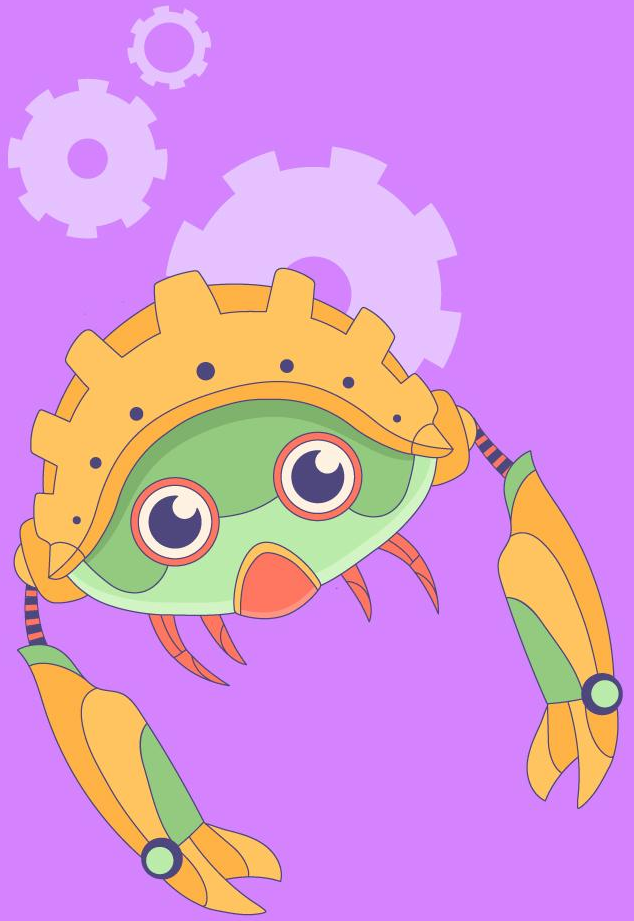
Hayden Stainsby

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

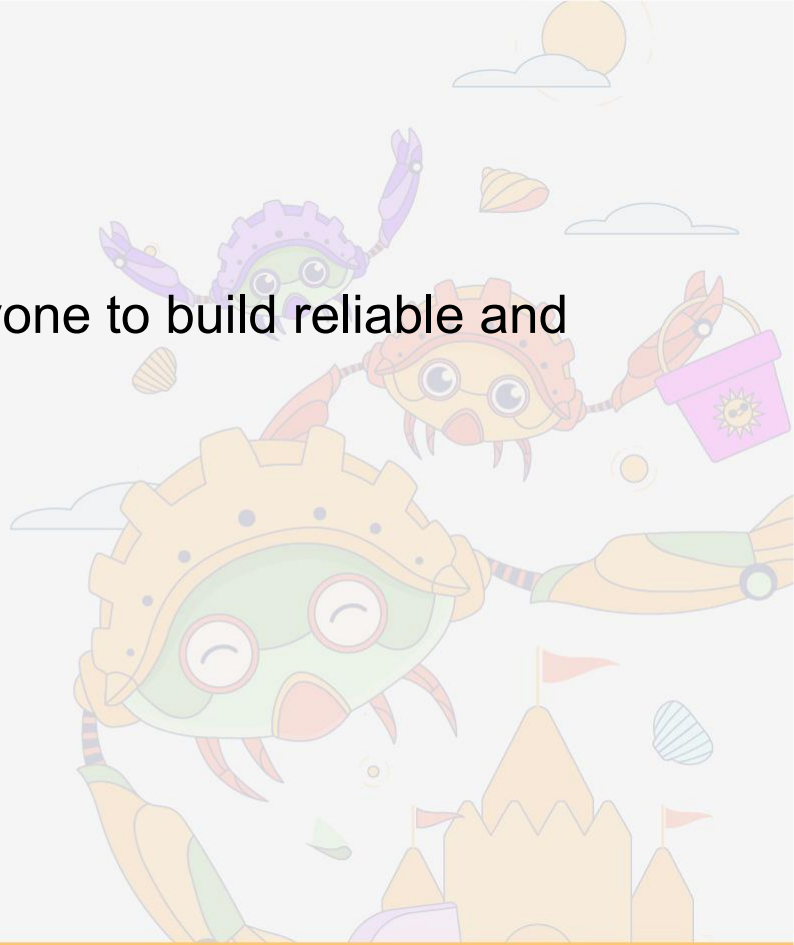
- Context
- Tokio
- Metrics
- Tokio Console
- Task Dump
- Present & Future
- Links

Context

First, a little bit of context.

