Presentation by Dion Dokter

What’s Rust all about?

tweede golf

Introduction

Who am I?

- Dion Dokter
- Bachelor’s Applied Computer Science at Saxion Enschede
- (Embedded) Rust since 2019
- Joined TG in late-2021 as embedded tech lead
- @Geoxion on Twitter, @diondokter on Mastodon

- LoRaWAN IoT
- UWB Real Time Localization System
- Async IoT with LTE

What to expect today?

Topics:

- Rust language
- Rust, FFI & C

The language

Origins

- Announced in 2010 by Mozilla & creator Graydon Hoare
- Aimed to replace C & C++ in Firefox
  - Initially with GC & green threads
- 1.0 version released in 2015
- Major edition upgrade in 2018 & 2021
  - Stable: Old code still compiles
- Now a foundation
- The project is on github
  - 74K stars
  - 4K+ contributors

Why Rust?

According to the website rust-lang.org:

- Performance -> Systems software
  - No runtime
  - No garbage collector
- Reliability -> Safe software
  - Memory safety
  - Thread safety
- Productivity -> Happy developers
  - Friendly compiler
  - Tooling & docs

Technical overview

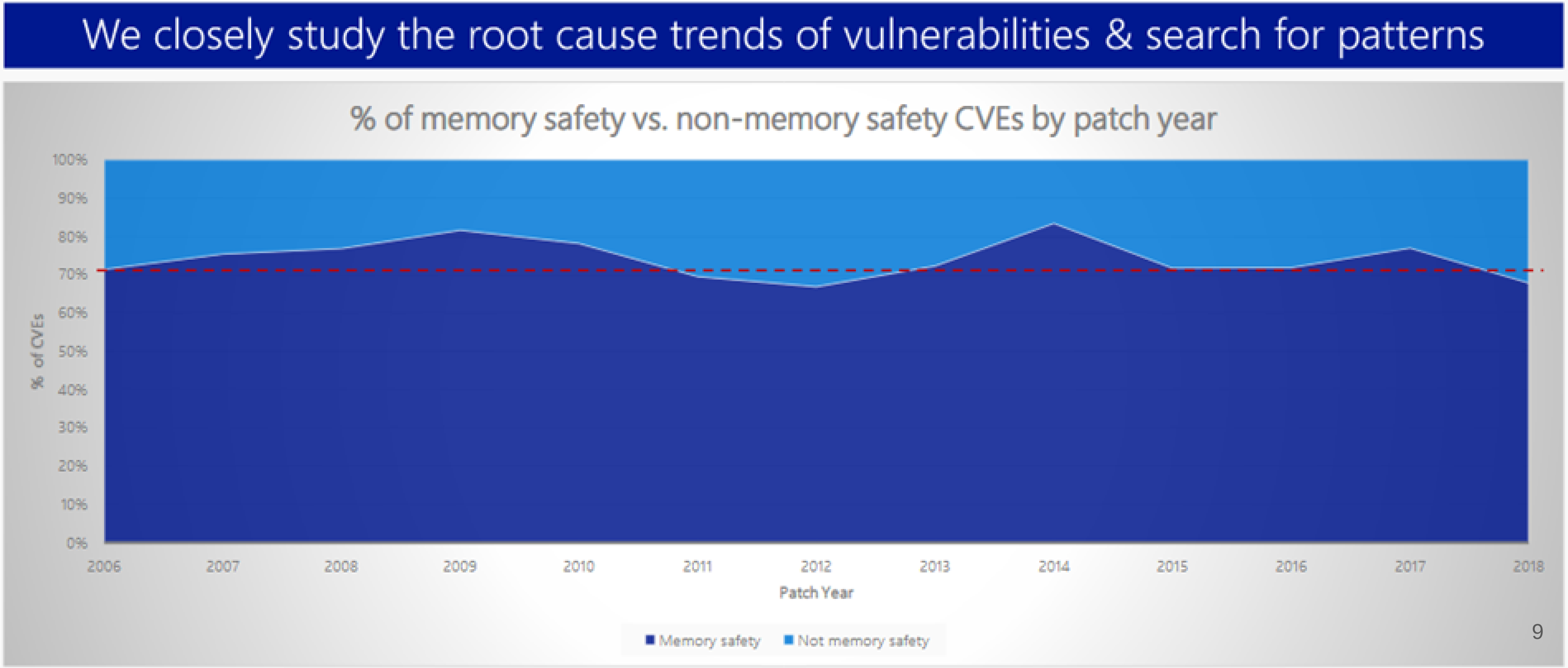
- Compiled language (machine code, not bytecode)
- Strongly statically typed
  - Elaborate type system
- Imperative with functional aspects
- No GC or runtime

Compared to C & C++

- No segfaults*
- No buffer overflows*
- No null pointers*
- No data races*
- Powerful type system
- Unified build system
- Dependency management

* In safe Rust (which is 99% of Rust)

Compared to C & C++



We closely study the root cause trends of vulnerabilities & search for patterns

% of memory safety vs. non-memory safety CVEs by patch year

Why not Rust?

- Compile times
- Learning curve
- No certifications yet
  - Ferrocene
  - AUTOSAR
- Library maturity

Syntax

C origins

Curly bracket style

ML & Haskell infused

Expression oriented

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

fn is_prime(n: u32) -> bool {
    let limit = (n as f32).sqrt() as u32;

    for i in 2..=limit {
        if n % i == 0 {
            return false;
        }
    }

    true
}
```

Syntax

- C origins
- Curly bracket style
- ML & Haskell infused
- Expression oriented

```
fn is_prime(n: u32) -> bool {
    let limit = (n as f32).sqrt() as u32;

    (2..=limit).map(|i| n % i).all(|p| p != 0)
}
```

Generates (almost) the same assembly!

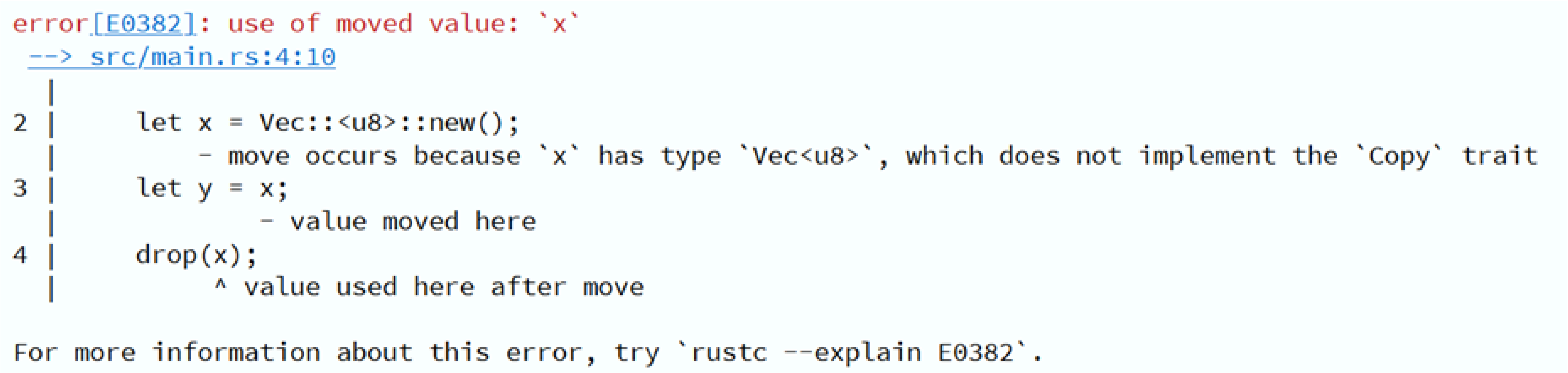
Ownership, moving & borrowing

All references (pointers) are checked at compile time:

- Every value has an owner, the variable
- Access can be borrowed by other variables
    - At most 1 mutable borrow OR infinite immutable borrows
- Ownership can be transferred by moving
- Owner out of scope = value dropped
    - Similar to C++ RAII
    - No GC required

Good compiler feedback

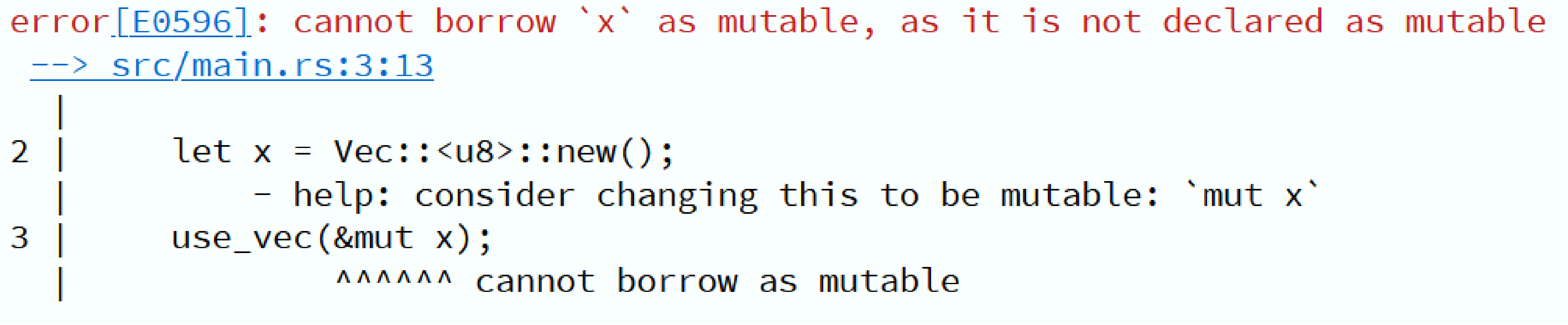
```
let x = Vec::<u8>::new();
let y = x;
drop(x);
```



```
error[E0382]: use of moved value: `x`
 --> src/main.rs:4:10
  |
2 |     let x = Vec::<u8>::new();
  |         - move occurs because `x` has type `Vec<u8>`, which does not implement the `Copy` trait
3 |     let y = x;
  |             - value moved here
4 |     drop(x);
  |          ^ value used here after move

For more information about this error, try `rustc --explain E0382`.
```

Good compiler feedback

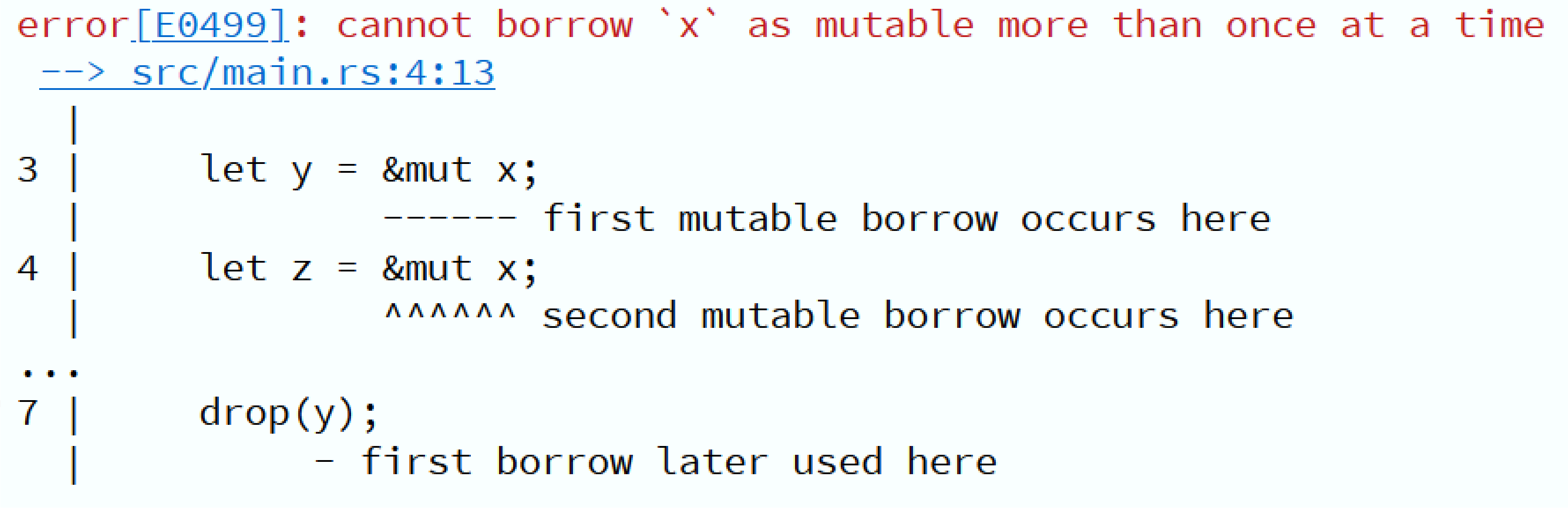
```
let x = Vec::<u8>::new();
use_vec(&mut x);

fn use_vec(x:  &mut Vec<u8>) {}
```



```
error[E0596]: cannot borrow `x` as mutable, as it is not declared as mutable
 --> src/main.rs:3:13
  |
2 |     let x = Vec::<u8>::new();
  |         - help: consider changing this to be mutable: `mut x`
3 |     use_vec(&mut x);
  |             ^^^^^^ cannot borrow as mutable
  |
```

Good compiler feedback

