Reversing Rust Binaries 

One Step Beyond `strings`

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Introduction

- Are you a seasoned reverse engineer, but you tremble when a Rust binary lands on your desk?
- When you encounter a Rust binary, do you just run `strings` on it and hope for the best?

One step beyond `strings`

Let's use `strings` as an approachable starting point for exploring reversing Rust binaries.

Today, we will do the following:

- Build a working Rust downloader.
- Learn about string metadata inside our downloader.
- Find the entry point of our downloader, using strings.
- Know where to find more information about the Rust runtime, standard library, and third-party libraries.

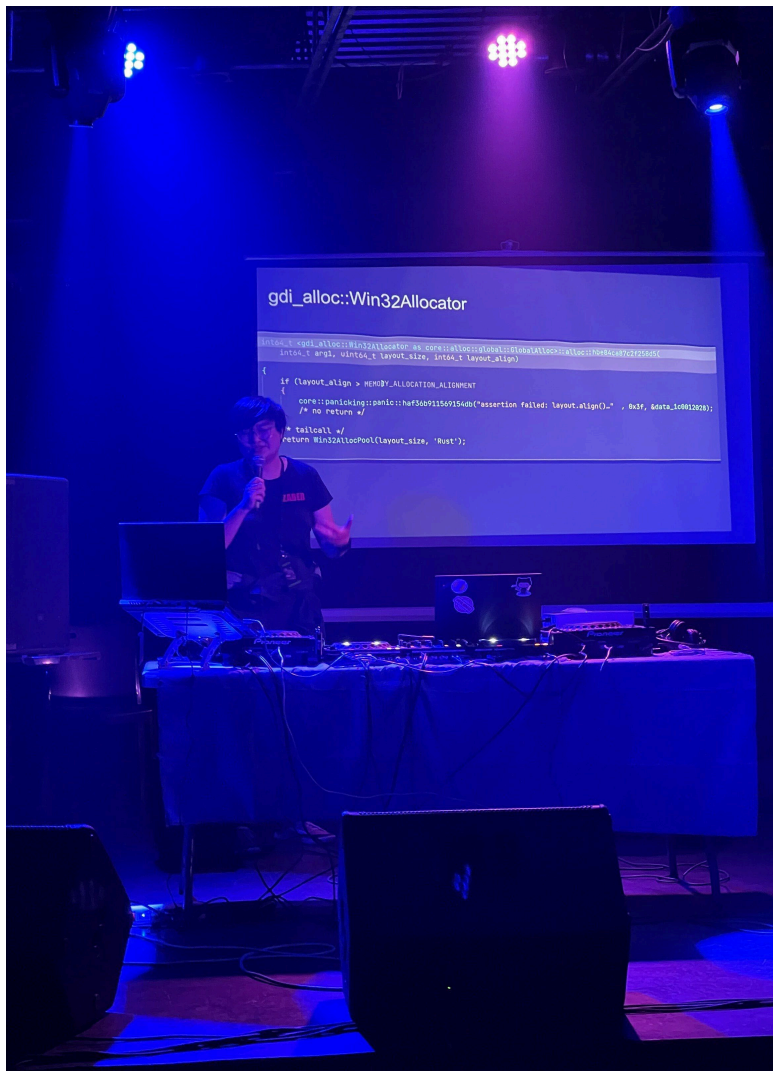
Setup and tools 🛠️

📎 Full setup instructions + prebuilt VM:

➡️ github.com/cxiao/rust-reversing-workshop-northsec-2024 ⬅️

- Rust toolchain
  - → Go to https://rustup.rs/ and follow the instructions for your OS!
  - → Make sure you can run `rustup` and `cargo` from your terminal, after installation
- Disassembler / decompiler
- Internet connection

My background

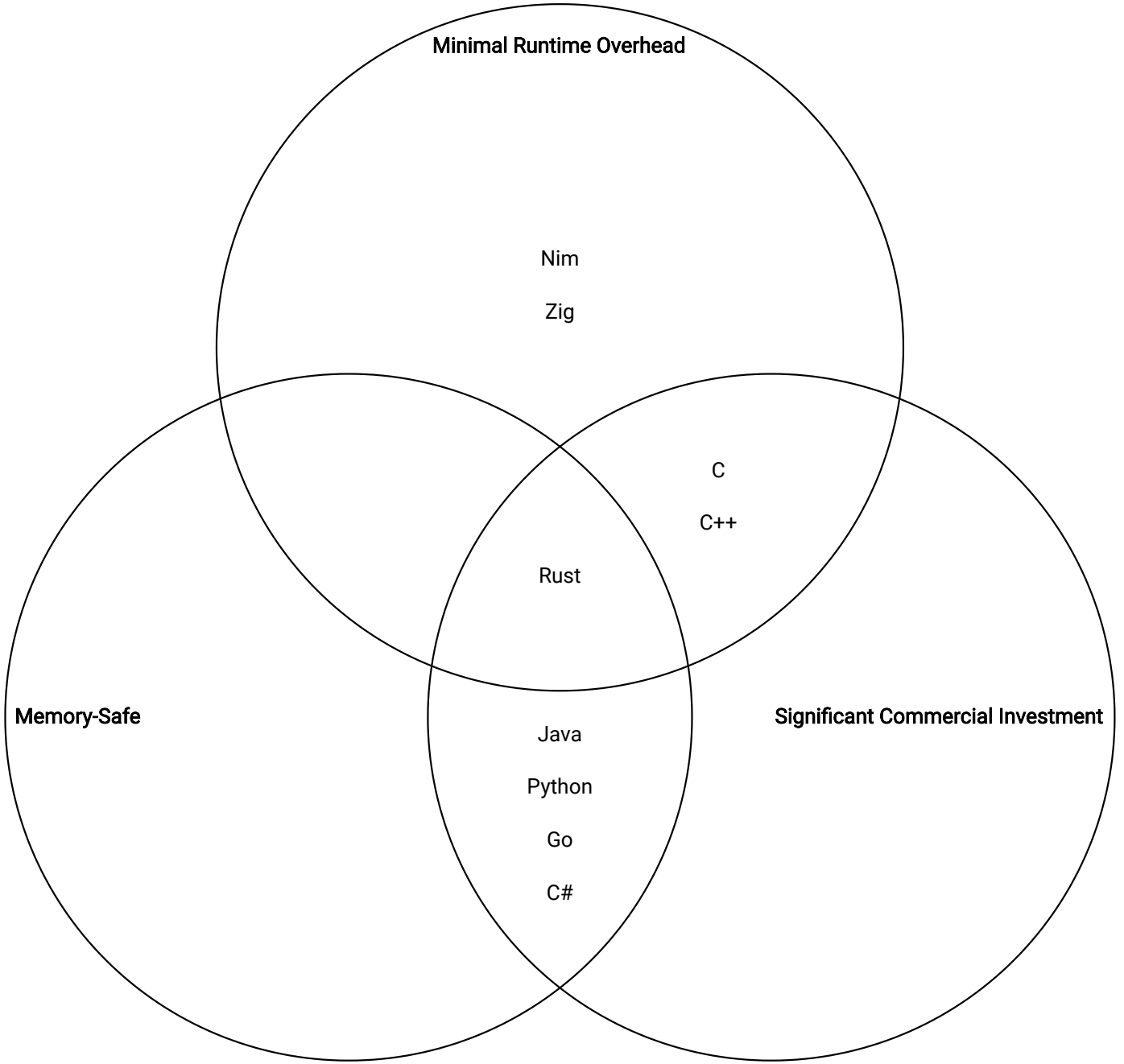


REcon 2023 lightning talk about Rust in the Windows kernel (thanks Sergei for the pic)

- I currently do malware analysis, reverse engineering, and cyber threat intelligence
- I used to be a C/C++ developer, and I'm interested in approaching things from the developer's perspective
- We were seeing more Rust malware in our analysis queue, and we needed practical skills to deal with them

Basic Information about Rust 

- Meant to fill the same “high performance, low overhead, systems programming language” niche as C or C++.
- Automatic memory management, but without garbage collection.
  - → Contrast with C or C++, where the programmer must manually manage memory.
  - → Contrast with C#, Java, Golang, etc., which automatically manage memory by using a garbage collector.
- Mature open-source library ecosystem.
- Significant investments in support and funding from major software vendors.


Minimal Runtime Overhead
Nim
Zig
C
C++
Rust
Memory-Safe
Java
Python
Go
C#
Significant Commercial Investment

Rust Malware-O-Meter 📈

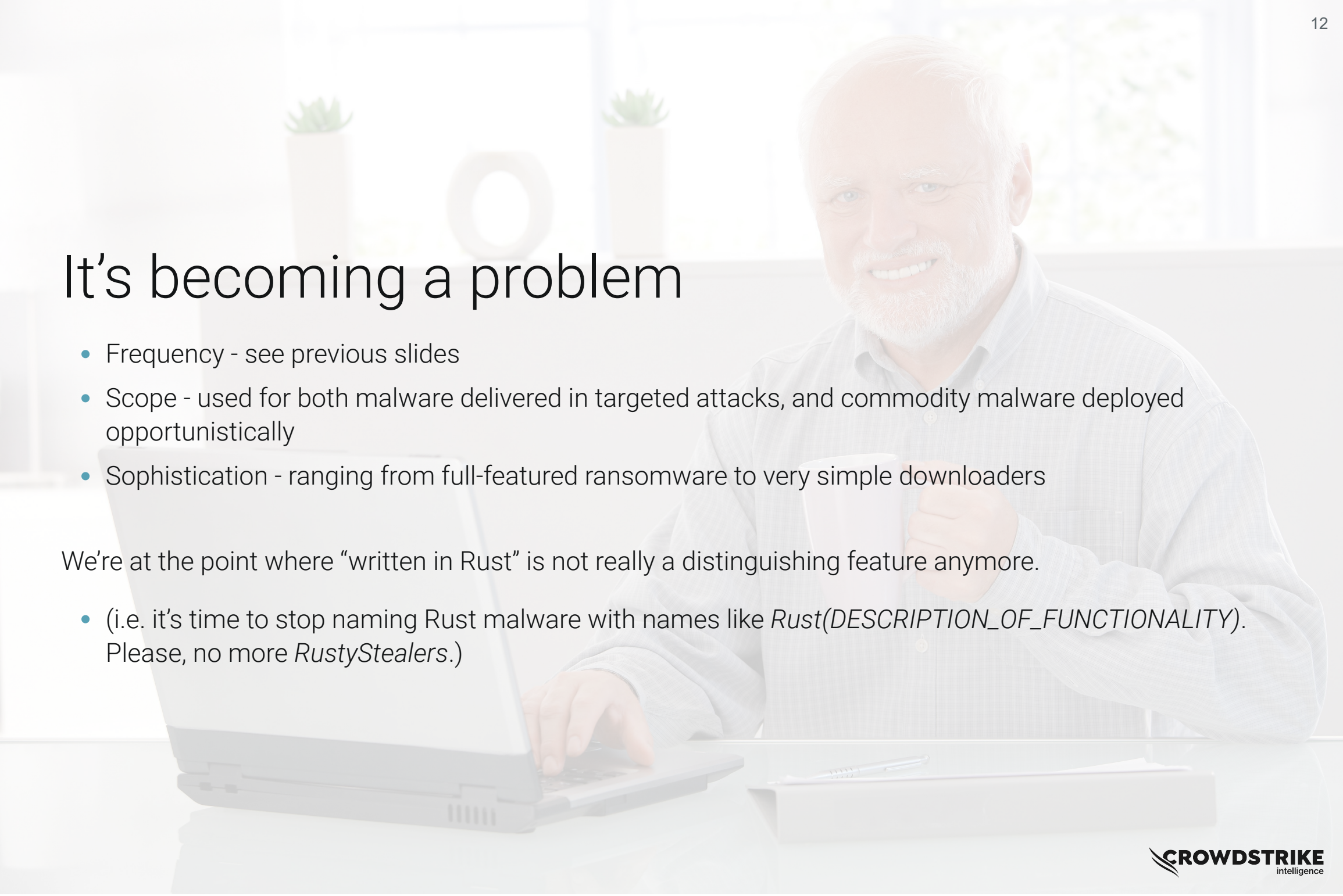
A selection of public reporting about new Rust malware in 2023 and 2024:

- 2023-04-21 - Jamf - BlueNoroff APT group targets macOS with ‘RustBucket’ Malware
- 2023-04-04 - Trustwave - Rilide: A New Malicious Browser Extension for Stealing Cryptocurrencies
- 2023-05-19 - Trend Micro - Rust-Based Info Stealers Abuse GitHub Codespaces
- 2023-07-19 - Palo Alto Networks - P2PInfect: The Rusty Peer-to-Peer Self-Replicating Worm
- 2023-11-09 - Bitdefender - Hive Ransomware’s Offspring: Hunters International Takes the Stage
- 2023-12-21 - Seqrite - Operation RusticWeb targets Indian Govt: From Rust-based malware to Web-service exfiltration
- 2024-01-18 - Google - Russian threat group COLDRIVER expands its targeting of Western officials to include the use of malware
- 2024-01-29 - Synacktiv - KrustyLoader - Rust Malware Linked to Ivanti ConnectSecure Compromises
- 2024-02-08 - Bitdefender - New macOS Backdoor Written in Rust Shows Possible Link with Windows Ransomware Group

Rust Malware-O-Meter 📈

CrowdStrike Falcon Intelligence reporting:

- 13 intelligence reports on Rust malware in 2022.
  - → Mostly just used by a few ransomware developers (ALPHA SPIDER, HIVE SPIDER)
- 29 intelligence reports on Rust malware in 2023.
  - → 👀
- 13 intelligence reports on Rust malware *so far* in 2024.
  - → Downloaders, loaders, backdoors, ransomware, infostealers, etc.



It’s becoming a problem

- Frequency - see previous slides
- Scope - used for both malware delivered in targeted attacks, and commodity malware deployed opportunistically
- Sophistication - ranging from full-featured ransomware to very simple downloaders

We’re at the point where “written in Rust” is not really a distinguishing feature anymore.

- (i.e. it’s time to stop naming Rust malware with names like *Rust(DESCRIPTION_OF_FUNCTIONALITY)*. Please, no more *RustyStealers*.)

How much Rust do I need to know?

We can't learn all of Rust today, but we will need to understand *some* Rust source code.

- Rust is a very different language from C.

  → We need to take the source emitted by our decompiler and go one abstraction level up.

- The Rust standard library is written in Rust, and so is the Rust compiler.

  → Sometimes, we will need to look at those when trying to figure out how something works.

