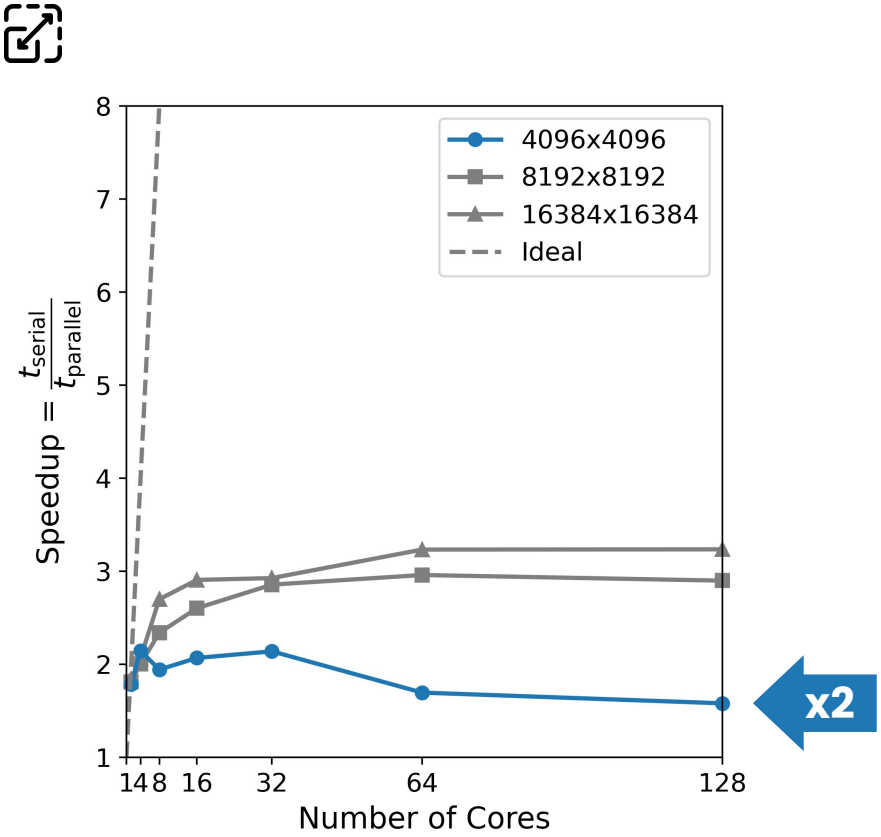
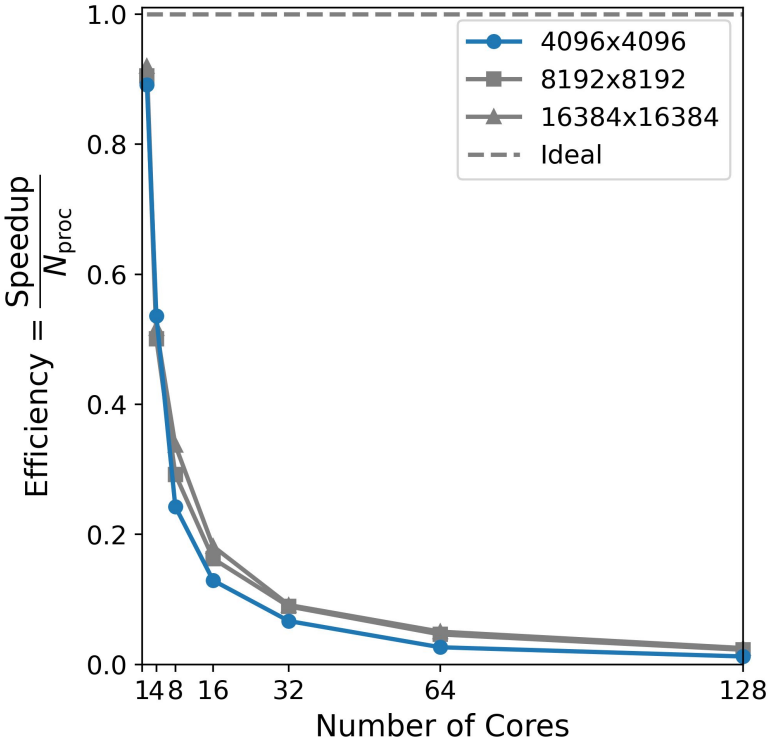