```
let mut x = Vec::<u8>::new();
let y = &mut x;
let z = &mut x;
drop(y);
```



```
error[E0499]: cannot borrow `x` as mutable more than once at a time
 --> src/main.rs:4:13
  |
3 |     let y = &mut x;
  |             ------ first mutable borrow occurs here
4 |     let z = &mut x;
  |             ^^^^^^ second mutable borrow occurs here
...
7 |     drop(y);
  |          - first borrow later used here
```

Traits & generics

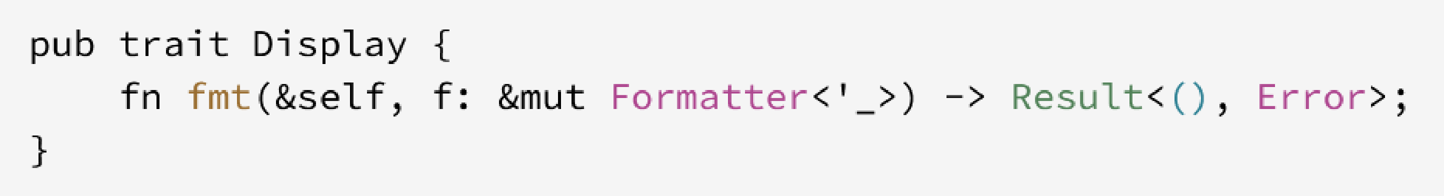
- Structs implement traits
- Traits are like interfaces in Java
- Generic bounds using traits (not unlike C++ concepts)
- Monomorphization (not unlike C++ templates)

- No classic OOP, so traits are the main abstraction mechanic

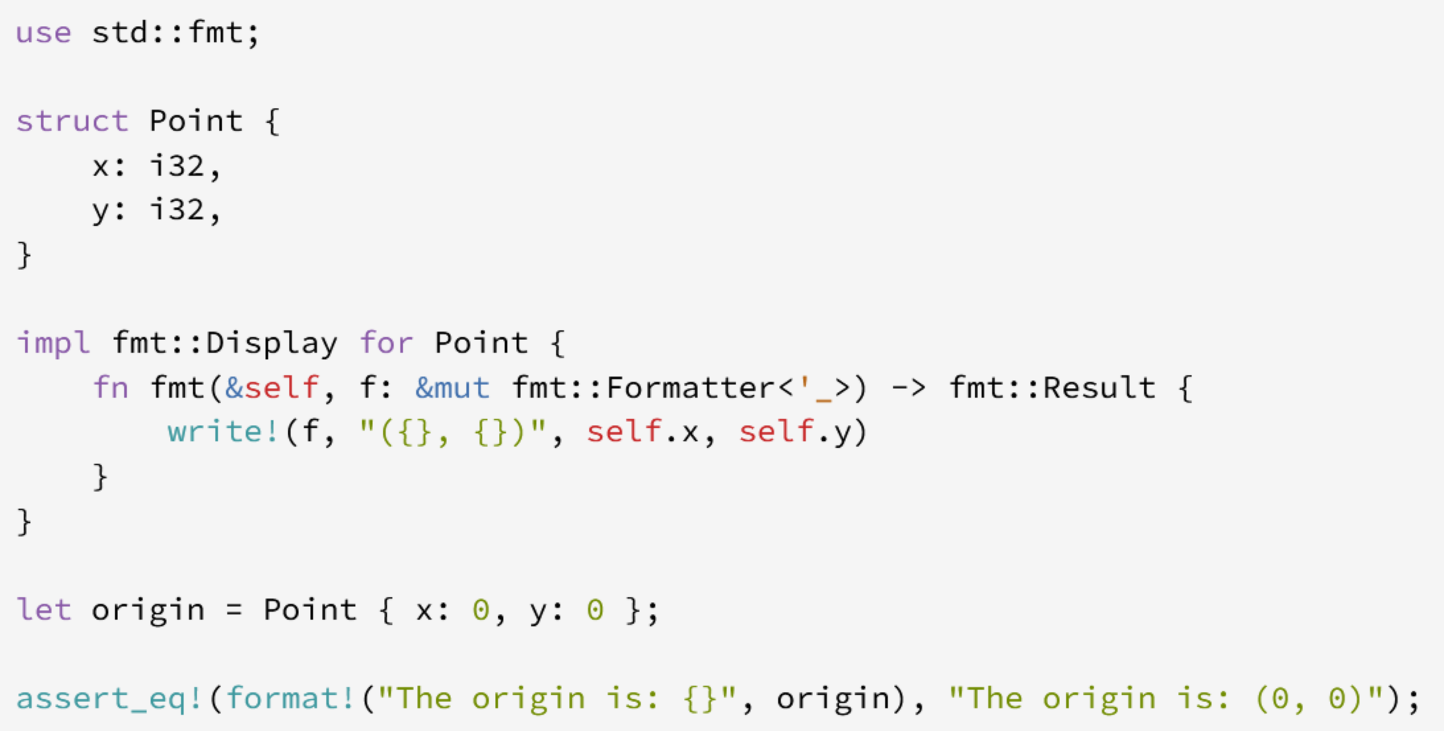
Traits & generics

Display trait

Anything that implements Display can be formatted



```
pub trait Display {
    fn fmt(&self, f: &mut Formatter<'_>) -> Result<(), Error>;
}
```

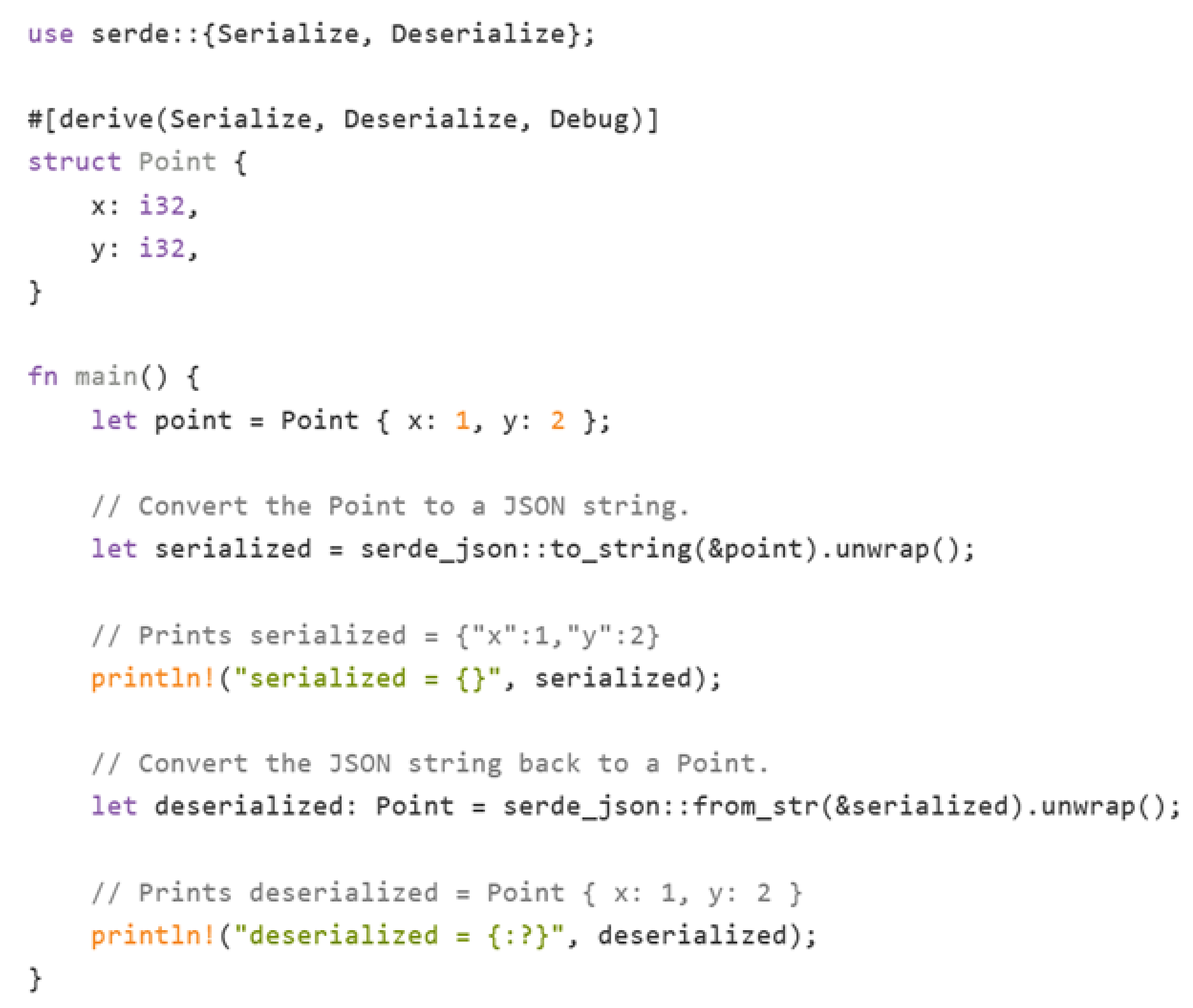


```
use std::fmt;

struct Point {
    x: i32,
    y: i32,
}

impl fmt::Display for Point {
    fn fmt(&self, f: &mut fmt::Formatter<'_>) -> fmt::Result {
        write!(f, "({}, {})", self.x, self.y)
    }
}

let origin = Point { x: 0, y: 0 };

assert_eq!(format!("The origin is: {}", origin), "The origin is: (0, 0)");
```

Traits & generics

Use #[derive()] to automatically implement traits

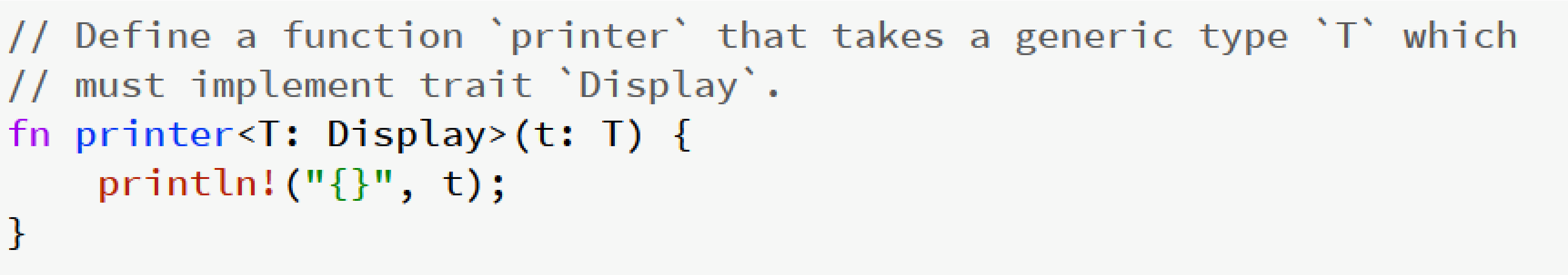
Serde is really cool btw



```rust
use serde::{Serialize, Deserialize};

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

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

    // Convert the Point to a JSON string.
    let serialized = serde_json::to_string(&point).unwrap();

    // Prints serialized = {"x":1,"y":2}
    println!("serialized = {}", serialized);

    // Convert the JSON string back to a Point.
    let deserialized: Point = serde_json::from_str(&serialized).unwrap();