Setup and tools 🛠️

- Rust toolchain
  - → Go to https://rustup.rs/ and follow the instructions for your OS!
  - → Make sure you can run `rustup` and `cargo` from your terminal, after installation
- Disassembler / decompiler
- Internet connection

📎 Full setup instructions + prebuilt VM: github.com/cxiao/rust-reversing-workshop-northsec-2024

Terminology and the Rust toolchain 

- `rustup`: The Rust toolchain installer and toolchain manager.
  - → Update installed toolchains
    - ⇾ e.g. “I want to update from Rust 1.77.0 to Rust 1.77.1
  - → Manage cross compilation support
    - ⇾ e.g. “I want to be able to cross compile to Windows”
  - → Install multiple Rust toolchain versions side by side
    - ⇾ e.g. “I want to install the latest nightly build of Rust, so I can try out this cool new language feature”

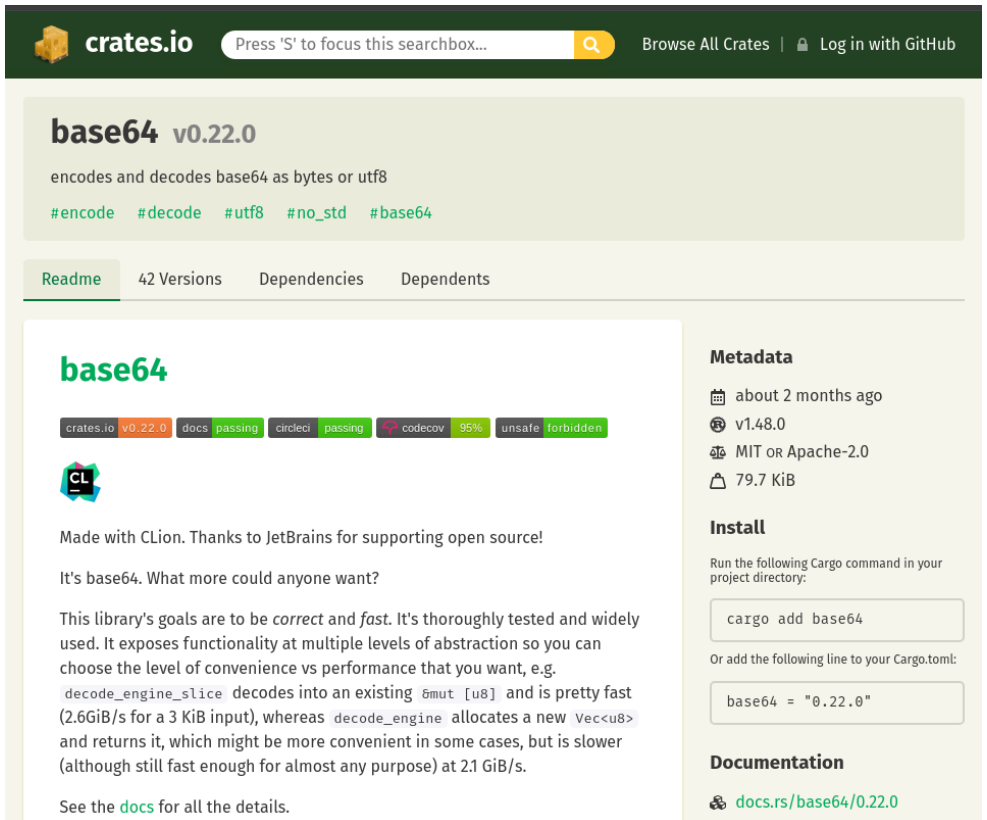
Terminology and tools 

`rustup update` makes it trivial for developers to grab the newest stable version of Rust, which comes out *every 6 weeks*! 

```
$ rustup update
info: syncing channel updates for 'stable'
info: downloading component 'rustc'
info: downloading component 'rust-std'
info: downloading component 'rust-docs'
info: downloading component 'cargo'
info: installing component 'rustc'
info: installing component 'rust-std'
info: installing component 'rust-docs'
info: installing component 'cargo'
info: checking for self-update
info: downloading self-update

  stable-x86_64-unknown-linux-gnu updated - rustc 1.77.2 (25ef9e3d8 2024-04-09)
```

Terminology and tools 

- `cargo`: The Rust build tool, package manager, and general “all in one developer tool”
  - → Build your project
    - ⇢ e.g. “I want to build my binary, in release mode.”
  - → Download new package dependencies for your project
    - ⇢ e.g. “I want to use the `base64` library, version 0.22.0, in my project”
- `rustc`: The actual Rust compiler.
  - → Cargo runs `rustc`, plus a linker, to build your binary.
- Crate: Rust’s terminology for a package, or library
  - → Central package repository for the Rust project: https://crates.io/



Building our own Rust binary

Building our very own downloader 

Let’s build a very simple Rust binary and reverse it!

We will build a downloader, which will download and run a shell script.

(This is actually not that far off from real malware we’re seeing.)

Setting up our first Rust program

```
cargo new simple-downloader
cd simple-downloader
```

```
$ cargo new simple-downloader
     Created binary (application) `simple-downloader` package

$ cd simple-downloader/

$ tree
.
├── Cargo.toml
└── src
    └── main.rs
```

The default `main.rs`

```
1  fn main() {
2      println!("Hello, world!");
3  }
```

The default `cargo.toml` manifest file

```toml
[package]
name = "simple-downloader"
version = "0.1.0"
edition = "2021"

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

[dependencies]
```

Notice how there's a lot missing here; a lot of the build configuration is based on default values, from Cargo's built-in build profiles!

Building our first Rust program

```
cd simple-downloader/
cargo build
```

```
$ cargo build
   Compiling simple-downloader v0.1.0 (/home/cxiao/presentations/rust-one-step-beyond-strings/simple-downloader)
    Finished dev [unoptimized + debuginfo] target(s) in 0.13s
```

With the defaults, note how this is an unoptimized build with full debugging information!

Cargo's default `dev` profile

The Cargo Book > Cargo Reference > Profiles > Default Profiles

» Default profiles

dev

The `dev` profile is used for normal development and debugging. It is the default for build commands like `cargo build`, and is used for `cargo install --debug`.

The default settings for the `dev` profile are:

```
[profile.dev]
opt-level = 0
debug = true
split-debuginfo = '...'  # Platform-specific.
strip = "none"
debug-assertions = true
overflow-checks = true
lto = false
panic = 'unwind'
incremental = true
codegen-units = 256
rpath = false
```

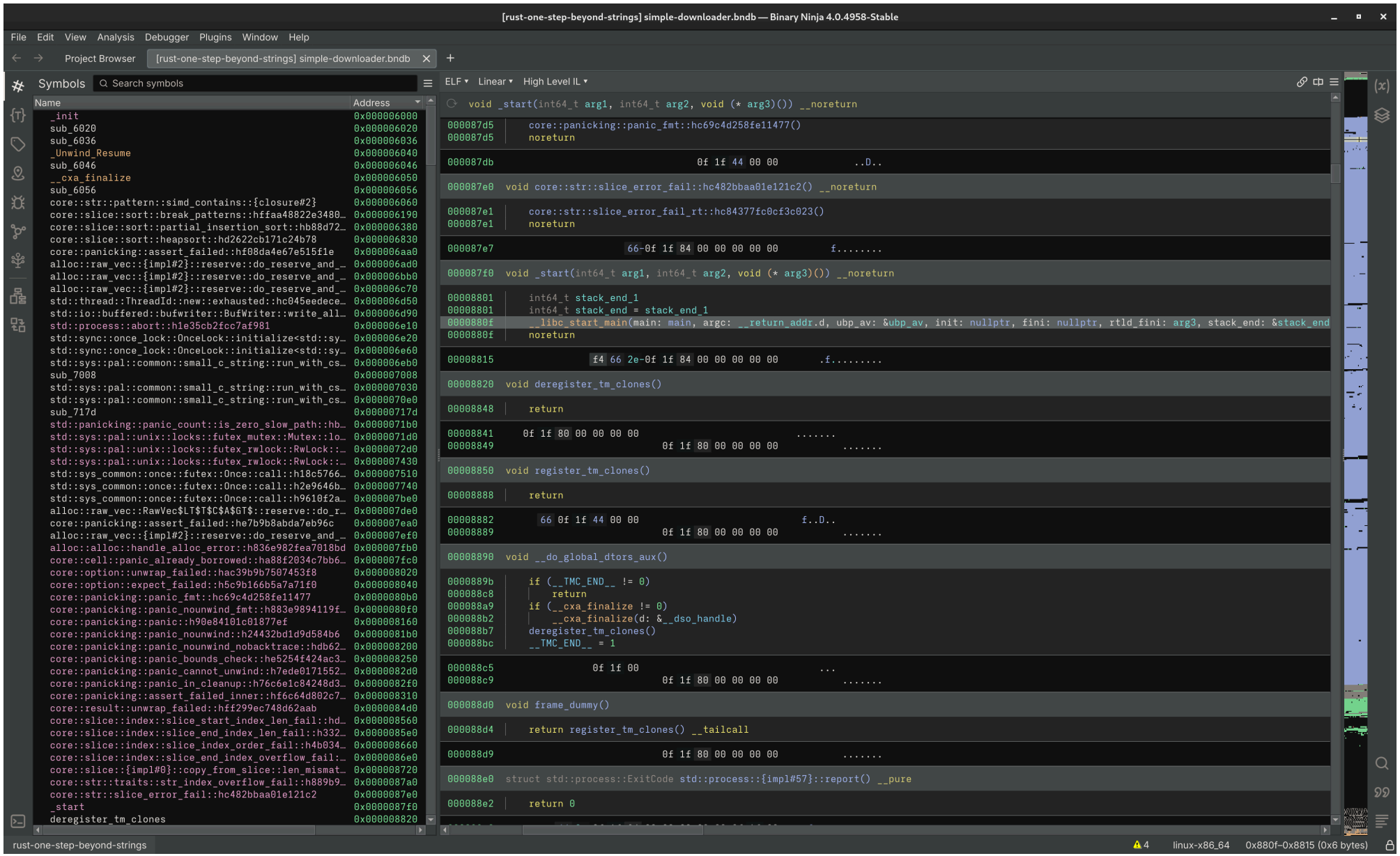
Running our first Rust program

```
cargo run
```

```
$ cargo run
    Finished dev [unoptimized + debuginfo] target(s) in 0.03s
     Running `target/debug/simple-downloader`
Hello, world!

$ file target/debug/simple-downloader
target/debug/simple-downloader: ELF 64-bit LSB pie executable, x86-64, version 1 (SYSV),
dynamically linked, interpreter /lib64/ld-linux-x86-64.so.2,
BuildID[sha1]=40da521231670b2f56459a8c981068ac28e57602, for GNU/Linux 3.2.0, with debug_info, not
stripped
```

Notice how this is not stripped!

Examining `target/debug/simple-downloader` in our disassembler tool



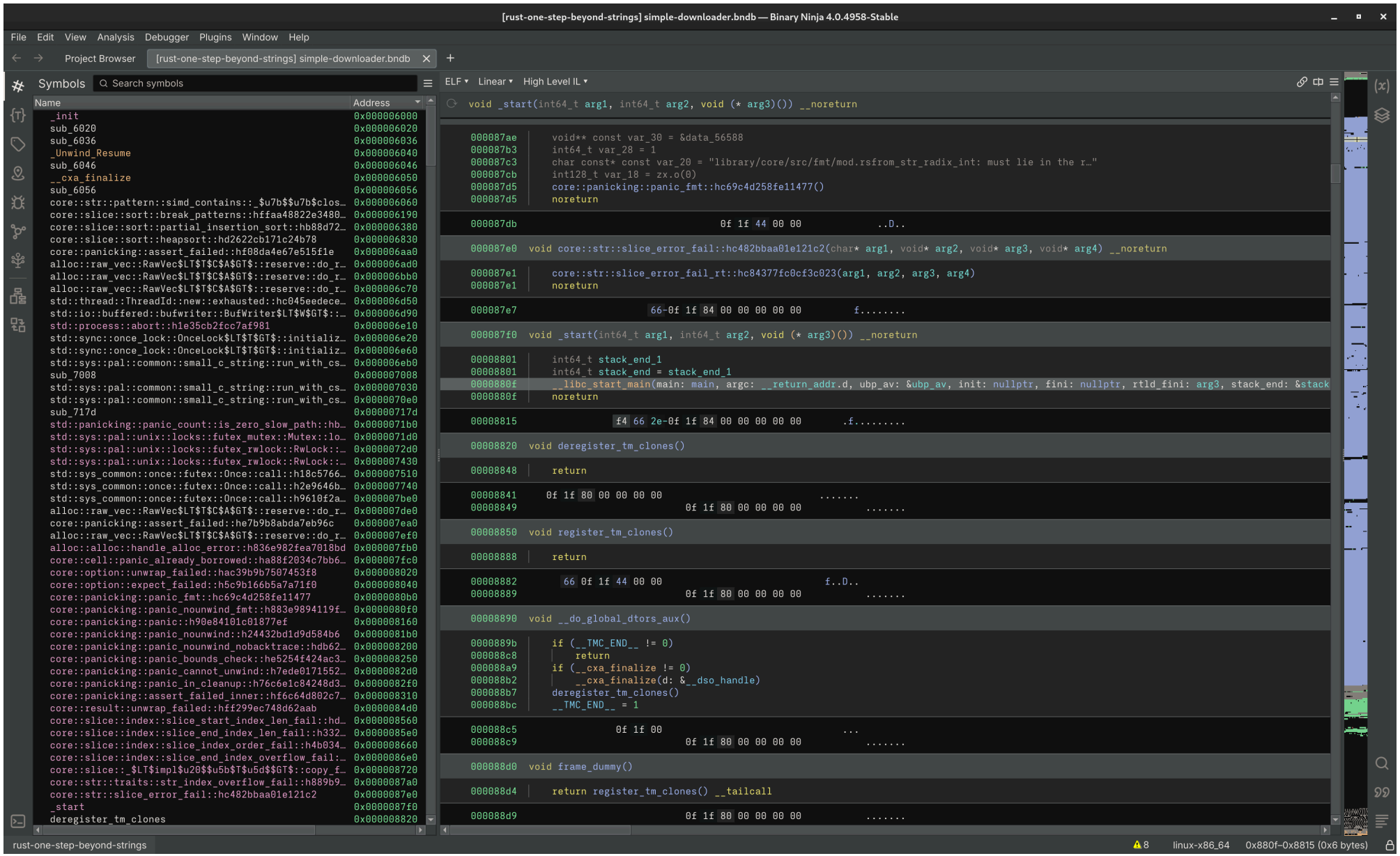
Building our first Rust program, in release mode

```
cargo build --release
```

```
$ cargo build --release
   Compiling simple-downloader v0.1.0 (/home/cxiao/presentations/rust-one-step-beyond-
strings/simple-downloader)
    Finished release [optimized] target(s) in 0.20s

$ cargo run --release
    Finished release [optimized] target(s) in 0.00s
     Running `target/release/simple-downloader`
Hello, world!

$ file target/release/simple-downloader
target/release/simple-downloader: ELF 64-bit LSB pie executable, x86-64, version 1 (SYSV),
dynamically linked, interpreter /lib64/ld-linux-x86-64.so.2,
BuildID[sha1]=0e80062c94bf80a1e9e49fbceced23848f783031, for GNU/Linux 3.2.0, not stripped
```

Notice how this file still isn't stripped!

Examining `target/release/simple-downloader` in our disassembler tool



Cargo's default `release` profile

The Cargo Book > Cargo Reference > Profiles > Default Profiles

Notice the use of `strip = "none"`

release

The `release` profile is intended for optimized artifacts used for releases and in production. This profile is used when the `--release` flag is used, and is the default for `cargo install`.

The default settings for the `release` profile are:

```
[profile.release]
opt-level = 3
debug = false
split-debuginfo = '...'  # Platform-specific.
strip = "none"
debug-assertions = false
overflow-checks = false
lto = false
panic = 'unwind'
incremental = false
codegen-units = 16
rpath = false
```

