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Rust (programming language)

Rust is a multi-paradigm, general-purpose programming language designed for performance and safety, especially safe concurrency.[12][13] Rust is syntactically similar to C++,[14] but can guarantee memory safety by using a *borrow checker* to validate references.[15] Rust achieves memory safety without garbage collection, and reference counting is optional.[16][17] Rust has been called a systems programming language and in addition to high-level features such as functional programming it also offers mechanisms for low-level memory management.

Rust was originally designed by Graydon Hoare at Mozilla Research,[18] with contributions from Dave Herman, Brendan Eich, and others.[19][20] The designers refined the language while writing the Servo experimental browser engine,[21] and the Rust compiler. It has gained increasing use in industry, and Microsoft has been experimenting with the language for secure and safety-critical software components.[22][23]

Rust has been voted the "most loved programming language" in the Stack Overflow Developer Survey every year since 2016, though only used by 7% of the respondents in 2021.[24]

Contents

Rust

The official Rust logo

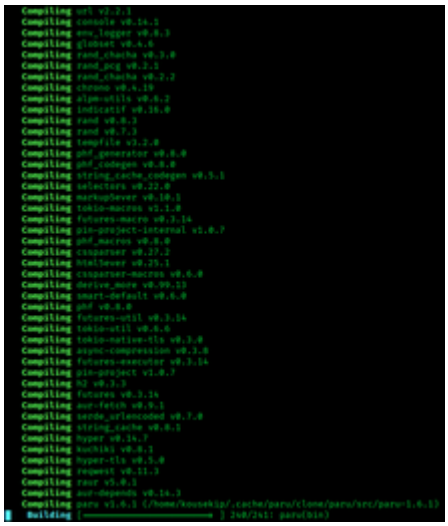
Paradigms	Multi-paradigm: concurrent, functional, generic, imperative, structured
Designed by	Graydon Hoare
Developer	The Rust Foundation
First appeared	July 7, 2010
Stable release	1.57.0[1] / December 2, 2021
Typing discipline	Affine, inferred, nominal, static, strong
Implementation language	Rust
Platform	AMD64 , i686, arm, AArch64, armv7, mips, mips64, mipsel, mips64el, powerpc, powerpc64, powerpc64le, risc-v, s390x[note 1]

OS	Windows, Linux, macOS, FreeBSD, NetBSD
License	MIT or Apache 2.0[2]
Filename extensions	.rs, .rlib
Website	www.rust-lang.org (http://www.rust-lang.org)
Influenced by	
Alef[3], C#[3], C++[3], Cyclone[3][4], Erlang[3], Haskell[3], Limbo[3], Newsqueak[3], OCaml[3], Ruby[3], Scheme[3], Standard ML[3], Swift[3][5]	
Influenced	
Crystal, Elm[6], Idris[7], Spark[8], Swift[9], Project Verona[10], Zig, PHP[11]	

History

The language grew out of a personal project begun in 2006 by Mozilla employee Graydon Hoare.[13] Hoare has stated that the project was possibly named after rust fungi and that the name is also a substring of "robust".[25] Mozilla began sponsoring the project in 2009[13] and announced it in 2010.[26][27] The same year, work shifted from the initial compiler (written in OCaml) to an LLVM-based self-hosting compiler written in Rust.[28] Named `rustc`, it successfully compiled itself in 2011.[29]

The first numbered pre-alpha release of the Rust compiler occurred in January 2012.[30] Rust 1.0, the first stable release, was released on May 15, 2015.[31][32] Following 1.0, stable point releases are delivered every six weeks, while features are developed in nightly Rust with daily releases, then tested with beta releases that last six weeks.[33][34] Every 2 to 3 years, a new Rust "Edition" is produced. This is to provide an easy reference point for changes due to the frequent nature of Rust's *Train release schedule,* as well as to provide a window to make breaking changes. Editions are largely compatible.[35]



An example of compiling a Rust program

Along with conventional static typing, before version 0.4, Rust also supported typestates. The typestate system modeled assertions before and after program statements, through use of a special `check` statement. Discrepancies could be discovered at compile time, rather than at runtime, as might be the case with assertions in C or C++ code. The typestate concept was not unique to Rust, as it was first introduced in the language NIL.[36] Typestates were removed because in practice they were little used,[37] though the same functionality can be achieved by leveraging Rust's move semantics.[38]

The object system style changed considerably within versions 0.2, 0.3, and 0.4 of Rust. Version 0.2 introduced classes for the first time, and version 0.3 added several features, including destructors and polymorphism through the use of interfaces. In Rust 0.4, traits were added as a means to provide inheritance; interfaces were unified with traits and removed as a separate feature. Classes were also removed and replaced by a combination of implementations and structured types.[39]

Starting in Rust 0.9 and ending in Rust 0.11, Rust had two built-in pointer types: ~ and @, simplifying the core memory model. It reimplemented those pointer types in the standard library as `Box` and (the now removed) `Gc`.

