Rust's Generic Programming

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Genericity and traits in Rust

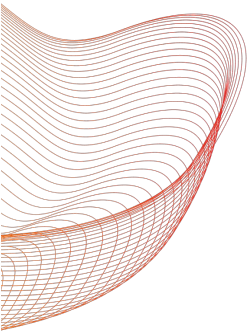
What is Generic Programming ?

Introduction to Generic Programming Paradigm

Definition of Generic Programming

History and evolution of the paradigm

List of programming languages with this feature



- style of computer programming
- seeks to abstract algorithms for increased reusability
- algorithms are written in terms of types to-be-specified-later
- Instantiation when needed for specific types provided as parameters.

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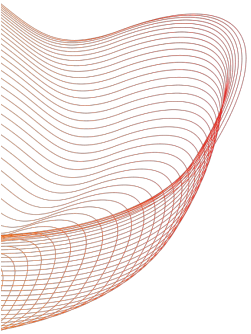

- since the late 1970s and early 1980s.
- ML (1970s) introduced polymorphic (generic) types
- Ada (1980s) added generic modules called "generic packages"
- Popularized by C++ STL developed by Alexander Stepanov in the early to mid-1990s
  - STL: provide generic algorithms and data structures, making extensive use of C++ templates

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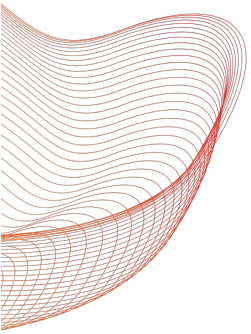
many modern programming languages have incorporated some form of generic programming:



- C++: template & STL
- Java: generics & Interfaces
- C#: generics
- Swift: generics
- Rust: generics & Traits
- Kotlin: generics
- Haskell: generics & Traits
- Scala: generics & Traits

Generic Programming in Rust

Rust

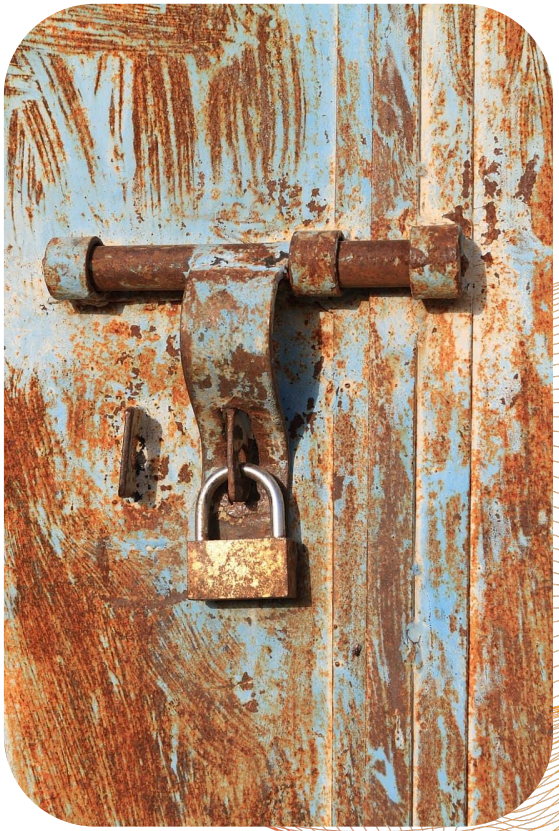
> Multi-paradigm

> 2015, 8 years ago

01 programming language that prioritizes **safety**, **speed**, and **concurrency**, making it well-suited for system-level and performance-critical applications

02 employs a **unique ownership model** with zero-cost abstractions to manage resources, offering a powerful **control over memory** management while avoiding common bugs like null pointer dereferencing and data races

03 expressive **type system** and supports **generic programming and trait-based composition**, facilitating code reusability and maintainability



Genericity and traits in programming languages

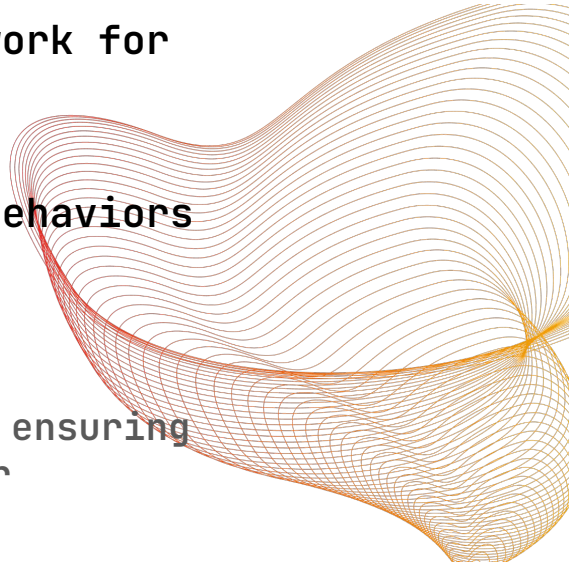
Genericity:

