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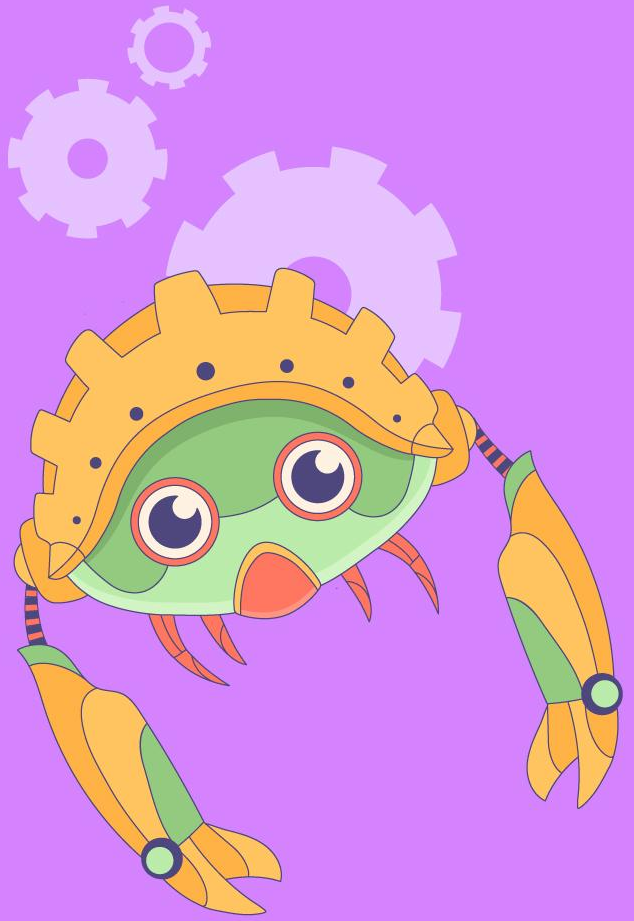
Engineering Manager @ HERE Technologies

Observing Tokio

Shining a light into your async runtime.



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Let's be friends!

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rust for lunch: lunch.rs

Overview

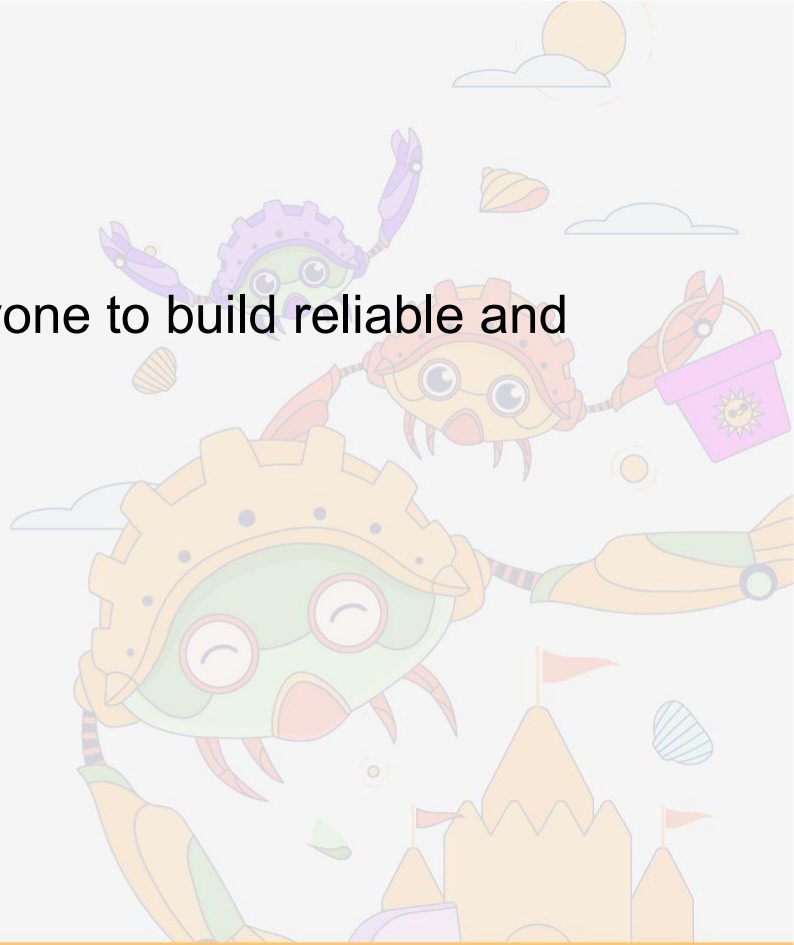
- Context
- Tokio
- Metrics
- Tokio Console
- Task Dump
- Present & Future
- Links

Context

First, a little bit of context.

Rust

- A language empowering everyone to build reliable and efficient software.
- …we're at RustLab, right?

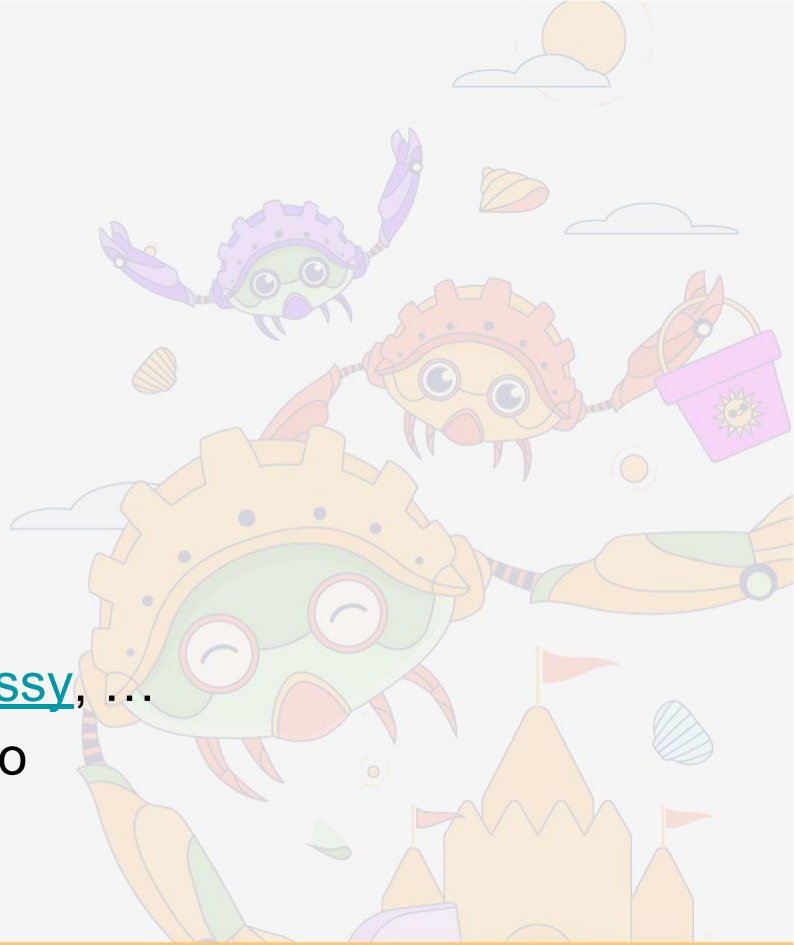


Asynchronous (async) programming

- A concurrent programming model
- Difference between parallelism and concurrency?
  - Parallelism is when you **do** many things at the same time
  - Concurrency is when you **wait** for many things at the same time
- Basic unit of concurrency: task
- Run many async tasks on few OS threads
- (Often) scheduling is cooperative

Rust, but async

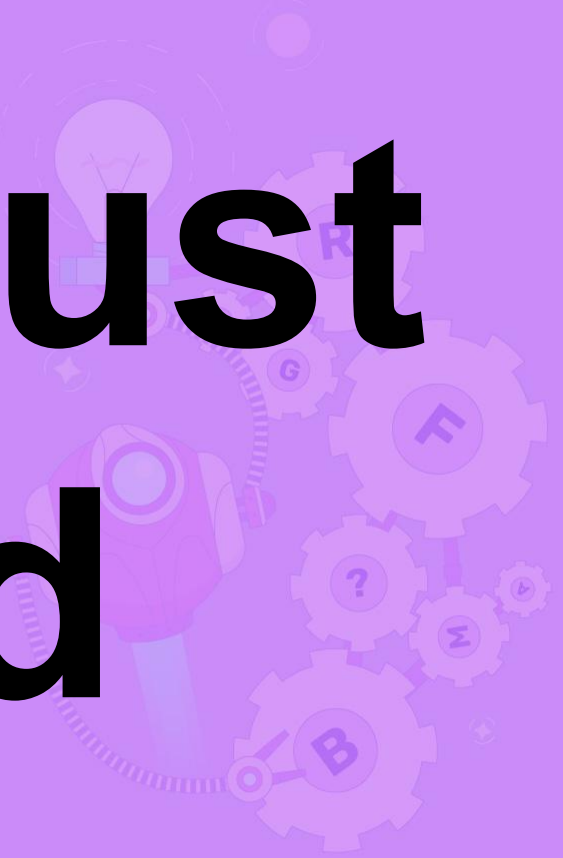
- Rust provides…
  - some async definitions
  - async/.await syntax
  - **no** async runtime!
- You get to pick your own
- Tokio, Async-std, Smol, Embassy, …
- It's likely that you're using Tokio



Async Rust can be a bit tricky

- Cooperative scheduling is fine until someone doesn't cooperate
- `async`/`.await` syntax gets converted into Futures
- Stack traces aren't so meaningful
- The debugger overly affects what happens next
- Sometimes your application just hangs...

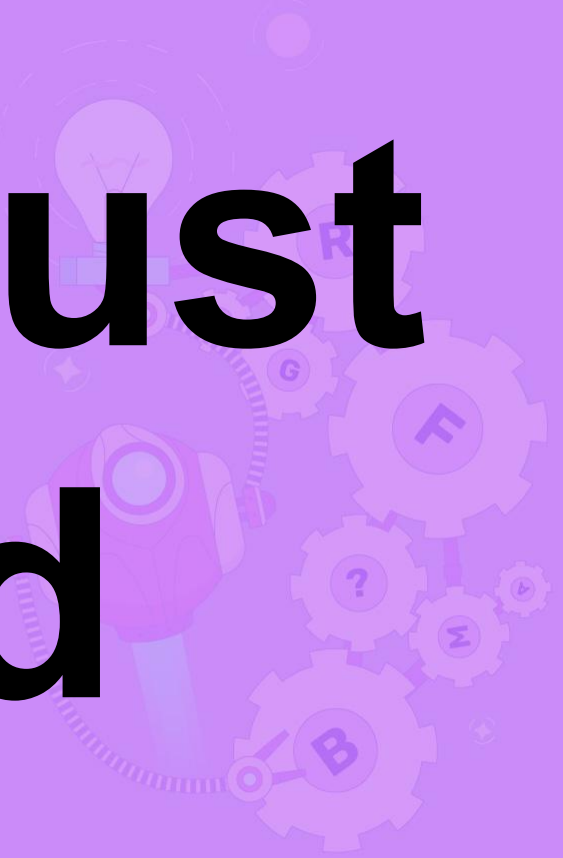
Async Rust is Hard



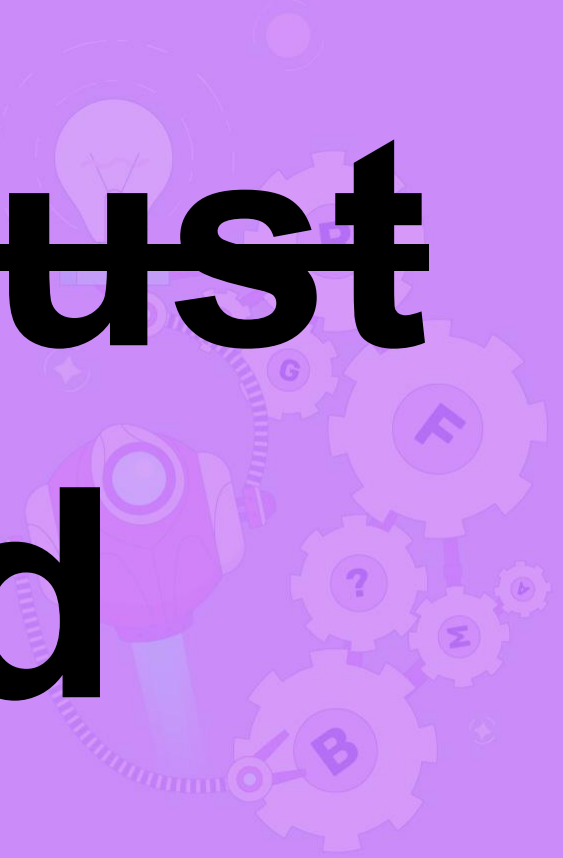
Last minute slide

- Wait!
- Async Rust is hard?
- Didn’t we already see this yesterday?
- Antonio Scandurra stole the premise of my talk! 😝
- Property-Testing Async Code in Rust
- The perfect companion for what I’m going to show
- Back to our regularly scheduled programming…

