Concurrency

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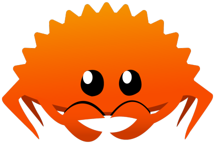
August 5, 2020

RustGraz community



Prologue

Recap: Rusty days

- Webference organized by Rust Wrocław
- 8 talks between 2020-07-27 and 2020-07-31
- I will give a short talk summary

Mon, 2020-07-27 — Steve Klabnik

“Should we have a Rust 2021 edition?”

Recap: Rust 2021 edition Talk

rustc is a multi-pass compiler: AST → HIR → MIR → LLVM-IR

HIR expand source code to simpler primitive statements (type checking, method lookup)

MIR is all about control flow (control-flow, borrow checking)

- *lowering*: “The MIR is then lowered to LLVM-IR”
- “cargo check” omits code generation step
- *goal*: “query-based” compiler (memoized answers)
- editions are not allowed to differ in MIR

nightly release every night

stable + beta release every six weeks

Recap: Rust 2021 edition Talk

Editions:

is	longer-term progress, breaking changes, new editions are opt-in, can't change everything
can	can introduce new keywords, repurpose syntax (e.g. deprecate trait, introduce dyn trait)
cannot	cannot change coherence rules, standard library

- when do editions happen? no policy
- edition 2018 (= rust 1.31) was "a really big project for the various teams" and "a lot of burnout amongst contributors" ("I was a total mess")
- editions feature-driven or time-boxed? time-boxed! 3 years is a nice compromise between yearly and 5-year releases
- Steve: We should have a 2021 edition. Much smaller than 2018.

Recap: Rust 2021 edition Talk

```
meisterluk@gardner ~ % cat test.rs
fn async() -> u64 {
    42
}

fn main() {
    println!("{}", async());
}

meisterluk@gardner ~ % rustc test.rs
```

Recap: Rusty days

```
meisterluk@gardner ~ % rustc --edition=2018 test.rs
error: expected identifier, found keyword `async`
 --> test.rs:1:4
  |
1 | fn async() -> u64 {
  |    ^^^^^ expected identifier, found keyword
  |
help: you can escape reserved keywords
      to use them as identifiers
  |
1 | fn r#async() -> u64 {
  |    ^^^^^^^
```

Mon, 2020-07-27 — Michalina Kotwica
“Low-level optimization of algebraic and similar structures”

Recap: Low-level optimization Talk

- type algebra
- unit & never type
- memory layout (ABI) of composite types (struct, enum, futures)
- struct Bar(u16, u8, u16, u8):
  `C: 11 11 33 xx 22 22 44 xx` `Rust: 11 11 22 22 33 44` (fields reordered)
- `Option` uses a discriminator, `Option<Option<u64>>` uses only one discriminator
- 41.2 % of enums have no type arguments, 16.4 % of enums have one type argument, 23.7 % of enums have two type arguments

Tue, 2020-07-28 — Peter Parkanyi

“Fast encrypted backups with Rust - ‘How I stopped worrying and love mmap’ ”

Recap: Fast encrypted backups Talk

https://github.com/rsdy/zerostash

- End-to-End Encryption
- latency and throughput
- Zero-metadata data stash: deduplicated, works as a file system and key/value store
- Cryptographic primitives:

  Passwords Argon2

  Indexing Blake2

  Compression LZ4

  Encryption ChaCha20-Poly1305

  Deduplication SeaHash
- Profiling: perf on Linux, Instruments on macOS
- mmap versus read

Wed, 2020-07-29 — Lachezar Lechev

“Drone Control - ‘Controlling a drone using Rust over WiFi’ ”

Recap: Drone Control Talk

`https://github.com/AeroRust/Welcome`

- TCP connections Handshake, establish connection
- JSON requests & responses
- ping-pong within 7s
- scroll crate: “A suite of powerful, extensible, generic, endian-aware Read/Write traits for byte buffers”