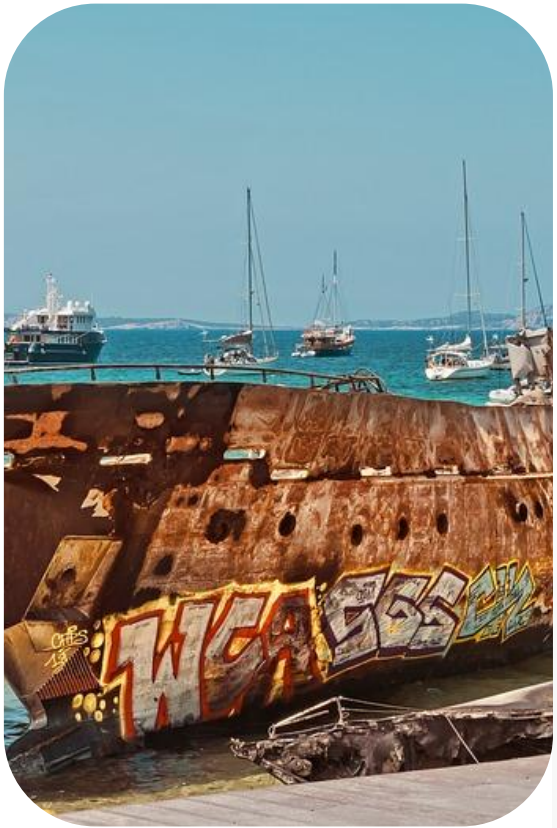
- Allows to write reusable code.
- Build data structures and functions that can work for multiple types of data

Traits:

- guarantee that a particular type has certain behaviors
- Specify and regroup common behaviors

> Using traits as bounds on generics allows to write safe-reusable code that works on multiple types while ensuring those types conform to a certain interface of behavior





Simple example of Generic Programming in Rust

> define a data type or function that doesn't specify the exact type it operates on

```rust
pub trait Summary {
    fn summarize(&self) -> String;
}

fn notify<T: Summary>(item: T) {
    println!("Breaking news! {}", item.summarize());
}
```

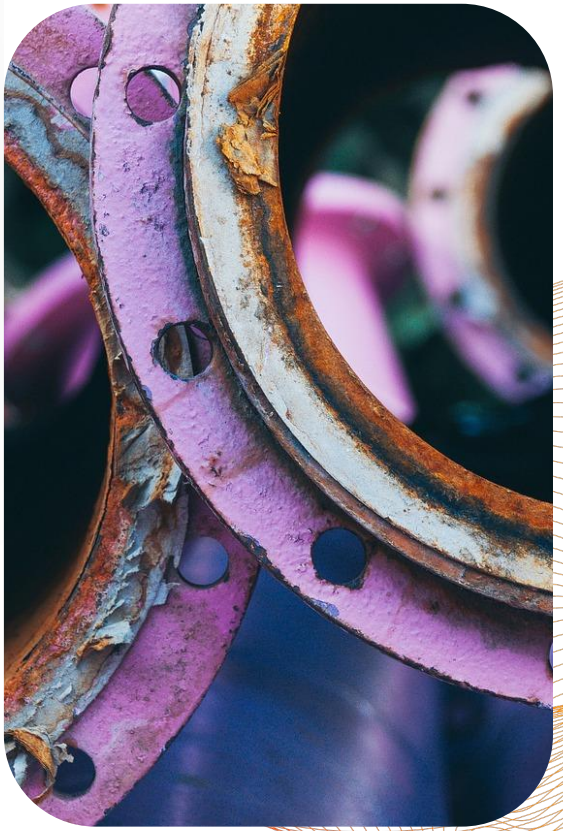
> define a data type or function that doesn't specify the exact type it operates on

More complex example of Generic Programming

```
fn largest<T: PartialOrd>(list: &[T]) -> T {
    let mut largest = list[0];

    for &item in list {
        if item > largest {
            largest = item;
        }
    }

    largest
}
```

```
struct Position {
    x: f32,
    y: f32,
}
```

```
struct Boxer {
    weight: f32,
    name: String,
}
```