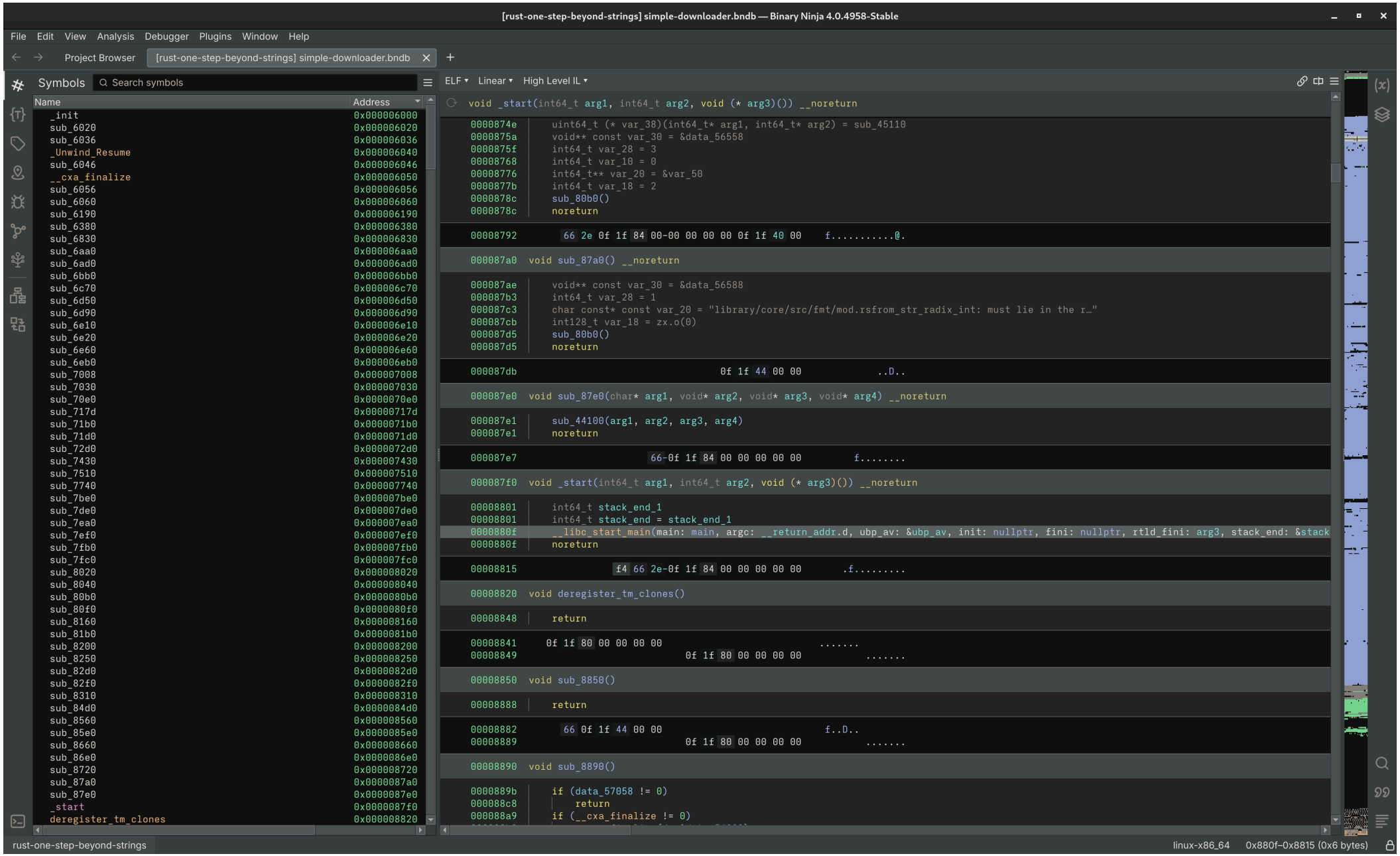
Actually removing metadata

🔗 The Cargo Book > Cargo Reference > Profiles > Profile Settings > strip

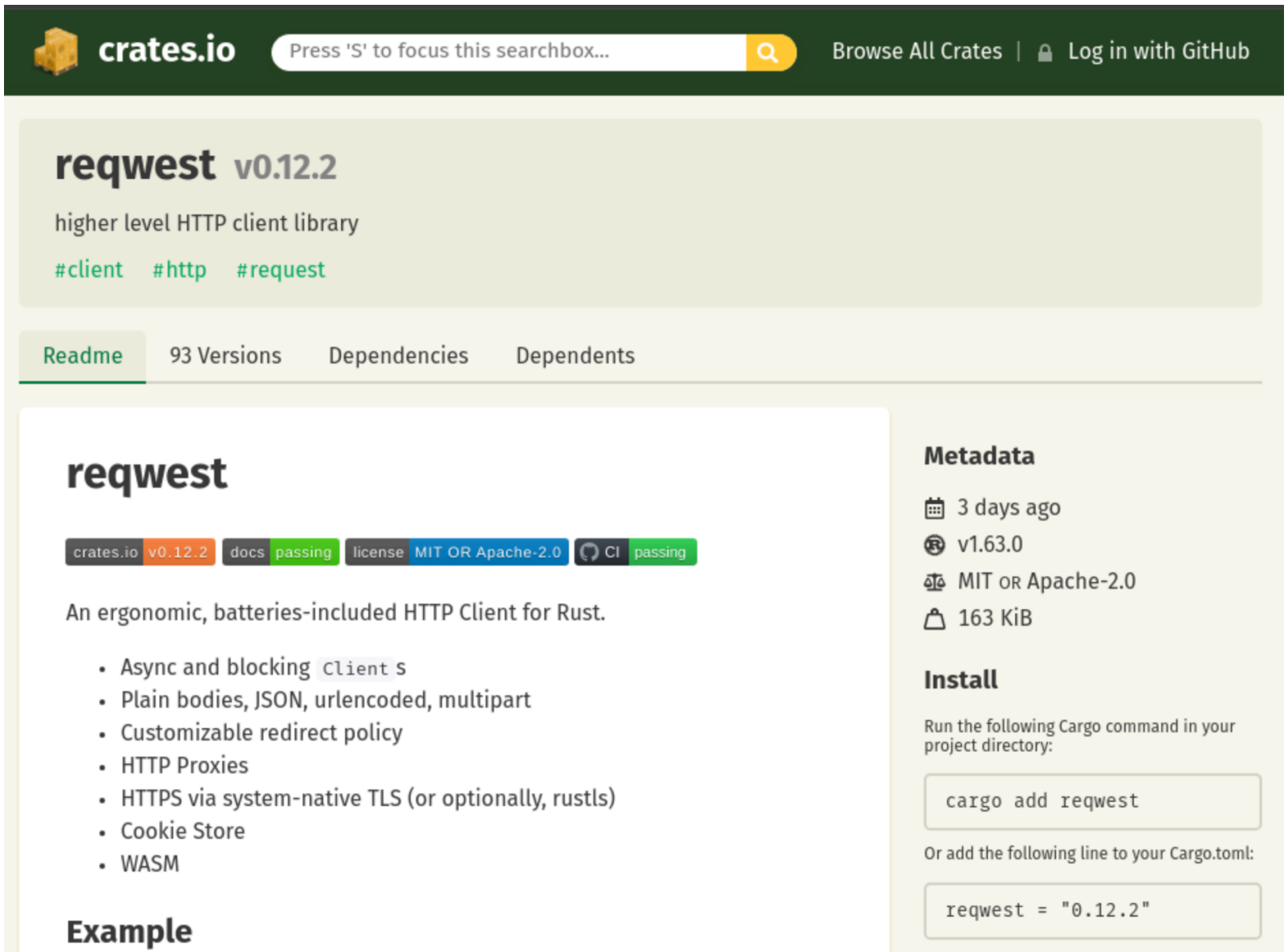
```toml
[package]
name = "simple-downloader"
version = "0.1.0"
edition = "2021"

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

[dependencies]

[profile.release]
strip = true # or strip = "symbols"
```

Building our Rust program, in release mode again

```
$ cargo build --release
   Compiling simple-downloader v0.1.0 (/home/cxiao/presentations/rust-one-step-beyond-
strings/simple-downloader)
    Finished release [optimized] target(s) in 0.22s

$ file target/release/simple-downloader
target/release/simple-downloader: ELF 64-bit LSB pie executable, x86-64, version 1 (SYSV),
dynamically linked, interpreter /lib64/ld-linux-x86-64.so.2,
BuildID[sha1]=8fa826275b714ff86a12498d3a9461e1eef61a3a, for GNU/Linux 3.2.0, stripped
```


[rust-one-step-beyond-strings] simple-downloader.bndb — Binary Ninja 4.0.4958-Stable
File Edit View Analysis Debugger Plugins Window Help
Project Browser
[rust-one-step-beyond-strings] simple-downloader.bndb
Symbols
Search symbols
Name
Address
_init 0x000006000
sub_6020 0x000006020
sub_6036 0x000006036
_Unwind_Resume 0x000006040
sub_6046 0x000006046
__cxa_finalize 0x000006050
sub_6056 0x000006056
sub_6060 0x000006060
sub_6190 0x000006190
sub_6380 0x000006380
sub_6830 0x000006830
sub_6aa0 0x000006aa0
sub_6ad0 0x000006ad0
sub_6bb0 0x000006bb0
sub_6c70 0x000006c70
sub_6d50 0x000006d50
sub_6d90 0x000006d90
sub_6e10 0x000006e10
sub_6e20 0x000006e20
sub_6e60 0x000006e60
sub_6eb0 0x000006eb0
sub_7008 0x000007008
sub_7030 0x000007030
sub_70e0 0x0000070e0
sub_717d 0x00000717d
sub_71b0 0x0000071b0
sub_71d0 0x0000071d0
sub_72d0 0x0000072d0
sub_7430 0x000007430
sub_7510 0x000007510
sub_7740 0x000007740
sub_7be0 0x000007be0
sub_7de0 0x000007de0
sub_7ea0 0x000007ea0
sub_7ef0 0x000007ef0
sub_7fb0 0x000007fb0
sub_7fc0 0x000007fc0
sub_8020 0x000008020
sub_8040 0x000008040
sub_80b0 0x0000080b0
sub_80f0 0x0000080f0
sub_8160 0x000008160
sub_81b0 0x0000081b0
sub_8200 0x000008200
sub_8250 0x000008250
sub_82d0 0x0000082d0
sub_82f0 0x0000082f0
sub_8310 0x000008310
sub_84d0 0x0000084d0
sub_8560 0x000008560
sub_85e0 0x0000085e0
sub_8660 0x000008660
sub_86e0 0x0000086e0
sub_8720 0x000008720
sub_87a0 0x0000087a0
sub_87e0 0x0000087e0
_start 0x0000087f0
deregister_tm_clones 0x000008820
ELF Linear High Level IL
void _start(int64_t arg1, int64_t arg2, void (* arg3)()) __noreturn
0000874e uint64_t (* var_38)(int64_t* arg1, int64_t* arg2) = sub_45110
0000875a void** const var_30 = &data_56558
0000875f int64_t var_28 = 3
00008768 int64_t var_10 = 0
00008776 int64_t** var_20 = &var_50
0000877b int64_t var_18 = 2
0000878c sub_80b0()
0000878c noreturn
00008792 66 2e 0f 1f 84 00-00 00 00 00 0f 1f 40 00 f..........@.
000087a0 void sub_87a0() __noreturn
000087ae void** const var_30 = &data_56588
000087b3 int64_t var_28 = 1
000087c3 char const* const var_20 = "library/core/src/fmt/mod.rsfrom_str_radix_int: must lie in the r…"
000087cb int128_t var_18 = zx.o(0)
000087d5 sub_80b0()
000087d5 noreturn
000087db 0f 1f 44 00 00 ..D..
000087e0 void sub_87e0(char* arg1, void* arg2, void* arg3, void* arg4) __noreturn
000087e1 sub_44100(arg1, arg2, arg3, arg4)
000087e1 noreturn
000087e7 66-0f 1f 84 00 00 00 00 00 f.......
000087f0 void _start(int64_t arg1, int64_t arg2, void (* arg3)()) __noreturn
00008801 int64_t stack_end_1
00008801 int64_t stack_end = stack_end_1
0000880f __libc_start_main(main: main, argc: __return_addr.d, ubp_av: &ubp_av, init: nullptr, fini: nullptr, rtld_fini: arg3, stack_end: &stack
0000880f noreturn
00008815 f4 66 2e-0f 1f 84 00 00 00 00 00 .f.........
00008820 void deregister_tm_clones()
00008848 return
00008841 0f 1f 80 00 00 00 00 ....
00008849 0f 1f 80 00 00 00 00 ....
00008850 void sub_8850()
00008888 return
00008882 66 0f 1f 44 00 00 f..D..
00008889 0f 1f 80 00 00 00 00 ....
00008890 void sub_8890()
0000889b if (data_57058 != 0)
000088c8 return
000088a9 if (__cxa_finalize != 0)
rust-one-step-beyond-strings
linux-x86_64
0x880f–0x8815 (0x6 bytes)

Adding a library 



Adding the `reqwest` library

```
cargo add reqwest --features blocking
```

```
$ cargo add reqwest --features blocking
    Updating crates.io index
      Adding reqwest v0.12.4 to dependencies.
             Features:
             + __tls
             + blocking
             + charset
             + default-tls
             + h2
             + http2
             + macos-system-configuration
             25 deactivated features
    Updating crates.io index
```

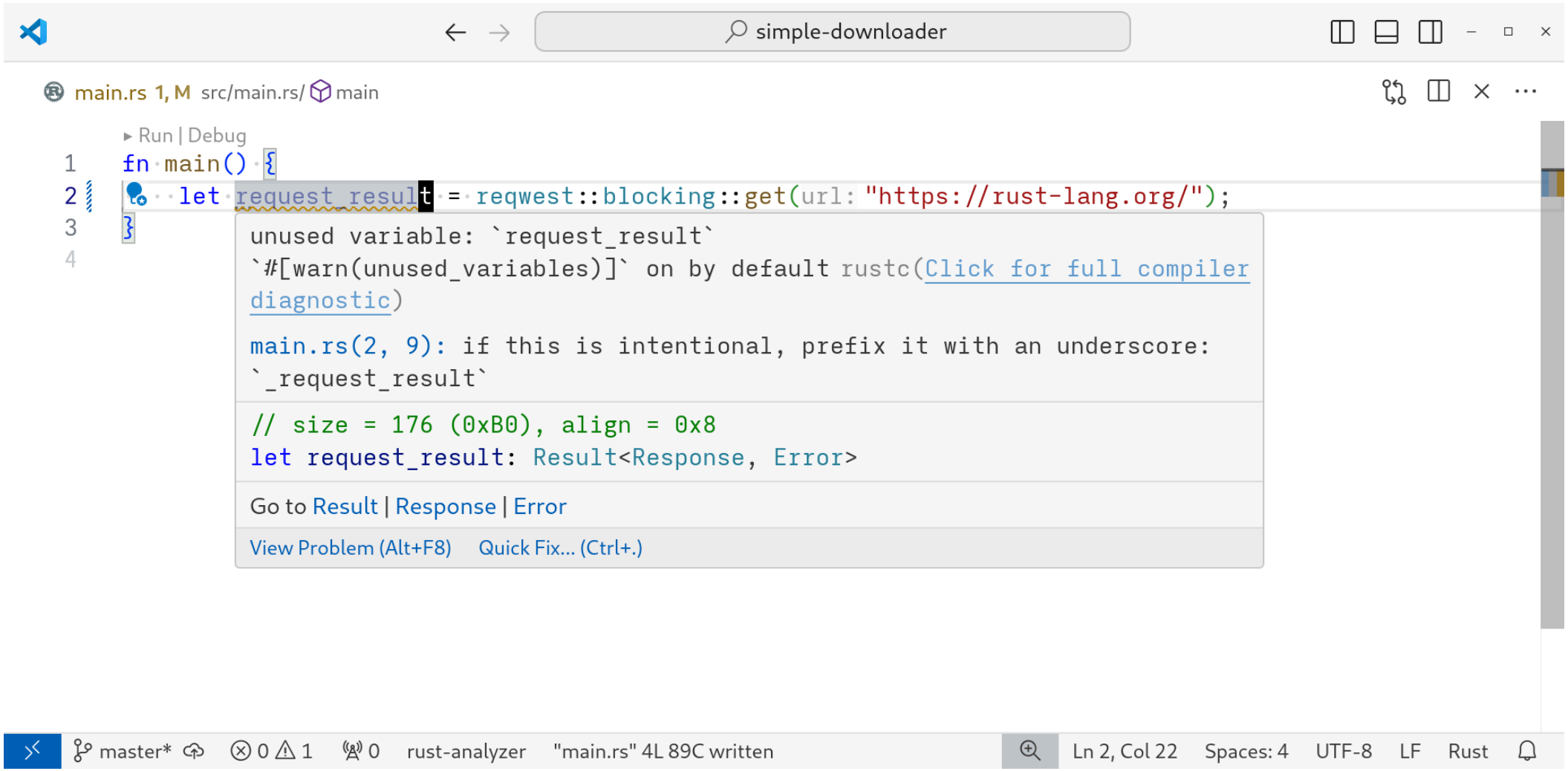
Updated `cargo.toml` with the `reqwest` library

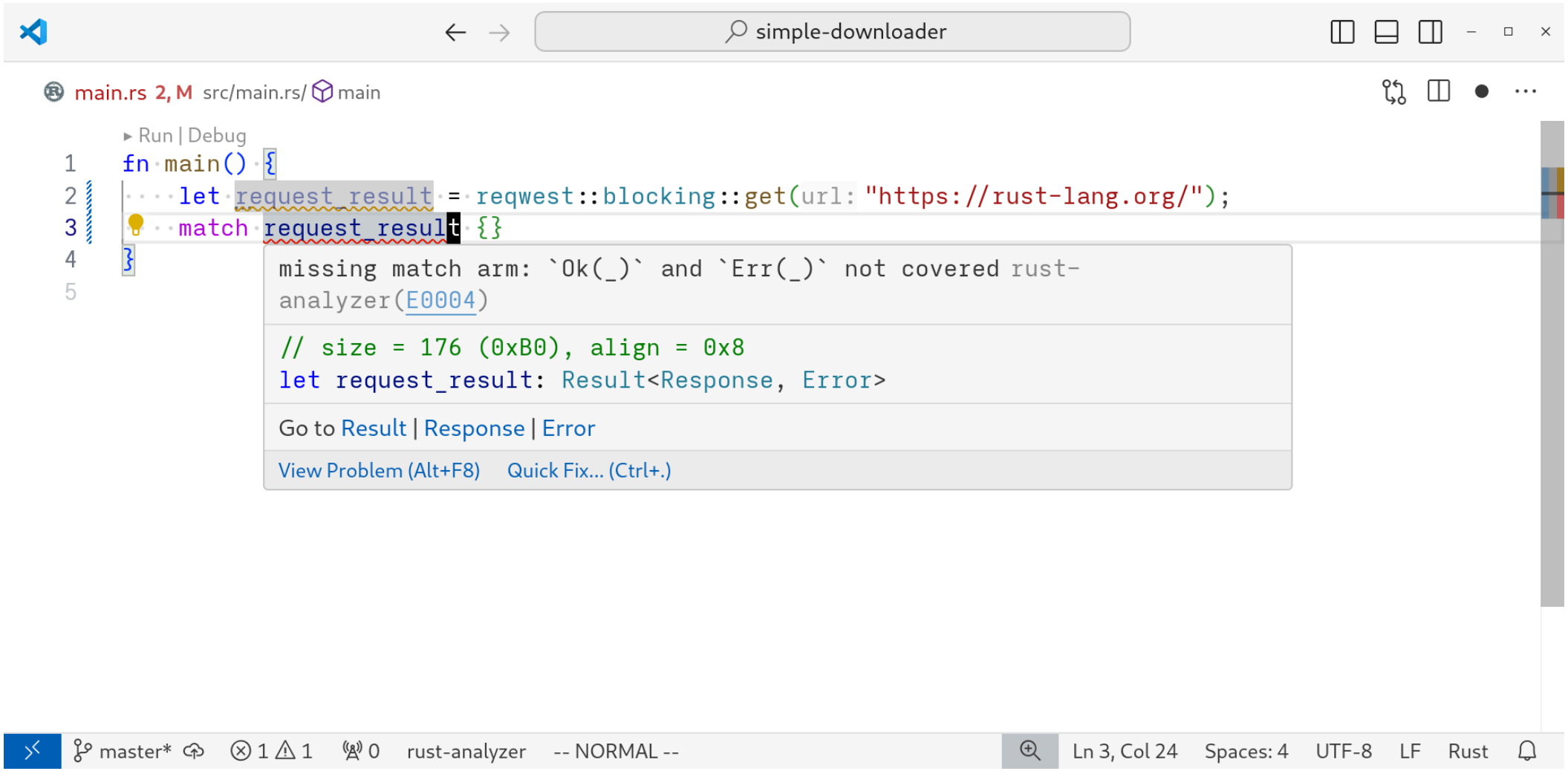
```toml
[package]
name = "simple-downloader"
version = "0.1.0"
edition = "2021"

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

[profile.release]
strip = true # or strip = "symbols"

[dependencies]
reqwest = { version = "0.12.2", features = ["blocking"] }
```