Wed, 2020-07-29 — Nell Shamrell - Harrington
“The Rust Borrow Checker - A Deep Dive”

Recap: Drone Control Talk

Slides on slideshare

- “Is the Borrow Checker a friend or a foe?”
- Stages of Compilation:
    1. Lexical Analysis
    2. Parsing
    3. Semantic Analysis (Borrow Checker!)
    4. Optimization
    5. Code Generation
- BC tracks initializations/moves and applies lifetime inference
- Lifetime of a variable has two definitions
    - “Span of time before the value of a variable gets freed”
    - “scope of a variable”
- “If you make a reference to a value, the lifetime of that reference cannot outlive the scope of the value”
- `https://rustc-dev-guide.rust-lang.org/`

Thu, 2020-07-30 - Jan-Erik Rediger

“Leveraging Rust to build cross-platform mobile libraries”

Recap: Mobile Libraries Talk

Slides on slideshare

- Firefox Telemetry project
- Collect performance metrics for our products, package pings at controlled schedules
- Three Principles
  - Stay Lean
  - Build Security
  - Engage Your Users
- Telemetry *scalars*: `Scalars.yaml` (metadata: bug_numbers, description, expires, notification_emails, ...)

Recap: Mobile Libraries Talk

- Glean core → Glean FFI → Glean Kotlin/Swift → Android/iOS app
- cbindgen crate: “A tool for generating C bindings to Rust code.”
- 10 Glean compilation targets supported
- Hello World with JNI (also see Otavio Pace’s talk)
- tagged unions are generated by bindgen for rust enums
- ProtoBuf to serialize data
- R8 minifies/optimizes JVM bytecode (successor to proguard)
- here: only invoke Rust code from Kotlin (never the other way around)

Fri, 2020-07-31 - Luca Palmieri

“Are we observable yet? Telemetry for Rust APIs - metrics, logging, distributed tracing”

Recap: Telemetry for Rust APIs Talk

- Developer of DonateDirect
- New project: fast versus reliable (metrics, tracing, logs, ...)
- Claim: convenience beats correctness
- Metrics give us an aggregate picture of the system state
- actix_web_prom crate provides a pluggable middleware with standard Prometheus metrics out of the box
- log crate and tracing crate to dump structured logging with JSON output and forward spans to elasticsearch and then kibana

Key takeaways:

- Lack of telemetry is a ticking bomb
- Diagnostic instrumentation has to be easy
- Metrics to alert and monitor system state
- High cardinality is key to being able to detect and triage unknown unknowns
- Span as unit of work abstraction
- You must be able to trace a request across different services

Fri, 2020-07-31 — Tim McNamara

“How 10 open source projects manage unsafe code”

Unsafe guidelines for the impatient:

- Use `#[deny(unsafe_code)]`
- Add comments to all unsafe blocks
- Let someone read the unsafe block comment.
  If they cannot explain afterwards, revise the comment

Remarks:

- Question `unsafe`! Look for safe alternatives
- rust std: “Unsafe code block need a comment explaining why they’re ok”
- “We try to create a situation where we, as a team, are building safe software and we are mentally switched on if we go to the unsafe module”
- UCG WG - Rust’s Unsafe Code Guidelines Working Group

Recap: Managing unsafe code Talk

- `actix_web` incident
- `#[deny(unsafe_code)]` and `#[allow(unsafe_code)]` (can be nested)
- cargo-geiger "detects usage of unsafe Rust in a Rust crate and its deps", introduces `#![forbid(unsafe_code)]`
- exa uses syscalls natively, BLAKE3 uses SIMD instructions, Firecracker interacts with a hybervisor, librsvg talks to GLib, toolshed deals with pointers in one module, terminusdb interacts with Prolog, Fuchsia OS interacts with the non-rust kernel