    // Prints deserialized = Point { x: 1, y: 2 }
    println!("deserialized = {:?}", deserialized);
}
```

Generic functions

Generic type is bounded by traits



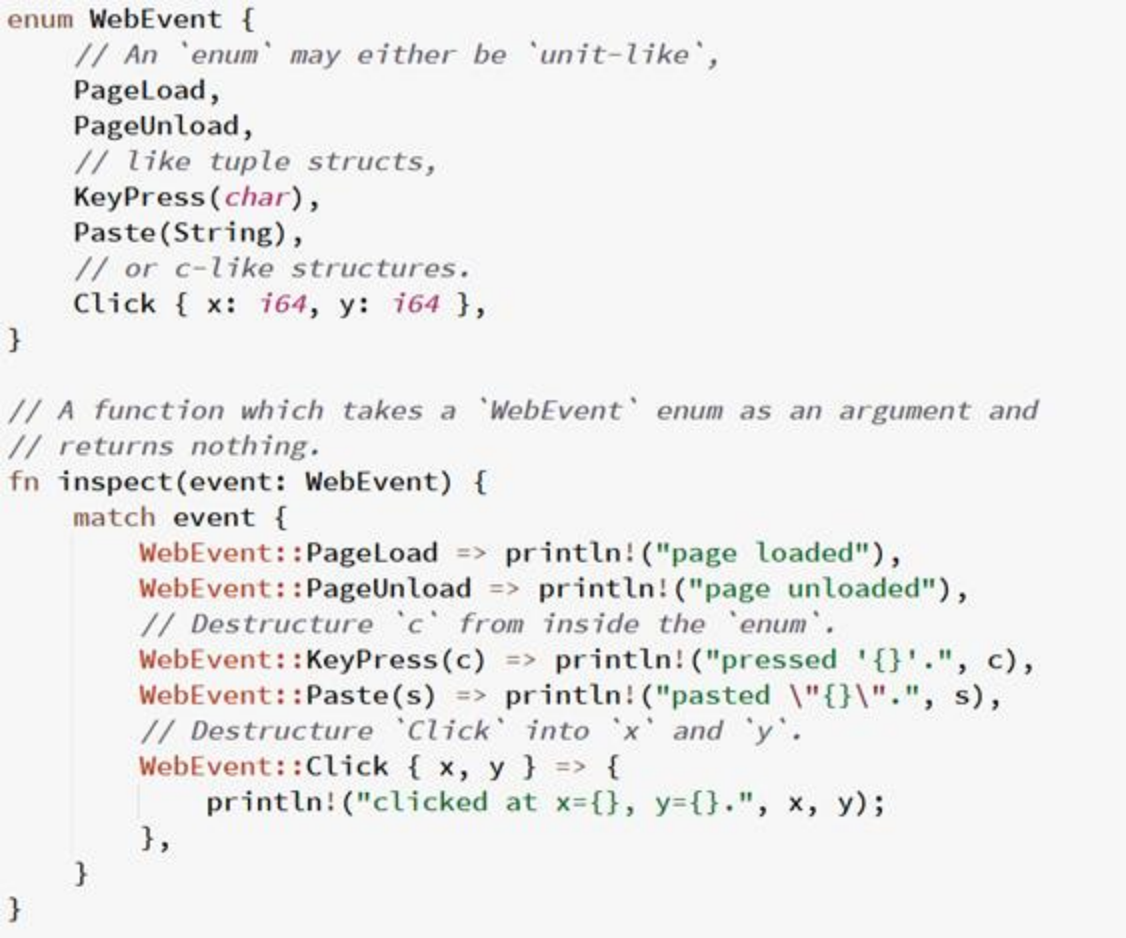
```
// Define a function `printer` that takes a generic type `T` which
// must implement trait `Display`.
fn printer<T: Display>(t: T) {
    println!("{}", t);
}
```

Enums

Enum variants can contain data.

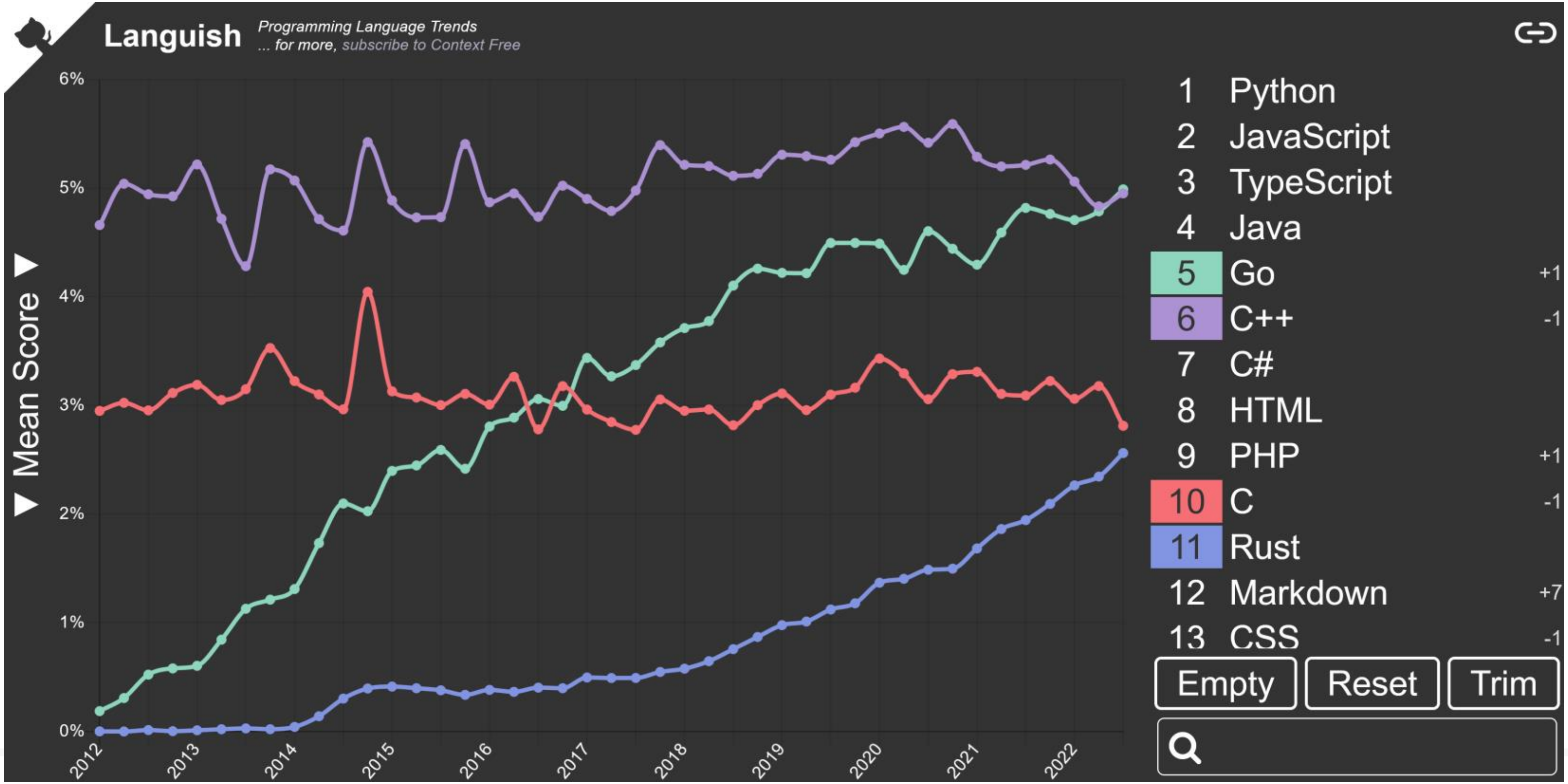
Enums can implement functions & traits.

Pattern matching on enums and much more.



```
enum WebEvent {
    // An `enum` may either be `unit-like`,
    PageLoad,
    PageUnload,
    // like tuple structs,
    KeyPress(char),
    Paste(String),
    // or c-like structures.
    Click { x: i64, y: i64 },
}