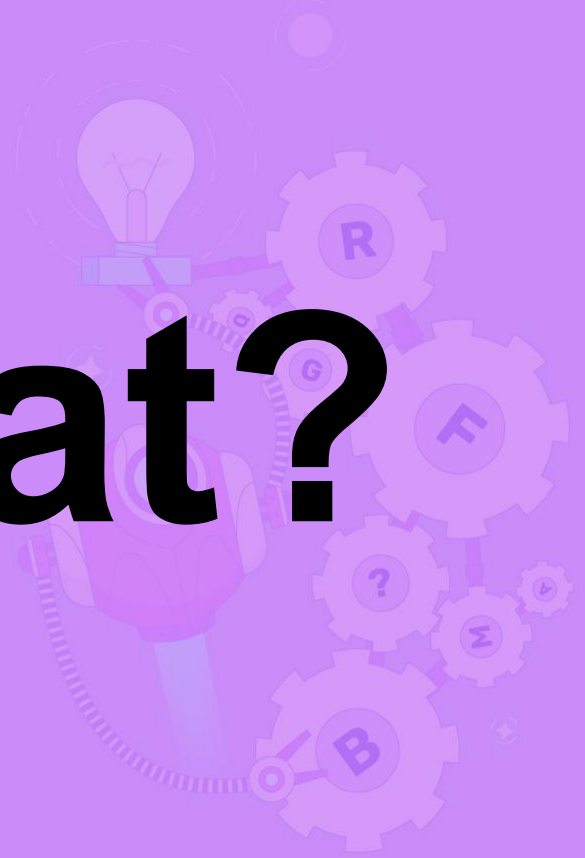
Async Rust is Hard



Async ~~Rust~~ is Hard

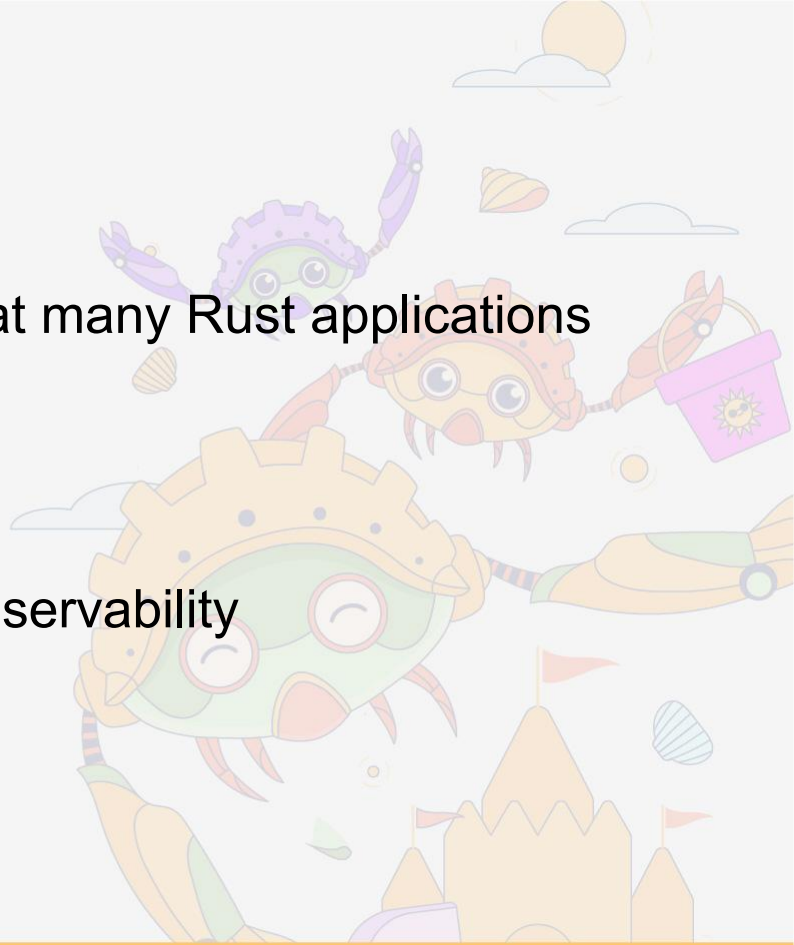


now what?



Superpowers

- Luckily we have something that many Rust applications don't have
- Superpowers!
- Actually: a runtime
- This is where we can insert observability



Observability

“[Observability is] a measure of how well you can understand and explain any state your system can get into, no matter how novel or bizarre.”

– Observability Engineering by Charity Majors, Liz Fong-Jones, and George Miranda (O'Reilly).

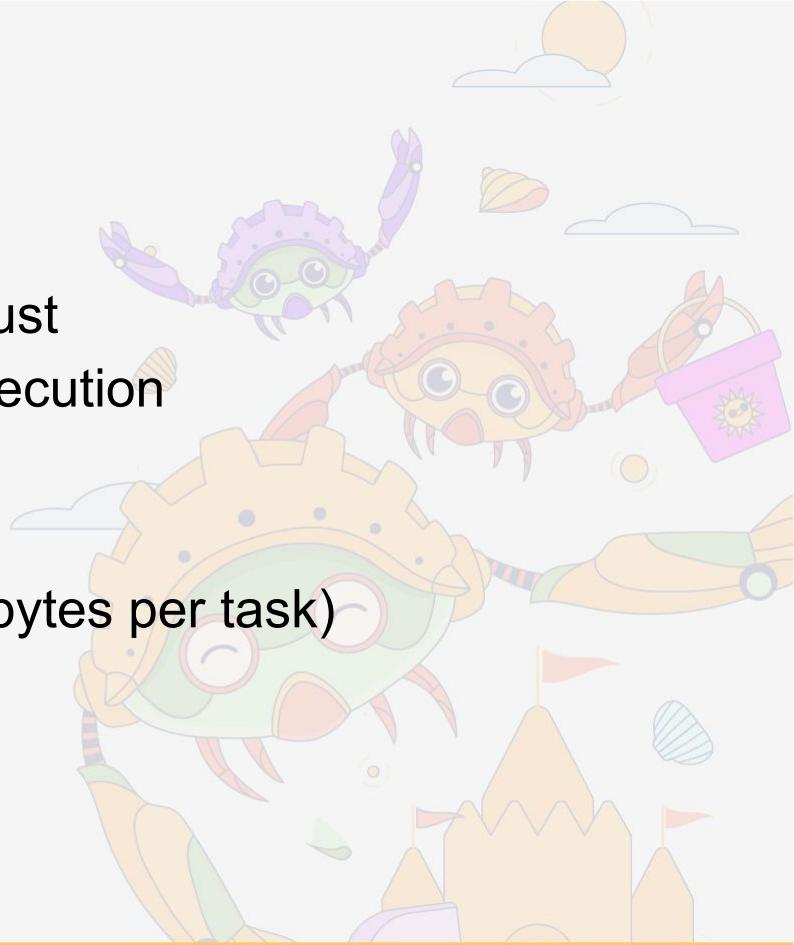
- Do we have "full" observability of Tokio?
- Not yet. But more than you might imagine!

Tokio

A runtime for writing reliable, asynchronous, and slim applications with the Rust programming language.

What is Tokio?

- A popular async runtime for Rust
- Drives task scheduling and execution
- Cooperative scheduling
- Work stealing
- Tasks are low-overhead (~88 bytes per task)



What else?

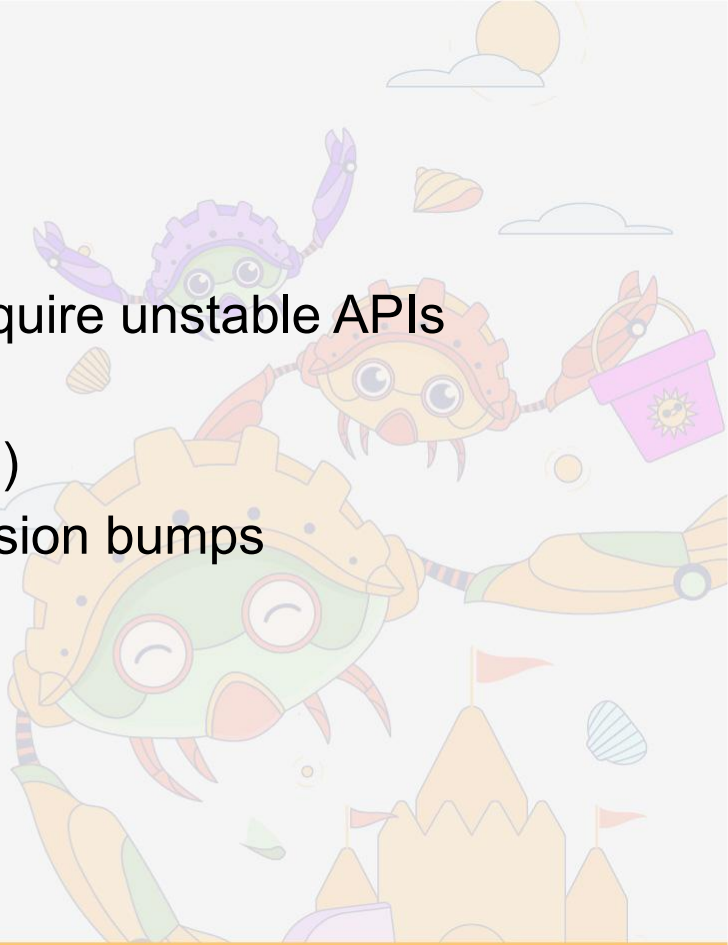
- Timers
- Synchronization primitives
- Network and file I/O
- Message passing channels
- ~~Kitchen sink~~
- "Batteries included"

Instrumentation

- Tokio has instrumentation built in
  - Metrics
  - Traces
  - Task Dumps
- This provides the observability we need

Unstable

- Most tools in this presentation require unstable APIs
- Unstable doesn't mean untested
- (although it does mean less used)
- API may break outside major version bumps



Unstable

```
# Set the RUSTFLAGS variable
RUSTFLAGS="--cfg tokio_unstable" cargo build

# Contents of .cargo/config
[build]
rustflags = ["--cfg", "tokio_unstable"]
```

Metrics

Monitor key metrics of tokio tasks and runtimes.

Metrics in Tokio

- Metrics are counts or measures aggregated over time
- Tokio has runtime metrics
- The tokio-metrics util crate adds functionality

Runtime metrics

- Available from runtime `Handle`
- 25 metrics, including
  - Active task count
  - Poll time histograms
  - Worker metrics
  - I/O driver metrics
  - and more...

Using runtime metrics

```rust
#[tokio::main]
async fn main() {
    let metrics: tokio::runtime::RuntimeMetrics = tokio::runtime::Handle::current().metrics();

    for _ in 0..10 {
        tokio::spawn(tokio::time::sleep(Duration::from_millis(10)));
    }

    let n = metrics.active_tasks_count();
    println!("Runtime has {} active tasks", n);
}
```

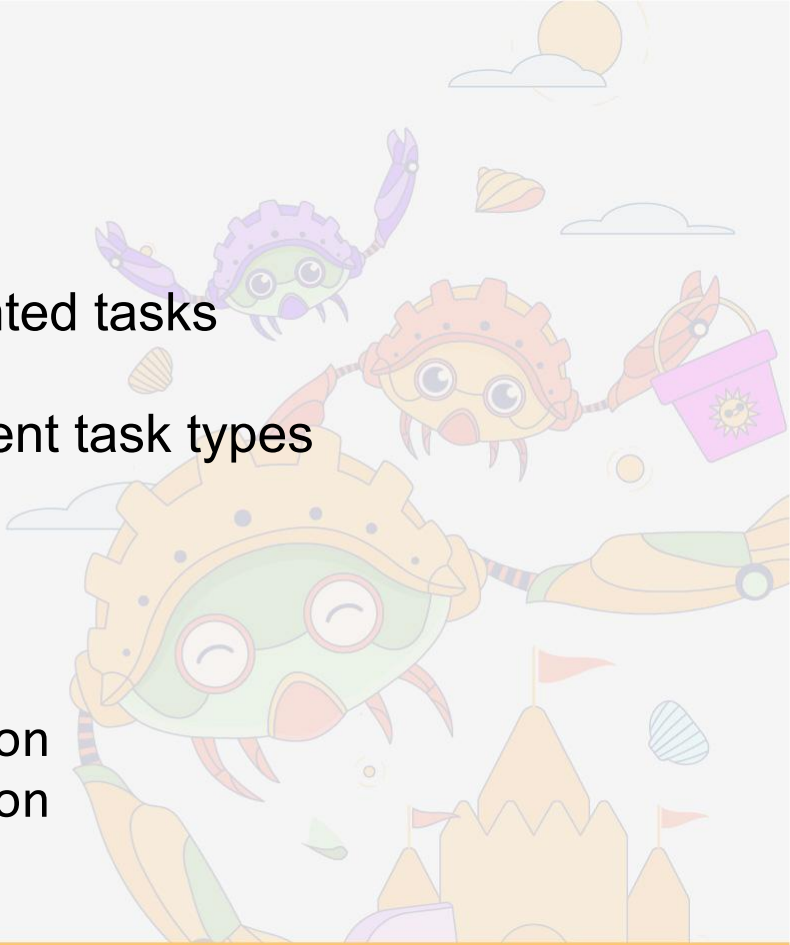
```
Runtime has 10 active tasks
```

`tokio-metrics` crate

- Provides patterns for monitoring tasks or whole runtimes
- Iterator yields metric intervals
- Metrics are provided for the interval since the last call
- Great for preparing metrics for a collector
  - e.g. Prometheus