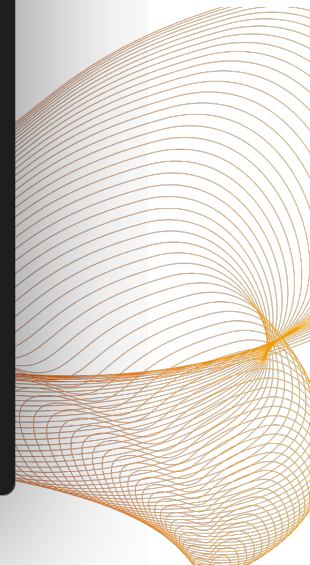
A simple example: Comparing things

```rust
use std::cmp::Ordering;

impl PartialOrd for Position {
    fn partial_cmp(&self, other: &Position) -> Option<Ordering> {
        if self.x == other.x && self.y == other.y {
            Some(Ordering::Equal)
        } else if self.x <= other.x && self.y <= other.y {
            Some(Ordering::Less)
        } else {
            Some(Ordering::Greater)
        }
    }
}
```

A simple example: Comparing things

```rust
use std::cmp::Ordering;

impl PartialEq for Position {
    fn eq(&self, other: &Position) -> bool {
        self.x == other.x && self.y == other.y
    }
}
```

```rust
impl PartialOrd for Boxer {
    fn partial_cmp(&self, other: &Boxer) -> Option<Ordering> {
        if self.weight == other.weight {
            Some(Ordering::Equal)
        } else if self.weight <= other.weight {
            Some(Ordering::Less)
        } else {
            Some(Ordering::Greater)
        }
    }
}

impl PartialEq for Boxer {
    fn eq(&self, other: &Boxer) -> bool {
        self.weight == other.weight
    }
}
```



A simple example: Comparing things

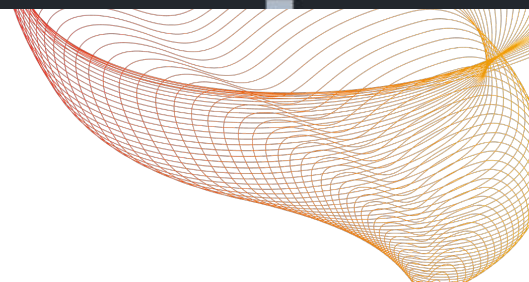
```
fn main() {

      // test largest function on Position
    let position1 = Position { x: 1.0, y: 2.0 };
    let position2 = Position { x: 2.0, y: 10.0 };
    let position3 = Position { x: 100.0, y: 200.0 };

    let positions = vec![position1, position2, position3];

    let largest_position = &largest(&positions);
    println!("largest position {{ x:{}, y:{} }}", largest_position.x,
largest_position.y);

  ...
```

A simple example: Comparing things

```
    // test largest function on boxer
    let boxer1 = Boxer { weight: 110.0, name: String::from("Mike Tyson")
};
    let boxer2 = Boxer { weight: 80.0, name: String::from("Muhammad Ali")
};
    let boxer3 = Boxer { weight: 100.0, name: String::from("George
Foreman") };
    let boxers = vec![boxer1, boxer2, boxer3];

    let largest_boxer = &largest(&boxers);
    println!("largest boxer {{ weight:{}, name:{} }}",
largest_boxer.weight, largest_boxer.name);

}
```

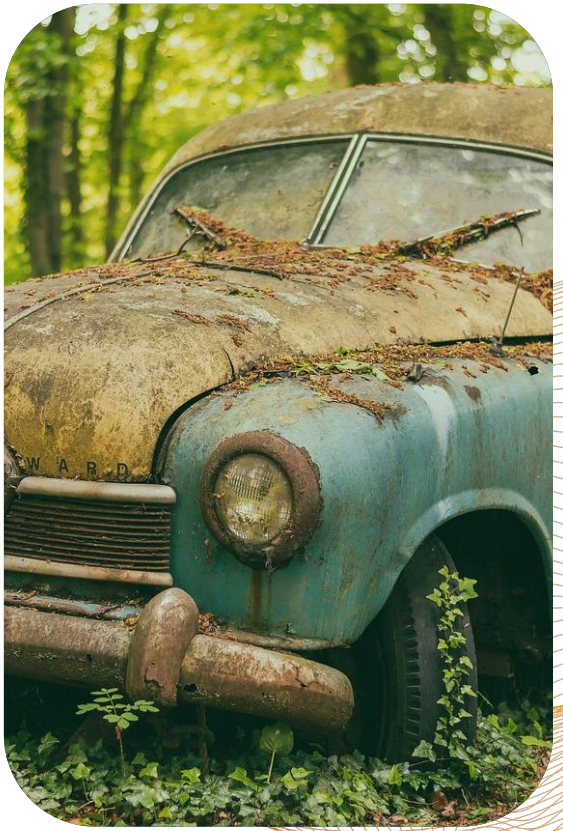
A simple example: Comparing things

```
〈onyr ★ kenzael〉〈rust_programming_paradigm_presentation〉〉 cargo run
   Compiling rust_programming_paradigm_presentation v0.1.0 (/home/onyr
esentation)
    Finished dev [unoptimized + debuginfo] target(s) in 0.13s
     Running `target/debug/rust_programming_paradigm_presentation`
Hello, world!
largest position { x:100, y:200 }
largest boxer { weight:110, name:Mike Tyson }
```