x2



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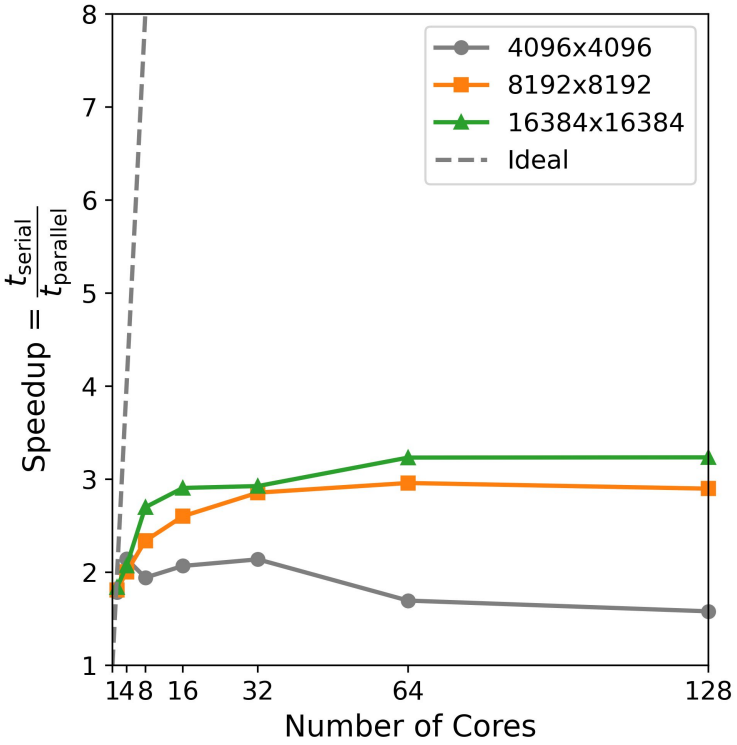
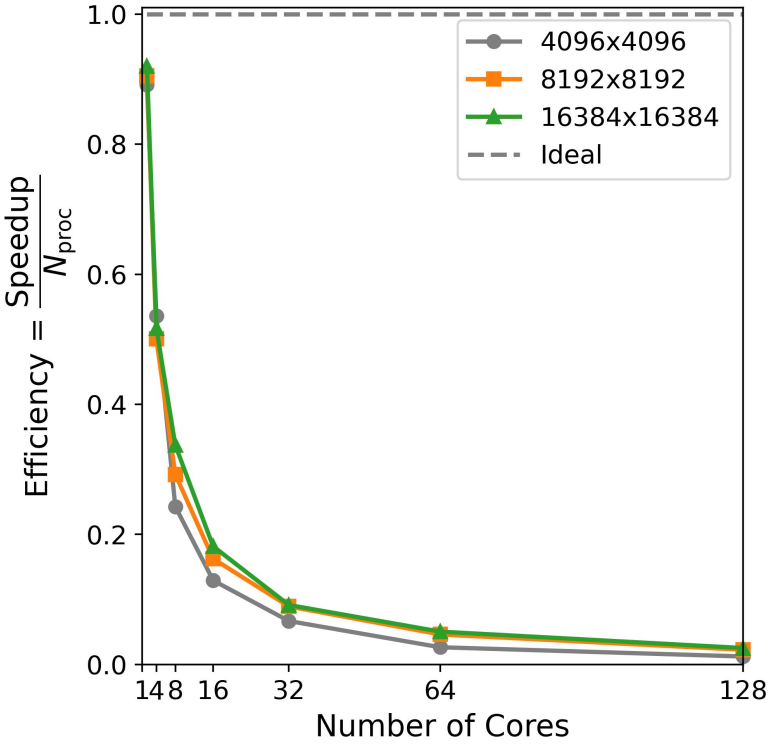