Task Monitor (no `tokio_unstable` required)

- Track key metrics of instrumented tasks
- Explicitly instrument tasks
- Use distinct monitors for different task types
- Recorded metrics
  - `total_poll_count`
  - `total_idle_duration`
- Derived metrics
  - `mean_scheduled_duration`
  - `mean_fast_poll_duration`



Slow polls and long delays

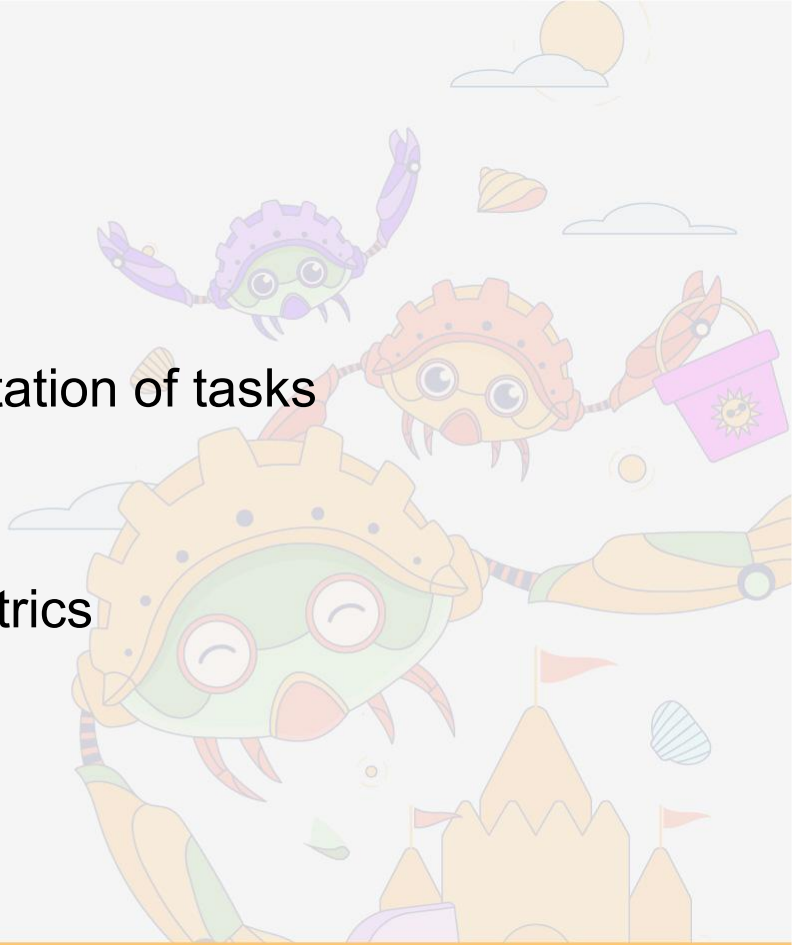
- Separate poll times into slow and fast (50µs)
- Separate schedule delays into long and short (50µs)
- Answer questions like, are my tasks…
  - taking longer to poll?
  - spending more time waiting to be polled?
  - spending more time waiting on external events to complete?
- Incredible documentation!

Using Task Monitor

```rust
let task_monitor = tokio_metrics::TaskMonitor::new();

for idx in 0..100 {
   tokio::spawn(task_monitor.clone().instrument(good_times(idx)));
}

let mut intervals = task_monitor.intervals();
for _ in 0..10 {
   tokio::time::sleep(Duration::from_millis(100)).await;
   let interval = intervals.next().unwrap();
   println!("{:#?}", interval);
}
```

Runtime Monitor

- Metrics for entire runtime
- No need for explicit instrumentation of tasks
- Wraps Tokio’s RuntimeMetrics
  - Intervals for metrics
  - Snapshot of all worker metrics
  - Derived metrics



Worker metrics

- Useful summaries of worker behavior
  - `max_busy_duration`
  - `mean_poll_duration_worker_max`
  - `min_steal_operations`
  - `max_overflow_count`

Using runtime monitor

```rust
let handle = tokio::runtime::Handle::current();
let runtime_monitor = tokio_metrics::RuntimeMonitor::new(&handle);

for _ in 0..10 {
    tokio::spawn(tokio::time::sleep(Duration::from_millis(10)));
}

let mut intervals = runtime_monitor.intervals();
for _ in 0..10 {
    let interval = intervals.next().unwrap();
    println!("{:?}", interval);
    tokio::time::sleep(Duration::from_millis(10)).await;
}
```

Integration with prometheus

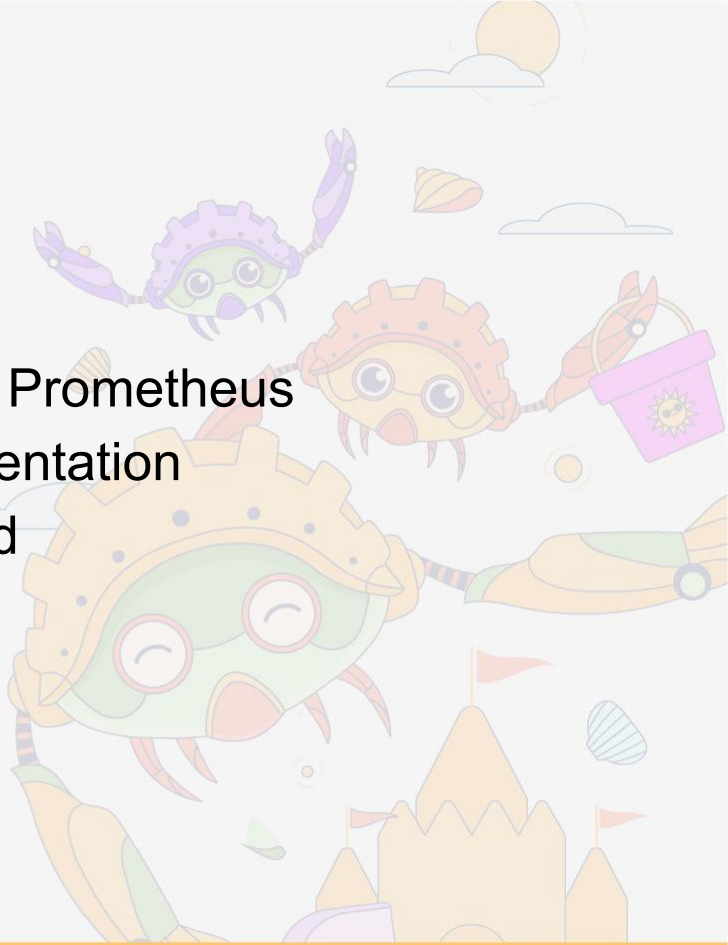
- Monitors are easy to integrate with collectors
- The `prometheus` crate for example
- But there is some boilerplate involved...

```
let tokio_metrics = TokioMetrics {
   worker_count: register(
       registry,
       IntGauge::with_opts(Opts::new(
           "tokio_worker_count_total",
           "The number of worker threads used by the runtime.",
       )),
   ),
   // Many more here...
}

// During `/metrics` request ...
let runtime_metrics = intervals.next().unwrap();
tokio_metrics.worker_count.set(runtime_metrics.workers_count as i64);
// And more ...
```

Did someone say pretty graphs?

Summary: Metrics

- Available from runtime Handle
- Can be exposed to tools such as Prometheus
- Task metrics for targeted instrumentation
  - No `tokio_unstable` required
- Lightweight
- Suitable for running in production



Tokio Console

A diagnostics and debugging tool for asynchronous Rust programs.

Introducing Tokio Console

- Built on tracing instrumentation in Tokio
- **Subscriber**
  - Collects and analyzes traces from within target application
- **Console**
  - Terminal application to visualize and explore runtime state
- **API**
  - gRPC API that defines the communication between subscriber and console

Enabling console subscriber

- Add the crate to your Cargo.toml

```
[dependencies]
console-subscriber = "0.2"
```

- Not using tracing yet? Easy!

```
#[tokio::main]
async fn main() {
    console_subscriber::init();
    // All your code ...
}
```

Enabling console subscriber

- Already using another tracing subscriber?
- Also easy!

```
fn tracing_setup() {
    use tracing_subscriber::prelude::*;

    let another_layer = // ...
    let console_layer =
         console_subscriber::ConsoleLayer::builder()
             .spawn();

    tracing_subscriber::registry()
        .with(console_layer)
        .with(another_layer)
        .init();
}
```

Start the console

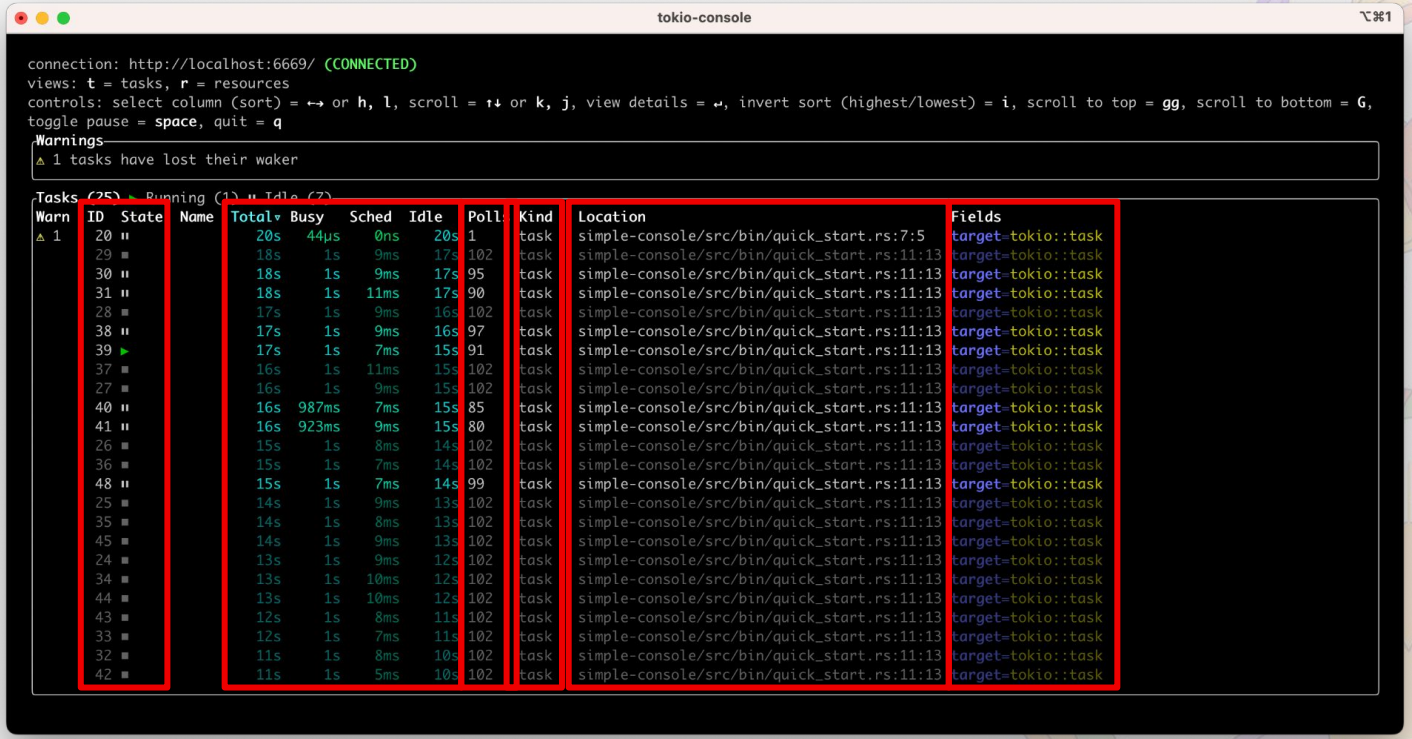
- Install from cargo
- And run from the command line
- For best experience, ensure UTF-8

```
cargo install tokio-console
```

```
tokio-console
```