Rust

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

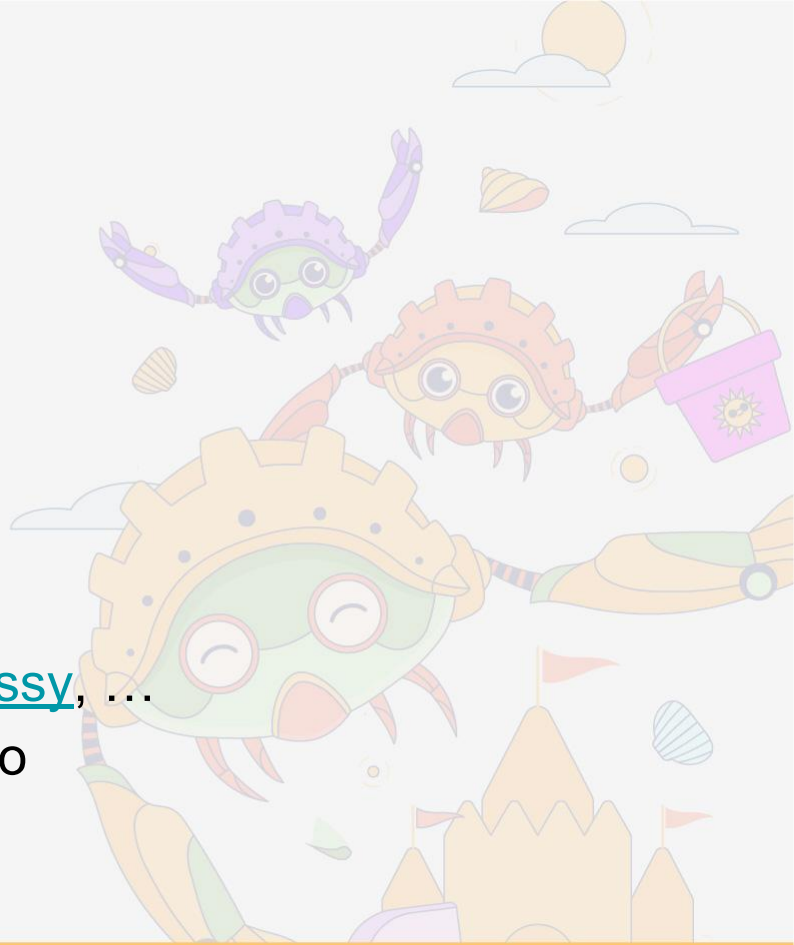


Asynchronous (async) programming

- 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

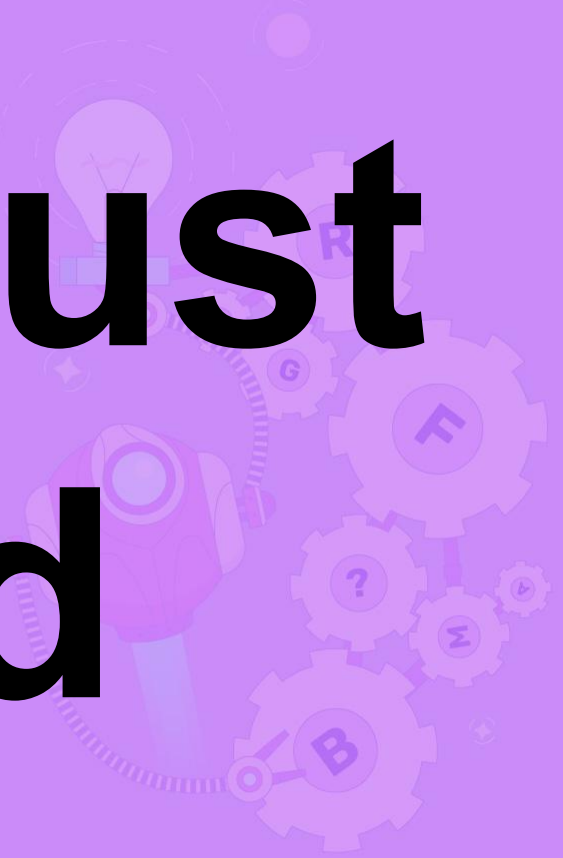
- Rust provides…
  - some async definitions
  - async/.await syntax
  - **no** async runtime!
- You get to pick your own
- Tokio, Async-std, Smol, Embassy, …
- It's likely that you're using Tokio



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...