// A function which takes a `WebEvent` enum as an argument and
// returns nothing.
fn inspect(event: WebEvent) {
    match event {
        WebEvent::PageLoad => println!("page loaded"),
        WebEvent::PageUnload => println!("page unloaded"),
        // Destructure `c` from inside the `enum`.
        WebEvent::KeyPress(c) => println!("pressed '{}'.", c),
        WebEvent::Paste(s) => println!("pasted \"{}\".", s),
        // Destructure `Click` into `x` and `y`.
        WebEvent::Click { x, y } => {
            println!("clicked at x={}, y={}.", x, y);
        },
    }
}
```

Increasingly popular



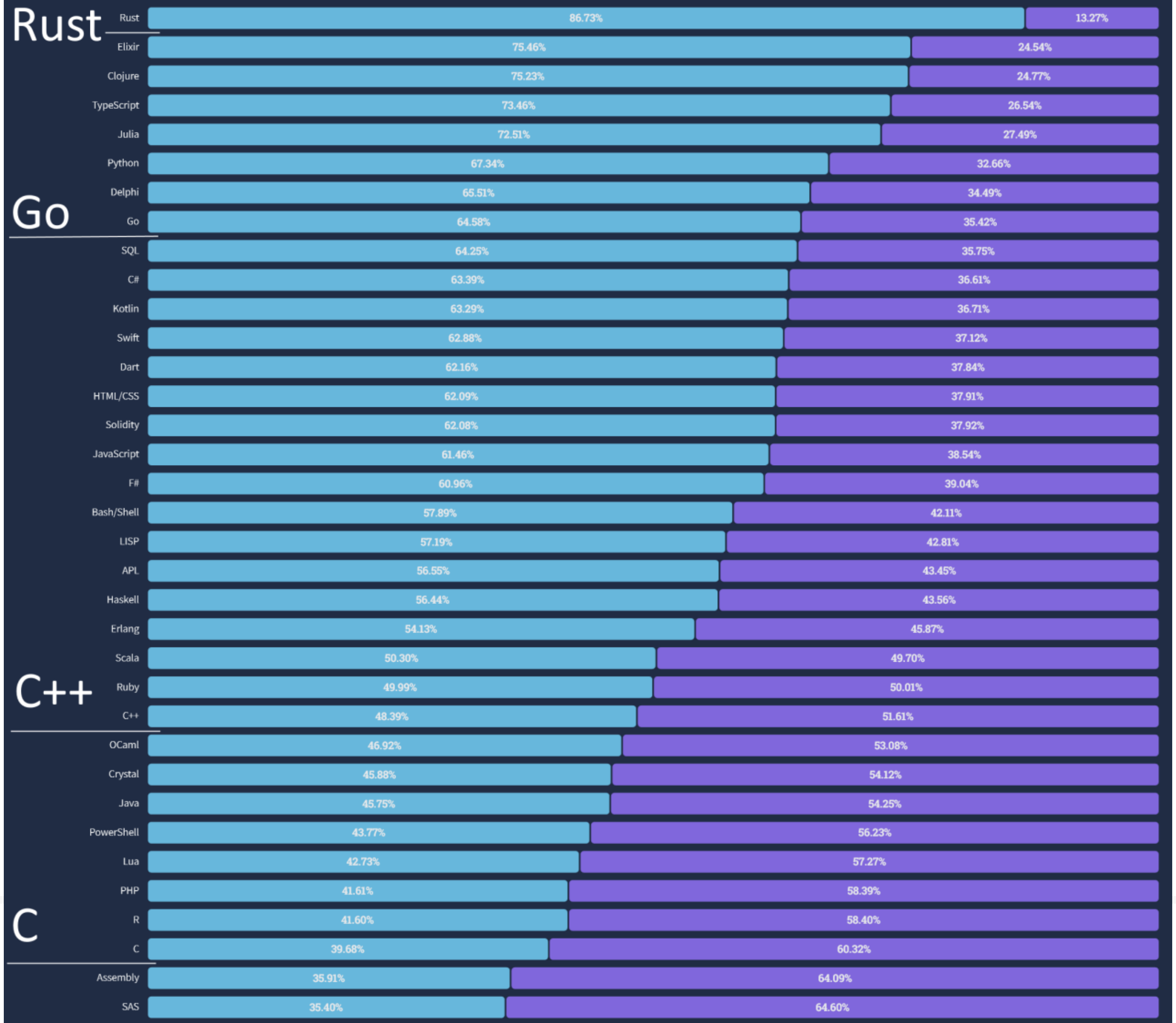
1	Python	
2	JavaScript	
3	TypeScript	
4	Java	
5	Go	+1
6	C++	-1
7	C#	
8	HTML	
9	PHP	+1
10	C	-1
11	Rust	
12	Markdown	+7
13	CSS	-1

https://tjpalmer.github.io/languish/

Very well liked

7 years in a row, Rust is the most loved language.

https://survey.stackoverflow.co/2022/#technology-most-loved-dreaded-and-wanted



Lots of big players are investing

Platinum

aws Google HUAWEI JFrog Meta Microsoft

moz://a

Silver

1Password arm AUTOMATA Dropbox EMBECOSM® ferrous systems FUTUREWEI Technologies Grafbase KDAB KEYROCK knóldus knols . commitment . results

Mainmatter Matter Labs OPEN SOURCE SECURITY ParaState SENTRY slint Spectral tabnine ⟨tag1⟩ TANGRAM VISION TECH FUND

Threema. TOYOTA connected 天市垣資本 TSY CAPITAL tweede golf Watchful Wyliodrin ZAMA

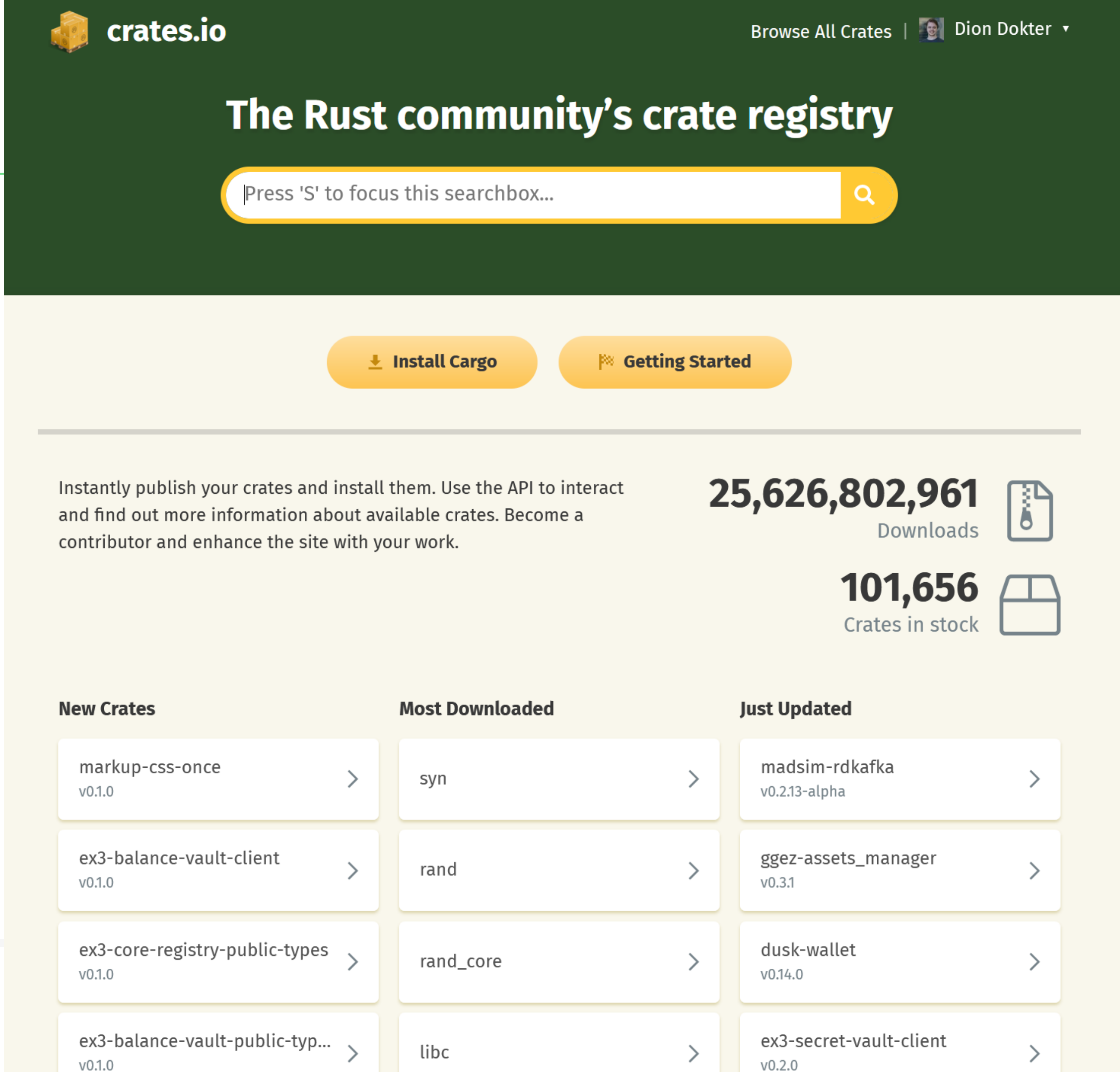
https://foundation.rust-lang.org/members/

Extra tools

Tools

Cargo:

- Build system
- Package manager



crates.io
Browse All Crates | Dion Dokter
Press 'S' to focus this searchbox...
Install Cargo
Getting Started

The Rust community's crate registry

Instantly publish your crates and install them. Use the API to interact and find out more information about available crates. Become a contributor and enhance the site with your work.

25,626,802,961
Downloads

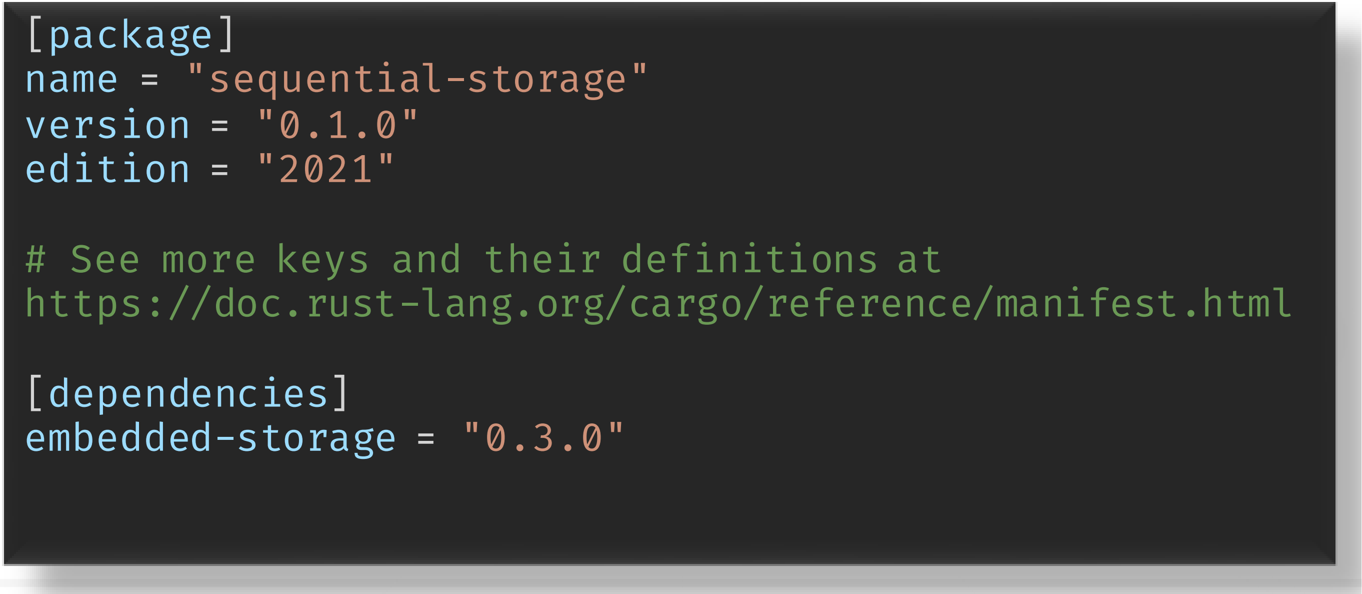
101,656
Crates in stock

New Crates	Most Downloaded	Just Updated
markup-css-once v0.1.0	syn	madsim-rdkafka v0.2.13-alpha
ex3-balance-vault-client v0.1.0	rand	ggez-assets_manager v0.3.1
ex3-core-registry-public-types v0.1.0	rand_core	dusk-wallet v0.14.0
ex3-balance-vault-public-typ... v0.1.0	libc	ex3-secret-vault-client v0.2.0

Tools

Cargo:

- Build system
- Package manager

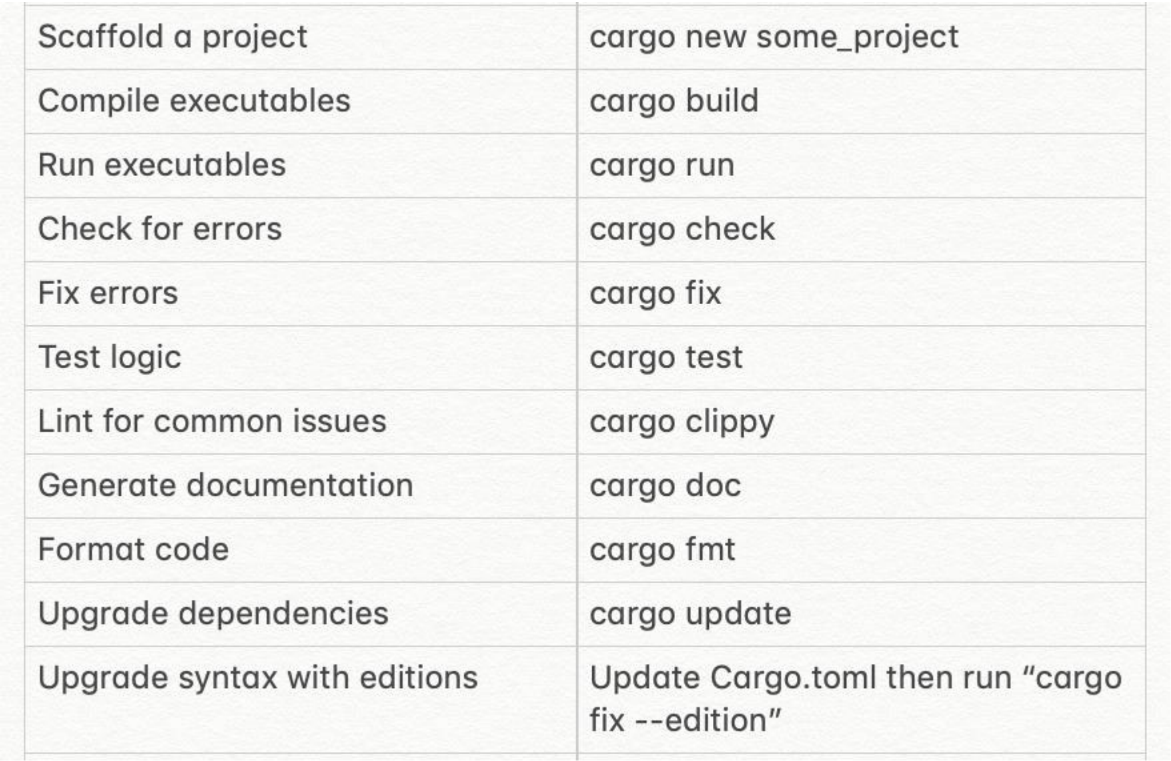


```toml
[package]
name = "sequential-storage"
version = "0.1.0"
edition = "2021"