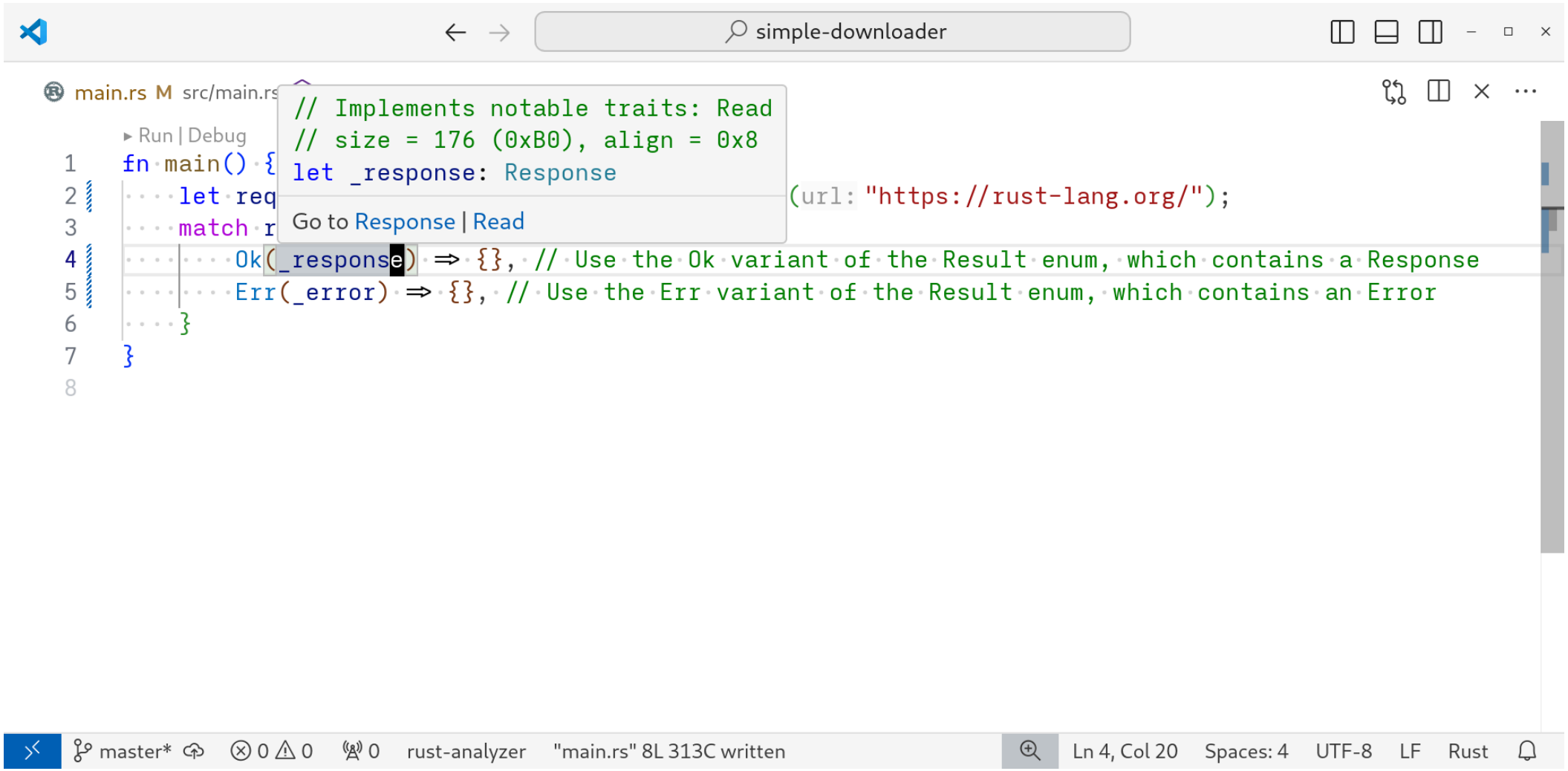
Writing the download functionality 

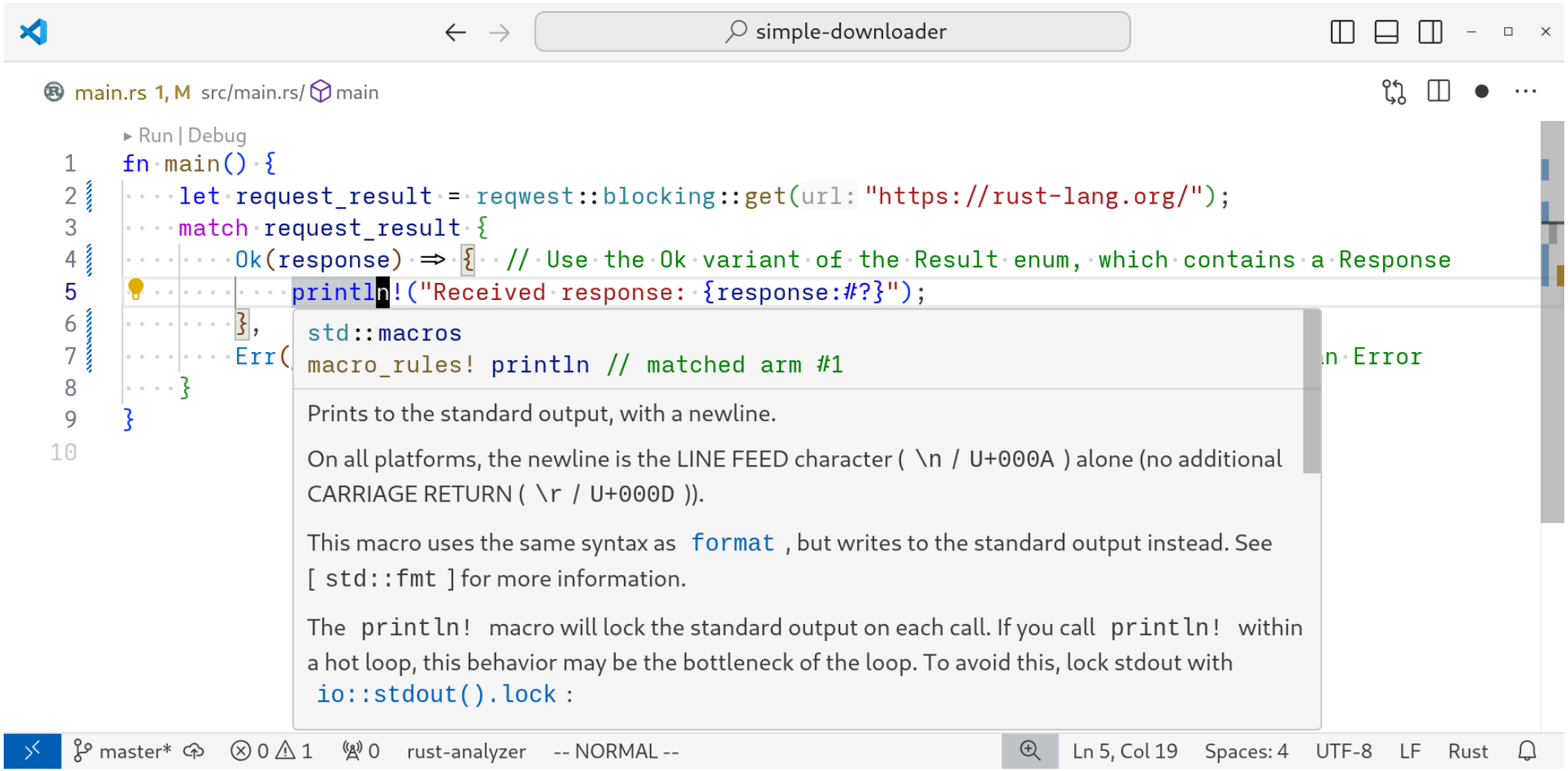
Literally copying the example from the `reqwest` documentation

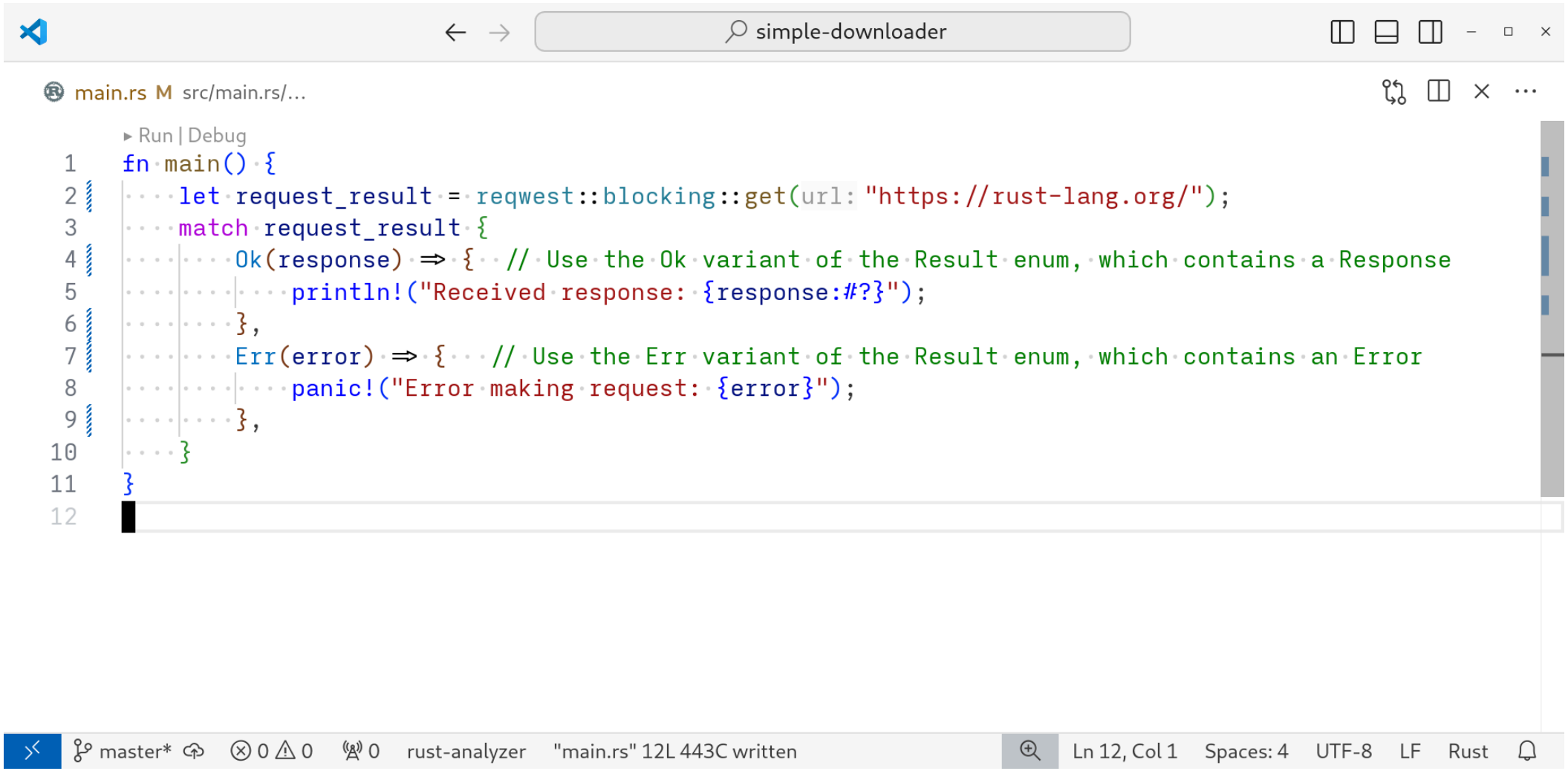
```rust
fn main() {
    let request_result = reqwest::blocking::get("https://sh.rustup.rs/rustup-init.sh")
    match request_result {
        Ok(response) => {  // Use the Ok variant of the Result enum, which contains a
            println!("Received response: {response:#?}");
        },
        Err(error) => {   // Use the Err variant of the Result enum, which contains an
            panic!("Error making request: {error}");
        },
    }
}
```








simple-downloader
main.rs 1, M src/main.rs/ main
Run | Debug
fn main() {
let request_result = reqwest::blocking::get(url: "https://rust-lang.org/");
match request_result {
Ok(response) => { // Use the Ok variant of the Result enum, which contains a Response
println!("Received response: {response:#?}");
},
Err(
n Error
}
}
std::macros
macro_rules! println // matched arm #1
Prints to the standard output, with a newline.
On all platforms, the newline is the LINE FEED character (\n / U+000A) alone (no additional CARRIAGE RETURN (\r / U+000D)).
This macro uses the same syntax as format , but writes to the standard output instead. See [std::fmt] for more information.
The println! macro will lock the standard output on each call. If you call println! within a hot loop, this behavior may be the bottleneck of the loop. To avoid this, lock stdout with io::stdout().lock :
master* 0 1 0 rust-analyzer -- NORMAL -- Ln 5, Col 19 Spaces: 4 UTF-8 LF Rust

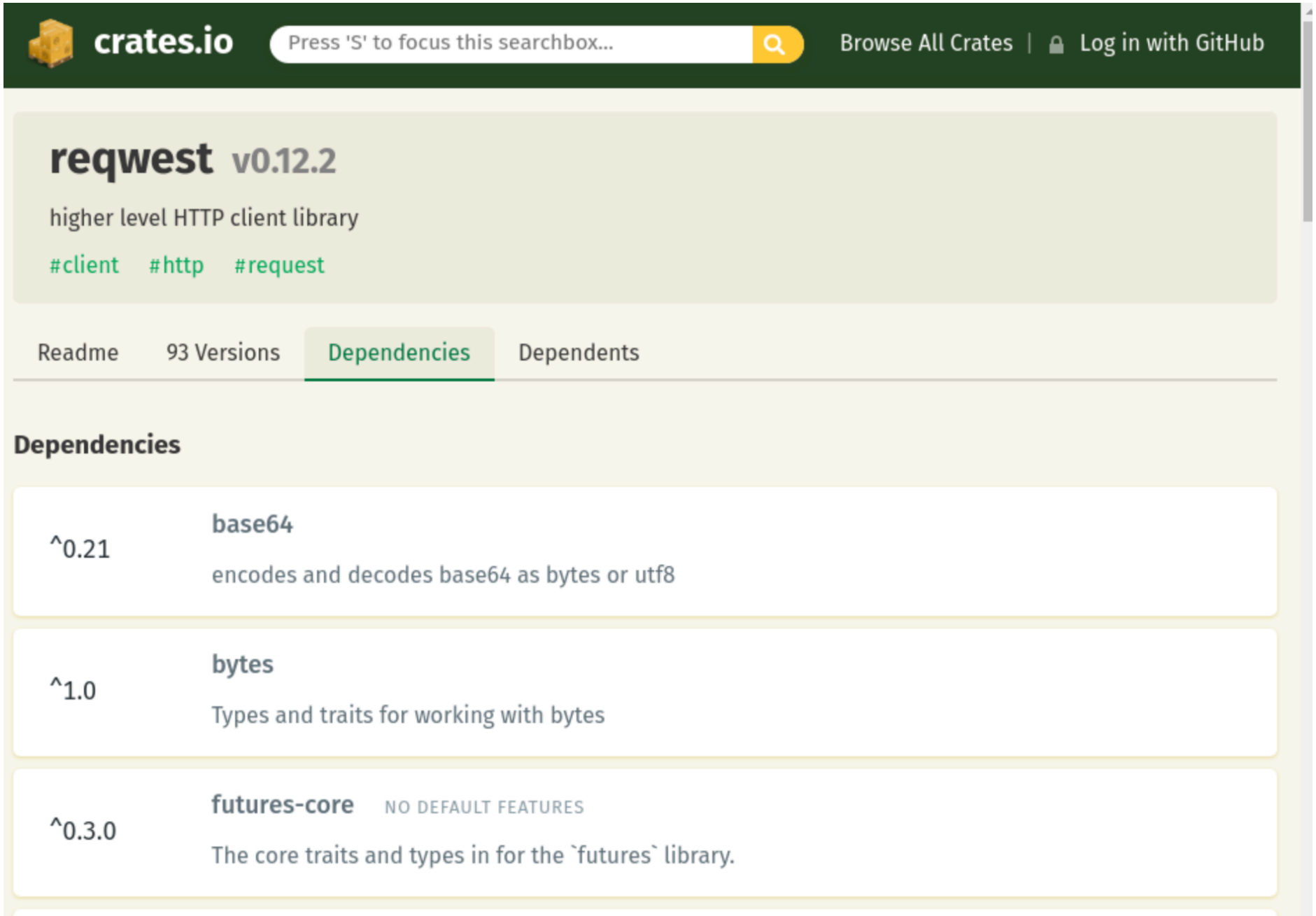


Building the binary, with just the download functionality

```
cargo build --release
```