Pros of Generic Programming in Rust

1. **Code Reusability**
2. **Type Safety**: generics checked at comp. time
3. **Performance: No runtime overhead.** At compile time, Rust uses a process called **monomorphization** where it generates non-generic versions of your generic code for each specific instance they are used, which makes the code as fast as writing it for a specific type.
4. **Better Abstraction**: better abstraction, shared behavior across different types. Easier encapsulation and reasoning



Cons of Generic Programming in Rust

1. **Increased Compile Times**: can increase compile times
2. **Complexity**: can make the code more complex and harder to read, especially for those new to these concepts.
3. **Error Messages**: error messages can sometimes become cryptic and hard to decipher
4. **Limitations of the Trait System**: Certain functionalities are difficult to implement using Rust's trait system.

Examples in other languages

C++ | Java | Haskell

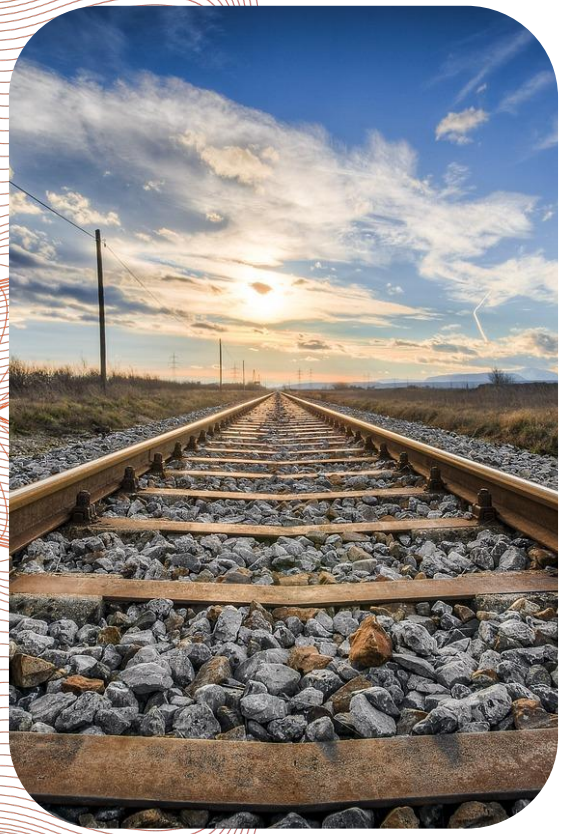
```cpp
#include <iostream>
#include <string>

// Define the interface
class Summarizable {
public:
    virtual std::string summarize() = 0; // pure virtual function
};

// Function that accepts a Summarizable object
template <typename T>
void notify(T& item) {
    static_assert(std::is_base_of<Summarizable, T>::value, "T must inherit from Summarizable");
    std::cout << "Breaking news! " << item.summarize() << std::endl;
}
```

C++ | Java | Haskell

```java
public interface Summarizable {
    String summarize();
}

public static <T extends Summarizable> void notify(T item) {
    System.out.println("Breaking news! " + item.summarize());
}
```

C++ Java Haskell

```haskell
{-# LANGUAGE TypeSynonymInstances, FlexibleInstances #-}

class Summarizable a where
    summarize :: a -> String

notify :: (Summarizable a) => a -> IO ()
notify item = putStrLn ("Breaking news! " ++ summarize item)
```



Conclusion

01 Further reading and resources

Ralf Jung, Jacques-Henri Jourdan, Robbert Krebbers, Derek Dreyer, “Safe systems programming in Rust” Communications of the ACM, Volume 64, Number 4 (2021), Pages 144-152

02 Summary of key takeaways

- **Genericity**: use different types for same thing
- **Traits**: define an expected behavior

> Increase in safe-reusable code
> No runtime overhead