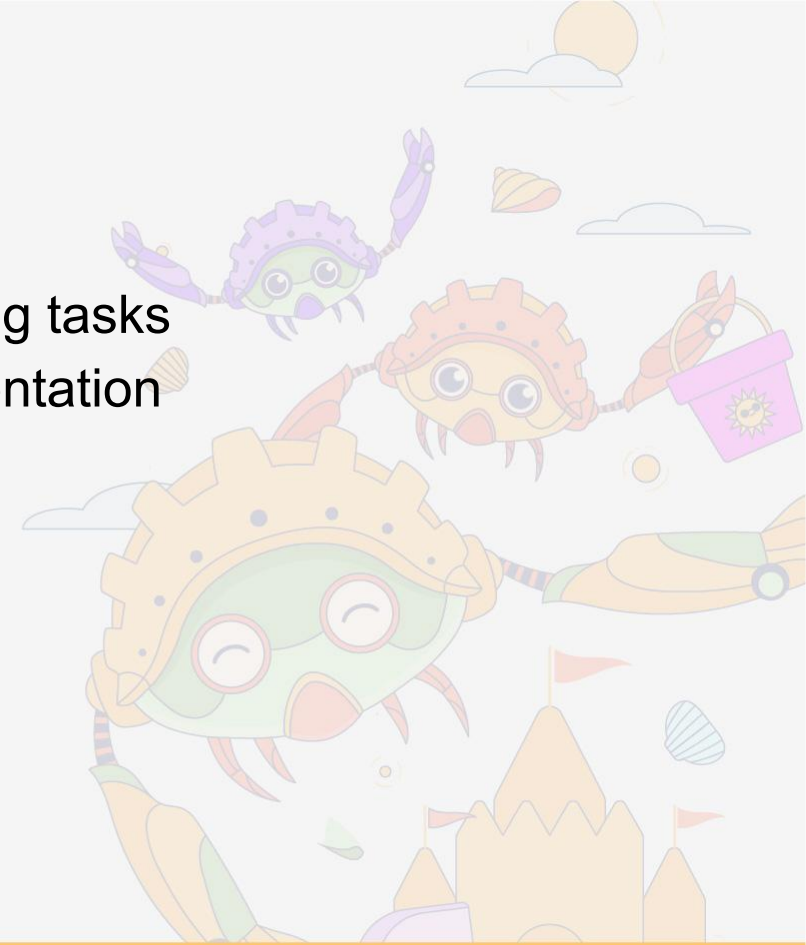
```
tokio-console --lang=en_us.UTF-8
# or
LANG="en_us.UTF-8" tokio-console
```

Task list


tokio-console
⌥⌘1
connection: http://localhost:6669/ (CONNECTED)
views: t = tasks, r = resources
controls: select column (sort) = ←→ or h, l, scroll = ↑↓ or k, j, view details = ↵, invert sort (highest/lowest) = i, scroll to top = gg, scroll to bottom = G, toggle pause = space, quit = q
Warnings
⚠ 1 tasks have lost their waker
Tasks (25) ▶ Running (1) ⏸ Idle (7)
Warn ID State Name Total Busy Sched Idle Polls Kind Location Fields
⚠ 1 20 ⏸ 20s 44µs 0ns 20s 1 task simple-console/src/bin/quick_start.rs:7:5 target=tokio::task
29 ■ 18s 1s 9ms 17s 102 task simple-console/src/bin/quick_start.rs:11:13 target=tokio::task
30 ⏸ 18s 1s 9ms 17s 95 task simple-console/src/bin/quick_start.rs:11:13 target=tokio::task
31 ⏸ 18s 1s 11ms 17s 90 task simple-console/src/bin/quick_start.rs:11:13 target=tokio::task
28 ■ 17s 1s 9ms 16s 102 task simple-console/src/bin/quick_start.rs:11:13 target=tokio::task
38 ⏸ 17s 1s 9ms 16s 97 task simple-console/src/bin/quick_start.rs:11:13 target=tokio::task
39 ▶ 17s 1s 7ms 15s 91 task simple-console/src/bin/quick_start.rs:11:13 target=tokio::task
37 ■ 16s 1s 11ms 15s 102 task simple-console/src/bin/quick_start.rs:11:13 target=tokio::task
27 ■ 16s 1s 9ms 15s 102 task simple-console/src/bin/quick_start.rs:11:13 target=tokio::task
40 ⏸ 16s 987ms 7ms 15s 85 task simple-console/src/bin/quick_start.rs:11:13 target=tokio::task
41 ⏸ 16s 923ms 9ms 15s 80 task simple-console/src/bin/quick_start.rs:11:13 target=tokio::task
26 ■ 15s 1s 8ms 14s 102 task simple-console/src/bin/quick_start.rs:11:13 target=tokio::task
36 ■ 15s 1s 7ms 14s 102 task simple-console/src/bin/quick_start.rs:11:13 target=tokio::task
48 ⏸ 15s 1s 7ms 14s 99 task simple-console/src/bin/quick_start.rs:11:13 target=tokio::task
25 ■ 14s 1s 9ms 13s 102 task simple-console/src/bin/quick_start.rs:11:13 target=tokio::task
35 ■ 14s 1s 8ms 13s 102 task simple-console/src/bin/quick_start.rs:11:13 target=tokio::task
45 ■ 14s 1s 9ms 13s 102 task simple-console/src/bin/quick_start.rs:11:13 target=tokio::task
24 ■ 13s 1s 9ms 12s 102 task simple-console/src/bin/quick_start.rs:11:13 target=tokio::task
34 ■ 13s 1s 10ms 12s 102 task simple-console/src/bin/quick_start.rs:11:13 target=tokio::task
44 ■ 13s 1s 10ms 12s 102 task simple-console/src/bin/quick_start.rs:11:13 target=tokio::task
43 ■ 12s 1s 8ms 11s 102 task simple-console/src/bin/quick_start.rs:11:13 target=tokio::task
33 ■ 12s 1s 7ms 11s 102 task simple-console/src/bin/quick_start.rs:11:13 target=tokio::task
32 ■ 11s 1s 8ms 10s 102 task simple-console/src/bin/quick_start.rs:11:13 target=tokio::task
42 ■ 11s 1s 5ms 10s 102 task simple-console/src/bin/quick_start.rs:11:13 target=tokio::task

Task Names

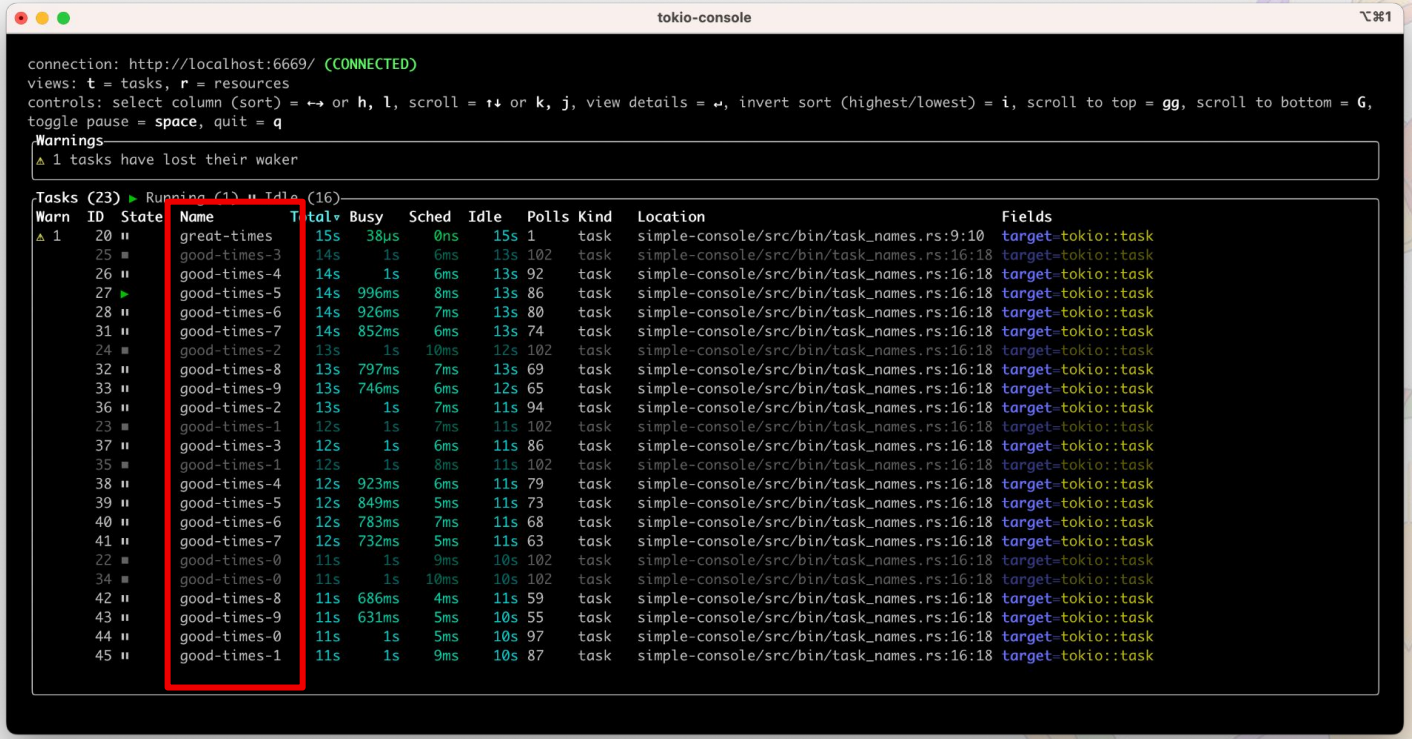
- Task builder API allows naming tasks
- Only used by tracing instrumentation
- Very useful in Tokio Console



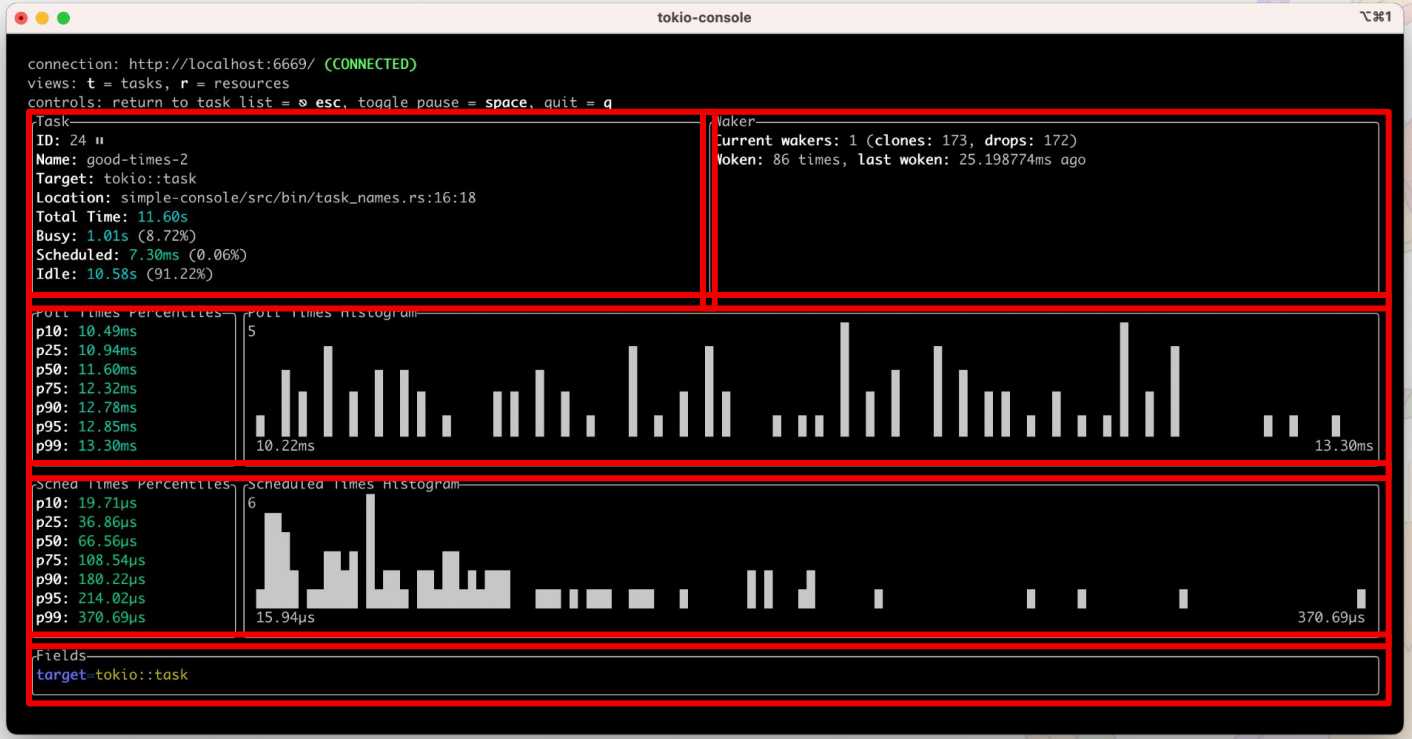
Sample code with task names

```rust
#[tokio::main]
async fn main() {
    console_subscriber::init();

    tokio::task::Builder::new()
        .name("great-times")
        .spawn(great_times())
        .unwrap();
}
```