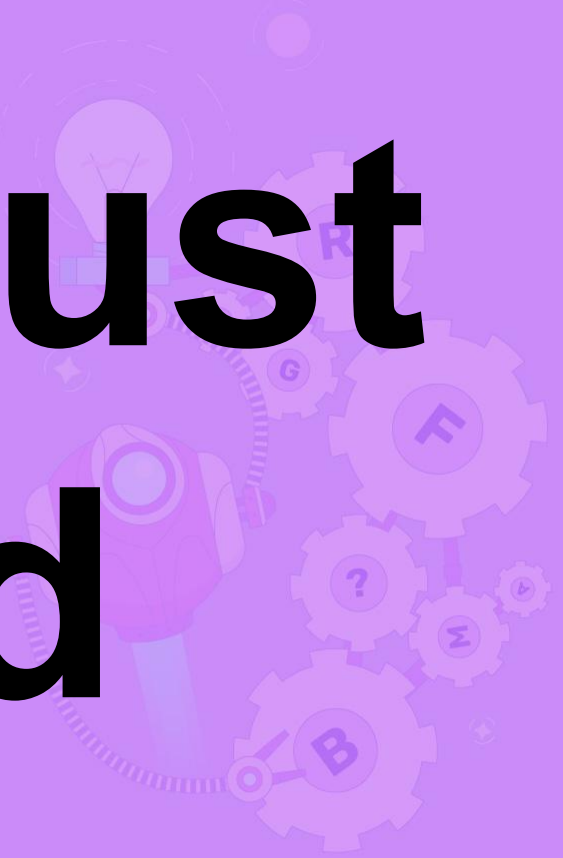
Async Rust is Hard



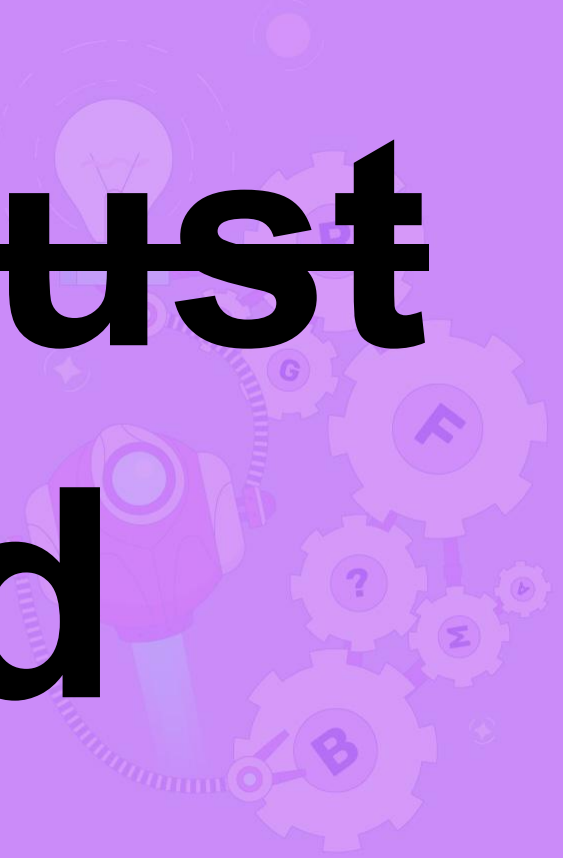
Last minute slide

- 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…

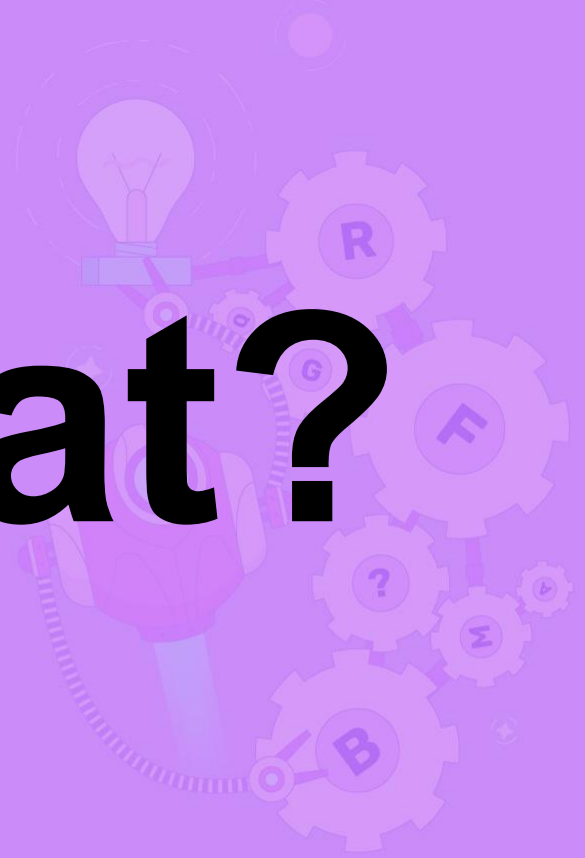
Async Rust is Hard



Async ~~Rust~~ is Hard

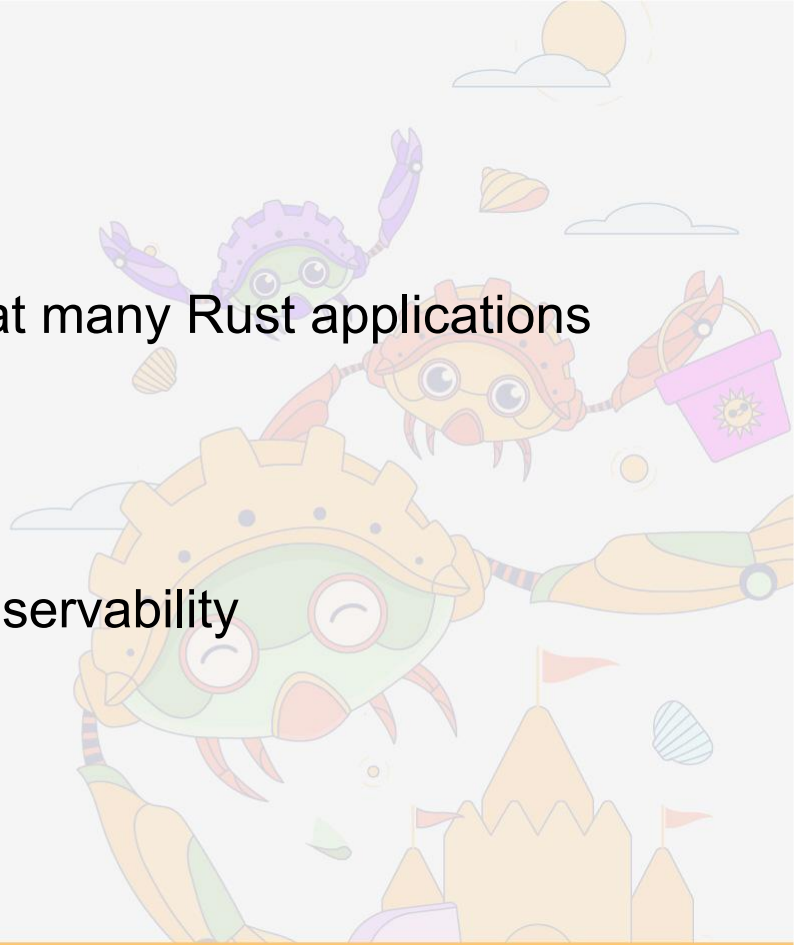


now what?



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).

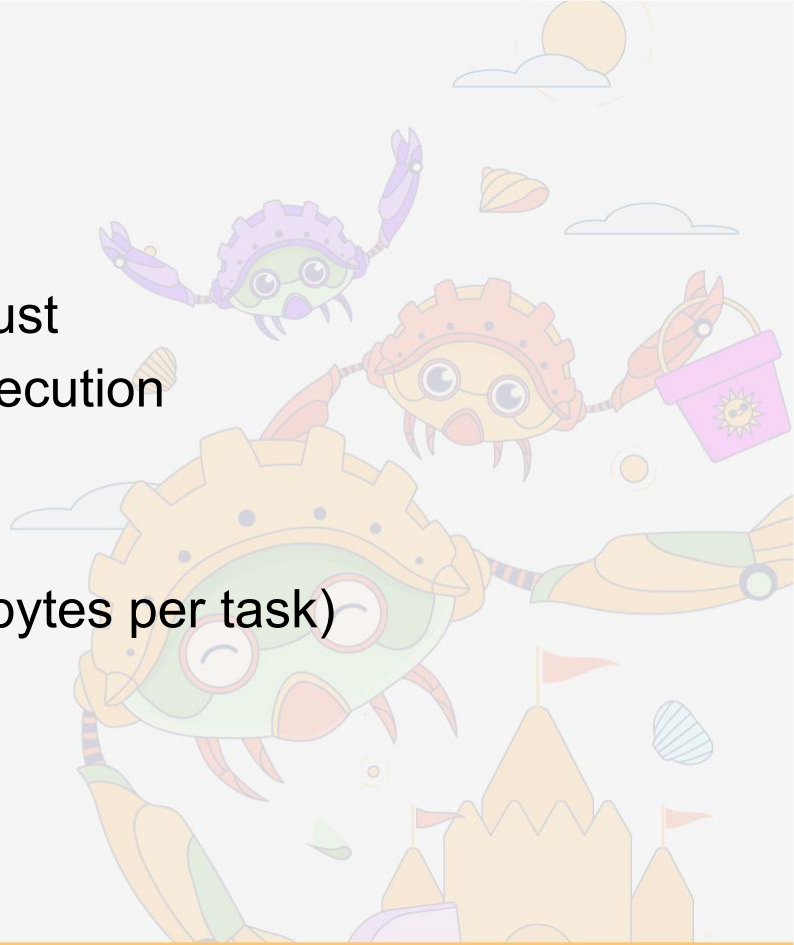
- Do we have "full" observability of Tokio?
- Not yet. But more than you might imagine!