x3



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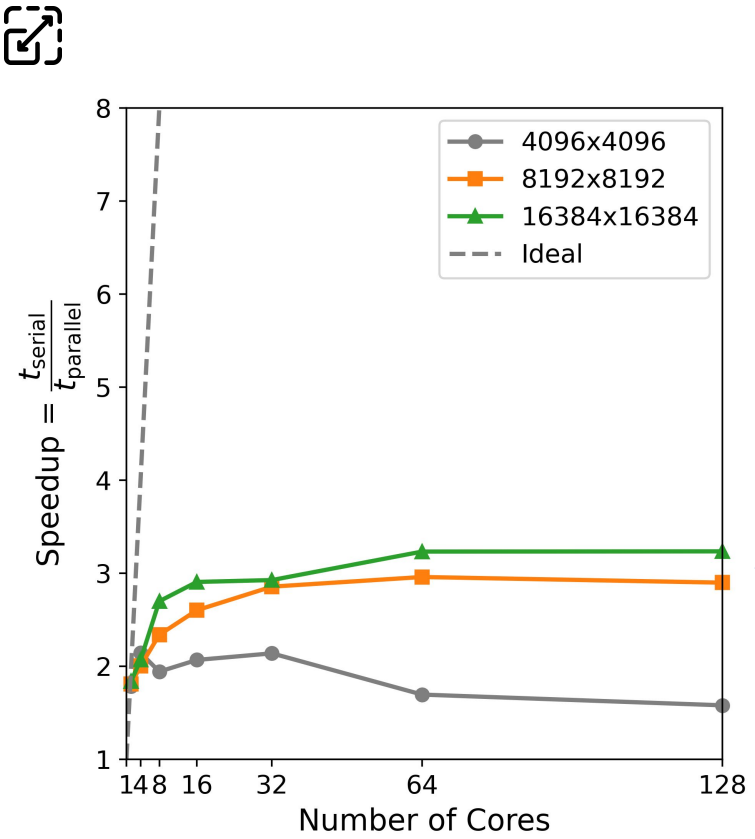

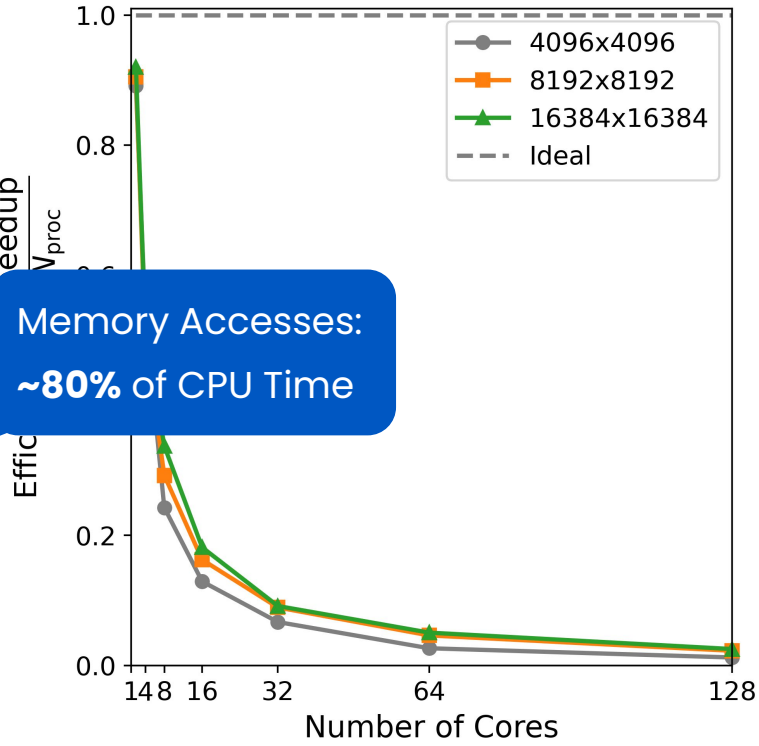

Memory Accesses:
~80% of CPU Time

Rust GPU Support Options

Crate	Kernel language	Portability	Stage of Development
cudarc	CUDA C	NVIDIA only	stable
rust-cuda	Rust	NVIDIA only	early
opencl3	OpenCL C	GPU portable	stable
CubeCL	Rust	GPU portable	early