Dialogue

Concurrency

Definition: concurrency

In computer science, concurrency *is the ability of different parts or units of a program, algorithm, or problem to be executed out-of-order or in partial order, without affecting the final outcome.*

—*Concurrency (computer science)*

Definition: parallelism

Parallel computing *is a type of computation in which many calculations or the execution of processes are carried out simultaneously.*

—*Parallel computing*

Models of concurrency

Formally, different models exist:

- Parallel random-access machine
- Actor model
- Petri nets
- Process calculi (CCS, CSP, π-calculus)
- Tuple spaces
- Simple Concurrent Object-Oriented Programming (CSOOP)
- Reo Coordination Language

… to design distributed systems.

Models of concurrency

For example, Erlang is famous for its distributed computational model.

But, in rust, we stick to a von-Neumann-like model:

- Instructions are executed in order.
- We have stacks, heaps, bss and data sections to organize the memory.
- We make syscalls to the kernel and compile against some ISA.

Thus it is a question of an API. We define *concurrent units* and they might run in *parallel*.

Definition: concurrency

Concurrency as a question of level of granularity:

1. Instruction
2. blocks of instructions
3. Function
4. Several stacks, one heap
5. Process

In general: performance as incentive.

Problems of concurrency

1. Data dependency (synchronization problem)

   let A and B be two concurrent units.
   Both want to increment x

   A reads that x is 41

   B reads that x is 41

   A increments x and gets $y := 42$

   B increments x and gets $z := 42$

   A writes $x := y$

   B writes $x := z$

   x is 42
2. Concurrent units need to exchange messages
3. Concurrent unit waits for an event
4. Interrupt concurrent unit (*preemption*)
5. Determine concurrent unit has finished

In rust (from low-level to high-level)

On instruction-level

SIMD instructions

SIMD = **s**ingle **i**nstruction, **m**ultiple **d**ata

Run one instruction, apply arithmetic/logic/data-handling/memory instructions to several values simultaneously. 8/16/32/64/128/512

RISC-V I prefer to talk about the RISC-V ISA, but RISC-V basically dropped its Packed SIMD extension and develops a new "P" extension. Thus, I switch to x86_64.

x86_64 Streaming SIMD Extensions (SSE) and Advanced Vector Extensions (AVX)

SSE and AVX

Operands (put into XMM/YMM registers):

SSE	four f32
SSE2	two f64, two i64, four i32, eight i16, sixteen u8
SSE3	(only 13 new instructions)
SSE4	(only 54 new instructions)
AVX	eight f32, four f64
AVX2	256-bit registers for almost everything
AVX-512	512-bit registers but instructions split into multiple extensions

SIMD support

```
% cat /proc/cpuinfo | grep "sse\|avx"
flags    : fpu … sse sse2 … ssse3 … sse4_1 sse4_2
           … avx … avx2 … flush_l1d
flags    : fpu … sse sse2 … ssse3 … sse4_1 sse4_2
           … avx … avx2 … flush_l1d
flags    : fpu … sse sse2 … ssse3 … sse4_1 sse4_2
           … avx … avx2 … flush_l1d
flags    : fpu … sse sse2 … ssse3 … sse4_1 sse4_2
           … avx … avx2 … flush_l1d
```

(No) SIMD instructions

```rust
fn foo(a: &[u8], b: &[u8], c: &mut [u8]) {
    for ((a, b), c) in a.iter().zip(b).zip(c) {
      println!("{} {} {}", a, b, c);
        *c = *a + *b;
    }
}

fn main() {
  let a: [u8; 4] = [0xDE, 0xAD, 0xBE, 0xEF];
  let b: [u8; 4] = [0x00, 0x01, 0x02, 0x03];
  let mut c = [0u8; 4];
  foo(&a, &b, &mut c);

  println!("{:?}", c);
}
```