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?

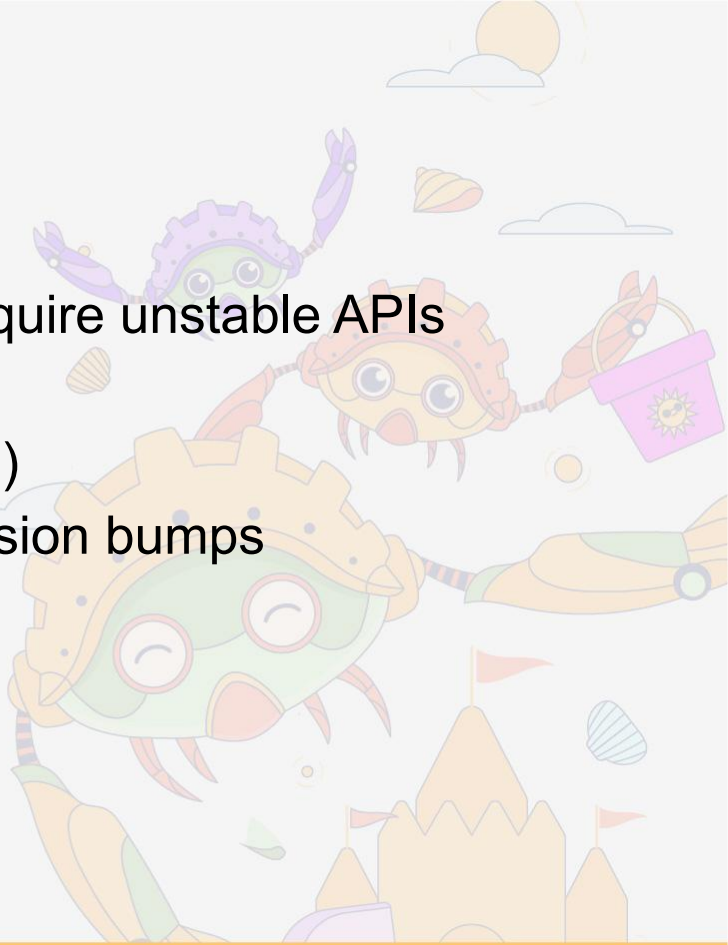
- Timers
- Synchronization primitives
- Network and file I/O
- Message passing channels
- ~~Kitchen sink~~
- "Batteries included"

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);
}
```

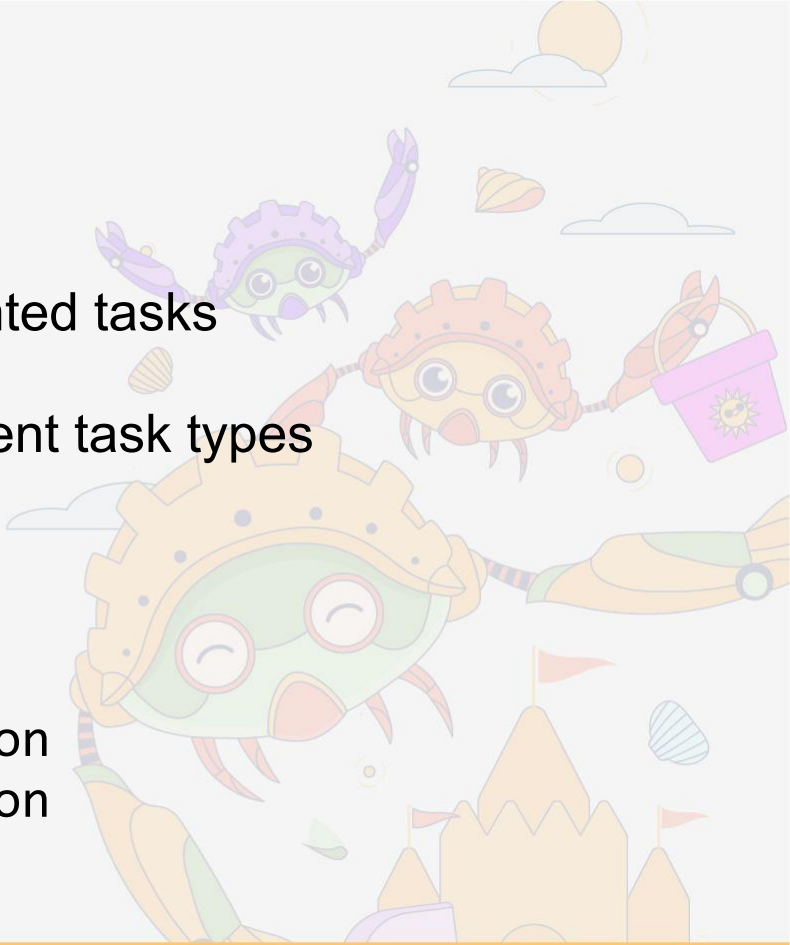
```
Runtime has 10 active tasks
```

`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

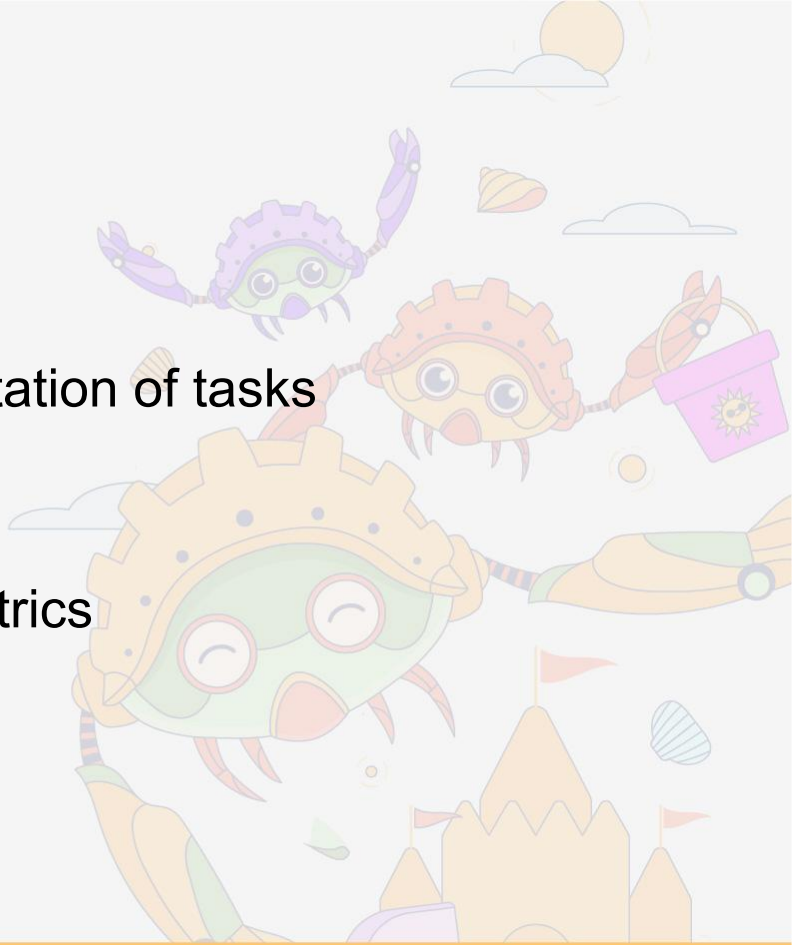
- Separate poll times into slow and fast (50µs)
- Separate schedule delays into long and short (50µs)
- Answer questions like, are my tasks…
  - taking longer to poll?
  - spending more time waiting to be polled?
  - spending more time waiting on external events to complete?
- Incredible documentation!

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

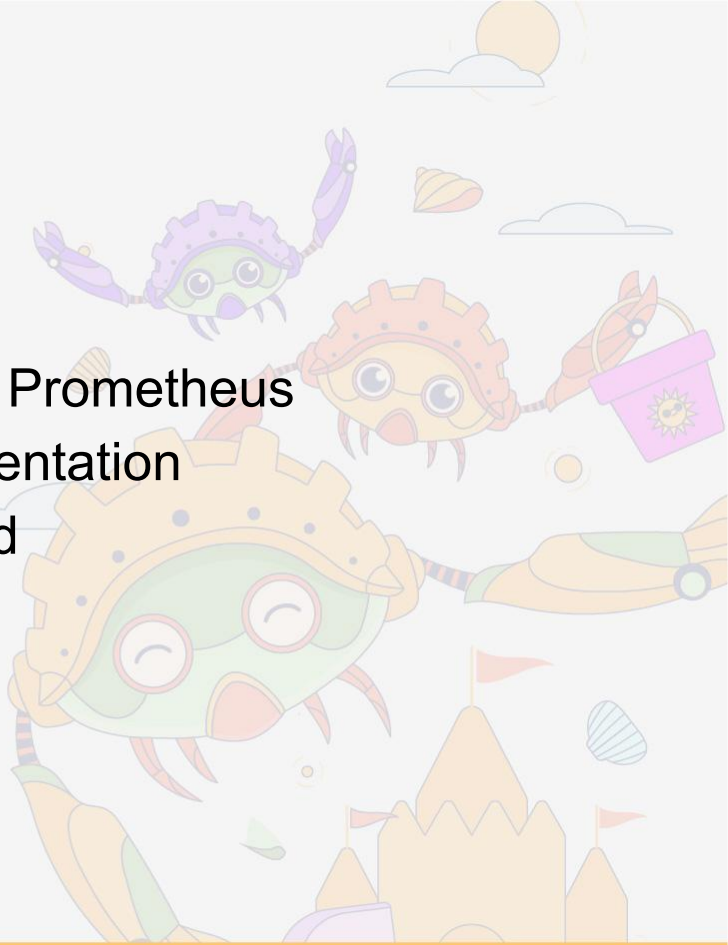
- Monitors are easy to integrate with collectors
- The `prometheus` crate for example
- But there is some boilerplate involved...