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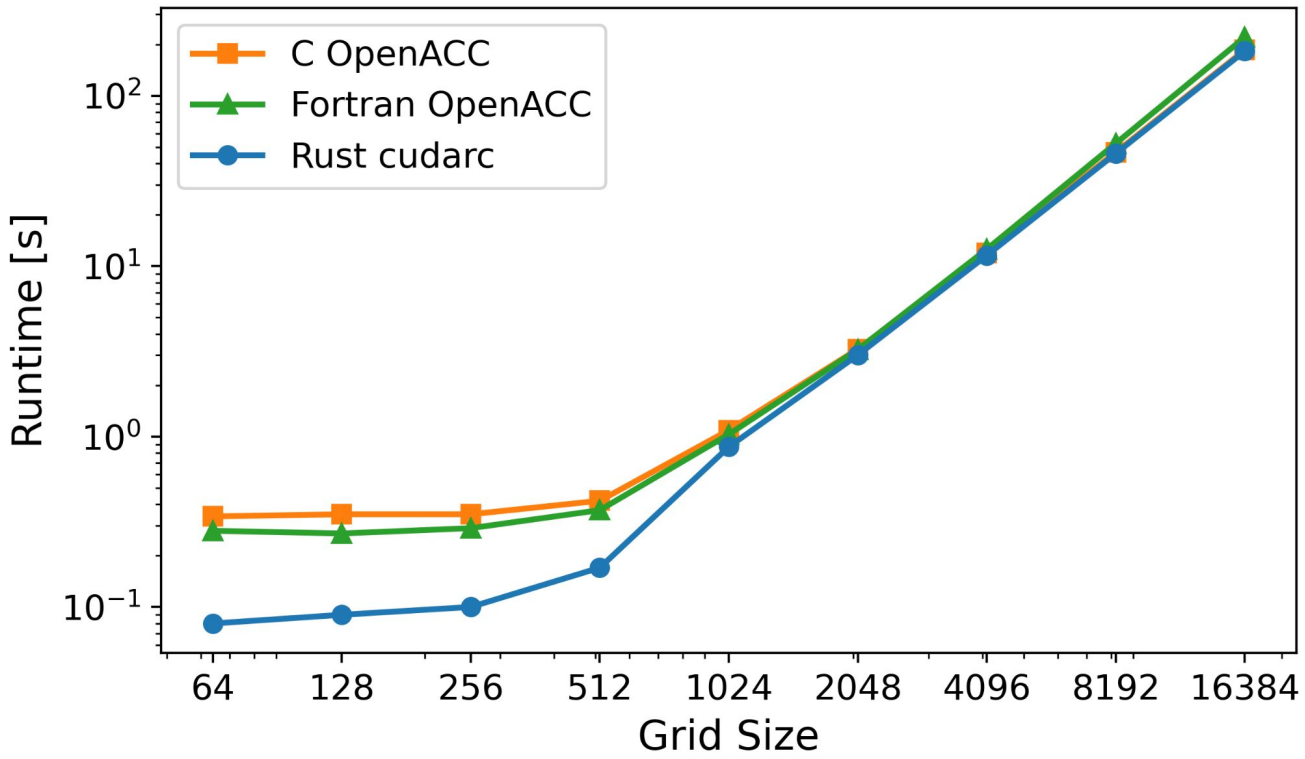
Single GPU


C OpenACC
Fortran OpenACC
Rust cudarc
Runtime [s]
10^2
10^1
10^0
10^{-1}
64
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256
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1024
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8192
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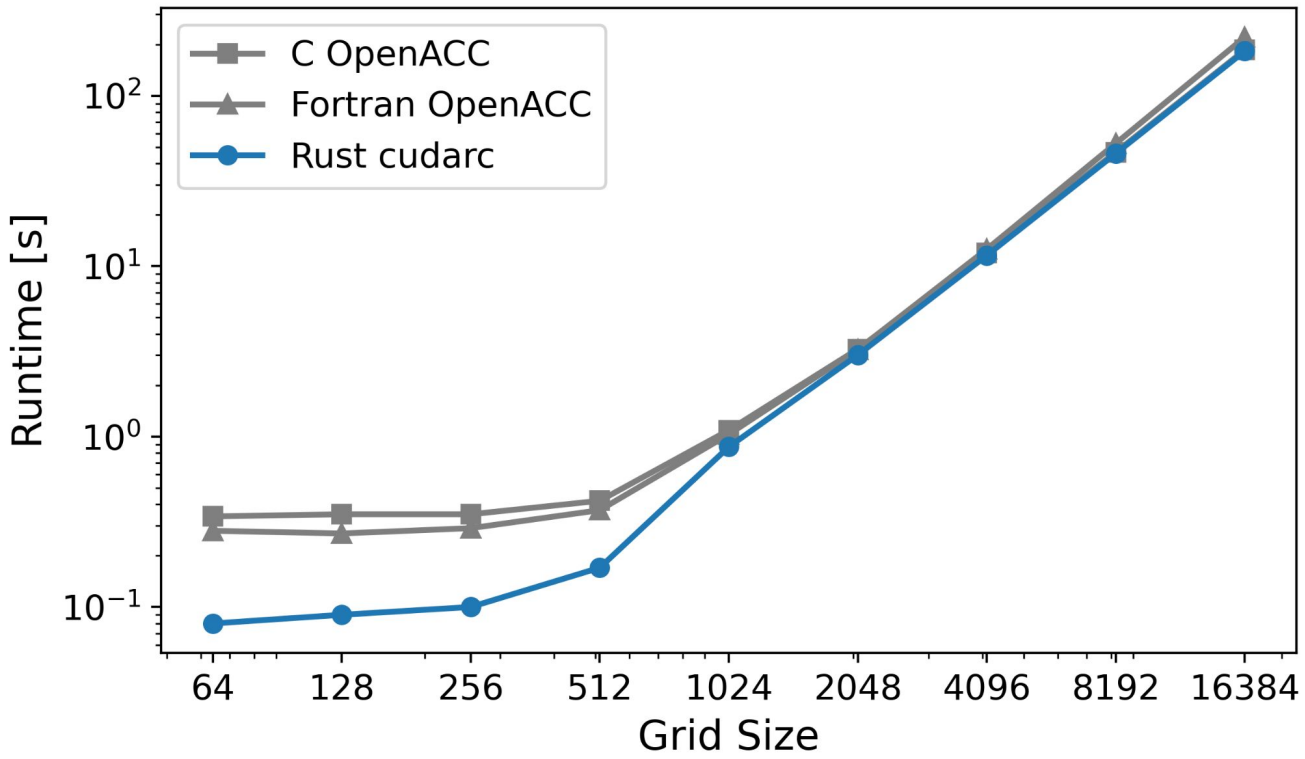
Grid Size