# See more keys and their definitions at
https://doc.rust-lang.org/cargo/reference/manifest.html

[dependencies]
embedded-storage = "0.3.0"
```

Tools

Cargo:

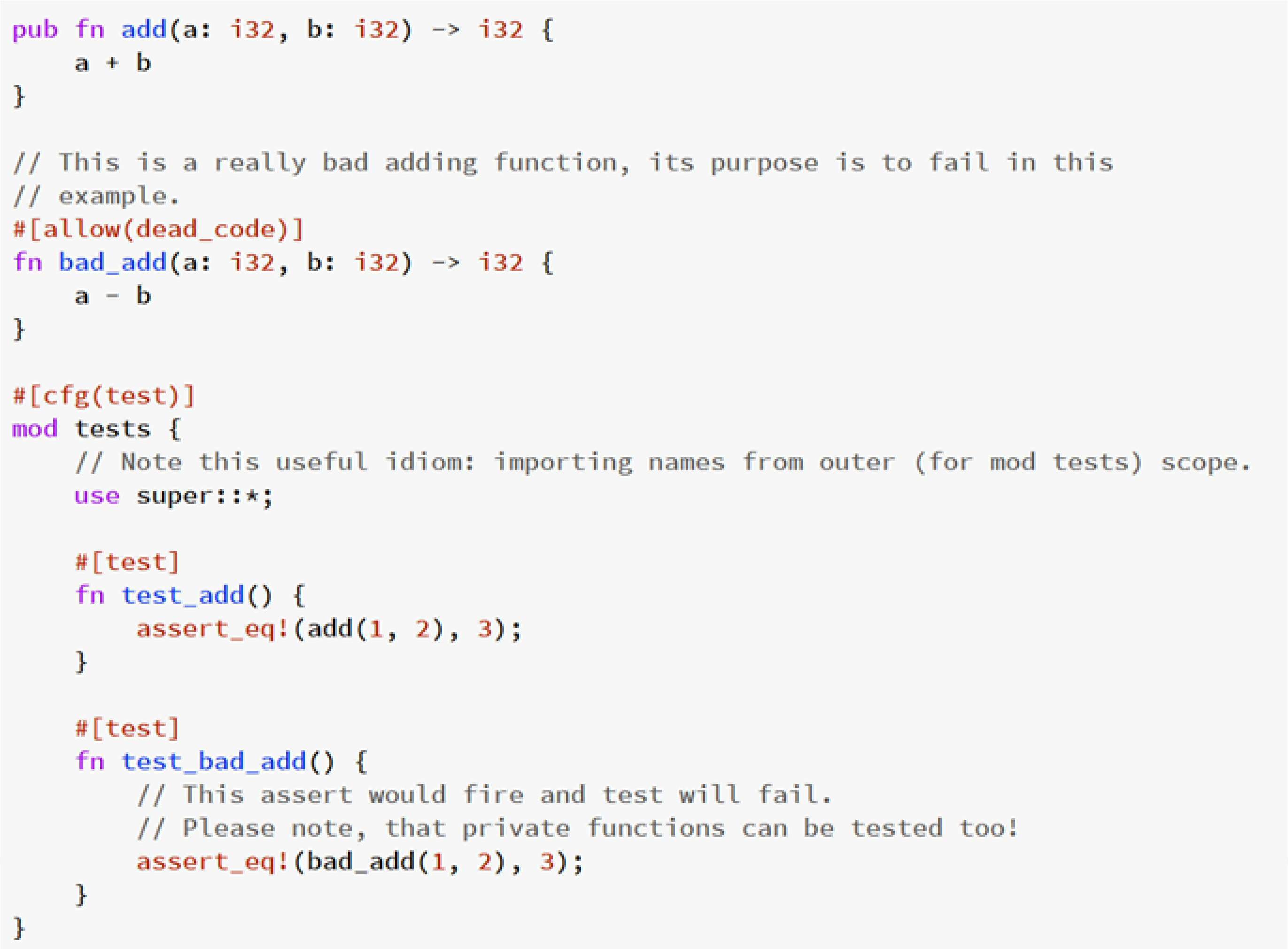
- Build system
- Package manager



Scaffold a project	cargo new some_project
Compile executables	cargo build
Run executables	cargo run
Check for errors	cargo check
Fix errors	cargo fix
Test logic	cargo test
Lint for common issues	cargo clippy
Generate documentation	cargo doc
Format code	cargo fmt
Upgrade dependencies	cargo update
Upgrade syntax with editions	Update Cargo.toml then run “cargo fix --edition”

Tools

Built-in unit testing

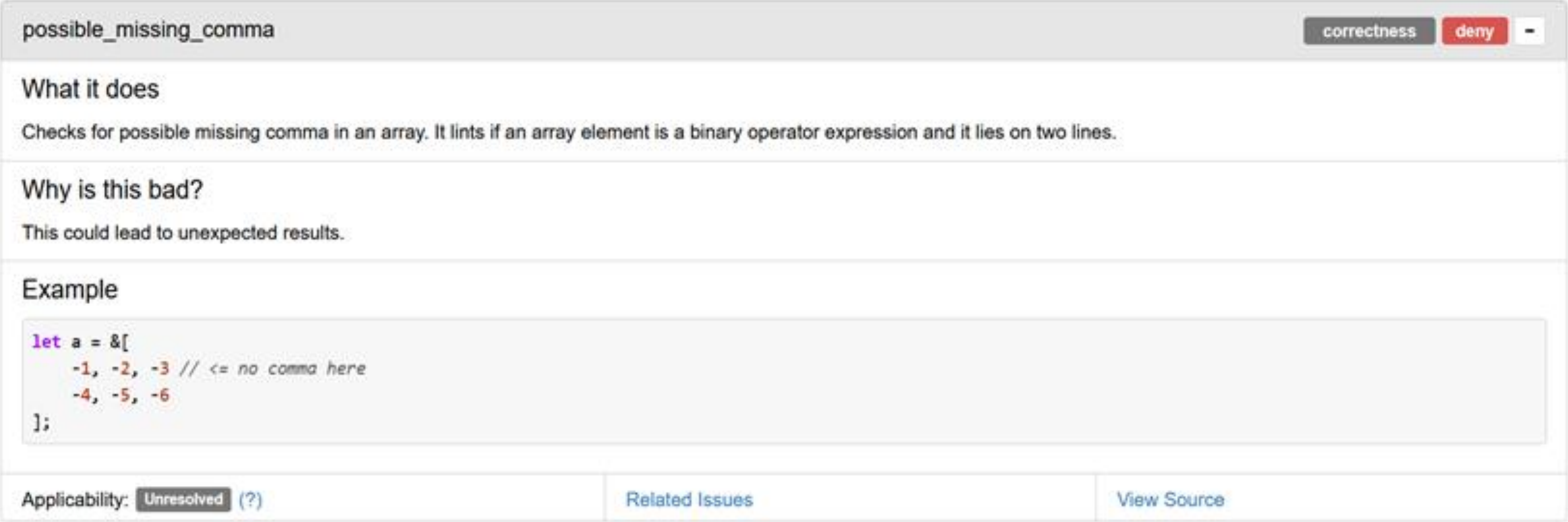


```
pub fn add(a: i32, b: i32) -> i32 {
    a + b
}

// This is a really bad adding function, its purpose is to fail in this
// example.
#[allow(dead_code)]
fn bad_add(a: i32, b: i32) -> i32 {
    a - b
}

#[cfg(test)]
mod tests {
    // Note this useful idiom: importing names from outer (for mod tests) scope.
    use super::*;

    #[test]
    fn test_add() {
        assert_eq!(add(1, 2), 3);
    }

    #[test]
    fn test_bad_add() {
        // This assert would fire and test will fail.
        // Please note, that private functions can be tested too!
        assert_eq!(bad_add(1, 2), 3);
    }
}
```

Tools

Clippy:

- Prevent common mistakes
- Small efficiency improvements



possible_missing_comma

What it does

Checks for possible missing comma in an array. It lints if an array element is a binary operator expression and it lies on two lines.

Why is this bad?

This could lead to unexpected results.

Example

```
let a = &[
    -1, -2, -3 // <= no comma here
    -4, -5, -6
];
```

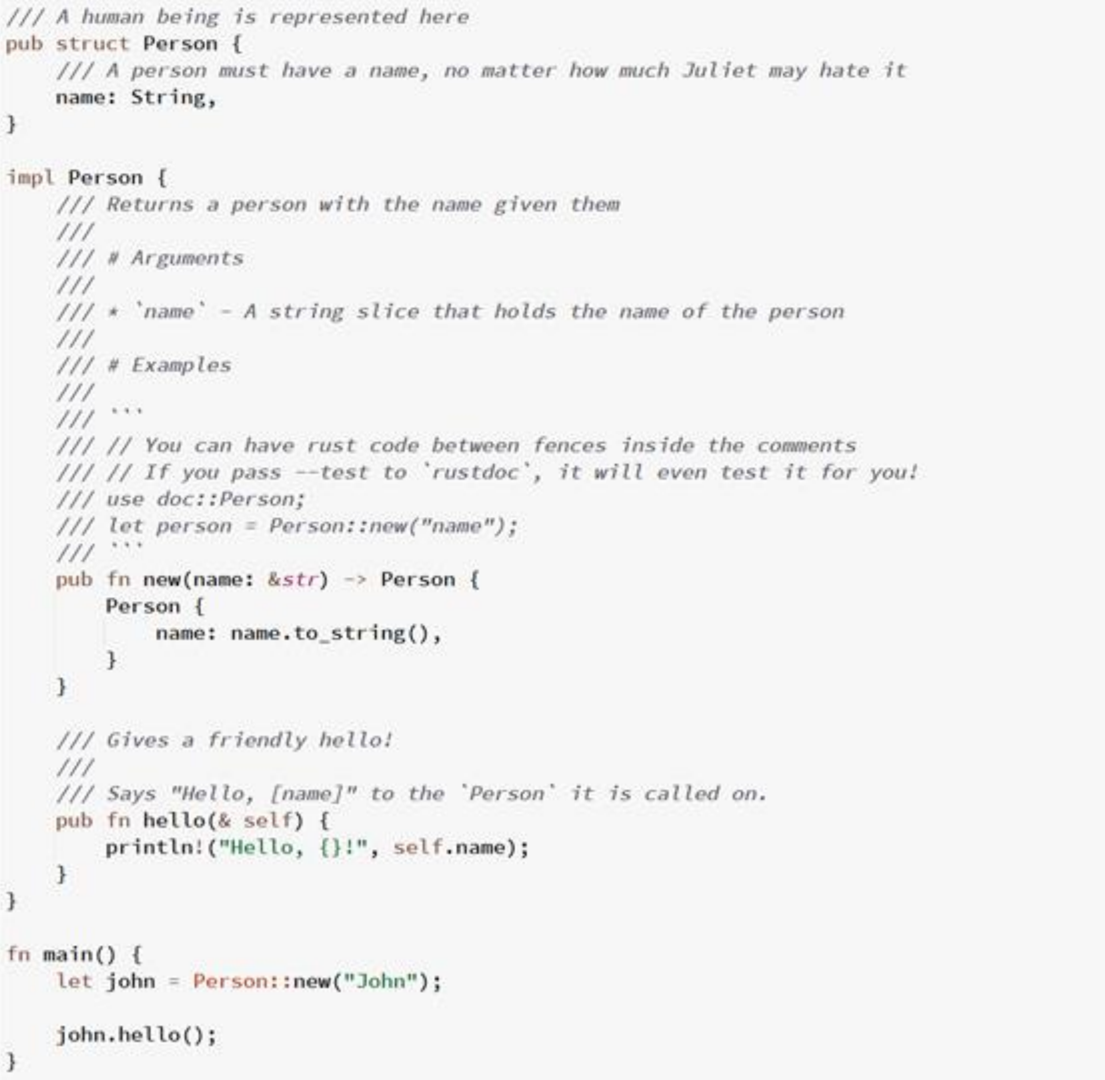
Tools

Docs:

Markdown

Generated to html (like doxygen)

docs.rs



```
/// A human being is represented here
pub struct Person {
    /// A person must have a name, no matter how much Juliet may hate it
    name: String,
}

impl Person {
    /// Returns a person with the name given them
    ///
    /// # Arguments
    ///
    /// * `name` - A string slice that holds the name of the person
    ///
    /// # Examples
    ///
    /// ```
    /// // You can have rust code between fences inside the comments
    /// // If you pass --test to `rustdoc`, it will even test it for you!
    /// use doc::Person;
    /// let person = Person::new("name");
    /// ```
    pub fn new(name: &str) -> Person {
        Person {
            name: name.to_string(),
        }
    }