The first time we build this after adding our `reqwest` dependency, we see that all of `reqwest`, and *its* dependencies, are being built:

```
$ cargo build --release
   Compiling libc v0.2.153
   Compiling proc-macro2 v1.0.79
   Compiling unicode-ident v1.0.12
   Compiling pin-project-lite v0.2.13
   Compiling once_cell v1.19.0
   Compiling bytes v1.6.0
   Compiling pkg-config v0.3.30
   Compiling vcpkg v0.2.15
   Compiling futures-core v0.3.30
   Compiling log v0.4.21
   Compiling cc v1.0.90
   Compiling autocfg v1.2.0
   Compiling itoa v1.0.11
   Compiling futures-sink v0.3.30
   Compiling tracing-core v0.1.32
   Compiling fnv v1.0.7
   Compiling slab v0.4.9
   Compiling http v1.1.0
```


crates.io
Press 'S' to focus this searchbox...
Browse All Crates | Log in with GitHub
reqwest v0.12.2
higher level HTTP client library
#client #http #request
Readme 93 Versions Dependencies Dependents
Dependencies
^0.21 base64
encodes and decodes base64 as bytes or utf8
^1.0 bytes
Types and traits for working with bytes
^0.3.0 futures-core NO DEFAULT FEATURES
The core traits and types in for the `futures` library.

Running the binary, with just the download functionality

```
cargo run --release
```

```
$ cargo run --release
    Finished release [optimized] target(s) in 0.09s
     Running `target/release/simple-downloader`
Received response: Response {
    url: Url {
        scheme: "https",
        cannot_be_a_base: false,
        username: "",
        password: None,
        host: Some(
            Domain(
                "www.rust-lang.org",
            ),
        ),
        port: None,
        path: "/",
        query: None,
        fragment: None,
    },
```

Reversing our binary, with just the download functionality

Exercise A: Initial string triage

What happens if we just run `strings` on our binary?

```
0x1f5000 | /home/cxiao/.cargo/registry/src/index.crates.io-6f17d22bba15001f/tokio-
1.37.0/src/sync/mpsc/list.rshttps://www.rust-lang.orgReceived response:
0x1f5090 | Error making request:
0x1f50b8 | failed to write whole
buffer/rustc/7cf61ebde7b22796c69757901dd346d0fe70bd97/library/std/src/io/mod.rsformatter
errorfatal runtime error: thread result panicked on drop
0x1f51d8 | /rustc/7cf61ebde7b22796c69757901dd346d0fe70bd97/library/core/src/sync/atomic.rsthere is
no such thing as a release failure orderingthere is no such thing as an acquire-release failure
ordering
0x1f52a0 | GGGGGGGGGGGGGGGGInactiveStreamIdMalformedHeadersinvalid ping
frame/home/cxiao/.cargo/registry/src/index.crates.io-6f17d22bba15001f/h2-
0.4.3/src/proto/ping_pong.rsinvalid pong frame
0x1f5358 | Arc counter
overflow/rustc/7cf61ebde7b22796c69757901dd346d0fe70bd97/library/alloc/src/sync.rs/home/cxiao/.cargo
6f17d22bba15001f/tokio-1.37.0/src/sync/oneshot.rscannot access a Thread Local Storage value during
or after
destruction/rustc/7cf61ebde7b22796c69757901dd346d0fe70bd97/library/std/src/thread/local.rsCannot
start a runtime from within a runtime. This happens because a function (like `block_on`) attempted
to block the current thread while the thread is being used to drive asynchronous tasks.failed to
```

Breaking down the strings

Rust strings are generally not null-terminated. All of this is from a single null-terminated string at `0x1f5358`:

```
Arc counter overflow
/rustc/7cf61ebde7b22796c69757901dd346d0fe70bd97/library/alloc/src/sync.rs
/home/cxiao/.cargo/registry/src/index.crates.io-6f17d22bba15001f/tokio-1.37.0/src/sync/oneshot.rs
cannot access a Thread Local Storage value during or after destruction
/rustc/7cf61ebde7b22796c69757901dd346d0fe70bd97/library/std/src/thread/local.rs
Cannot start a runtime from within a runtime. This happens because a function (like `block_on`)
attempted to block the current thread while the thread is being used to drive asynchronous tasks.
failed to park thread
/home/cxiao/.cargo/registry/src/index.crates.io-6f17d22bba15001f/tokio-
1.37.0/src/runtime/scheduler/multi_thread/mod.rs
/home/cxiao/.cargo/registry/src/index.crates.io-6f17d22bba15001f/tokio-
1.37.0/src/runtime/scheduler/current_thread/mod.rs
Failed to `Enter::block_on`
UnexpectedFramePayloadTooBigRejectedReleaseCapacityTooBigOverflowedStreamIdMissingUriSchemeAndA
called after complete
```

Breaking down the strings

What metadata can we get from this?

- The version of Rust this binary was compiled with:

  `/rustc/7cf61ebde7b22796c69757901dd346d0fe70bd97/library/alloc/src/sync.rs`

  → Specifically, this is the Git commit hash of the main Rust language Git repository.

  → 🖇 github.com/rust-lang/rust/blob/7cf61ebde7b22796c69757901dd346d0fe70bd97/library/alloc/src/sync.rs

🤔`library/alloc/src/sync.rs` is a source file that is part of the *standard library*. `rustc`, however, is the Rust *compiler*. Why are these both here?

The Language, the Compiler, and the Standard Library

The Rust compiler and standard library are in the same repository and are released together.

Therefore, when we talk about “Rust version 1.77.1”, we mean both

- “Rust compiler (`rustc`) version 1.77.1”, *and*
- “Rust standard library version 1.77.1”

1.76.0

- Released on: *8 February, 2024*
- Branched from master on: *22 December, 2023*

Language

- Document Rust ABI compatibility between various types
- Also: guarantee that char and u32 are ABI-compatible
- Add lint `ambiguous_wide_pointer_comparisons` that supersedes `clippy::vtable_address_comparisons`

Compiler

- Lint pinned `#[must_use]` pointers (in particular, `Box<T>` where `T` is `#[must_use]`) in `unused_must_use`.
- Soundness fix: fix computing the offset of an unsized field in a packed struct
- Soundness fix: fix dynamic size/align computation logic for packed types with dyn Trait tail
- Add `$message_type` field to distinguish json diagnostic outputs
- Enable Rust to use the EHCont security feature of Windows
- Add tier 3 {x86_64,i686}-win7-windows-msvc targets
- Add tier 3 aarch64-apple-watchos target
- Add tier 3 arm64e-apple-ios & arm64e-apple-darwin targets

Refer to Rust's [platform support page][platform-support-doc] for more information on Rust's tiered platform support.

Libraries

- Add a column number to `dbg!()`
- Add `std::hash::{DefaultHasher, RandomState}` exports
- Fix rounding issue with exponents in fmt
- Add T: ?Sized to `RwLockReadGuard` and `RwLockWriteGuard`'s Debug impls.
- Windows: Allow `File::create` to work on hidden files

https://releases.rs/docs/1.76

Breaking down the strings

- The Cargo home path of the machine where the binary was built: `/home/cxiao/.cargo/`
- Some, but not all of the dependency tree for the binary: `/home/cxiao/.cargo/registry/src/index.crates.io-6f17d22bba15001f/tokio-1.37.0/`

  → Why not the entire dependency tree? We will see soon…

Metadata for this binary, with `rustbininfo`

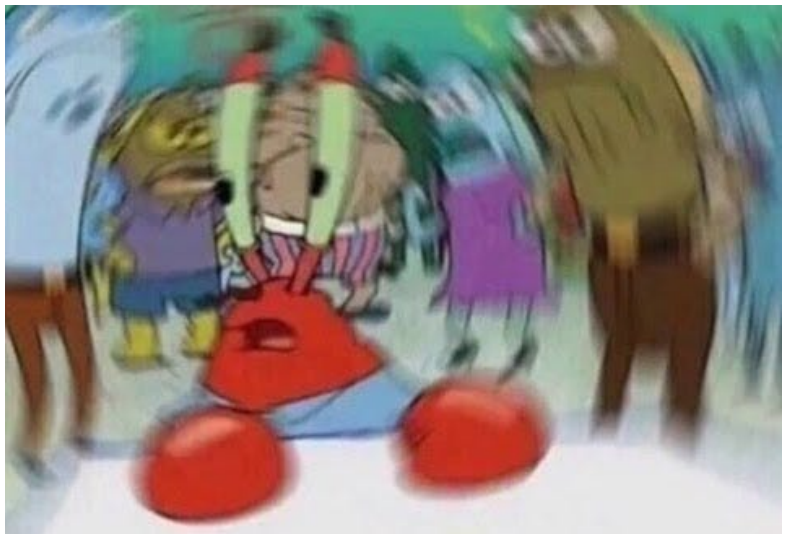
🛠️ github.com/N0fix/rustbininfo

```
$ rustbininfo info ~/presentations/rust-one-step-beyond-strings/samples/simple-downloader-release-build-stripped

TargetRustInfo(
    rustc_version='1.77.1',
    rustc_commit_hash='7cf61ebde7b22796c69757901dd346d0fe70bd97',
    dependencies=[
        Crate(name='base64', version='0.21.7', features=[], repository=None),
        Crate(name='bytes', version='1.6.0', features=[], repository=None),
        Crate(name='encoding_rs', version='0.8.33', features=[], repository=None),
        Crate(name='futures-channel', version='0.3.30', features=[], repository=None),
        Crate(name='futures-core', version='0.3.30', features=[], repository=None),
        Crate(name='futures-util', version='0.3.30', features=[], repository=None),
        Crate(name='h2', version='0.4.3', features=[], repository=None),
        Crate(name='hashbrown', version='0.14.3', features=[], repository=None),
        Crate(name='http', version='1.1.0', features=[], repository=None),
        Crate(name='http-body-util', version='0.1.1', features=[], repository=None),
        Crate(name='httparse', version='1.8.0', features=[], repository=None),
        Crate(name='hyper', version='1.2.0', features=[], repository=None),
        Crate(name='hyper-tls', version='0.6.0', features=[], repository=None),
        Crate(name='hyper-util', version='0.1.3', features=[], repository=None),
        Crate(name='idna', version='0.5.0', features=[], repository=None),
```

Where do these strings come from? The concept of `panic`

Unrecoverable, unexpected errors that cannot be caught or handled.

- The standard behaviour is that the current thread exits (after calling destructors)
- Can be added by the programmer (like we did in our program)
- Also lots of places in the standard library where it can occur:
  - → Bounds check failures at runtime
  - → Assertion failures
  - → Malformed or unexpected state



In fact, there are some good examples of these conditions in the strings we just looked at!

Why is this here? Where does this information show up?

Let’s trigger the code path in our binary where the request fails, and the panic occurs.

```
thread 'main' panicked at src/main.rs:8:13:
Error making request: error sending request for url (https://localhost:1234/)
note: run with `RUST_BACKTRACE=1` environment variable to display a backtrace
```

👀 Interesting that we have a line and column number there…

Looking at the `panic!` in our unstripped binary

```
1  // ⚠ This is a Ghidra decompilation, not real source code!
2  void simple_downloader::main(void)
3  {
4    reqwest::blocking::get(local_e0,"https://sh.rustup.rs/rustup-init.sh",0x23);
5    if (local_e0[0] == 3) { // ⚠🟦← Handle the state where the request failed
6      local_190[0] = local_d8;
7      local_258 = _<>::fmt;
8      local_330 = &PTR_s_Error_making_request:_003fd6d0;
9      local_328 = (undefined ***)0x1;
10     pvStack_310 = (void *)0x0;
11     ppppuStack_320 = (undefined ****)&local_260;
12     local_318 = 1;
13     local_260 = local_190;
14     // ⚠🟦↓ Where our actual panic occurs,
15     // and where the printed panic message is constructed.
16     core::panicking::panic_fmt(&local_330,&PTR_s_src/main.rs_003fd6e0);
17 }
```

Looking into the guts of `panic`

```rust
pub const fn core::panicking::panic_fmt(fmt: fmt::Arguments<'_>) -> ! {
    if cfg!(feature = "panic_immediate_abort") {
        super::intrinsics::abort()
    }

    // NOTE This function never crosses the FFI boundary; it's a Rust-to-Rust call
    // that gets resolved to the `#[panic_handler]` function.
    extern "Rust" {
        #[lang = "panic_impl"]
        fn panic_impl(pi: &PanicInfo<'_>) -> !;
    }

    // ⚠️⬇️ This is our function call that we see in the decompilation!
    let pi = PanicInfo::internal_constructor(
        Some(&fmt),
        Location::caller(), // ⚠️⬅️ Constructor for a `core::panic::Location`
        /* can_unwind */ true,
        /* force_no_backtrace */ false,
    );

    // SAFETY: `panic_impl` is defined in safe Rust code and thus is safe to call.
    unsafe { panic_impl(&pi) }
}
```

- 📖 Docs: doc.rust-lang.org/core/panicking/fn.panic_fmt.html
- 💿 Source: github.com/rust-lang/rust/blob/1.77.1/library/core/src/panicking.rs#L52

The `core::panic::Location` metadata struct

```
pub struct core::panic::Location<'a> {
    file: &'a str,
    line: u32,
    col: u32,
}
```

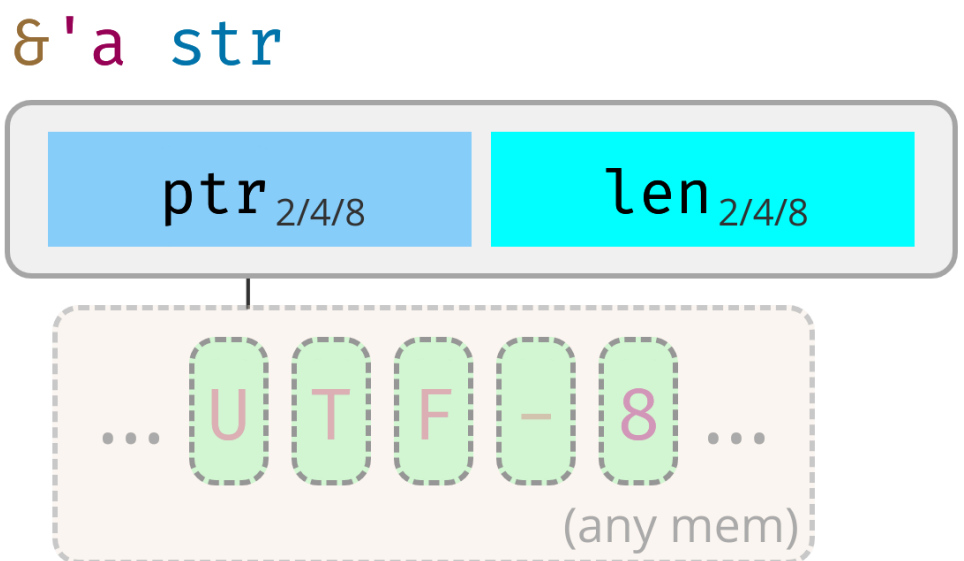
- 📖 Docs (unofficial, but contains internal info): stdrs.dev/nightly/x86_64-unknown-linux-gnu/core/panic/struct.Location.html
- 💿 Source: github.com/rust-lang/rust/blob/1.77.1/library/core/src/panic/location.rs#L33

⚠ Caution: Type layouts in compiled Rust binaries are not stable!

- You must do the work of examining the data in your particular binary, and deducing from that what the layout of `core::panic::Location` in *your* particular binary is!