```
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

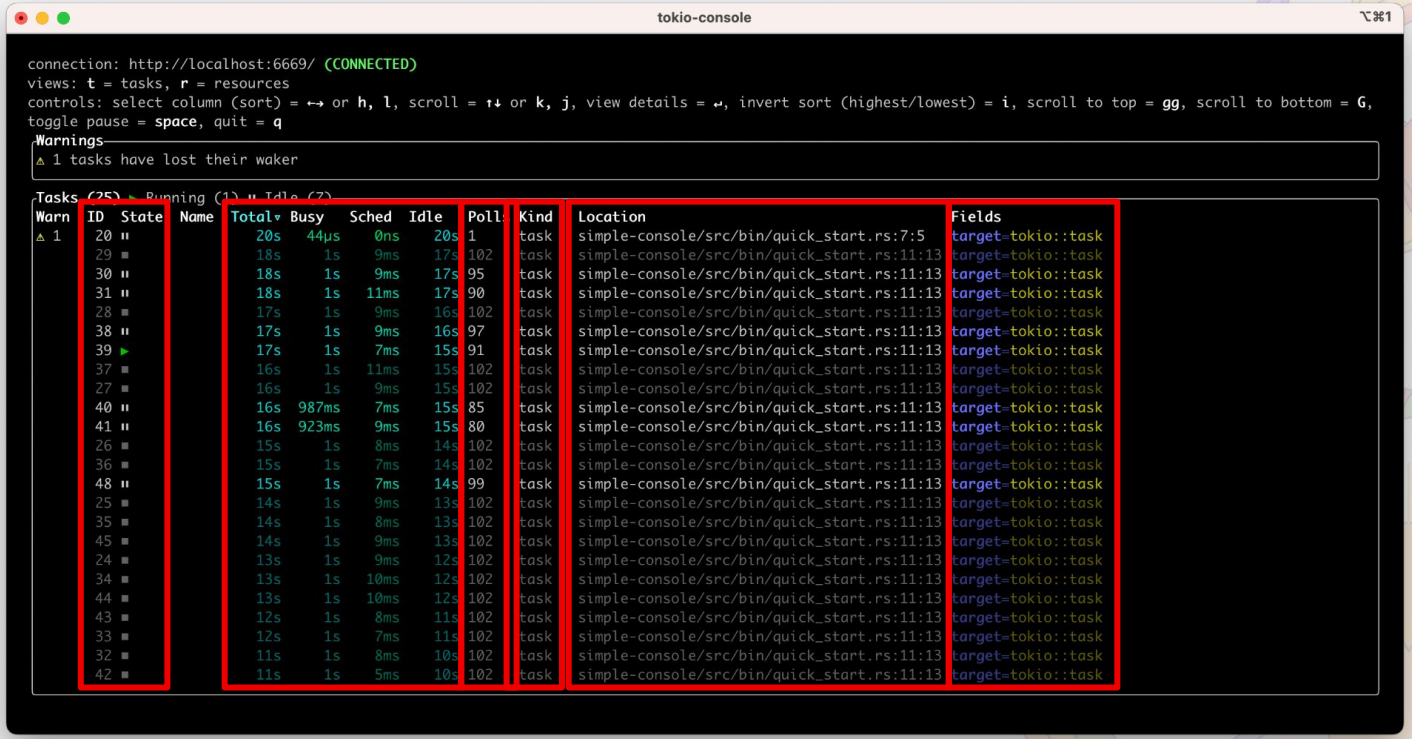
- Install from cargo
- And run from the command line
- For best experience, ensure UTF-8

```
cargo install tokio-console
```

```
tokio-console
```