    /// Gives a friendly hello!
    ///
    /// Says "Hello, [name]" to the `Person` it is called on.
    pub fn hello(& self) {
        println!("Hello, {}!", self.name);
    }
}

fn main() {
    let john = Person::new("John");

    john.hello();
}
```

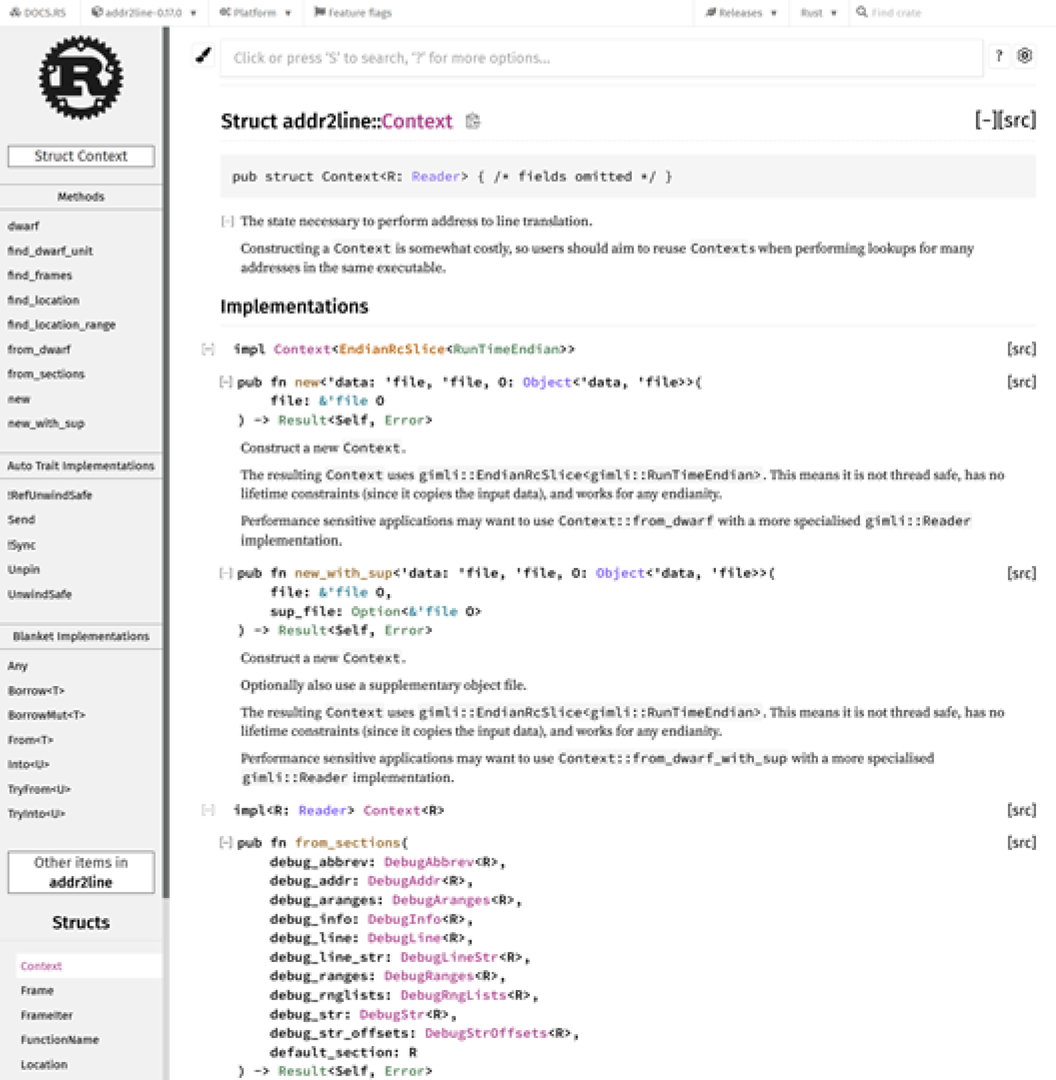
Tools

Docs:

Markdown

Generated to html (like doxygen)

docs.rs



Struct addr2line::Context

[-][src]

```
pub struct Context<R: Reader> { /* fields omitted */ }
```

[-] The state necessary to perform address to line translation.

Constructing a `Context` is somewhat costly, so users should aim to reuse `Context`s when performing lookups for many addresses in the same executable.

Implementations

```
[-] impl Context<EndianRcSlice<RunTimeEndian>>                    [src]

[-] pub fn new<'data: 'file, 'file, O: Object<'data, 'file>>(    [src]
        file: &'file O
    ) -> Result<Self, Error>
```

Construct a new `Context`.

The resulting `Context` uses `gimli::EndianRcSlice<gimli::RunTimeEndian>`. This means it is not thread safe, has no lifetime constraints (since it copies the input data), and works for any endianity.

Performance sensitive applications may want to use `Context::from_dwarf` with a more specialised `gimli::Reader` implementation.

```
[-] pub fn new_with_sup<'data: 'file, 'file, O: Object<'data, 'file>>(    [src]
        file: &'file O,
        sup_file: Option<&'file O>
    ) -> Result<Self, Error>
```

Construct a new `Context`.

Optionally also use a supplementary object file.

The resulting `Context` uses `gimli::EndianRcSlice<gimli::RunTimeEndian>`. This means it is not thread safe, has no lifetime constraints (since it copies the input data), and works for any endianity.

Performance sensitive applications may want to use `Context::from_dwarf_with_sup` with a more specialised `gimli::Reader` implementation.

```
[-] impl<R: Reader> Context<R>                    [src]

[-] pub fn from_sections(                         [src]
        debug_abbrev: DebugAbbrev<R>,
        debug_addr: DebugAddr<R>,
        debug_aranges: DebugAranges<R>,
        debug_info: DebugInfo<R>,
        debug_line: DebugLine<R>,
        debug_line_str: DebugLineStr<R>,
        debug_ranges: DebugRanges<R>,
        debug_rnglists: DebugRngLists<R>,
        debug_str: DebugStr<R>,
        debug_str_offsets: DebugStrOffsets<R>,
        default_section: R
    ) -> Result<Self, Error>
```

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Many more tools

- rustfmt: Code formatting
- Criterion: Microbenchmarking
- Bindings
    - rust-bindgen
    - cxx
- Any text editor using LSP (for Rust Analyzer plugin)
- Any IntelliJ IDE (for IntelliJ Rust plugin)

FFI & C

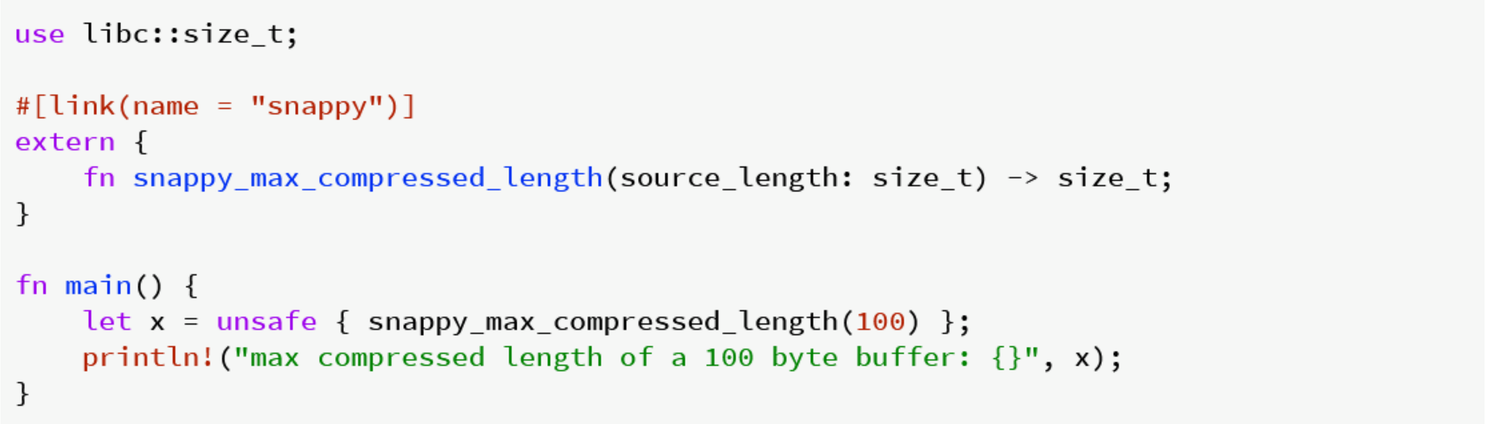
Why FFI

We cannot rewrite everything in Rust.

Sometimes we want to use a C library.

FFI

We can call C function. We need to define it and link with the C binary.

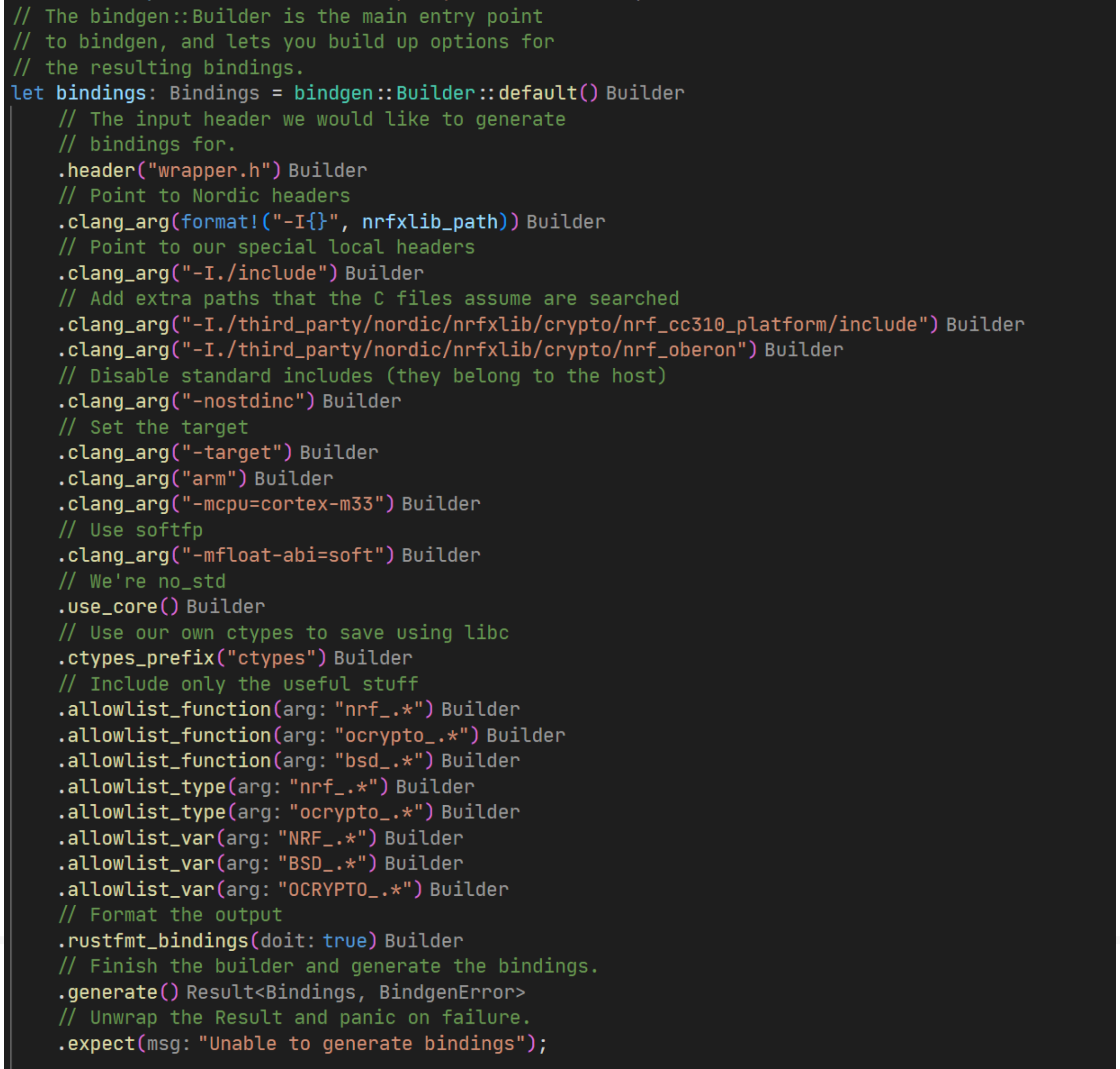


```rust
use libc::size_t;

#[link(name = "snappy")]
extern {
    fn snappy_max_compressed_length(source_length: size_t) -> size_t;
}

fn main() {
    let x = unsafe { snappy_max_compressed_length(100) };
    println!("max compressed length of a 100 byte buffer: {}", x);
}
```

https://doc.rust-lang.org/nomicon/ffi.html

Let’s automate

We can generate the functions using bindgen