Type layouts in memory: The "pointer to constant string" type, `&str`

- 🕮 Docs: doc.rust-lang.org/std/primitive.str.html
- 🖇 Cheat Sheet: cheats.rs/#pointer-meta



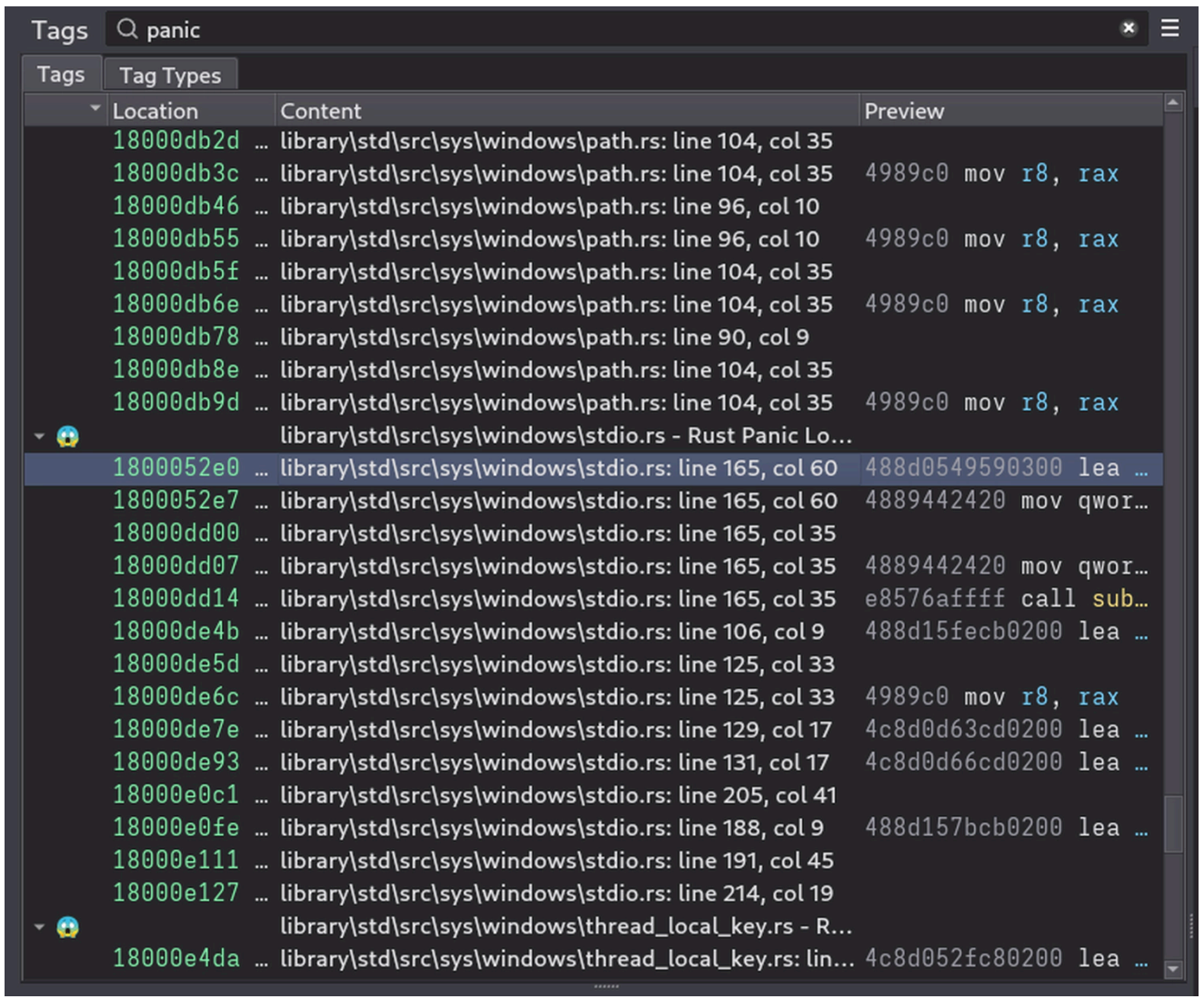
String slice reference (i.e., the reference type of string type `str`), with meta `len` being byte length.

Putting it all together: `core::panic::Location` structs in our binary

```
                PTR_s_src/main.rs_003fd6e0          XREF[1]:  main:00148ea9(*)
003fd6e0 8a 11 31 00 00 00 00 00      addr    s_src/main.rs_0031118a                = "src/main.rs"
003fd6e8 0b                           ??      0Bh
003fd6e9 00                           ??      00h
003fd6ea 00                           ??      00h
003fd6eb 00                           ??      00h
003fd6ec 00                           ??      00h
003fd6ed 00                           ??      00h
003fd6ee 00                           ??      00h
003fd6ef 00                           ??      00h
003fd6f0 1c                           ??      1Ch
003fd6f1 00                           ??      00h
003fd6f2 00                           ??      00h
003fd6f3 00                           ??      00h
003fd6f4 0d                           ??      0Dh
003fd6f5 00                           ??      00h
003fd6f6 00                           ??      00h
003fd6f7 00                           ??      00h
```

Using the `panic` metadata to our advantage

- Using panic metadata to recover source code information from Rust binaries - cxiao.net



Limits of relying on `panic` metadata

The metadata doesn't *have* to be there, and developers can remove it:

```
RUSTFLAGS="-Zlocation-detail=none" cargo +nightly build --release
```

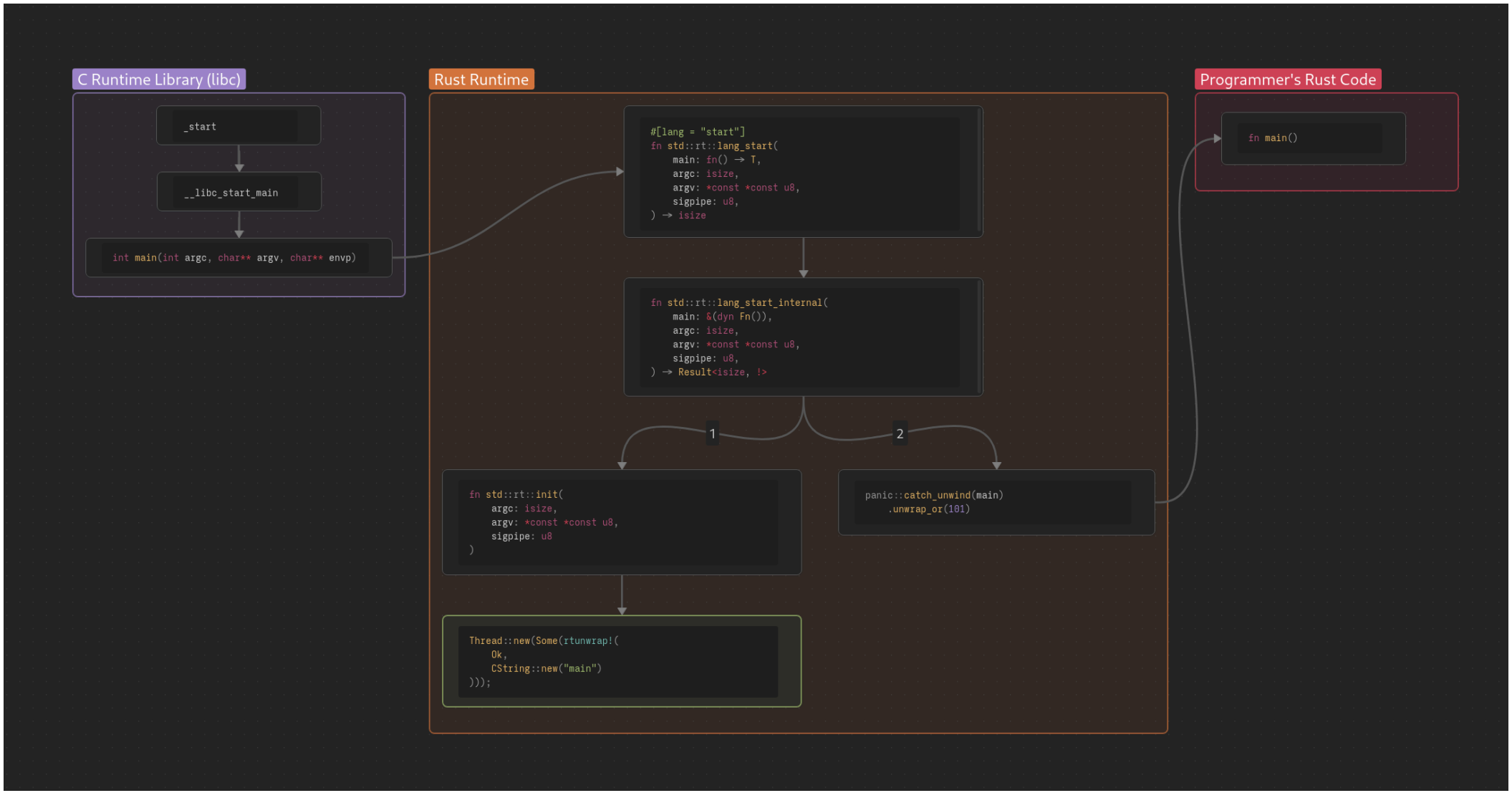
Most Rust malware we're seeing still has this information intact, though.

In general, this is a good example of how understanding the language features *helps us* as reversers.

Exercise B: Finding the entry point

We’re going to switch over to our stripped binary now, and find its entry point.

A quick look at the runtime initialization



github.com/rust-lang/rust/blob/1.77.1/library/std/src/rt.rs#L159

```
#[cfg(not(any(test, doctest)))]
#[lang = "start"]
fn lang_start<T: crate::process::Termination + 'static>(
    main: fn() -> T,
    argc: isize,
    argv: *const *const u8,
    sigpipe: u8,
) -> isize {
    let Ok(v) = lang_start_internal(
        &move || crate::sys_common::backtrace::__rust_begin_short_backtrace(main).repo
        argc,
        argv,
        sigpipe,
    );
    v
}
```

github.com/rust-lang/rust/blob/1.77.1/library/std/src/rt.rs#L125

```
1  // To reduce the generated code of the new `lang_start`, this function is doing
2  // the real work.
3  #[cfg(not(test))]
4  fn lang_start_internal(
5      main: &(dyn Fn() -> i32 + Sync + crate::panic::RefUnwindSafe),
6      argc: isize,
7      argv: *const *const u8,
8      sigpipe: u8,
9  ) -> Result<isize, !> {
10     use crate::{mem, panic};
11     let rt_abort = move |e| {
12         mem::forget(e);
13         rtabort!("initialization or cleanup bug");
14     };
15     // Guard against the code called by this function from unwinding outside of the Ru
16     // code, which is UB. This is a requirement imposed by a combination of how the
17     // `#[lang="start"]` attribute is implemented as well as by the implementation of
18     // mechanism itself.
19     //
```

github.com/rust-lang/rust/blob/1.77.1/library/std/src/rt.rs#L104

```
unsafe fn init(argc: isize, argv: *const *const u8, sigpipe: u8) {
    unsafe {
        sys::init(argc, argv, sigpipe);

        let main_guard = sys::thread::guard::init();
        // Next, set up the current Thread with the guard information we just
        // created. Note that this isn't necessary in general for new threads,
        // but we just do this to name the main thread and to give it correct
        // info about the stack bounds.
        let thread = Thread::new(Some(rtunwrap!(Ok, CString::new("main"))));
        thread_info::set(main_guard, thread);
    }
}
```

github.com/rust-lang/rust/blob/1.77.1/library/std/src/sys/pal/unix/mod.rs#L49

```
1  pub unsafe fn init(argc: isize, argv: *const *const u8, sigpipe: u8) {
2      // The standard streams might be closed on application startup. To prevent
3      // std::io::{stdin, stdout,stderr} objects from using other unrelated file
4      // resources opened later, we reopen standards streams when they are closed.
5      sanitize_standard_fds();
6
7      // By default, some platforms will send a *signal* when an EPIPE error
8      // would otherwise be delivered. This runtime doesn't install a SIGPIPE
9      // handler, causing it to kill the program, which isn't exactly what we
10     // want!
11     //
12     // Hence, we set SIGPIPE to ignore when the program starts up in order
13     // to prevent this problem. Add `#[unix_sigpipe = "..."]` above `fn main()` to
14     // alter this behavior.
15     reset_sigpipe(sigpipe);
16
17     stack_overflow::init();
18     args::init(argc, argv);
19
```

Finding our `main` function, with the power of `strings`

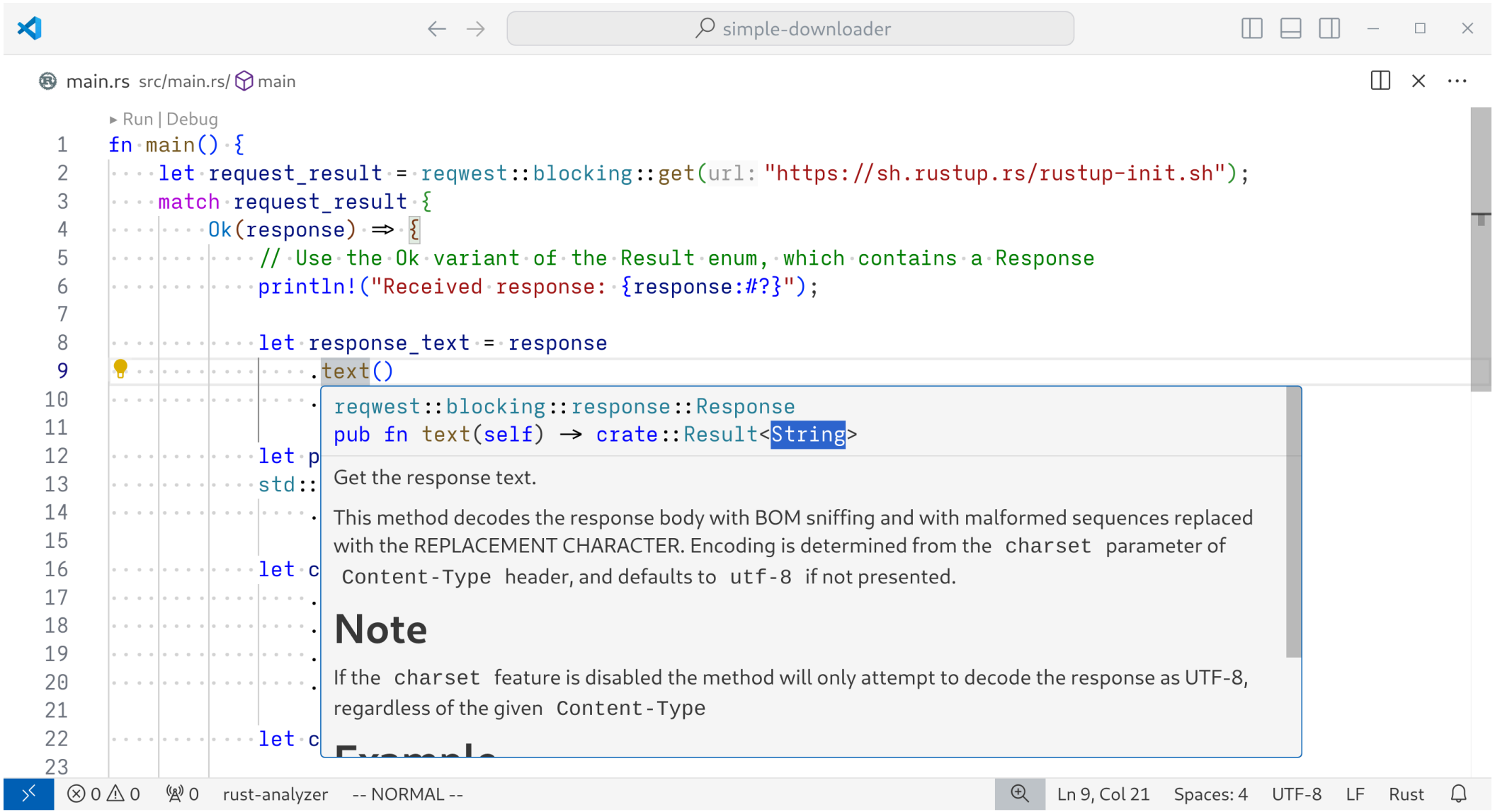
Let's match what we just saw in the Rust runtime source code with what we have in the disassembly and decompilation!

```
239 LAB_002d81ca:
240         uStack_150 = 0x2d81e9;
241         FUN_00301460(&local_130,"mainnameVarsArgs",4);
242         if (local_130 == (undefined **)0x8000000000000000) {
243                     /* try { // try from 002d8207 to 002d820c has its CatchHandler @ 002d8520 */
244           uStack_150 = 0x2d820d;
245           uVar15 = FUN_002d8960(local_128,local_120);
246                     /* try { // try from 002d820d to 002d821a has its CatchHandler @ 002d855d */
247           uStack_150 = 0x2d821b;
248           FUN_002dfc20(&local_100,uVar15);
249                     /* try { // try from 002d821b to 002d8220 has its CatchHandler @ 002d847d */
250           uStack_150 = 0x2d8221;
251           iVar8 = (**(code **)(param_2 + 0x28))(param_1);
252           if (DAT_00422e58 != 4) {
253             local_130 = (undefined **)CONCAT71(local_130._1_7_,1);
254             local_d8._0_8_ = &local_130;
255                     /* try { // try from 002d8239 to 002d8242 has its CatchHandler @ 002d8453 */
256             uStack_150 = 0x2d8243;
257             FUN_00144ec0(local_d8);
258           }
259           return (long)iVar8;
260         }
```