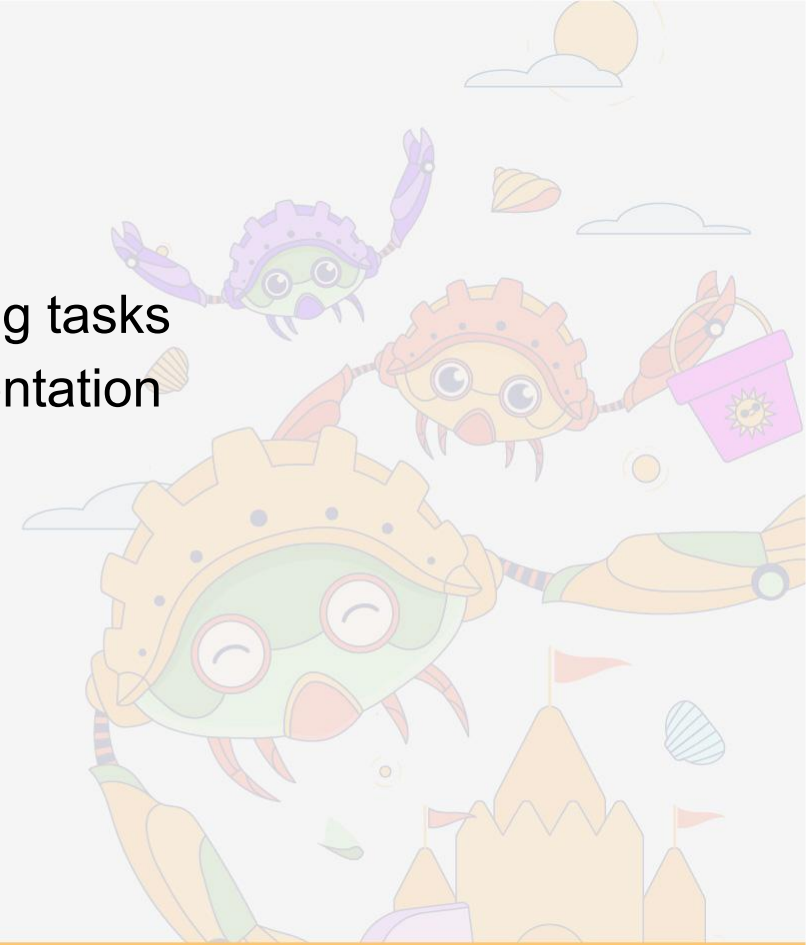
```
tokio-console --lang=en_us.UTF-8
# or
LANG="en_us.UTF-8" tokio-console
```

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

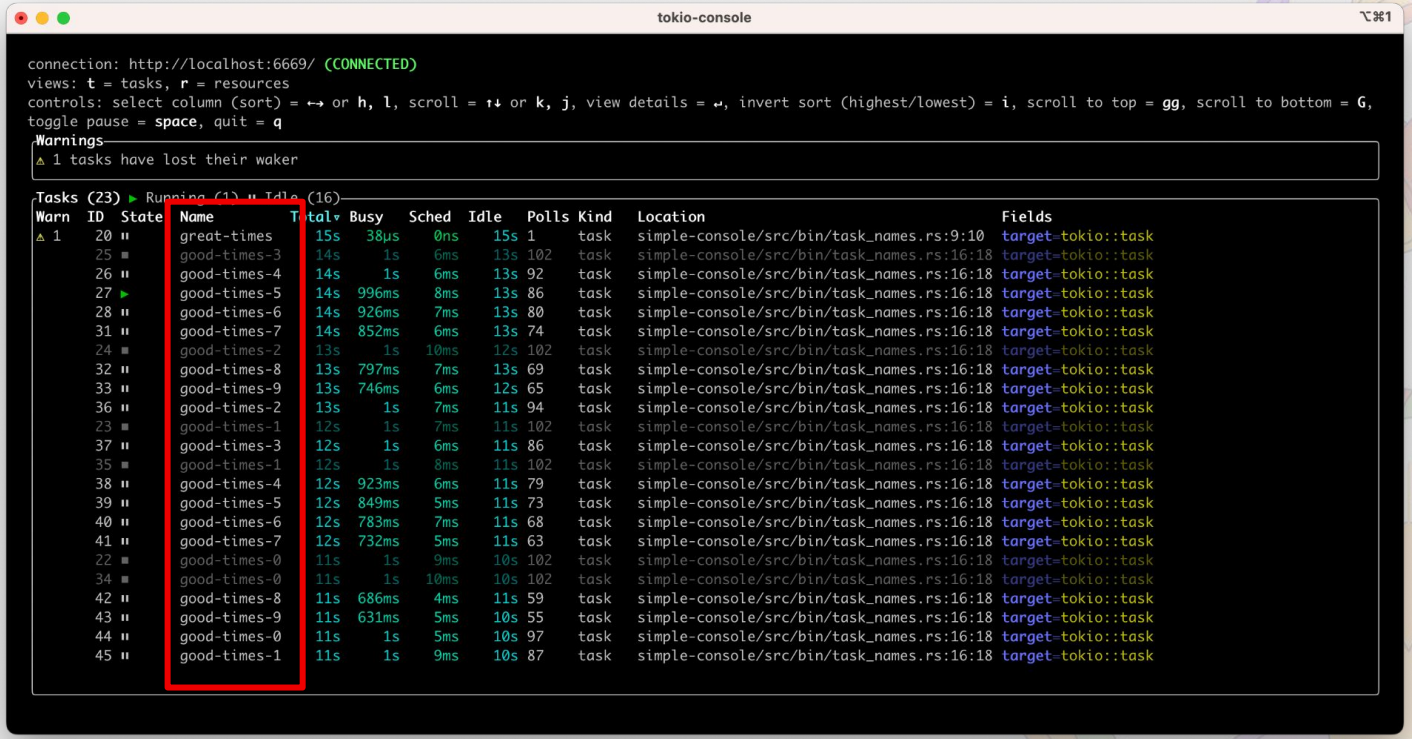
- Task builder API allows naming tasks
- Only used by tracing instrumentation
- Very useful in Tokio Console