```
// The bindgen::Builder is the main entry point
// to bindgen, and lets you build up options for
// the resulting bindings.
let bindings: Bindings = bindgen::Builder::default() Builder
    // The input header we would like to generate
    // bindings for.
    .header("wrapper.h") Builder
    // Point to Nordic headers
    .clang_arg(format!("-I{}", nrfxlib_path)) Builder
    // Point to our special local headers
    .clang_arg("-I./include") Builder
    // Add extra paths that the C files assume are searched
    .clang_arg("-I./third_party/nordic/nrfxlib/crypto/nrf_cc310_platform/include") Builder
    .clang_arg("-I./third_party/nordic/nrfxlib/crypto/nrf_oberon") Builder
    // Disable standard includes (they belong to the host)
    .clang_arg("-nostdinc") Builder
    // Set the target
    .clang_arg("-target") Builder
    .clang_arg("arm") Builder
    .clang_arg("-mcpu=cortex-m33") Builder
    // Use softfp
    .clang_arg("-mfloat-abi=soft") Builder
    // We're no_std
    .use_core() Builder
    // Use our own ctypes to save using libc
    .ctypes_prefix("ctypes") Builder
    // Include only the useful stuff
    .allowlist_function(arg: "nrf_.*") Builder
    .allowlist_function(arg: "ocrypto_.*") Builder
    .allowlist_function(arg: "bsd_.*") Builder
    .allowlist_type(arg: "nrf_.*") Builder
    .allowlist_type(arg: "ocrypto_.*") Builder
    .allowlist_var(arg: "NRF_.*") Builder
    .allowlist_var(arg: "BSD_.*") Builder
    .allowlist_var(arg: "OCRYPTO_.*") Builder
    // Format the output
    .rustfmt_bindings(doit: true) Builder
    // Finish the builder and generate the bindings.
    .generate() Result<Bindings, BindgenError>
    // Unwrap the Result and panic on failure.
    .expect(msg: "Unable to generate bindings");
```

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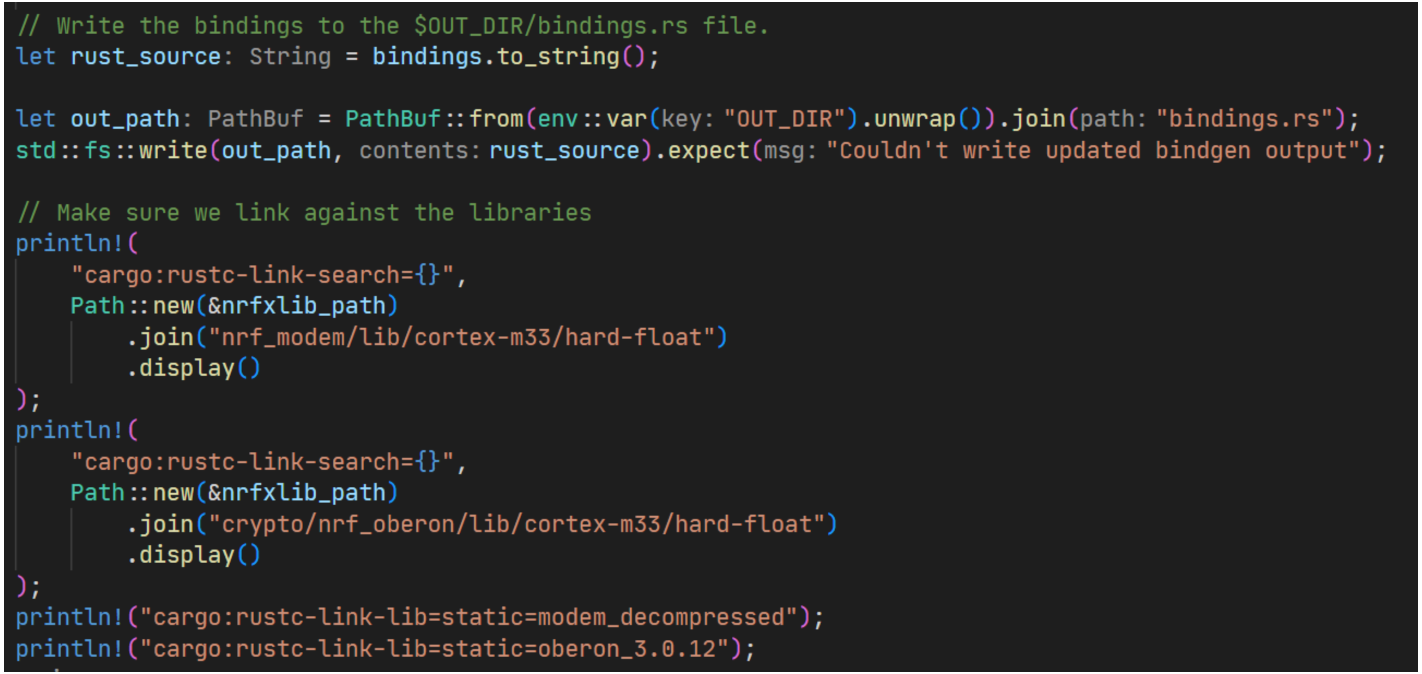
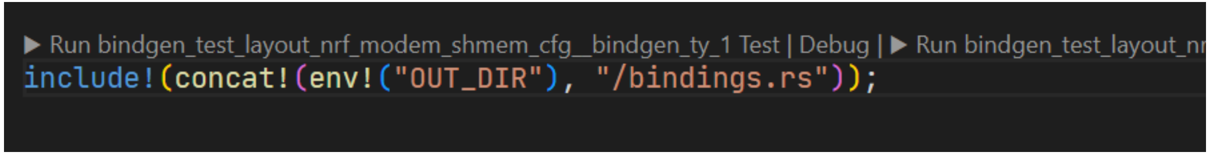
Let’s automate

Output the file and let the compiler link with the C binary

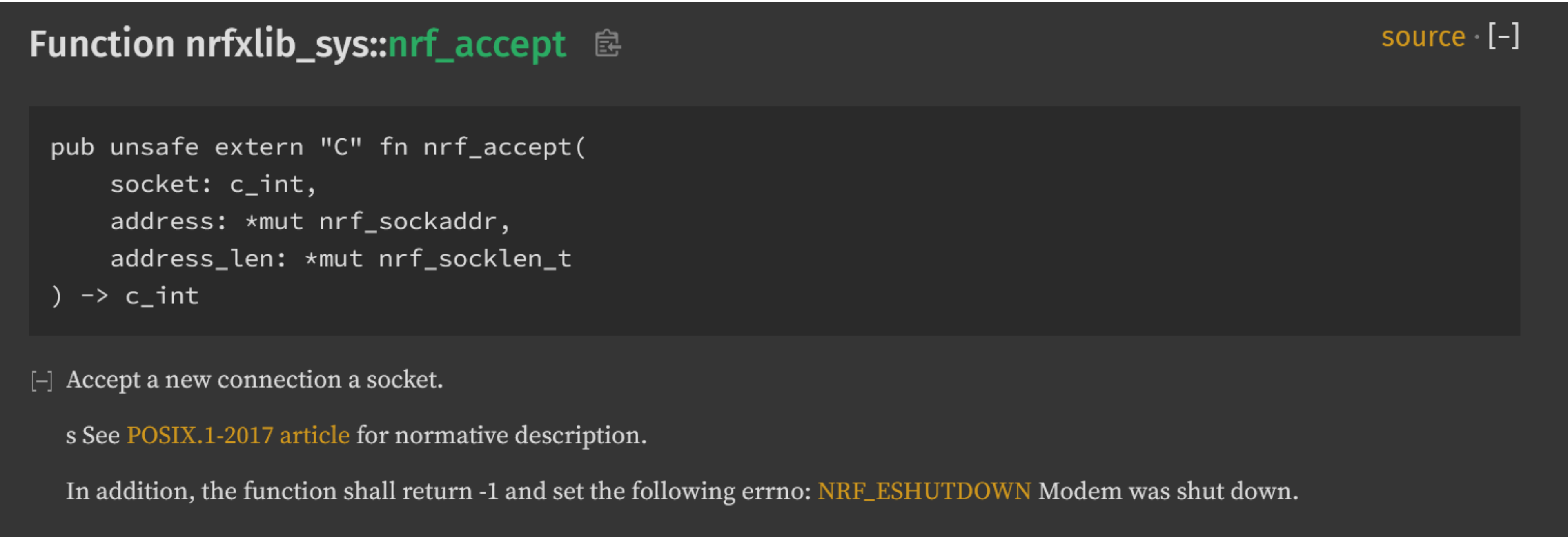


```
// Write the bindings to the $OUT_DIR/bindings.rs file.
let rust_source: String = bindings.to_string();

let out_path: PathBuf = PathBuf::from(env::var(key: "OUT_DIR").unwrap()).join(path: "bindings.rs");
std::fs::write(out_path, contents: rust_source).expect(msg: "Couldn't write updated bindgen output");

// Make sure we link against the libraries
println!(
    "cargo:rustc-link-search={}",
    Path::new(&nrfxlib_path)
        .join("nrf_modem/lib/cortex-m33/hard-float")
        .display()
);
println!(
    "cargo:rustc-link-search={}",
    Path::new(&nrfxlib_path)
        .join("crypto/nrf_oberon/lib/cortex-m33/hard-float")
        .display()
);
println!("cargo:rustc-link-lib=static=modem_decompressed");
println!("cargo:rustc-link-lib=static=oberon_3.0.12");
```



```
▶ Run bindgen_test_layout_nrf_modem_shmem_cfg__bindgen_ty_1 Test | Debug | ▶ Run bindgen_test_layout_nr
include!(concat!(env!("OUT_DIR"), "/bindings.rs"));
```

Now we can use it



Function nrfxlib_sys::nrf_accept