Writing the shell script running functionality

```
fn main() {
    let request_result = reqwest::blocking::get("https://sh.rustup.rs/rustup-init.sh")
    match request_result {
        Ok(response) => {
            // Use the Ok variant of the Result enum, which contains a Response
            println!("Received response: {response:#?}");

            let response_text = response
                .text()
                .expect("Could not get any text from response body");

            let payload_path = std::env::temp_dir().join("payload");
            std::fs::write(payload_path.clone(), response_text)
                .expect("Could not write payload to temporary path");

            let command_result = std::process::Command::new("/bin/sh")
                .arg(payload_path.as_os_str())
                .arg("--help")
                .output()
```

Our first encounter with the `String` type

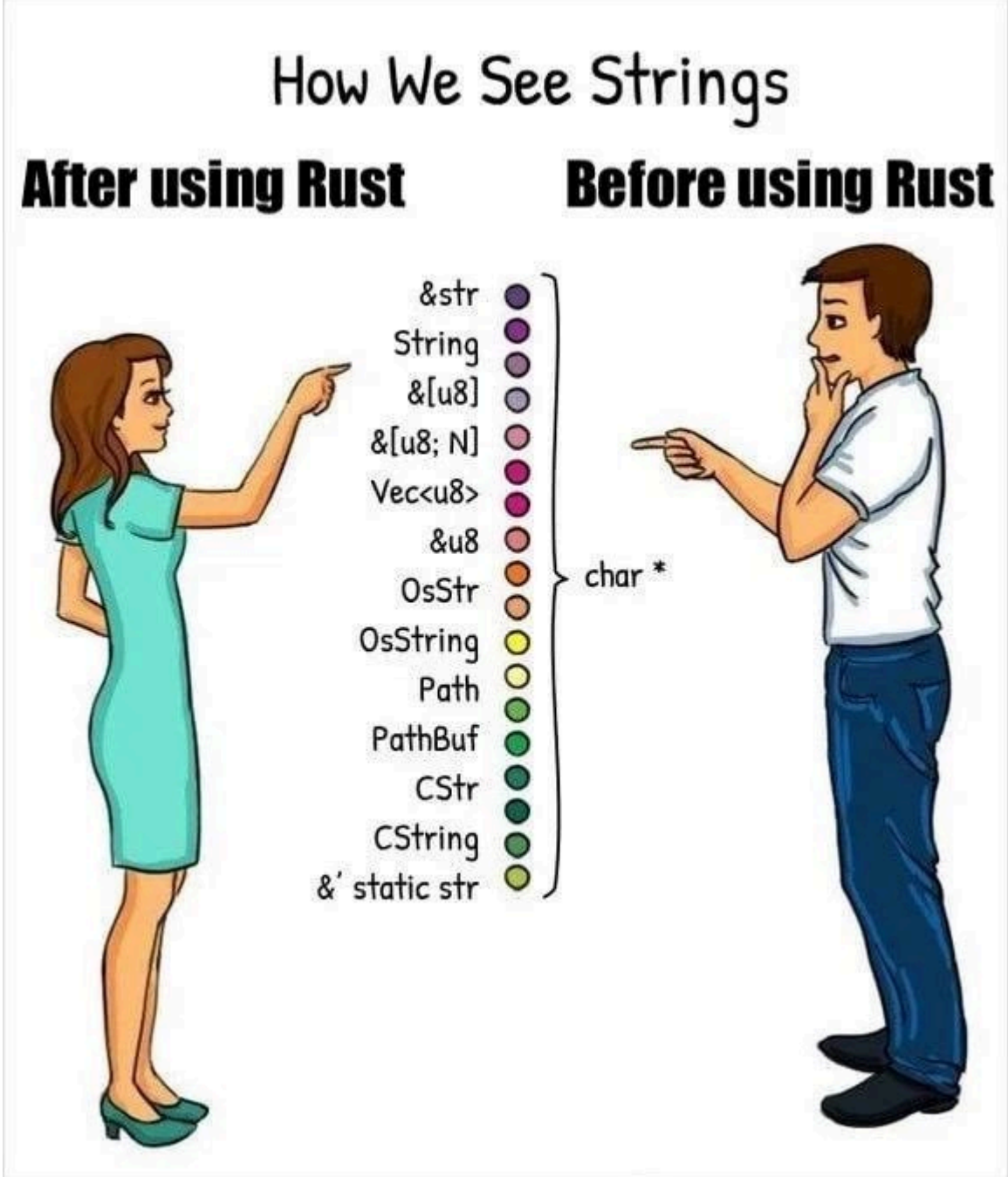


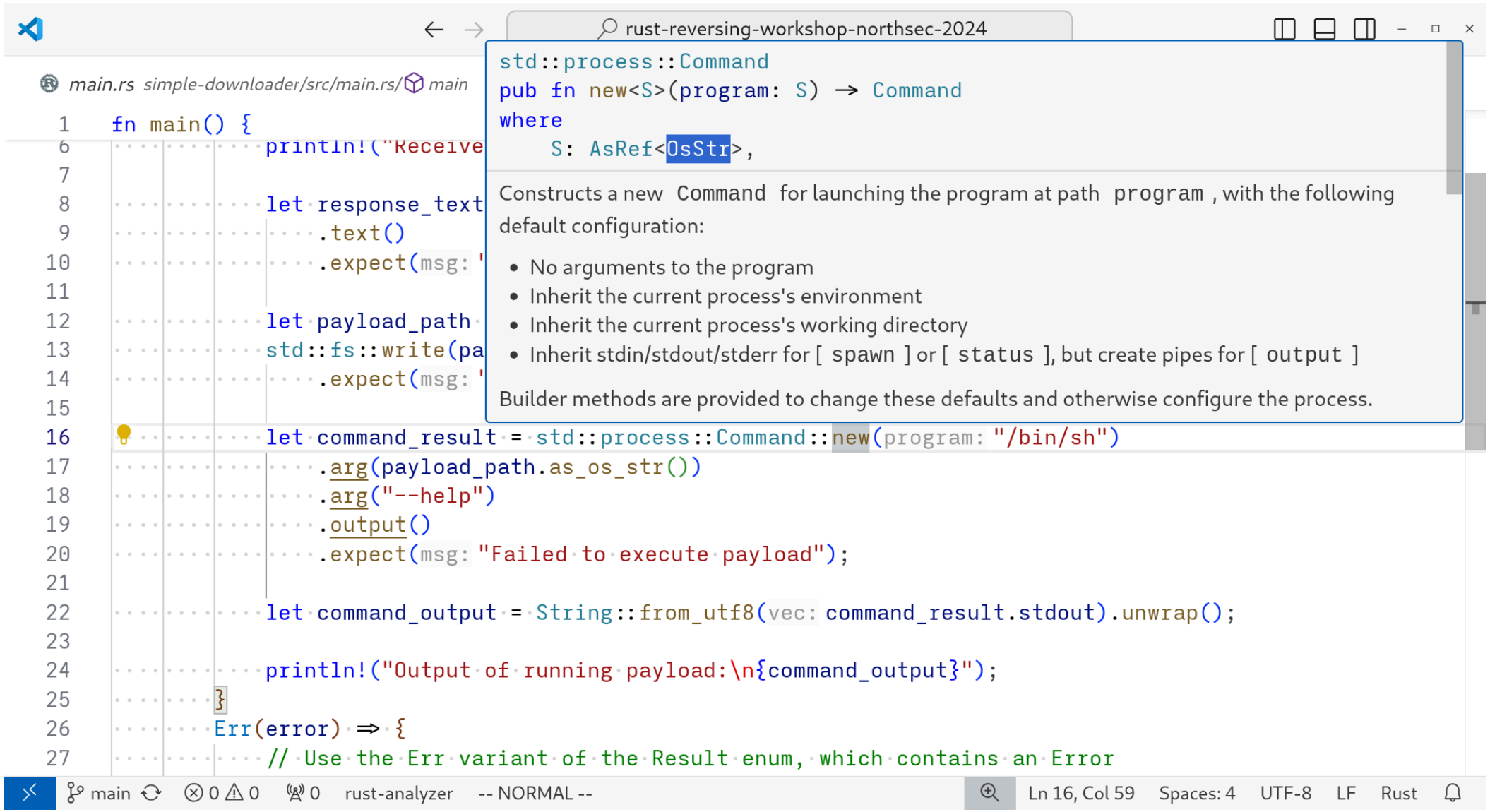
Type layouts in memory: String

- 📖 Docs: doc.rust-lang.org/std/primitive.str.html / unofficial docs with internals
- 📎 Cheat Sheet: cheats.rs/#owned-strings

The different Rust string types

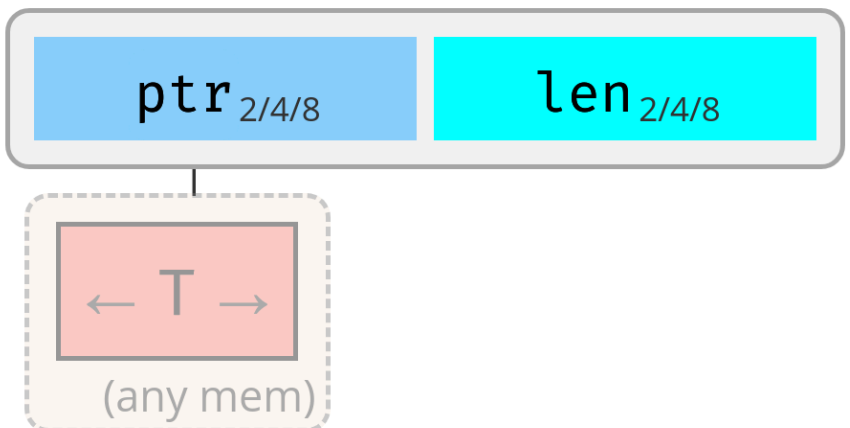
How We See Strings




rust-reversing-workshop-northsec-2024
main.rs simple-downloader/src/main.rs/ main
std::process::Command
pub fn new<S>(program: S) -> Command
where
S: AsRef<OsStr>,
Constructs a new Command for launching the program at path program, with the following default configuration:
No arguments to the program
Inherit the current process's environment
Inherit the current process's working directory
Inherit stdin/stdout/stderr for [spawn] or [status], but create pipes for [output]
Builder methods are provided to change these defaults and otherwise configure the process.
fn main() {
println!("Receive
let response_text
.text()
.expect(msg: '
let payload_path
std::fs::write(pa
.expect(msg: '
let command_result = std::process::Command::new(program: "/bin/sh")
.arg(payload_path.as_os_str())
.arg("--help")
.output()
.expect(msg: "Failed to execute payload");
let command_output = String::from_utf8(vec: command_result.stdout).unwrap();
println!("Output of running payload:\n{command_output}");
}
Err(error) => {
// Use the Err variant of the Result enum, which contains an Error
main 0 0 0 rust-analyzer -- NORMAL -- Ln 16, Col 59 Spaces: 4 UTF-8 LF Rust

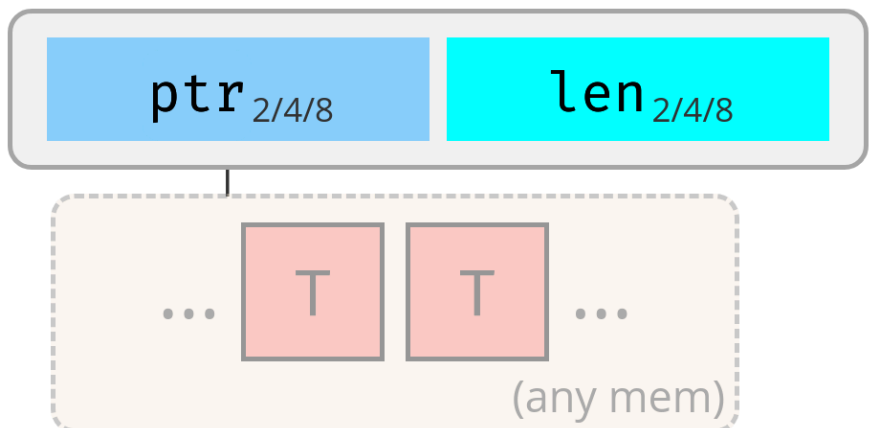
Type layouts in memory: Pointers to dynamically sized structures in general

`&'a T`



If `T` is a DST `struct` such as `S { x: [u8] }` meta field `len` is count of dyn. sized content.

`&'a [T]`



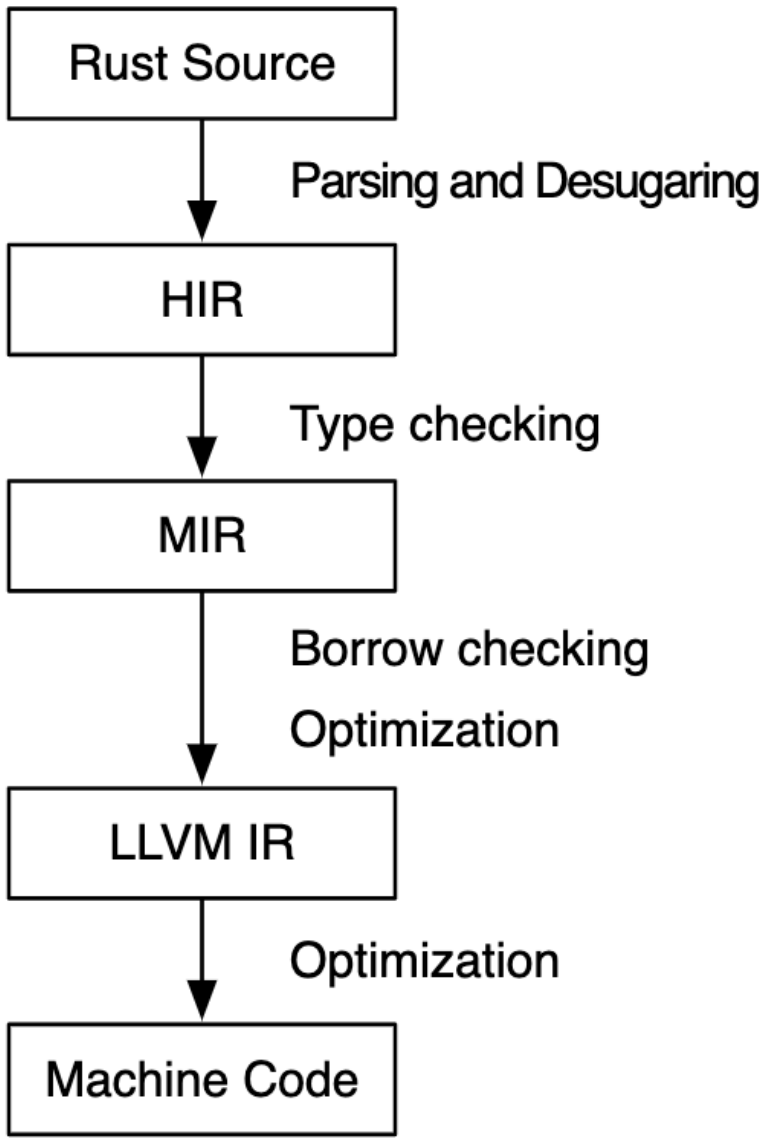
Regular **slice reference** (i.e., the reference type of a slice type `[T]`) [↑] often seen as `&[T]` if `'a` elided.