(No) SIMD instructions

On godbolt with `-C opt-level=1` (or 0):

```
.LBB58_2:
; …
mov     rdx, qword ptr [rsp + 24]
movzx   ecx, byte ptr [rcx]
add     cl, byte ptr [rax]
mov     byte ptr [rdx], cl
mov     rdi, r14
; …
jne     .LBB58_2
```

SIMD instructions

On godbolt with `-C opt-level=2` (or higher):

```
movdqu  xmm2, xmmword ptr [rdx + rcx + 32]
paddb   xmm2, xmm0
movdqu  xmm0, xmmword ptr [rdx + rcx + 48]
paddb   xmm0, xmm1
movdqu  xmmword ptr [r8 + rcx + 32], xmm2
```

paddb: “add packed integer” instruction

via std::arch (“SIMD and vendor intrinsics module”):

```
#[cfg(all(
  any(target_arch = "x86", target_arch = "x86_64"),
  target_feature = "avx2"
))]
fn foo() {
  #[cfg(target_arch = "x86")]
  use std::arch::x86::_mm256_add_epi64;
  #[cfg(target_arch = "x86_64")]
  use std::arch::x86_64::_mm256_add_epi64;

  unsafe {
    _mm256_add_epi64(...);
  }
}
```

SIMD summary

- rust uses the LLVM stack, which implements *auto-vectorization*
- usually, we get SIMD instructions for free
- sometimes, you want to use the explicitly
- you can always use inline assembly with unsafe (`x86::time::rdtsc`)
- packed_simd provides a high-level API
- also: faster, ssimd
- mostly, libraries are specific for an application domain, e.g.:
  - numeric-array crate
  - directx_math crate
  - pqcrypto-classicmceliece crate

On instruction-level

On OS thread level

Copy stack, share heap.

- rust uses the LLVM stack, which implements *auto-vectorization*

async & await

Similar to C# and JavaScript. `async` keyword.

```
async fn sub() -> u8 {
  42u8
}

fn main() {
  println!("{}", sub())
}
```

```
meisterluk@gardner ~ % rustc --edition=2018 async1.rs
error[E0277]: `impl std::future::Future`
              doesn't implement `std::fmt::Display`
 --> async1.rs:6:20
  |
6 |     println!("{}", sub())
  |                    ^^^^^ `impl std::future::Future`
  |      cannot be formatted with the default formatter
  |
  = help: the trait `std::fmt::Display` is not implemented for
    `impl std::future::Future`
  = note: in format strings you may be able to use `{:?}`
    (or {:#?} for pretty-print) instead
  = note: required by `std::fmt::Display::fmt`
  = note: this error originates in a macro (in Nightly builds,
    run with -Z macro-backtrace for more info)

error: aborting due to previous error

For more information about this error, try `rustc --explain E0277`.
```

A future represents a value, that is not ready yet. Eventually, the future resolves to a value.
—withoutboats in a Rust Latam talk 2019

`await` keyword. Not `await X`, but `X.await`.

```
async fn sub() -> u8 {
    42u8
}

fn main() {
    println!("{}", sub().await)
}
```

```
meisterluk@gardner ~ % rustc --edition=2018 async2.rs
error[E0728]: `await` is only allowed inside `async`
              functions and blocks
 --> async2.rs:6:20
  |
5 | fn main() {
  |    ---- this is not `async`
6 |     println!("{}", sub().await)
  |                    ^^^^^^^^^^^ only allowed
  |         inside `async` functions and blocks

error: aborting due to previous error

For more information about this error, try `rustc --explain E0728`.
```

So who can call the first async function? the *executor* (scheduler)

- e.g. async-std, smol, tokio
- executor is thus exchangable
- executor allocates memory per future
- futures are like state machines between states

the *reactor*:

- Executor: is future X ready to go? Yes, then go. Else:
- Reactor: I will take care of the future and report back when its ready

```rust
use smol::io;

async fn sub() -> u8 {
  42u8
}


fn main() -> io::Result<()> {
    smol::run(async {
        println!("{}", sub().await);
        Ok(())
    })
    // prints 42
}
```

```rust
async fn sub() -> u8 {
    42u8
}

fn main() {
    async {
        println!("{}", sub().await)
    };
}
```

```
meisterluk@gardner ~ % rustc --edition=2018 async3.rs
warning: unused implementer of `std::future::Future`
         that must be used
 --> async3.rs:6:5
  |
6 | /     async {
7 | |         println!("{}", sub().await)
8 | |     };
  | |______^
  |
  = note: `#[warn(unused_must_use)]` on by default
  = note: futures do nothing unless you `.await`
          or poll them

warning: 1 warning emitted

meisterluk@gardner ~ % ./async3    # prints nothing
```

Other async/await implementations:

- Calling an async function, schedules it
- Javascript calls *Promise*, what rust calls *Future*
- Green threads: a scheduler is compiled in every executable to manage small threads (M:N threading) (not OS threads!) (e.g. erlang, golang goroutines). rust 1.0 dropped green threads.

Rust implementations:

- Zero-cost: only await schedules the function ("lazy")

futures, an official Rust crate that lives in the rust-lang repository A runtime of your choosing, such as Tokio, async$_std, smol, etc.$

```rust
fn get_two_sites() {
  // Spawn two threads to do work.
  let thread_one = thread::spawn(|| download("https://foo.com"));
  let thread_two = thread::spawn(|| download("https://bar.com"));

  // Wait for both threads to complete.
  thread_one.join().expect("thread one panicked");
  thread_two.join().expect("thread two panicked");
}
```

threading approach via async-book

```
async fn get_two_sites_async() {
  // Create two different "futures" which, when run to completion,
  // will asynchronously download the webpages.
  let future_one = download_async("https://foo.com");
  let future_two = download_async("https://bar.com");

  // Run both futures to completion at the same time.
  join!(future_one, future_two);
}
```

async approach via async-book

async & await summary

- Async-await is a way to write functions that can ”pause”, return control to the runtime, and then pick up from where they left off
- proposed 2016, didn’t make edition 2018, landed in rust 1.39
- Memory management
- wasm-bindgen-futures binds Rust Future to Javascript Promise

async & await summary

locking ——-

mutex → drop semaphores condvars Arc atomic operations

FnOnce, FnMut, Fn

threading ———

thread::spawn Arc Sync, Send traits lightweight threads? channels which stdlib fn is threadsafe typical producer-consumer example sync & await memory ordering / barrier move data structures between threads future #CPUs Executer takes # of concurrent units

multiprocessing & IPC ————————

shared memory pipes temp files mmap

TODO

TODO smaller source code

```
/// Desugar `ExprKind::Try` from: `<expr>?` into:
/// ```rust
/// match Try::into_result(<expr>) {
///   Ok(val) => #[allow(unreachable_code)] val,
///   Err(err) =>
///     #[allow(unreachable_code)]
///     // If there is an enclosing `try {...}`:
///     break 'catch_target Try::from_error(From::from(err)),
///     // Otherwise:
///     return Try::from_error(From::from(err)),
/// }
/// ```
```

via expr.rs line 1166, `try {…}` is experimental.

Epilogue

Quiz

TODO Q1

TODO Q2

TODO Q3?

TODO Q4

Quiz

TODO Q1

TODO A1

TODO Q2

TODO Q3?

TODO Q4

Quiz

TODO Q1
: TODO A1

TODO Q2
: TODO

TODO Q3?

TODO Q4

Quiz

TODO Q1
: TODO A1

TODO Q2
: TODO

TODO Q3?
: TODO

TODO Q4

Quiz

TODO Q1

TODO A1

TODO Q2

TODO

TODO Q3?

TODO

TODO Q4

TODO

Next time

Next meetup	Wed, 2020/08/26
Topic	I/O (files, file formats, simple TCP server)

Thank you!