```
pub unsafe extern "C" fn nrf_accept(
    socket: c_int,
    address: *mut nrf_sockaddr,
    address_len: *mut nrf_socklen_t
) -> c_int
```

[−] Accept a new connection a socket.

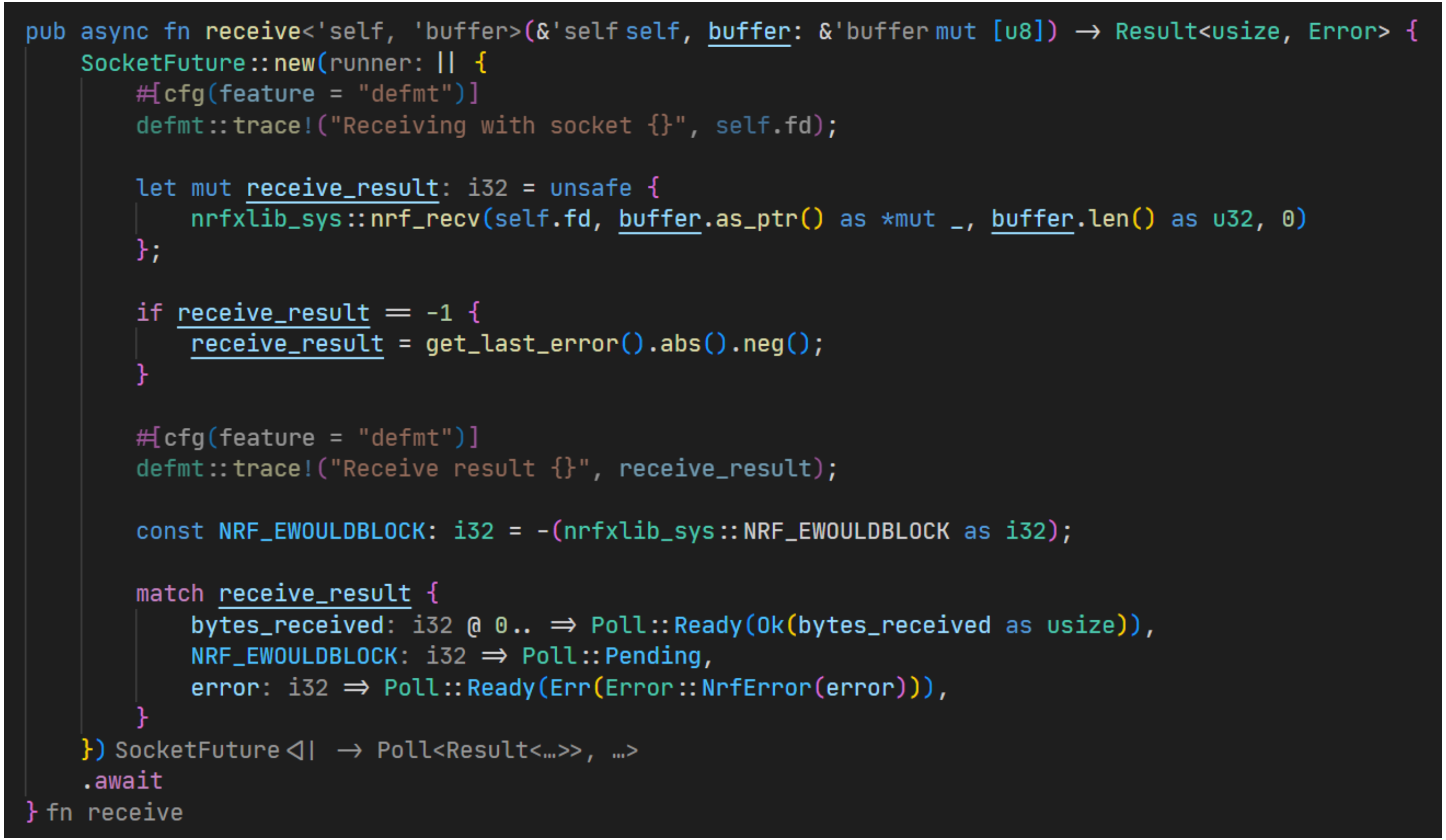
s See POSIX.1-2017 article for normative description.

In addition, the function shall return -1 and set the following errno: NRF_ESHUTDOWN Modem was shut down.

tweede golf https://github.com/nrf-rs/nrfxlib-sys

High level wrapper

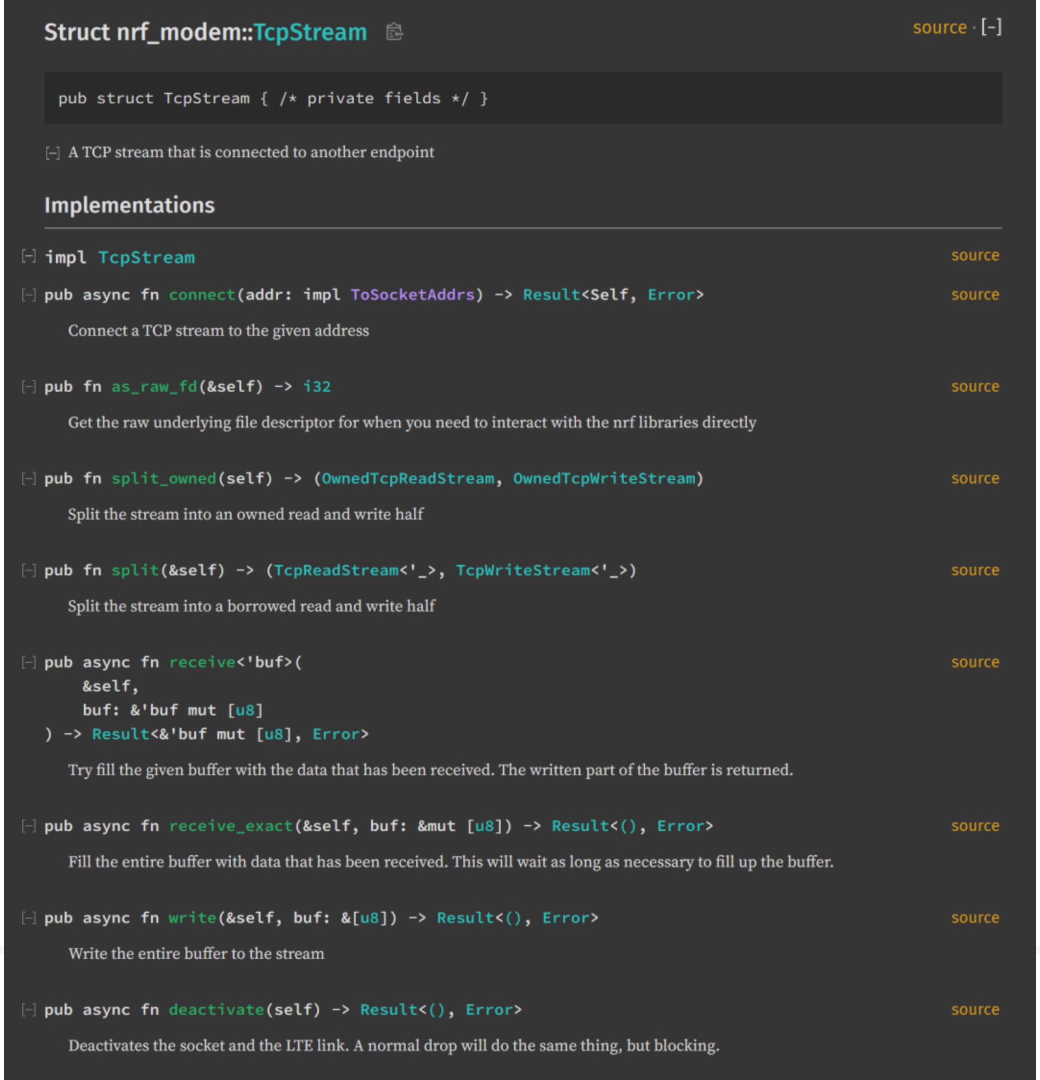
Use the low level C function to create a proper Rust wrapper



```rust
pub async fn receive<'self, 'buffer>(&'self self, buffer: &'buffer mut [u8]) → Result<usize, Error> {
    SocketFuture::new(runner: || {
        #[cfg(feature = "defmt")]
        defmt::trace!("Receiving with socket {}", self.fd);

        let mut receive_result: i32 = unsafe {
            nrfxlib_sys::nrf_recv(self.fd, buffer.as_ptr() as *mut _, buffer.len() as u32, 0)
        };

        if receive_result == -1 {
            receive_result = get_last_error().abs().neg();
        }

        #[cfg(feature = "defmt")]
        defmt::trace!("Receive result {}", receive_result);

        const NRF_EWOULDBLOCK: i32 = -(nrfxlib_sys::NRF_EWOULDBLOCK as i32);

        match receive_result {
            bytes_received: i32 @ 0.. ⇒ Poll::Ready(Ok(bytes_received as usize)),
            NRF_EWOULDBLOCK: i32 ⇒ Poll::Pending,
            error: i32 ⇒ Poll::Ready(Err(Error::NrfError(error))),
        }
    }) SocketFuture<|| → Poll<Result<…>>, …>
    .await
} fn receive
```

Very nice interface

Easy to use,
hard to misuse



Struct nrf_modem::TcpStream

source · [-]

```
pub struct TcpStream { /* private fields */ }
```

[-] A TCP stream that is connected to another endpoint

Implementations

```
[-] impl TcpStream
```

source

```
[-] pub async fn connect(addr: impl ToSocketAddrs) -> Result<Self, Error>
```

source

Connect a TCP stream to the given address

```
[-] pub fn as_raw_fd(&self) -> i32
```

source

Get the raw underlying file descriptor for when you need to interact with the nrf libraries directly

```
[-] pub fn split_owned(self) -> (OwnedTcpReadStream, OwnedTcpWriteStream)
```

source

Split the stream into an owned read and write half

```
[-] pub fn split(&self) -> (TcpReadStream<'_>, TcpWriteStream<'_>)
```

source

Split the stream into a borrowed read and write half

```
[-] pub async fn receive<'buf>(
        &self,
        buf: &'buf mut [u8]
    ) -> Result<&'buf mut [u8], Error>
```

source

Try fill the given buffer with the data that has been received. The written part of the buffer is returned.

```
[-] pub async fn receive_exact(&self, buf: &mut [u8]) -> Result<(), Error>
```

source

Fill the entire buffer with data that has been received. This will wait as long as necessary to fill up the buffer.

```
[-] pub async fn write(&self, buf: &[u8]) -> Result<(), Error>
```

source

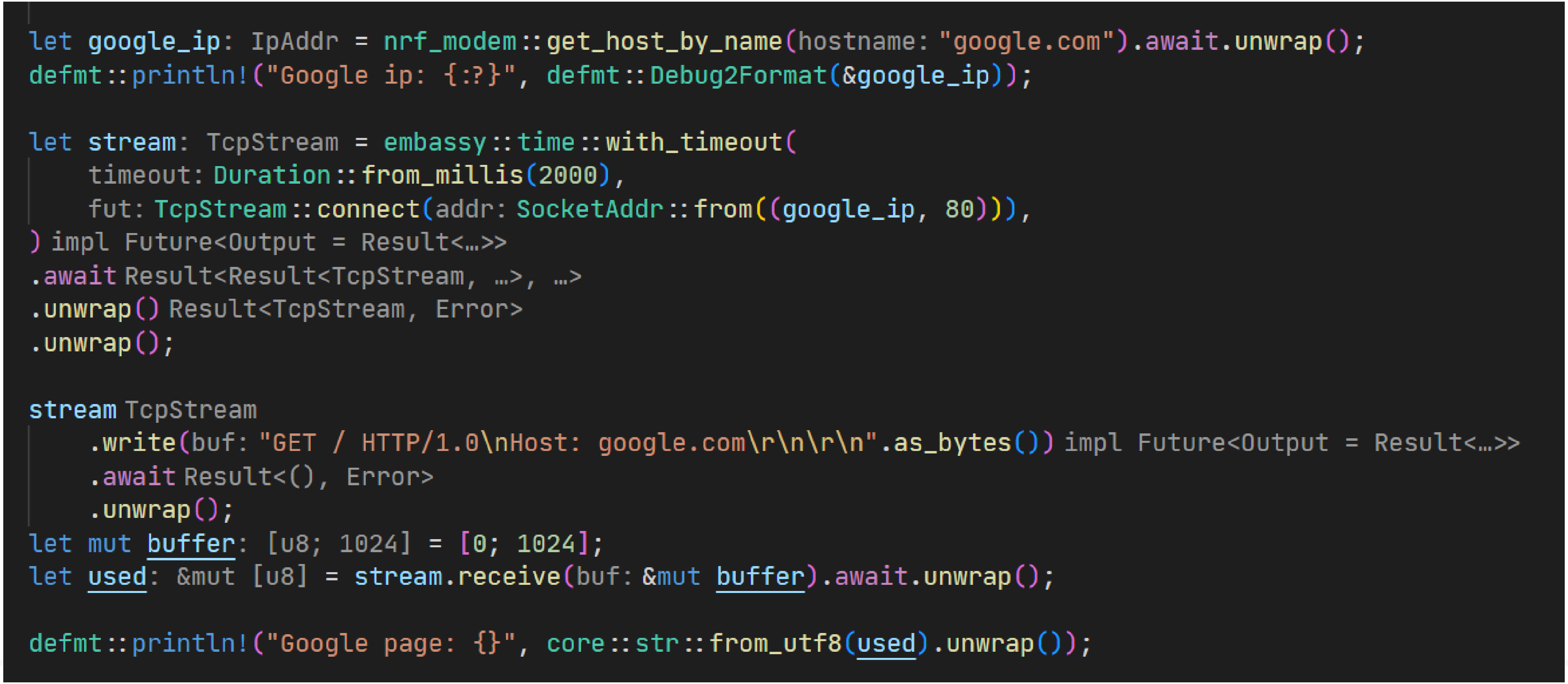
Write the entire buffer to the stream

```
[-] pub async fn deactivate(self) -> Result<(), Error>
```

source

Deactivates the socket and the LTE link. A normal drop will do the same thing, but blocking.

Now we can use it



```
let google_ip: IpAddr = nrf_modem::get_host_by_name(hostname: "google.com").await.unwrap();
defmt::println!("Google ip: {:?}", defmt::Debug2Format(&google_ip));

let stream: TcpStream = embassy::time::with_timeout(
    timeout: Duration::from_millis(2000),
    fut: TcpStream::connect(addr: SocketAddr::from((google_ip, 80))),
) impl Future<Output = Result<…>>
.await Result<Result<TcpStream, …>, …>
.unwrap() Result<TcpStream, Error>
.unwrap();

stream TcpStream
    .write(buf: "GET / HTTP/1.0\nHost: google.com\r\n\r\n".as_bytes()) impl Future<Output = Result<…>>
    .await Result<(), Error>
    .unwrap();
let mut buffer: [u8; 1024] = [0; 1024];
let used: &mut [u8] = stream.receive(buf: &mut buffer).await.unwrap();

defmt::println!("Google page: {}", core::str::from_utf8(used).unwrap());
```

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