Looking at these strings inside the binary

```
1 // ⚠ This is a Ghidra decompilation, not real source code!
2 [...]
3     if (ppuVar5 == (undefined **)0x0) {
4       std::sys::pal::unix::process::process_common::Command::new(&local_330,"/bin/sh",
5       memcpy(&local_260,&local_330,0xd0);
6       std::sys::pal::unix::process::process_common::Command::arg(&local_260,__src,loca
7       std::sys::pal::unix::process::process_common::Command::arg(&local_260,"--help",6
8       std::process::Command::output(&local_330,&local_260);
9 [...]
```

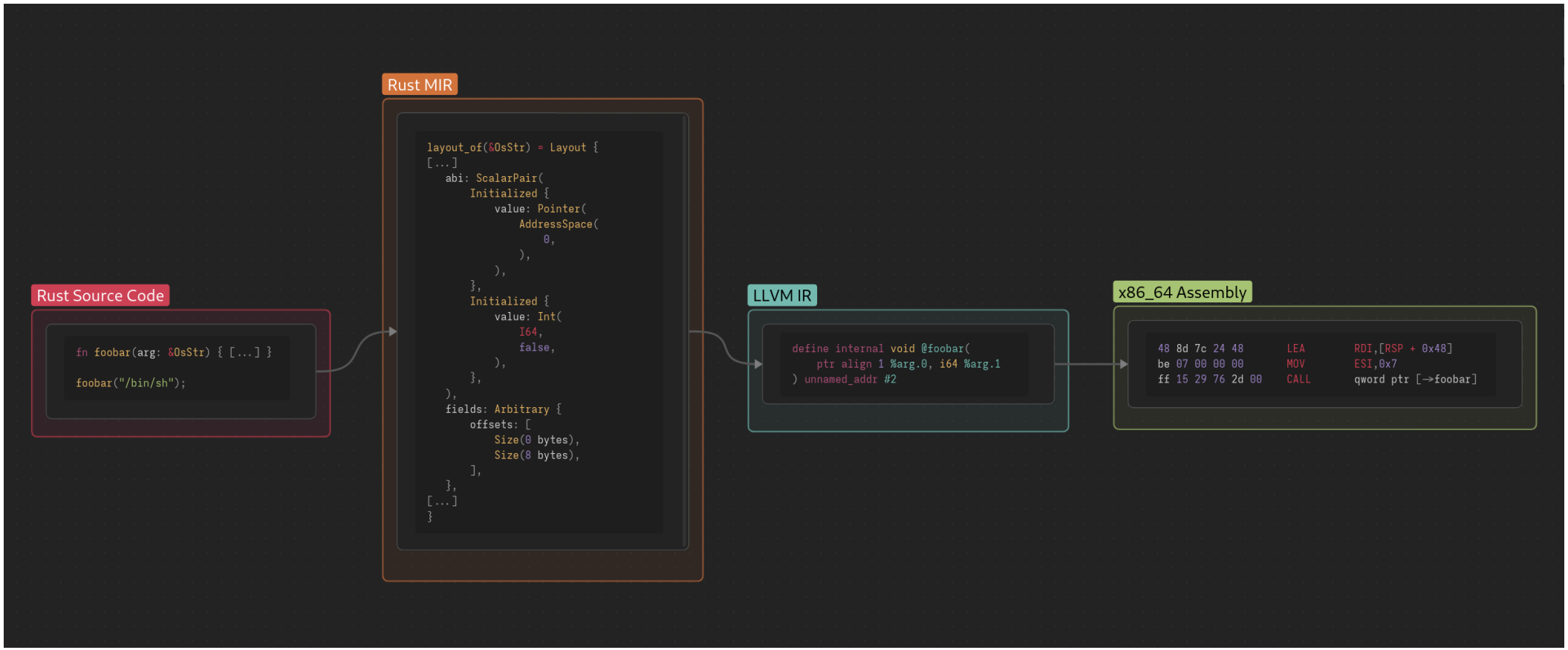
🤔 `Command::new(program: &OsStr)` just takes an `&OsStr`, so why are we seeing it take so many arguments here?

A very brief introduction to how the Rust compiler works



From 2016-04-19 Rust Blog post: Introducing MIR

Getting from &OsStr to assembly



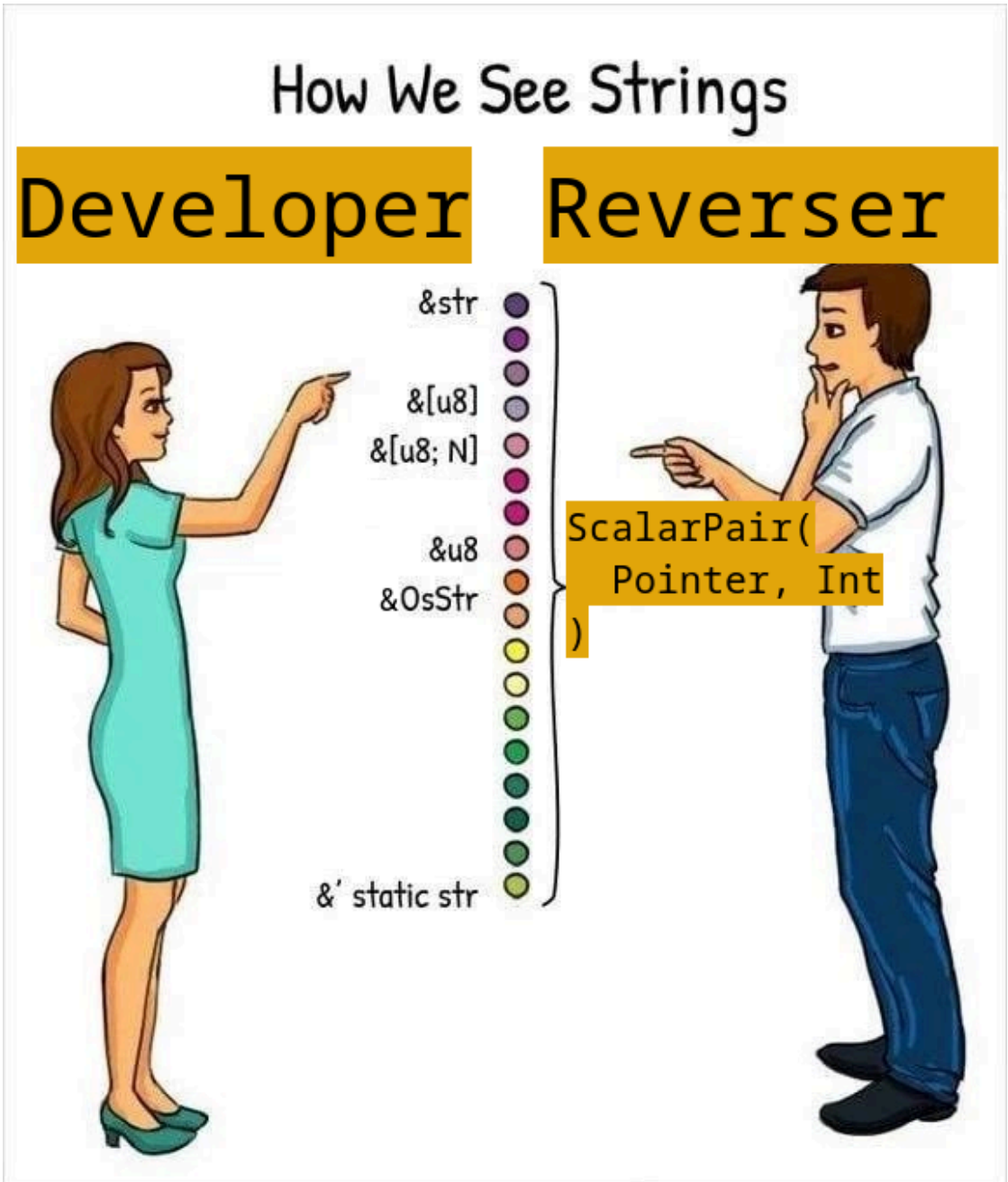
Inspecting our type layouts

- Ralf Jung - Debugging rustc type layouts
- Live in the Rust Playground

```rust
#![feature(rustc_attrs)]

use std::ffi::OsStr;

#[rustc_layout(debug)]
type T = &OsStr;
```

```
layout_of(&OsStr) = Layout {
   size: Size(16 bytes),
       align: AbiAndPrefAlign {
           abi: Align(8 bytes),
           pref: Align(8 bytes),
       },
       abi: ScalarPair(
           Initialized {
               value: Pointer(
                   AddressSpace(
                       0,
                   ),
               ),
               valid_range: 1..=18446744073709551615,
           },
           Initialized {
               value: Int(
                   I64,
                   false,
               ),
               valid_range: 0..=18446744073709551615,
           },
       ),
```

```
24        fields: Arbitrary {
25            offsets: [
26                Size(0 bytes),
27                Size(8 bytes)
```


How We See Strings
Developer
Reverser
&str
&[u8]
&[u8; N]
&u8
&OsStr
&' static str
ScalarPair(
Pointer, Int
)

Inspecting our type layouts

- 🥏 Nicholas Nethercote - The Rust Performance Book - Type Sizes
- 🛠️ Binary Ninja Rust Type Layout Helper Plugin

```
type: `std::sys::windows::pipe::AsyncPipe<'_>`:
48 bytes, alignment: 8 bytes
    field `.state`: 16 bytes
    field `.pipe`: 8 bytes
    field `.event`: 8 bytes
    field `.overlapped`: 8 bytes
    field `.dst`: 8 bytes
type: `std::sys::windows::pipe::State`: 16
bytes, alignment: 8 bytes
    discriminant: 8 bytes
    variant `Read`: 8 bytes
        field `.0`: 8 bytes
    variant `NotReading`: 0 bytes
    variant `Reading`: 0 bytes
type: `std::sys::windows::process::Command`: 176
bytes, alignment: 8 bytes
    field `.cwd`: 32 bytes
    field `.program`: 32 bytes
    field `.env`: 32 bytes
```

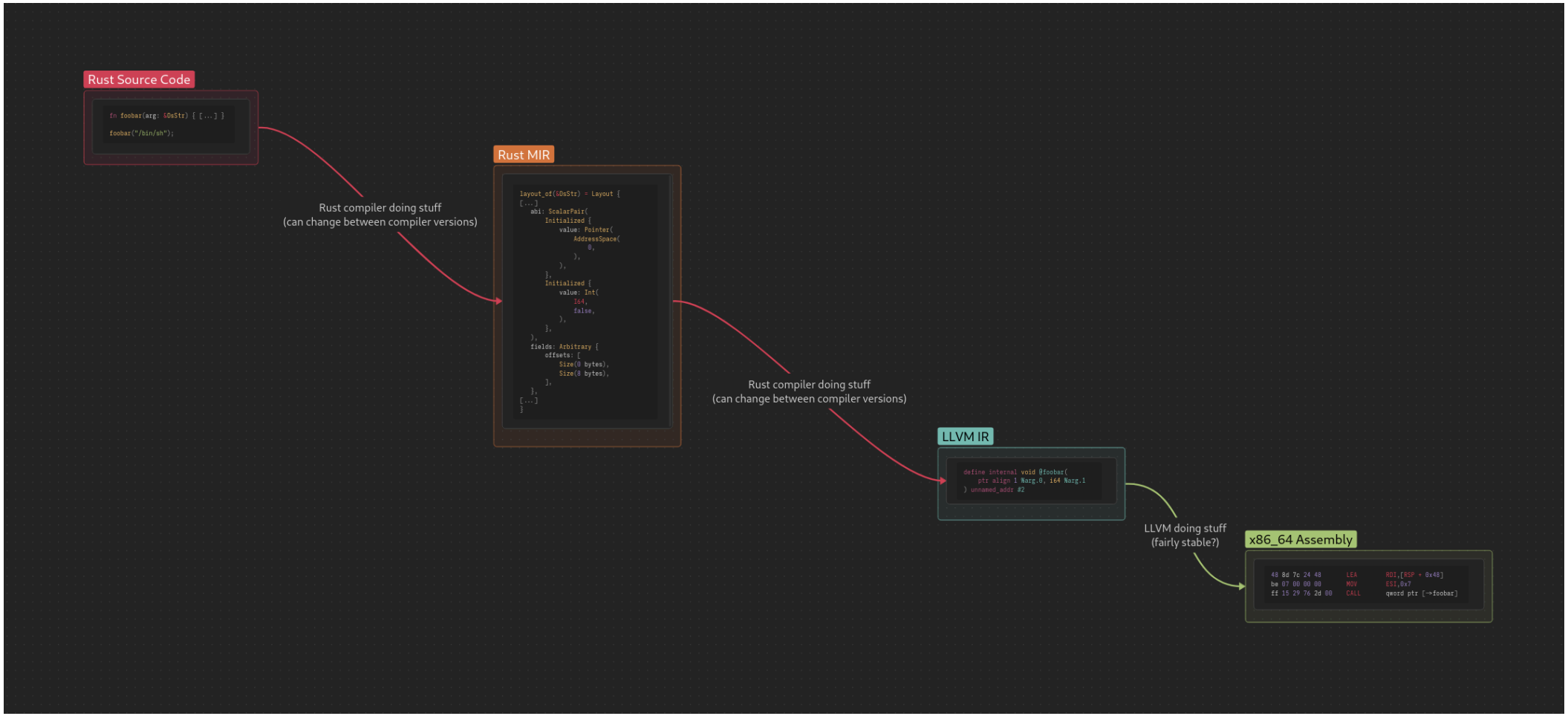
A note about Ghidra's "`__rustcall`", and Rust calling conventions in general

In general, the Rust compiler can do *whatever it wants* for function calls from Rust code to other Rust code - there is no "Rust ABI"!

Ghidra is defining a "`__rustcall`" here based on the registers that typically get used in x86_64 Rust code for Linux, and some analysis about how the compiler typically clobbers registers, but in reality there will be times where the decompilation is incorrect, and where you have to fix up the calling convention.

Ghidra/Processors/x86/data/extensions/rust/unix/cc.xml

```
<prototype name="__rustcall" extrapop="8" stackshift="8"
    <input pointermax="8">
[...]
    <pentry minsize="1" maxsize="8">
        <register name="RDI"/>
    </pentry>
    <pentry minsize="1" maxsize="8">
        <register name="RSI"/>
    </pentry>
    <pentry minsize="1" maxsize="8">
        <register name="RDX"/>
    </pentry>
    <pentry minsize="1" maxsize="8">
        <register name="RCX"/>
    </pentry>
    <pentry minsize="1" maxsize="8">
        <register name="R8"/>
    </pentry>
    <pentry minsize="1" maxsize="8">
        <register name="R9"/>
    </pentry>
    <pentry minsize="1" maxsize="500" align="8">
        <addr offset="8" space="stack"/>
    </pentry>
    <rule>
        <datatype name="any" minsize="9" maxsize="16" />
        <join align="true"/>
```


Rust Source Code
fn foobar(arg: &OsStr) { [...] }
foobar("/bin/sh");
Rust compiler doing stuff
(can change between compiler versions)
Rust MIR
layout_of(&OsStr) = Layout {
[...]
abi: ScalarPair(
Initialized {
value: Pointer(
AddressSpace(
0,
),
),
},
Initialized {
value: Int(
I64,
false,
),
},
),
fields: Arbitrary {
offsets: [
Size(0 bytes),
Size(8 bytes),
],
},
[...]
}
Rust compiler doing stuff
(can change between compiler versions)
LLVM IR
define internal void @foobar(
ptr align 1 %arg.0, i64 %arg.1
) unnamed_addr #2
LLVM doing stuff
(fairly stable?)
x86_64 Assembly
48 8d 7c 24 48 LEA RDI,[RSP + 0x48]
be 07 00 00 00 MOV ESI,0x7
ff 15 29 76 2d 00 CALL qword ptr [→foobar]

It’s just using the OS APIs under the hood

```
1  // ⚠ This is a Ghidra decompilation, not real source code!
2  undefined ** std::fs::write::inner(void *param_1,ulong param_2,void *param_3,ulong par
3  {
4  [...]
5    if (param_2 < 0x180) {
6      memcpy(&local_1b0,param_1,param_2);
7      *(undefined *)((long)&local_1b0 + param_2) = 0;
8      core::ffi::c_str::CStr::from_bytes_with_nul(&local_1c8,&local_1b0,param_2 + 1);
9      if (local_1c8 != 0) {
10       local_1d0 = &PTR_DAT_0041c428;
11       return local_1d0;
12     }
13     sys::pal::unix::fs::File::open_c(&local_1d8,local_1c0,&local_1e8);
14     __fd = local_1d4;
15     ppuVar3 = local_1d0;
16   }
17 [...]
18   if (local_1d8 == 0) {
19     if (param_4 != 0) {
```

Conclusion 

What did we learn here?

1. A centralized, open-source, well-documented standard library and compiler makes it easier for us to learn about what's going on under the hood.
2. A mature library ecosystem, a fairly high-level language, and general developer friendliness in the tooling means that Rust malware authors don't actually have to write a lot of code or spend a lot of effort, to generate something that's difficult for reversers.

What's next for Rust reversing?

- Building function signatures for standard and third-party libraries
  - → https://github.com/N0fix/rustbinsign is promising so far, but needs some work still
  - → You can get pre-built FLIRT signatures for many versions of Windows Rust standard libraries at https://github.com/N0fix/rust-std-sigs !
- Recovery of standard library type layouts and data

Acknowledgements

Thank you to everyone I have ever discussed Rust reversing with, who has sent me samples, who has looked at samples with me, and who has helped me out in understanding Rust better.

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- Johannes
- Josh
- Ken
- Leland
- Nordgaren
- N0fix

Questions?

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illustration of how we all feel