Task list with names

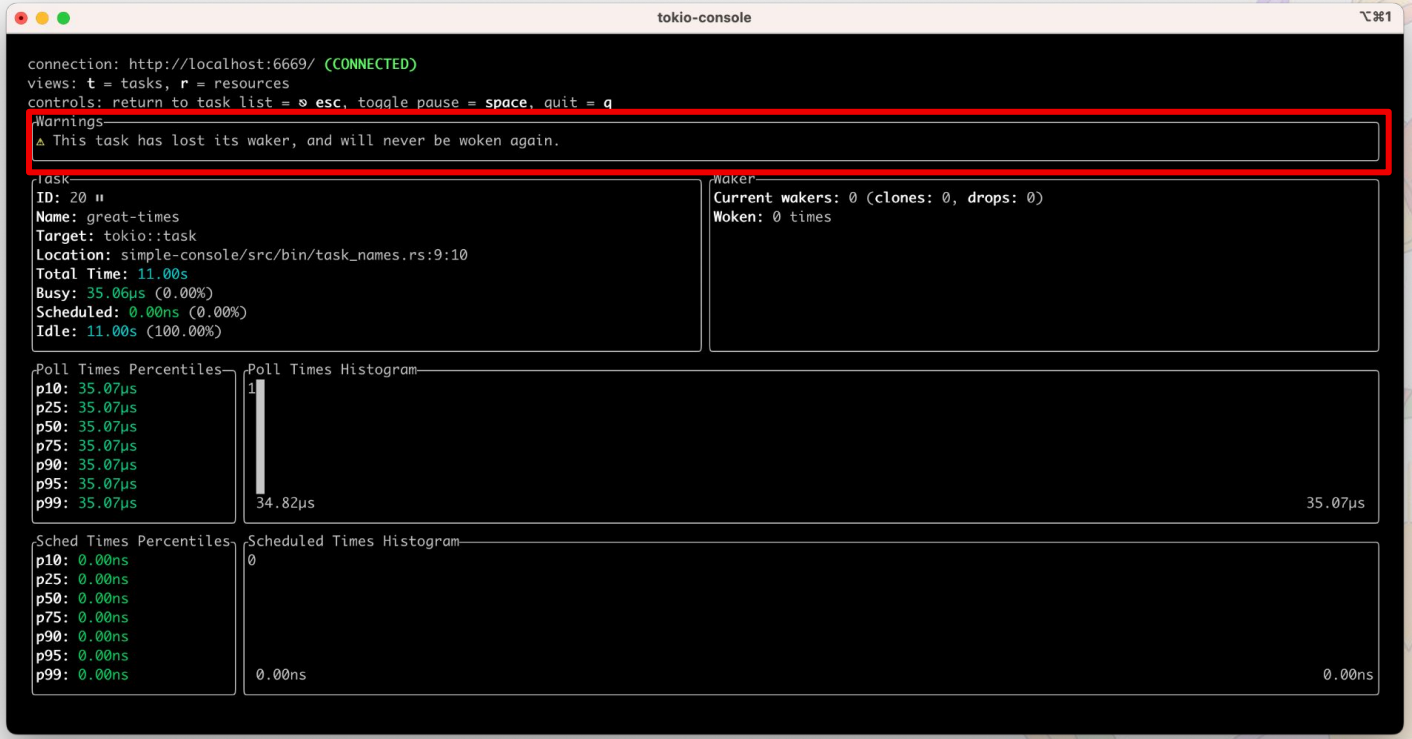


Task details



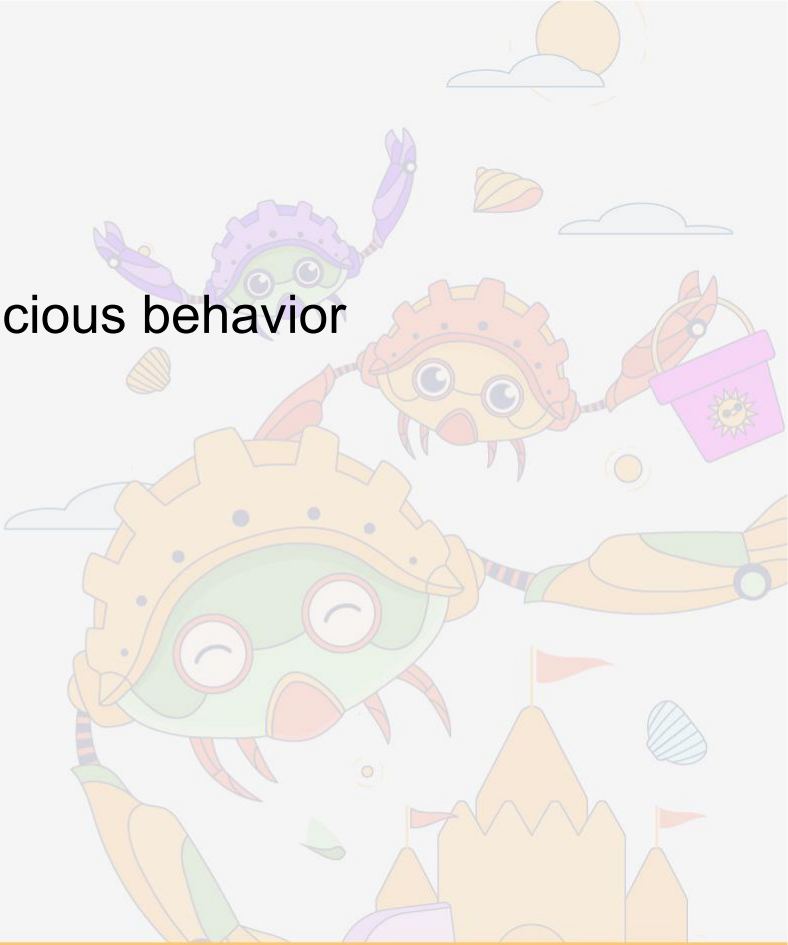
A wild warning has appeared!

Task details



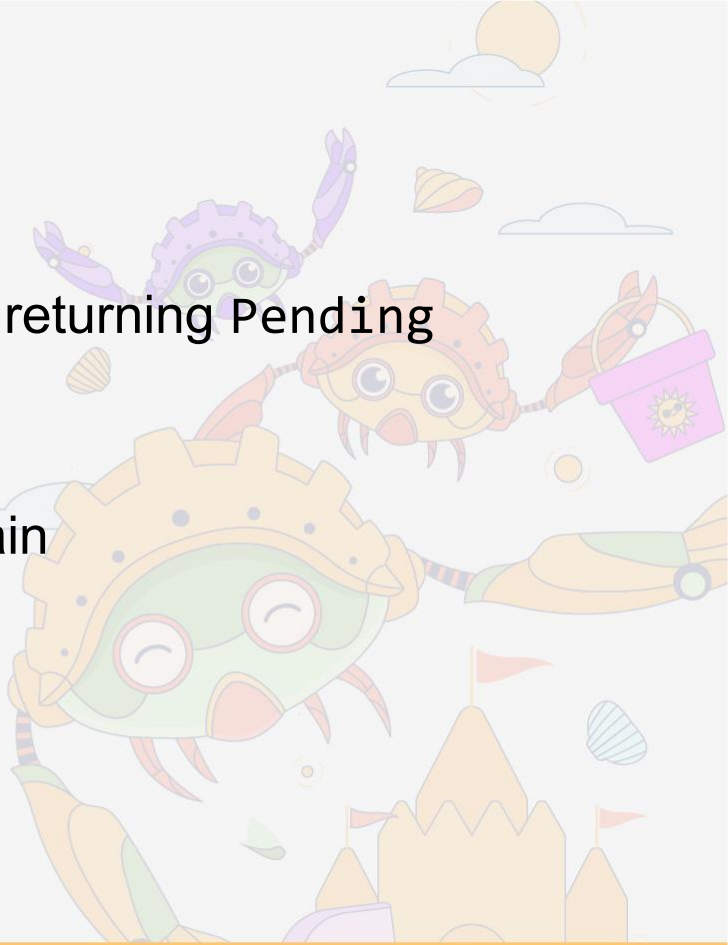
Lints

- Tokio console can detect suspicious behavior
- Detection provided by lints
  - Lost waker
  - Self wakes
  - Never yielded
  - More to come...



Lost waker

- An idle task must be woken after returning `Pending`
- Done via the “waker”
- If the waker isn’t held on to…
- The task will never be woken again

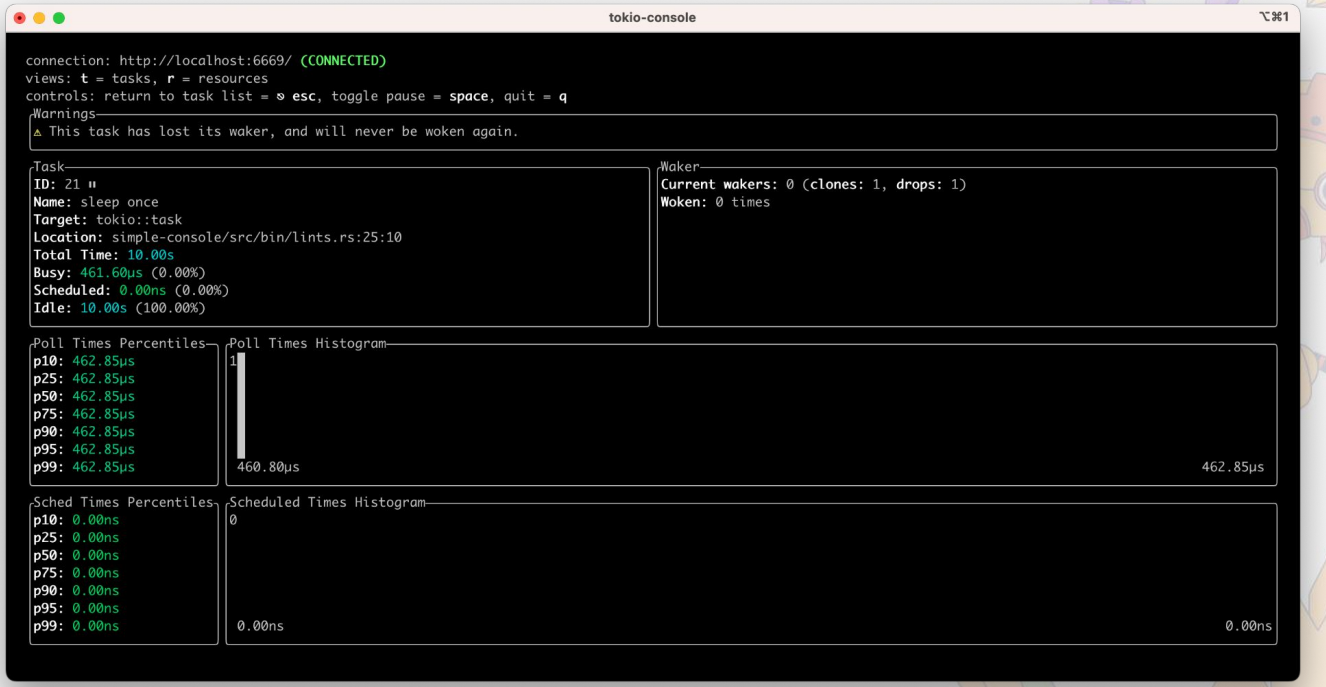


Lost waker - what could it be?

```rust
fn poll(
    mut self: std::pin::Pin<&mut Self>,
    cx: &mut std::task::Context<'_>,
) -> std::task::Poll<Self::Output> {
    if !self.slept {
        let mut sleep = Box::pin(tokio::time::sleep(Duration::from_millis(100)));
        if let Poll::Ready(_) = sleep.poll_unpin(cx) {
            self.slept = true
        }
        return Poll::Pending;
    }
    Poll::Ready(())
}
```

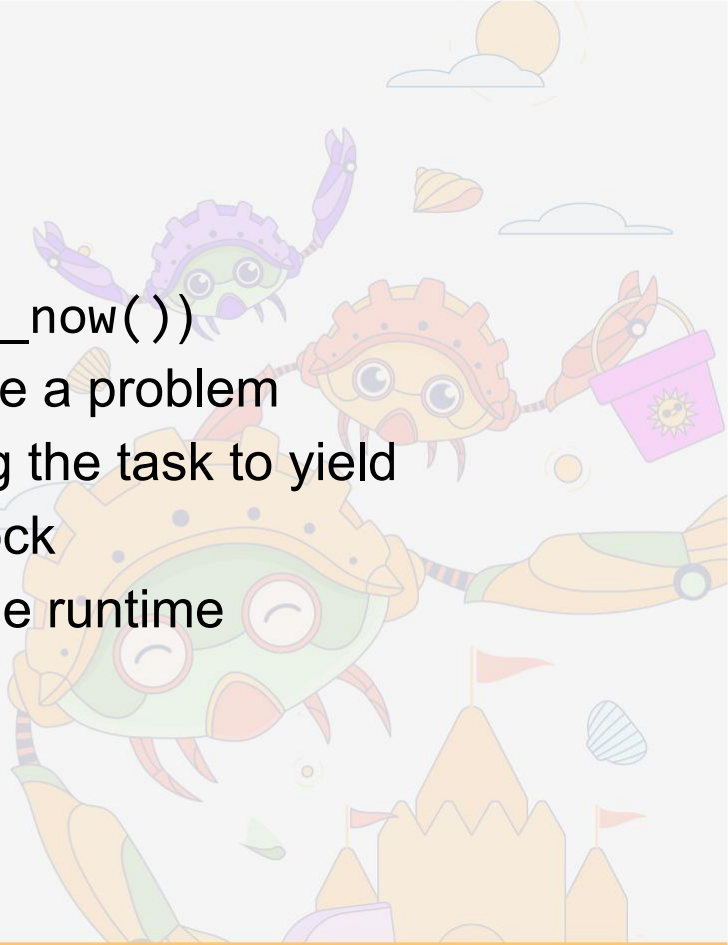
We're not keeping `sleep` anywhere!