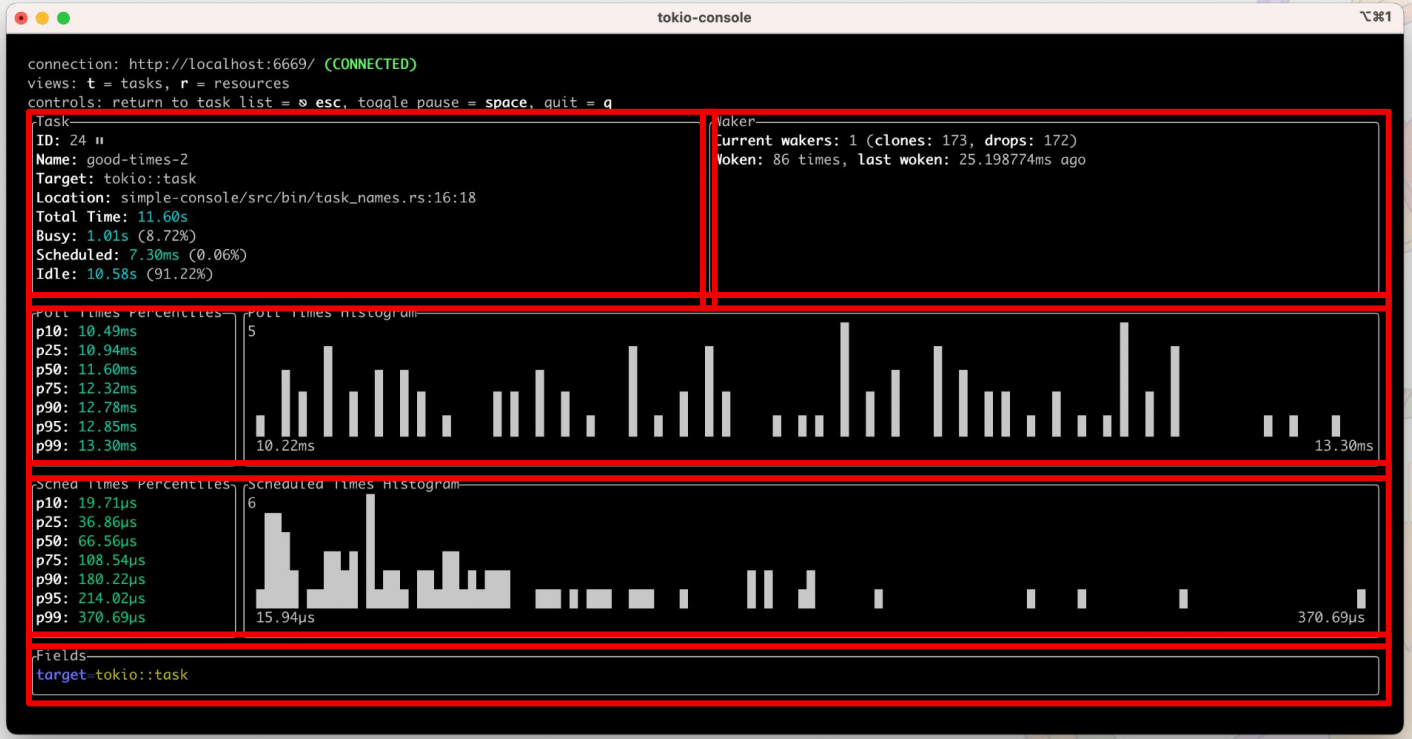
Sample code with task names

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

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

Task list with names

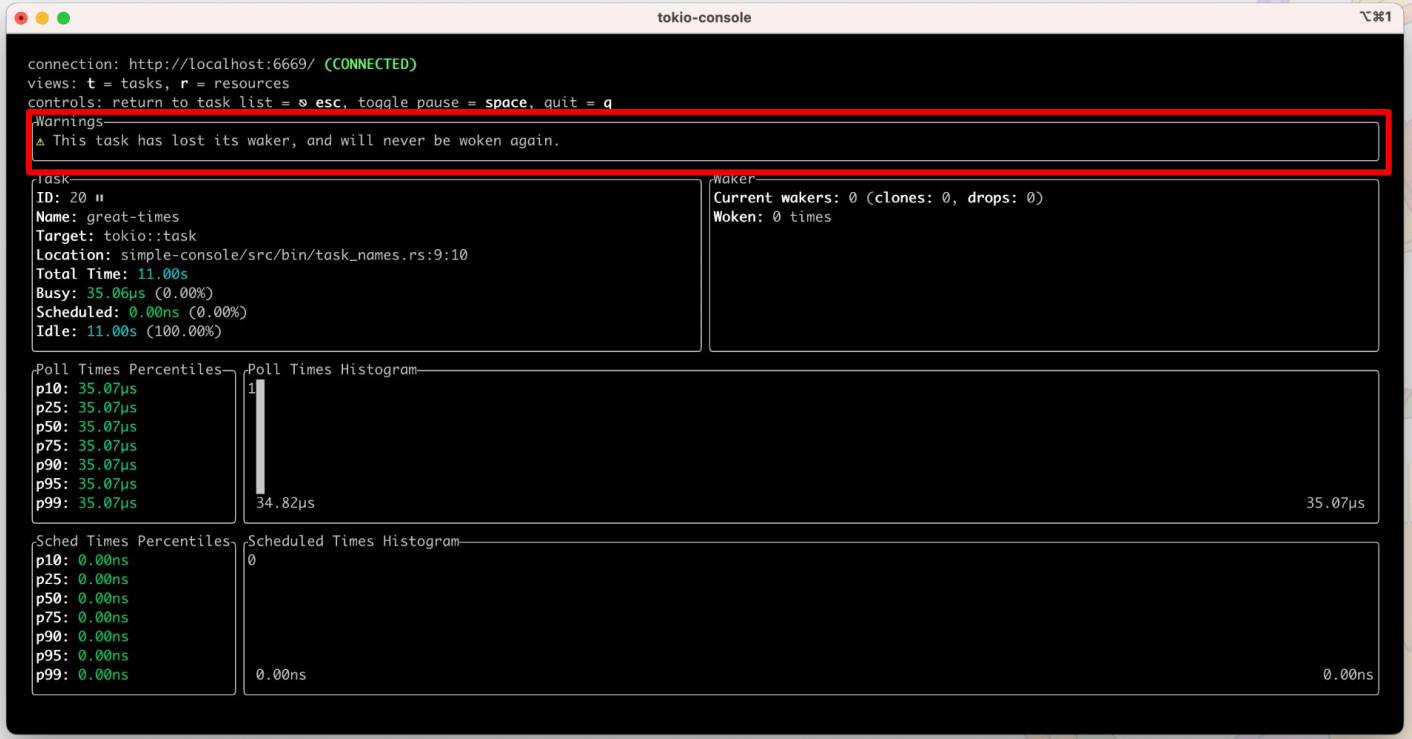