Single GPU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Usability

Strengths

Weaknesses

Usability

Strengths

Easy-to-use packaging

Crates

Cargo

Weaknesses

Usability

Strengths

Easy-to-use packaging

Compile-time errors

Weaknesses

```
error: could not compile `project` (bin
"project") due to 1 previous error
```

Usability

Strengths

- Easy-to-use packaging
- Compile-time errors
- Quality error messages

Weaknesses

```
12 |     let x = 5;
   |         - first assignment to `x`
14 |     x = 10;
   |     ^^^^^^ cannot assign twice to
immutable variable
   |
help: consider making this binding mutable
   |
12 |     let mut x = 5;
   |         +++
```

Usability

Strengths

- Easy-to-use packaging
- Compile-time errors
- Quality error messages

Weaknesses

- Ownership system

```
{
    let a = 5;  // a is owner
    let b = a;  // b is owner
}
                // out of scope,
                // value dropped
```

Usability

Strengths

- Easy-to-use packaging
- Compile-time errors
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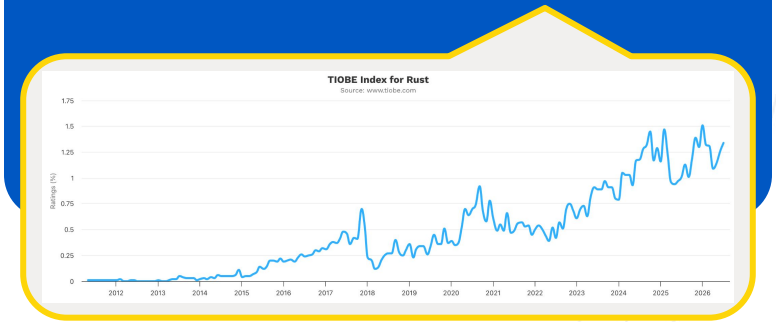
Weaknesses

- Ownership system
- Young language



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Weaknesses

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Conclusion

Main Takeaways

- Developed Rust implementation of shallow water model
- CPU and GPU performance comparable to C and Fortran, faster than Python
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- Explore and develop distributed memory code in Rust using MPI
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Link to repository: https://github.com/NCAR/SWM/tree/swm_rust

Backup Slides

Running the Code

Rust

```
$ M=2048 N=2048 cargo run --release
   Compiling project v0.1.0 ($USER/project-dir)
    Finished `release` profile [optimized] target(s) in 0.47s
     Running `target/release/project`
```

C

```
$ gcc -DM=2048 -DN=2048 -O3 project.c -o project
$ ./project
```

Fortran

```
$ gfortran -DM=2048 -DN=2048 -O3 project.f90 -o project
$ ./project
```

Python

```
$ python project.py --M=2048 --N=2048
```

Usability

Strengths

Easy-to-use packaging

- Crates have good documentation
- Cargo, Rust's build system and package manager, makes it easy to add crates and manage dependencies
- Similarity to other popular packages, e.g. ndarray ↔ NumPy

Compile-time errors

- Debugging happens before runtime
- Avoids seg faults

Quality error messages

- Understandable messaging, useful tips to debug

Weaknesses

Ownership system

- Memory is managed through a set of rules called ownership
- More involved than some other memory-safe languages
- Learning this new system may increase time to code development

Young language

- Still developing, software community growing
- Fewer examples, crates, documentation than some other popular languages/packages

Ownership Rules

1. Each value in Rust has a owner.

2. There can only be one owner at a time.

3. When the owner goes out of scope, the value will be dropped.