Lost waker - diagnostics



Self wakes

- A task may self wake (e.g. `yield_now()`)
- Self waking too often may indicate a problem
  - Tokio's coop budget is forcing the task to yield
  - The task would otherwise block
  - Consider moving it outside the runtime

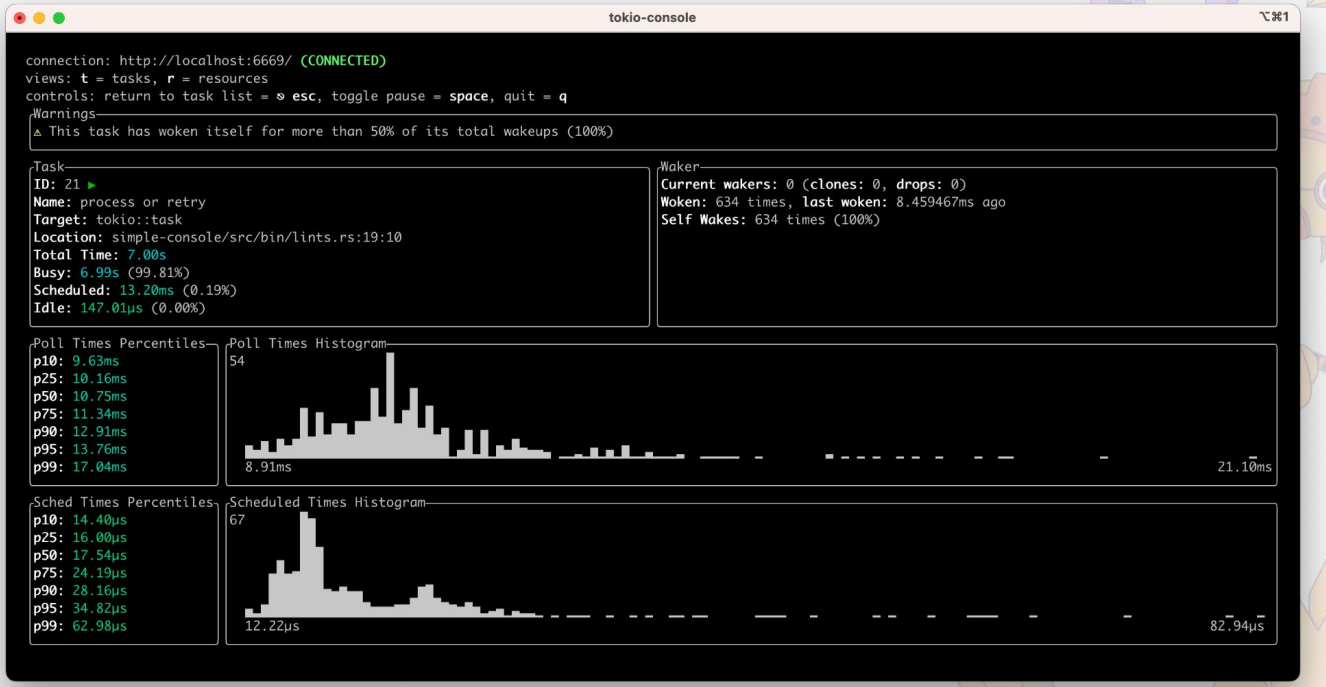


Self wakes - what could it be?

```rust
async fn process_or_retry(tx: mpsc::Sender<Msg>, mut rx: mpsc::Receiver<Msg>) {
    while let Some(msg) = rx.recv().await {
        if !msg.ready() {
            msg.step(); // 10µs
            tx.send(msg).await.unwrap();
        } else {
            msg.process() // 40µs
        }
    }
}
```

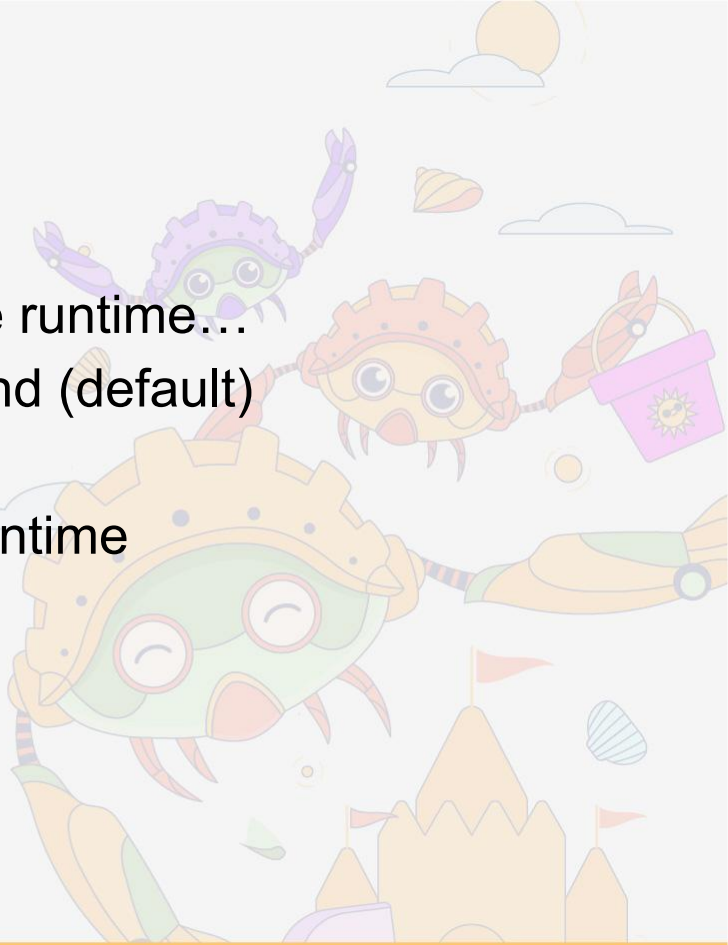
We might be keeping our queue “always ready”!

Self wakes - diagnostics



Never yielded

- The task has never yielded to the runtime…
- and has been running for 1 second (default)
- The task is blocking
- Consider moving it outside the runtime

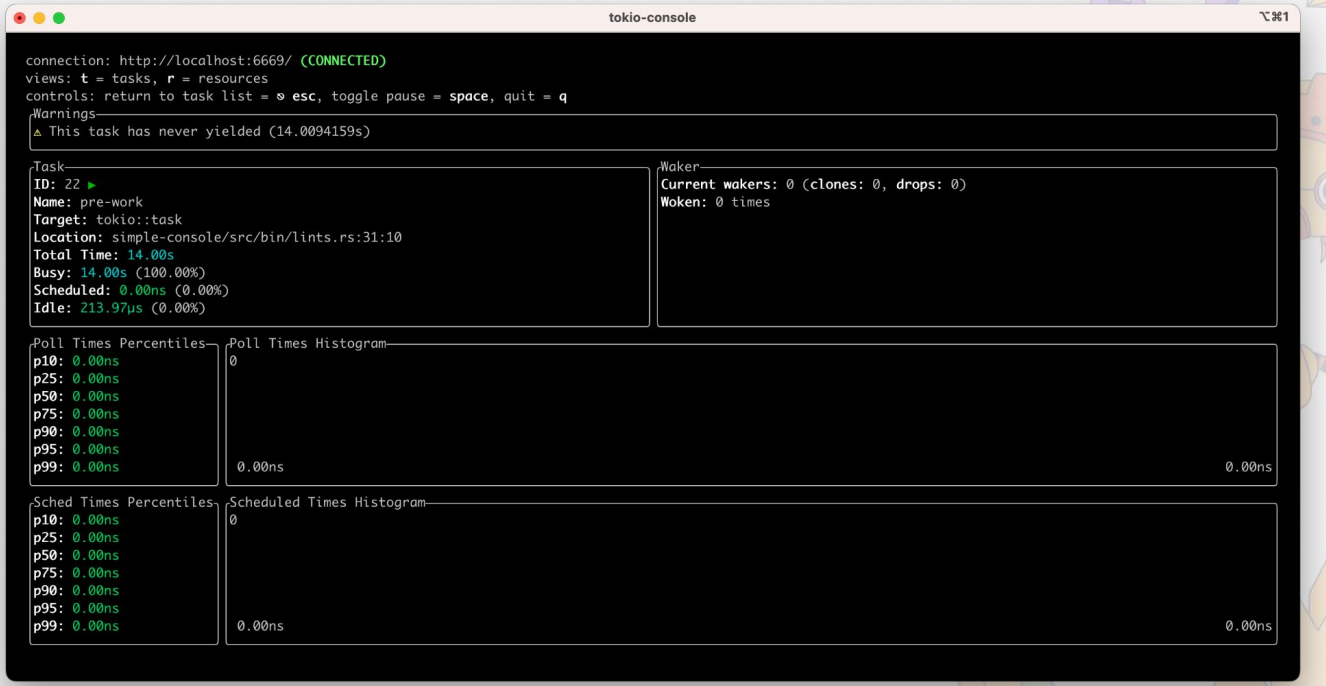


Never yielded - what could it be?

```rust
async fn do_work() {
    let initial_items = pre_work().await;

    for item in initial_items {
        process_item(item).await;
        task::yield_now().await;
    }
}
```

How long does this take?

Never yielded - diagnostics



Summary: Tokio Console

- Built on tracing instrumentation in Tokio
- Console subscriber collects and aggregates
- Tokio console visualizes application state
- Warns about possibly incorrect behavior

Task Dump

Capture a snapshot of the runtime's state.

Dumping tasks

- Records a snapshot of all tasks on a runtime
- Each task includes a backtrace from all "leaf futures"
  - Leaf futures are top most future on the callstack
  - Requires leaf futures to be instrumented
- Like thread dumps (Java) but for Rust!
- Some limitations apply

Extra config

```
# Set the RUSTFLAGS variable
RUSTFLAGS="--cfg tokio_unstable --cfg tokio_taskdump"cargo build

# Contents of .cargo/config
[build]
rustflags = ["--cfg", "tokio_unstable", "--cfg", "tokio_taskdump"]
```

Creating a task dump

```
let handle = tokio::runtime::Handle::current();

if let Ok(dump) = tokio::time::timeout(Duration::from_secs(2), handle.dump()).await {
    for (i, task) in dump.tasks().iter().enumerate() {
        let trace = task.trace();
        println!("TASK {i}:");
        println!("{trace}\n");
    }
}
```

Sleep task dump

- A task that only awaits a sleep
- Backtrace starts at the inner poll

```rust
tokio::spawn(async {
    tokio::time::sleep(Duration::from_millis(100))
        .await;
});
```

```
TASK 0:
─ dump_sleep::main::{{closure}}::{{closure}} at src/bin/dump_sleep.rs:9:56
  └─ <tokio::time::sleep::Sleep as core::future::future::Future>::poll at <crates.io>/tokio-1.33.0/src/time/sleep.rs:448:22
     └─ tokio::time::sleep::Sleep::poll_elapsed at <crates.io>/tokio-1.33.0/src/time/sleep.rs:404:16
```

Sleep task dump (zoom)

```
├ dump_sleep::main::{{closure}}::{{closure}}
└ <tokio::time::sleep::Sleep as core::future::future::Future>::poll
  └ tokio::time::sleep::Sleep::poll_elapsed
```

Deeper task dump

```rust
/// In main()
tokio::spawn(async { a().await });

async fn a() { b().await }
async fn b() { c().await }
async fn c() { tokio::time::sleep(Duration::from_millis(100)).await }
```

```
— dump_deeper::main::{{closure}}::{{closure}} at src/bin/dump_deeper.rs:18:13
  └─ dump_deeper::a::{{closure}} at src/bin/dump_deeper.rs:4:9
     └─ dump_deeper::b::{{closure}} at src/bin/dump_deeper.rs:8:9
        └─ dump_deeper::c::{{closure}} at src/bin/dump_deeper.rs:12:52
           └─ <tokio::time::sleep::Sleep as core::future::future::Future>::poll at <crates.io>/tokio-1.33.0/src/time/sleep.rs:448:22
              └─ tokio::time::sleep::Sleep::poll_elapsed at <crates.io>/tokio-1.33.0/src/time/sleep.rs:404:16
```