In January 2014, before the first stable release, Rust 1.0, the editor-in-chief of *Dr. Dobb's*, Andrew Binstock, commented on Rust's chances of becoming a competitor to C++ and to the other up-and-coming languages D, Go, and Nim (then Nimrod). According to Binstock, while Rust was "widely viewed as a remarkably elegant language", adoption slowed because it repeatedly changed between versions.[40]

Rust has a foreign function interface (FFI) that can be called from, e.g., C language, and can call C. While calling C++ has historically been challenging (from any language), Rust has a library, CXX, to allow calling to or from C++, and "CXX has zero or negligible overhead."[41]

In August 2020, Mozilla laid off 250 of its 1,000 employees worldwide as part of a corporate restructuring caused by the long-term impact of the COVID-19 pandemic.[42][43] Among those laid off were most of the Rust team,[44] while the Servo team was completely disbanded.[45] The event raised concerns about the future of Rust.[46]

In the following week, the Rust Core Team acknowledged the severe impact of the layoffs and announced that plans for a Rust foundation were underway. The first goal of the foundation would be taking ownership of all trademarks and domain names, and also take financial responsibility for their costs.[47]

On February 8, 2021 the formation of the Rust Foundation was officially announced by its five founding companies (AWS, Huawei, Google, Microsoft, and Mozilla).[48][49]

On April 6, 2021, Google announced support for Rust within Android Open Source Project as an alternative to C/C++.[50]

Syntax

Here is a "Hello, World!" program written in Rust. The `println!` macro prints the message to standard output.

```
fn main() {
    println!("Hello, World!");
}
```

The syntax of Rust is similar to C and C++, with blocks of code delimited by curly brackets, and control flow keywords such as `if`, `else`, `while`, and `for`, although the specific syntax for defining functions is more similar to Pascal. Despite the resemblance to C and C++, the syntax of Rust is closer to that of the ML family of languages and the Haskell language. Nearly every part of a function body is an expression,[51] even control flow operators. For example, the ordinary `if` expression also takes the place of C's ternary conditional, an idiom used by ALGOL 60. As in Lisp, a function need not end with a `return` expression: in this case if the semicolon is omitted, the last expression in the function creates the return value, as seen in the following recursive implementation of the factorial function:

```
fn factorial(i: u64) -> u64 {
    match i {
        0 => 1,
        n => n * factorial(n-1)
    }
}
```

The following iterative implementation uses the `..=` operator to create an inclusive range:

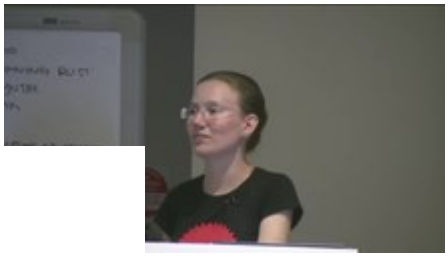
```
fn factorial(i: u64) -> u64 {
    (2..=i).product()
}
```

More advanced features in Rust include the use of generic functions to achieve type polymorphism. The following is a Rust program to calculate the sum of two things, for which addition is implemented, using a generic function:

```
use std::ops::Add;

fn Sum<T:Add<Output = T> + Copy> (num1: T, num2: T) -> T {
    num1 + num2
}

fn main() {
    let result1 = Sum(10,20);
    println!("Sum is: {:?}", result1);

    let result2 = Sum(10.23,20.45);
    println!("Sum is: {:?}", result2);
}
```

Features

Rust is intended to be a language for highly concurrent and highly safe systems,[52] and *programming in the large*, that is, creating and maintaining boundaries that preserve large-system integrity.[53] This has led to a feature set with an emphasis on safety, control of memory layout, and concurrency.



A presentation on Rust by Emily Dunham from Mozilla's Rust team (linux.conf.au conference, Hobart, 2017)

Memory safety

Rust is designed to be memory safe. It does not permit null pointers, dangling pointers, or data races.[54][55][56] Data values can be initialized only through a fixed set of forms, all of which require their inputs to be already initialized.[57] To replicate pointers being either valid or `NULL`, such as in linked list or binary tree data structures, the Rust core library provides an option type, which can be used to test whether a pointer has `Some` value or `None`.[55] Rust has added syntax to manage lifetimes, which are checked at compile time by the *borrow checker*. Unsafe code can subvert some of these restrictions using the `unsafe` keyword.[15]

Memory management

Rust does not use automated garbage collection. Memory and other resources are managed through the resource acquisition is initialization convention,[58] with optional reference counting. Rust provides deterministic management of resources, with very low overhead.[59] Rust favors stack allocation of values and does not perform implicit boxing.