Deeper task dump (zoom)

```
— dump_deeper::main::{{closure}}::{{closure}}
  └— dump_deeper::a::{{closure}}
     └— dump_deeper::b::{{closure}}
        └— dump_deeper::c::{{closure}}
           └— <tokio::time::sleep::Sleep as core::future::future::Future>::poll
              └— tokio::time::sleep::Sleep::poll_elapsed
```

Select task dump

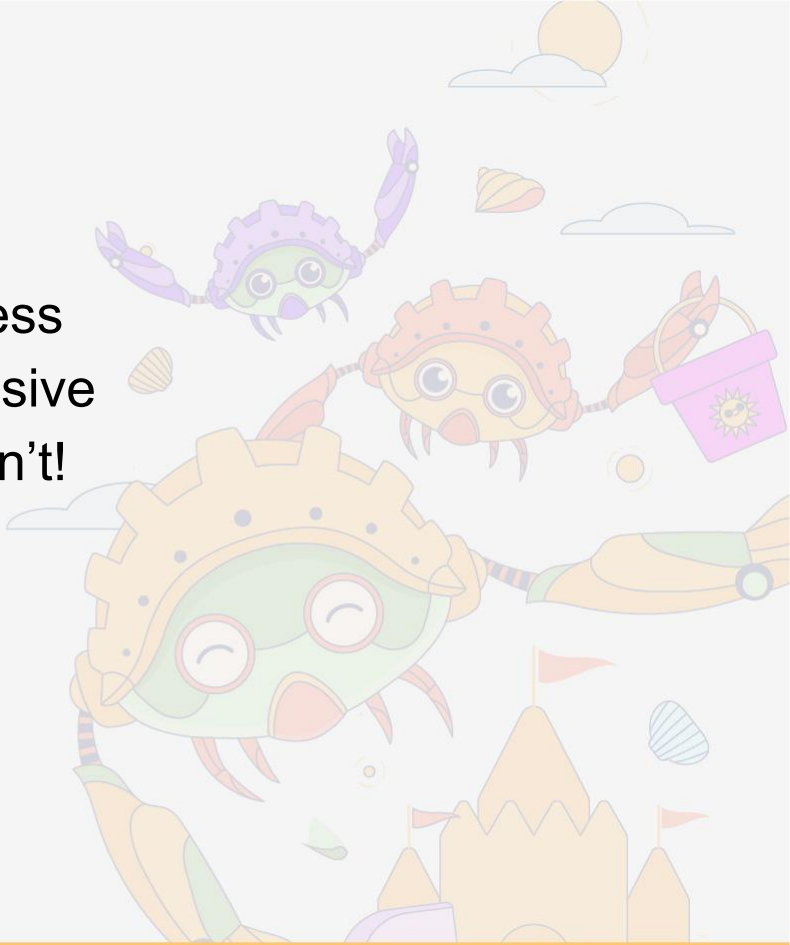
```rust
let barrier = Arc::new(Barrier::new(2));
let (_tx, mut rx) = mpsc::channel::<u64>(2);

tokio::spawn(async move {
    //  A task awaiting multiple futures will have a branched backtrace
    tokio::select! {
        _ = barrier.wait() => {}
        _ = tokio::time::sleep(Duration::from_millis(100)) => {}
        _ = rx.recv() => {}
    }
});
```

Select task dump

```
╼ dump_select::main::{{closure}}::{{closure}} at src/bin/dump_select.rs:11:9
 └╴ <tokio::future::poll_fn::PollFn<F> as core::future::future::Future>::poll at <crates.io>/tokio-1.33.0/src/future/poll_fn.rs:58:9
    # MPSC Channel receive
    ├╴ dump_select::main::{{closure}}::{{closure}}::{{closure}} at <crates.io>/tokio-1.33.0/src/macros/select.rs:524:49
    │  └╴ tokio::sync::mpsc::bounded::Receiver<T>::recv::{{closure}} at <crates.io>/tokio-1.33.0/src/sync/mpsc/bounded.rs:230:42
    │     └╴ <tokio::future::poll_fn::PollFn<F> as core::future::future::Future>::poll at <crates.io>/tokio-1.33.0/src/future/poll_fn.rs:58:9
    │        └╴ tokio::sync::mpsc::bounded::Receiver<T>::recv::{{closure}}::{{closure}} at <crates.io>/tokio-1.33.0/src/sync/mpsc/bounded.rs:230:22
    │           └╴ tokio::sync::mpsc::chan::Rx<T,S>::recv at <crates.io>/tokio-1.33.0/src/sync/mpsc/chan.rs:246:16
    # Sleep
    ├╴ dump_select::main::{{closure}}::{{closure}}::{{closure}} at <crates.io>/tokio-1.33.0/src/macros/select.rs:524:49
    │  └╴ <tokio::time::sleep::Sleep as core::future::future::Future>::poll at <crates.io>/tokio-1.33.0/src/time/sleep.rs:448:22
    │     └╴ tokio::time::sleep::Sleep::poll_elapsed at <crates.io>/tokio-1.33.0/src/time/sleep.rs:404:16
    # Barrier wait
    └╴ dump_select::main::{{closure}}::{{closure}}::{{closure}} at <crates.io>/tokio-1.33.0/src/macros/select.rs:524:49
       └╴ tokio::sync::barrier::Barrier::wait::{{closure}} at <crates.io>/tokio-1.33.0/src/sync/barrier.rs:129:10
          └╴ <tokio::util::trace::InstrumentedAsyncOp<F> as core::future::future::Future>::poll at <crates.io>/tokio-1.33.0/src/util/trace.rs:81:46
             └╴ tokio::sync::barrier::Barrier::wait_internal::{{closure}} at <crates.io>/tokio-1.33.0/src/sync/barrier.rs:183:36
                └╴ tokio::sync::watch::Receiver<T>::changed::{{closure}} at <crates.io>/tokio-1.33.0/src/sync/watch.rs:715:55
                   └╴ tokio::sync::watch::changed_impl::{{closure}} at <crates.io>/tokio-1.33.0/src/sync/watch.rs:881:18
                      └╴ <tokio::sync::notify::Notified as core::future::future::Future>::poll at <crates.io>/tokio-1.33.0/src/sync/notify.rs:1108:9
                         └╴ tokio::sync::notify::Notified::poll_notified at <crates.io>/tokio-1.33.0/src/sync/notify.rs:100
```

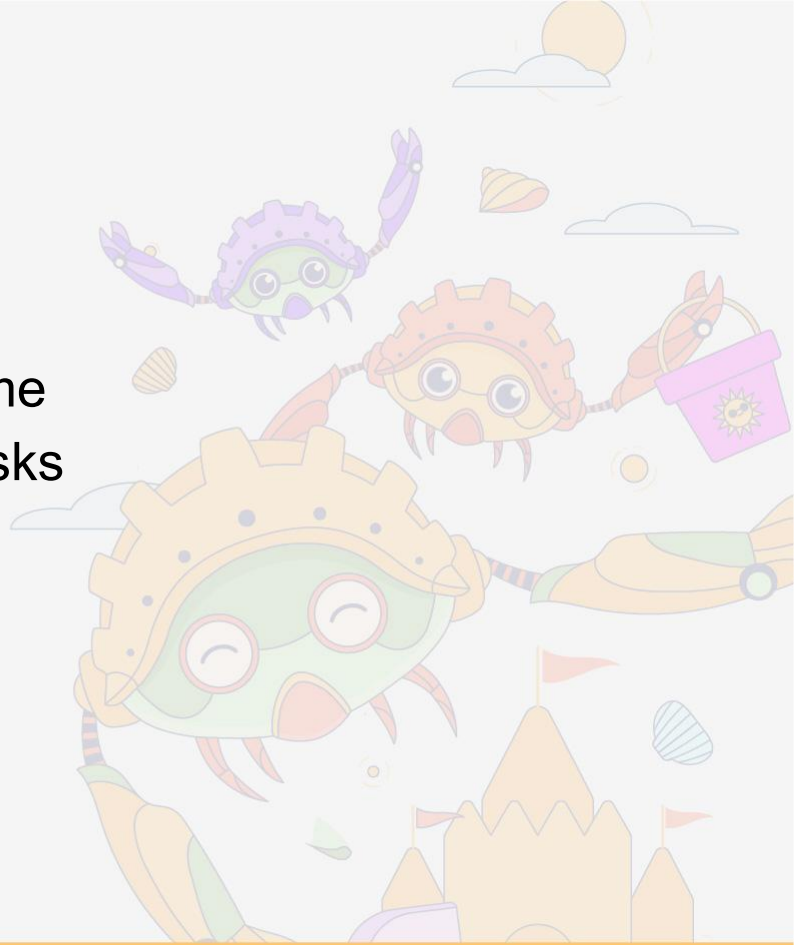
Caveats

- Task dumps are work in progress
- Creating a task dump is expensive
  - But enabling the feature isn’t!
- Not much metadata available
  - Task names and IDs
  - Function parameters
- Only supported on Linux



Summary: Task dumps

- New Tokio feature
- Capture a snapshot of a runtime
- Useful for pinpointing stuck tasks



Present & Future

So, what's next?

Observability tools

Tool	Level of Detail	Use in Production
Metrics	Low	Yes!
Tokio Console	Medium	Careful!
Task Dump	High	Not Yet!

The Future: Metrics

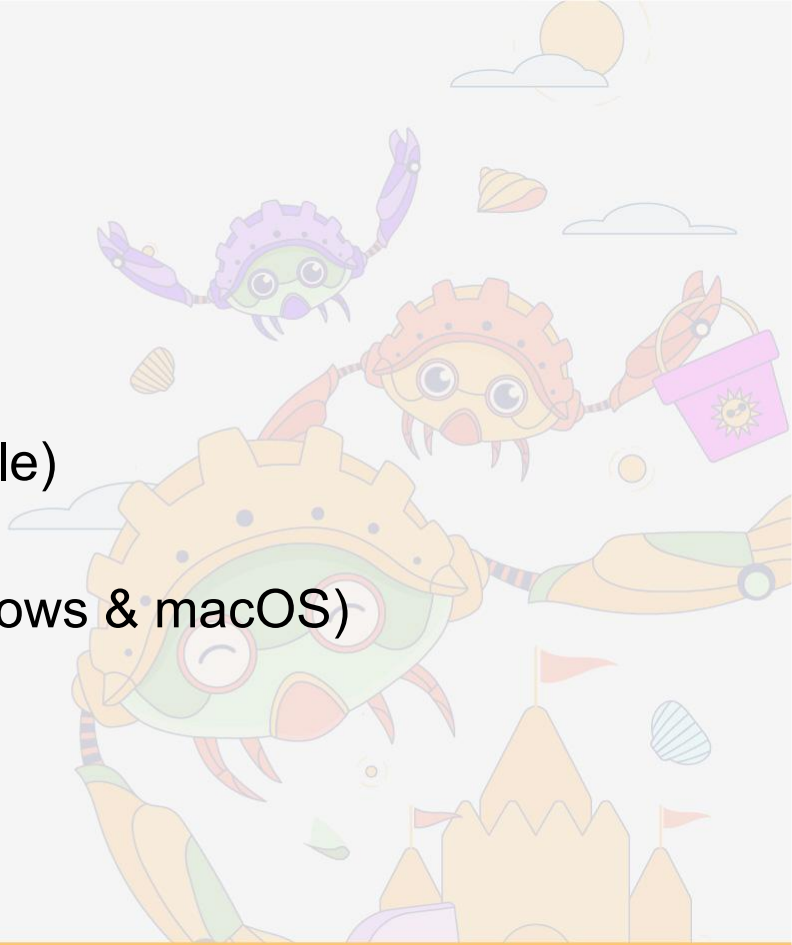
- Additional metrics
- Simpler collector integration