There is the concept of references (using the & symbol), which does not involve run-time reference counting. The safety of such pointers is verified at compile time, preventing dangling pointers and other forms of undefined behavior. Rust's type system separates shared, immutable pointers of the

form &T from unique, mutable pointers of the form `&mut T`. A mutable pointer can be coerced to an immutable pointer, but not vice versa.

Ownership

Rust has an ownership system where all values have a unique owner, and the scope of the value is the same as the scope of the owner.[60][61] Values can be passed by immutable reference, using `&T`, by mutable reference, using `&mut T`, or by value, using `T`. At all times, there can either be multiple immutable references or one mutable reference (an implicit readers–writer lock). The Rust compiler enforces these rules at compile time and also checks that all references are valid.

Types and polymorphism

Rust's type system supports a mechanism called traits, inspired by type classes in the Haskell language. Traits annotate types, and are used to define *shared behavior* between different types: for example, floats and integers might both implement an "Add" trait because they can both be added; and any type that can be printed out as a string implements the "Display" or "Debug" traits. This facility is known as ad hoc polymorphism.

Rust uses type inference for variables declared with the keyword `let`. Such variables do not require a value to be initially assigned to determine their type. A compile time error results if any branch of code leaves the variable without an assignment.[62] Variables assigned multiple times must be marked with the keyword `mut` (short for mutable).

A function can be given generic parameters, which allows the same function to be applied to different types. Generic functions can constrain the generic type to implement a particular trait or traits; for example, an "add one" function might require the type to implement "Add". This means that a generic function can be type-checked as soon as it is defined.

The implementation of Rust generics is similar to the typical implementation of C++ templates: a separate copy of the code is generated for each instantiation. This is called monomorphization and contrasts with the type erasure scheme typically used in Java and Haskell. Rust's type erasure is also available by using the keyword `dyn`. The benefit of monomorphization is optimized code for each specific use case; the drawback is increased compile time and size of the resulting binaries.

In Rust, user-defined types are created with the `struct` keyword. These types usually contains fields of data like objects or classes in other languages. The `impl` keyword can define methods for the struct (data and function are defined separately in a struct) or implement a trait for the structure. A trait is a contract that a structure has certain required methods implemented. Traits are used to restrict generic parameters and because traits can provide a struct with more methods than the user defined. For example, the trait `Iterator` requires that the `next` method be defined for the type. Once the `next` method is defined the trait provides common functional helper methods over the iterator like map or filter.

The object system within Rust is based around implementations, traits and structured types. Implementations fulfill a role similar to that of classes within other languages and are defined with the keyword `impl`. Traits provide inheritance and polymorphism; they allow methods to be defined and mixed in to implementations. Structured types are used to define fields. Implementations and traits cannot define fields themselves, and only traits can provide inheritance. Among other benefits, this prevents the diamond problem of multiple inheritance, as in C++. In other words, Rust supports interface inheritance but replaces implementation inheritance with composition; see composition over inheritance.

Components

Rust features a large number of components that extend the Rust feature set and make Rust development easier. Component installation is typically managed by *rustup,* a Rust toolchain installer developed by the Rust project.[63]

Cargo

Cargo is Rust's build system and package manager. Cargo handles downloading dependencies, and building dependencies. Cargo also acts as a wrapper for *clippy* and other Rust components. It requires projects to follow a certain directory structure.[64]

The dependencies for a Rust package are specified in a *Cargo.toml* file along with version requirements, telling Cargo which versions of the dependency are compatible with the package. By default, Cargo sources its dependencies from the user-contributed registry *crates.io (https://crates.io)* but Git repositories and packages in the local filesystem can be specified as dependencies, too.[65]

Rustfmt

Rustfmt is a code formatter for Rust. It takes Rust source code as input and changes the whitespace and indentation to produce formatted code in accordance to the Rust style guide or rules specified in a rustfmt.toml file. Rustfmt can be invoked as a standalone program or on a Rust project through Cargo. [66][67]

Clippy

Clippy is Rust's built-in linting tool to improve the correctness, performance, and readability of Rust code. It was created in 2014[68] and named after the eponymous Microsoft Office feature.[69] As of 2021, Clippy has more than 450 rules,[70] which can be browsed online and filtered by category.[71] Some rules are disabled by default.

RLS

RLS is a language server that provides IDEs and text editors with more information about a Rust project. It provides linting checks via *Clippy*, formatting via *Rustfmt,* automatic code completion via *Racer*, among other functions.[72] Development of *Racer* was slowed down in favor of *rust-analyzer*.[73]

Language extensions

It is possible to extend the Rust language using the procedural macro mechanism.[74]

Procedural macros use Rust functions that run at compile time to modify the compiler's token stream. This complements the declarative macro mechanism (also known as *macros by example*), which uses pattern matching to achieve similar goals.

Procedural macros come in three flavors:

- Function-like macros `custom!(...)`

- Derive macros `#[derive(CustomDerive)]`
- Attribute macros `#[custom_attribute]`

The `println!` macro is an example of a function-like macro and `serde_derive`[75] is a commonly used library for generating code for reading and writing data in many formats such as JSON. Attribute macros are commonly used for language bindings such as the `extendr` library for Rust bindings to R.[76]

The following code shows the use of the `Serialize`, `Deserialize` and `Debug` derive procedural macros to implement JSON reading and writing as well as the ability to format a structure for debugging.

```
use serde_json::{Serialize, Deserialize};

#[derive(Serialize, Deserialize, Debug)]
struct Point {
    x: i32,
    y: i32,
}

fn main() {
    let point = Point { x: 1, y: 2 };

    let serialized = serde_json::to_string(&point).unwrap();
    println!("serialized = {}", serialized);

    let deserialized: Point = serde_json::from_str(&serialized).unwrap();
    println!("deserialized = {:?}", deserialized);
}
```

Performance

Rust aims "to be as efficient and portable as idiomatic C++, without sacrificing safety".[77] Since Rust utilizes LLVM, any performance improvements in LLVM also carry over to Rust.[78]

Adoption

Rust was the third-most-loved programming language in the 2015 Stack Overflow annual survey[80] and took first place for 2016–2021.[81][82]

Some Rust users refer to themselves as Rustaceans (a pun on crustacean) and use Ferris as their unofficial mascot.[79]

Web browsers

Firefox has two projects written in Rust: the Servo parallel browser engine[83] developed by Mozilla in collaboration with Samsung;[84] and Quantum, which is composed of several sub-projects for improving Mozilla's Gecko browser engine.[85]

Experimental operating systems

- Redox, a "full-blown Unix-like operating system" including a microkernel[86]
- Theseus, OS with "intralingual design" and a fundamental architecture which embodies Rust concepts[87]

Game engines

- Bevy (https://bevyengine.org/), a data-driven ECS game engine built in Rust.
- Amethyst (https://amethyst.rs/), a data-driven and data-oriented game engine.

Other

- Deno, a secure runtime for JavaScript and TypeScript, is built with V8, Rust, and Tokio[88]
- Discord uses Rust for portions of its backend, as well as client-side video encoding,[89] to augment the core infrastructure written in Elixir.[90]
- exa, a "modern replacement for ls"
- The Google Fuchsia capability-based operating system has some tools written in Rust[91]
- Microsoft Azure IoT Edge, a platform used to run Azure services and artificial intelligence on IoT devices, has components implemented in Rust[92]
- OpenDNS uses Rust in two of its components[93][94][95]
- Polkadot (cryptocurrency), an interconnected internet of blockchains, is written in Rust
- Ruffle, an open-source SWF emulator written in Rust[96]
- Stratis: a file system manager for Fedora[97] and RHEL 8[98]
- TerminusDB, an open source graph database designed for collaboratively building and curating knowledge graphs[99]
- Such applications as Figma, and Dropbox are written in Rust as well as some components for Amazon, Facebook, and Discord[100]

Governance

The **Rust Foundation** is a non-profit membership organization incorporated in Delaware, United States, with the primary purposes of supporting the maintenance and development of the language, cultivating the Rust project team members and user communities, managing the technical infrastructure underlying the development of Rust, and managing and stewarding the Rust trademark.

It was established on February 8, 2021, with five founding corporate members (Amazon Web Services, Huawei, Google, Microsoft, and Mozilla).[101] The foundation's board is chaired by Shane Miller.[102] Starting in late 2021, its Executive Director and CEO is Rebecca Rumbul .[103] Prior to this, Ashley Williams was interim executive director.[104]

Rust Foundation

Formation	February 8, 2021
Founders	Amazon Web Services Google Huawei Microsoft Mozilla Foundation
Type	Nonprofit organization
Location	United States
Chairperson	Shane Miller
Executive Director	Rebecca Rumbul
Website	foundation.rust-lang.org (https://foundation.rust-lang.org)

Development

Rust conferences include:

- RustConf: an annual conference in Portland, Oregon. Held annually since 2016 (except in 2020 and 2021 because of the COVID-19 pandemic).[105]
- Rust Belt Rust: a #rustlang conference in the Rust Belt[106]

- RustFest: Europe's @rustlang conference[107]
- RustCon Asia
- Rust LATAM
- Oxidize Global[108]

See also

- Comparison of programming languages

Notes

1. The list is incomplete; degree of stdlib support varies

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External links

- Official website (https://www.rust-lang.org/)
- Rust-lang (https://github.com/rust-lang) on GitHub

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