The Future: Tokio Console

- More lints
- More usability features
  - Filtering
  - Custom span integration

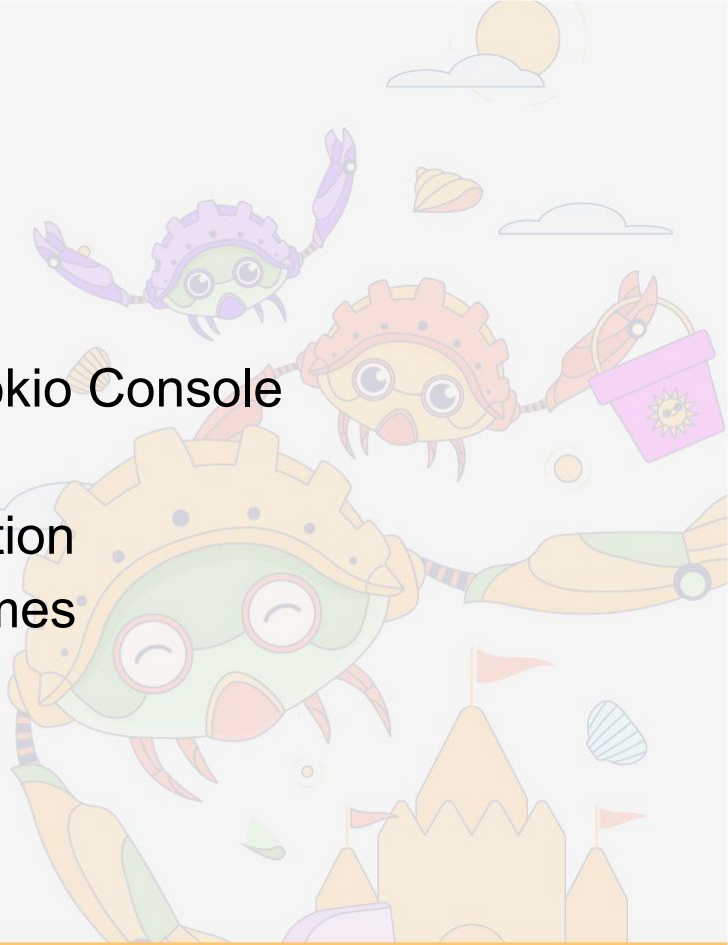
The Future: Task Dump

- Task identifiers
  - Task ID
  - Name (like in Tokio Console)
- More backtrace metadata
- Support more platforms (Windows & macOS)



The Future: Ecosystem

- Better integration
  - Metrics and task dumps in Tokio Console
  - Or together elsewhere!
- Standardize runtime instrumentation
  - Instrument other async runtimes

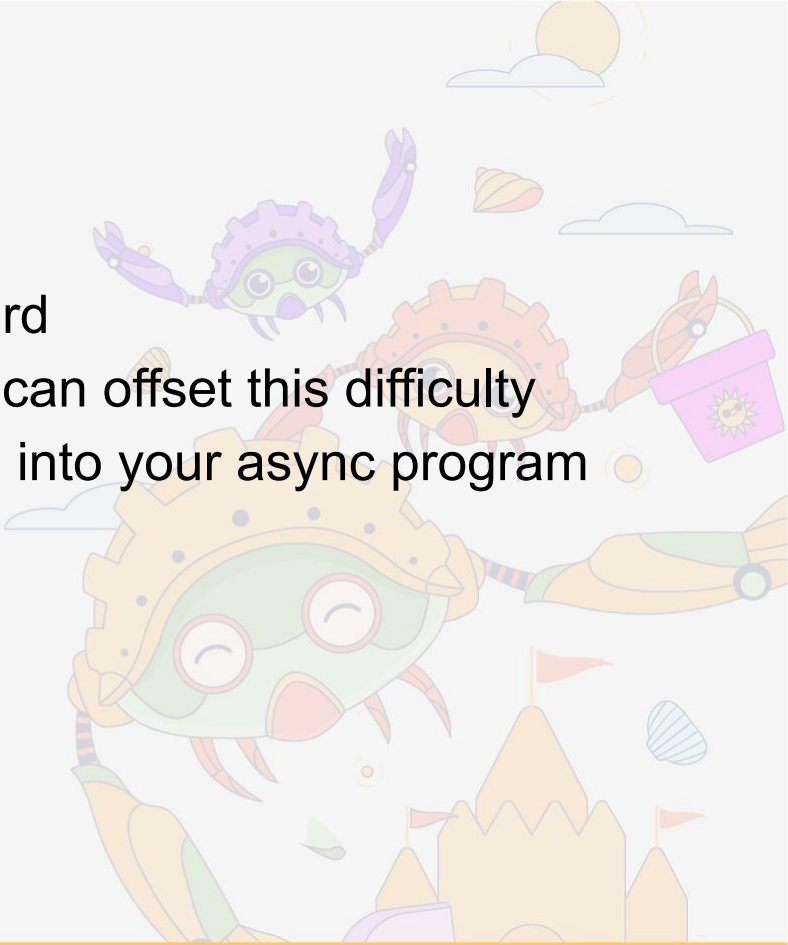


The Future: Ecosystem

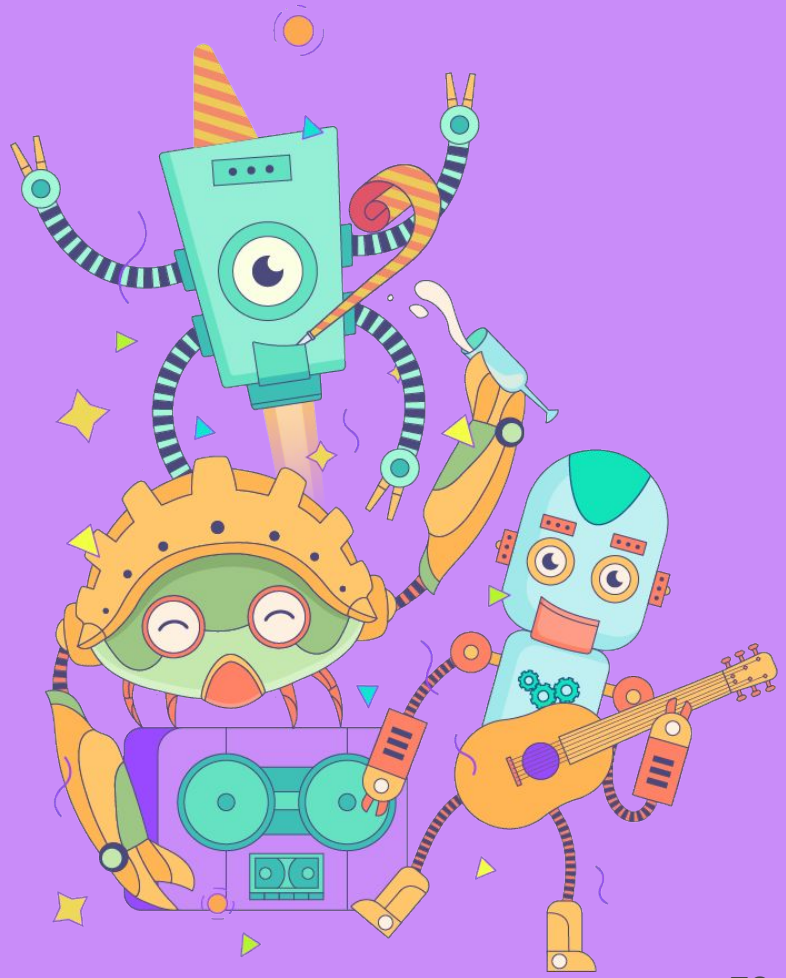
- You!
  - All these tools are open source
  - Many are developed in maintainer “free time”
  - Want to help?
    - Join us on the Tokio Discord

Final thoughts

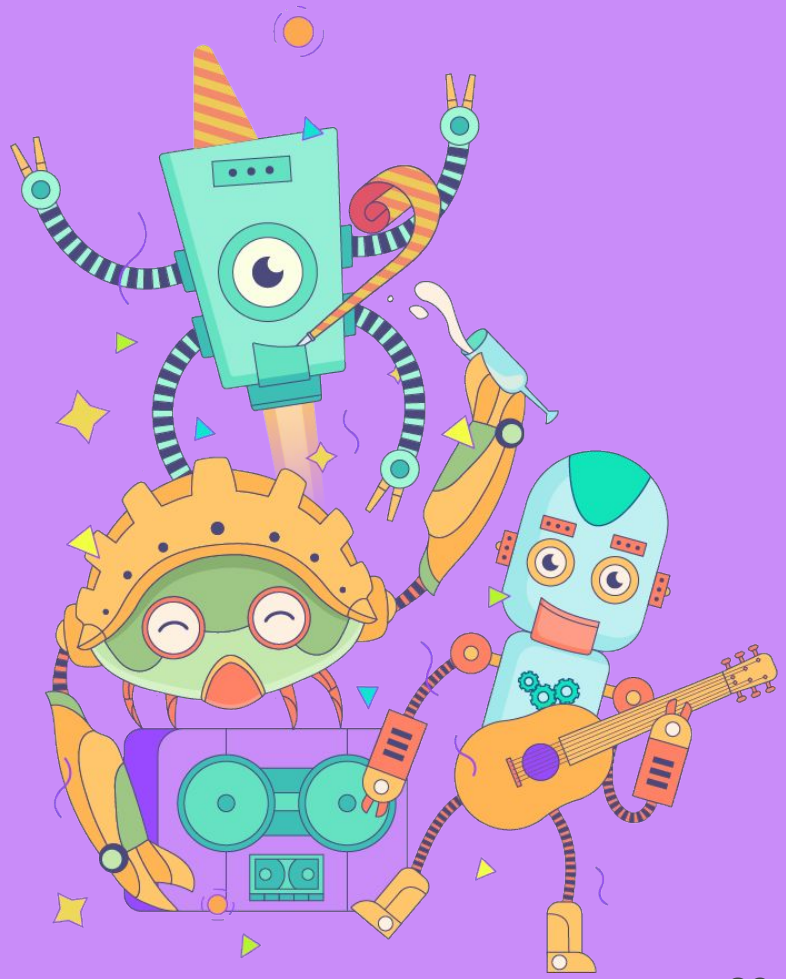
- Async programming can be hard
- Instrumentation of the runtime can offset this difficulty
- There are many options to see into your async program
- We're not there yet



Thank-you for listening



Questions?



Links

Tokio

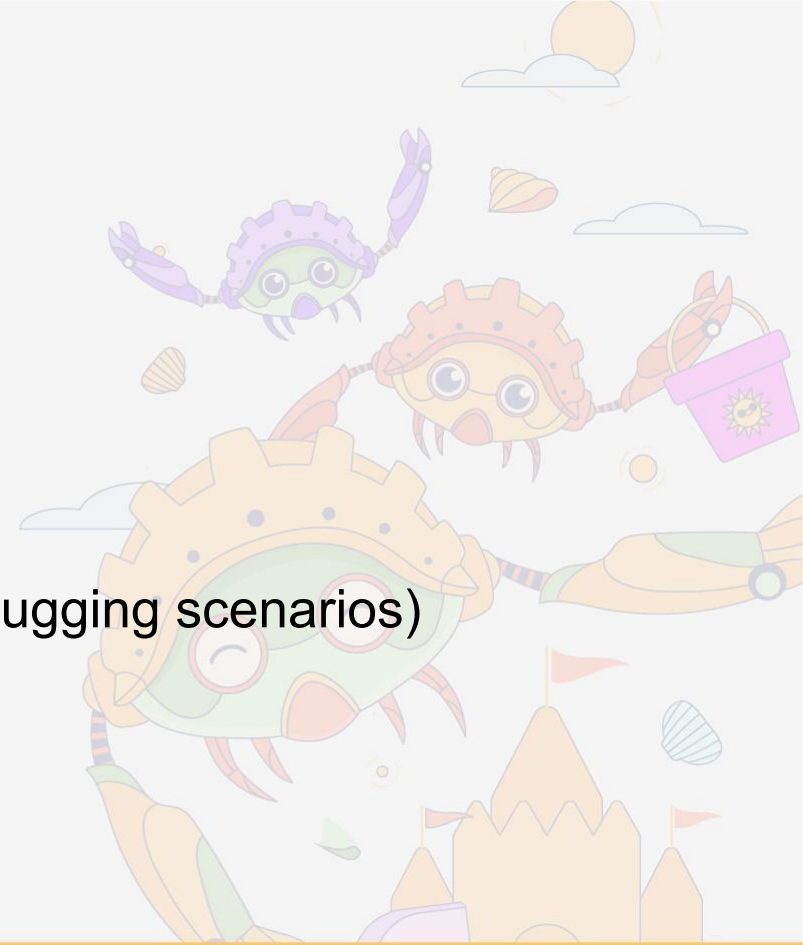
- Web-site
- Code
- docs.rs
- Discord server

Other async runtimes

- Async-std
- Smol
- Embassy

Metrics

- Tokio crate
  - RuntimeMetrics
- tokio-metrics crate
  - RuntimeMonitor
  - TaskMonitor (detailed debugging scenarios)



Tokio Console

- [console code]
- [console-subscriber on docs.rs]
- [tokio-console on docs.rs]

Task Dump

- Handle::dump()
- task dump stabilization issue

Links

Hayden Stainsby

- Email
- Web-site
- GitHub
- Mastodon
- Rust for Lunch

Introduction

Async Rust can be hard. Stack traces are meaningless, the debugger changes everything, and sometimes your program just hangs forever.

But there are many tools that can help you look inside!

We'll explore how to observe the inner workings of Tokio using Metrics, Tokio Console, and Task Dumps.