Task details



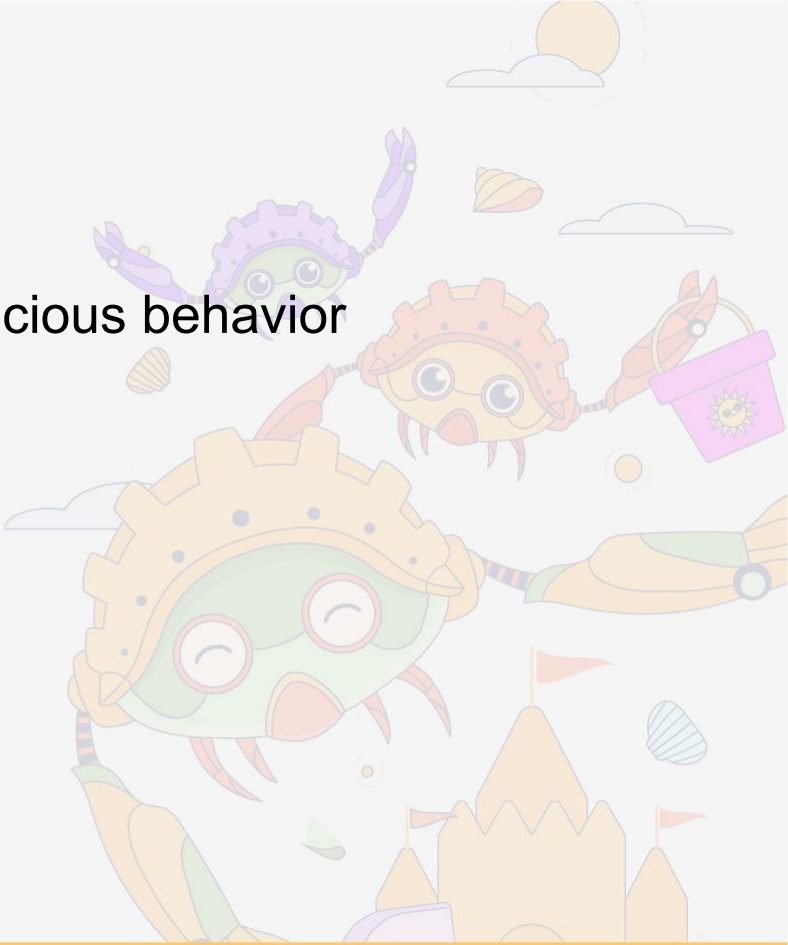
A wild warning has appeared!

Task details



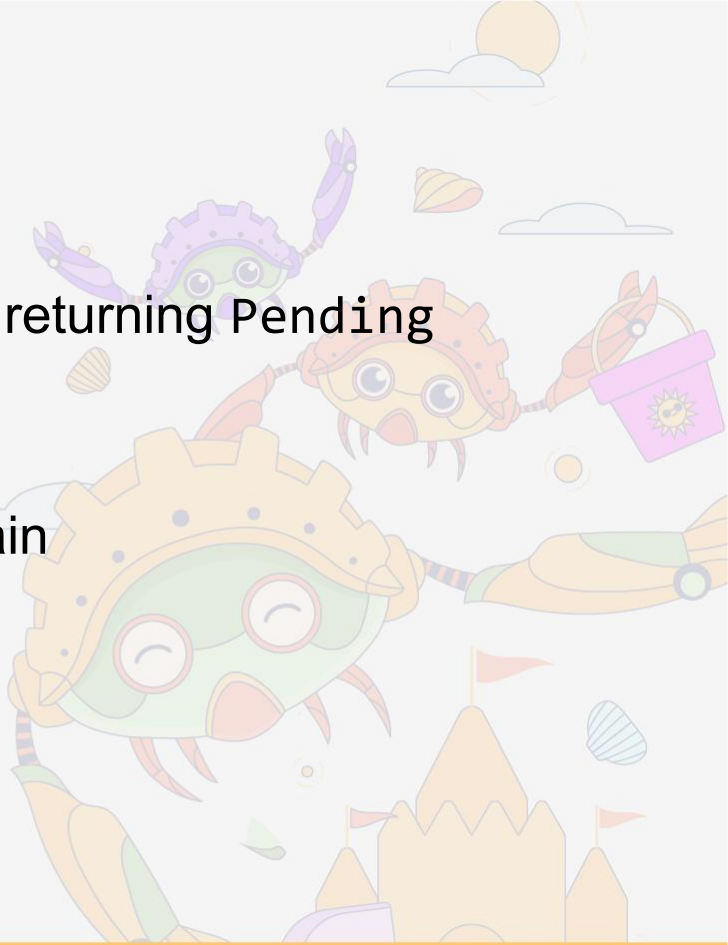
Lints

- 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

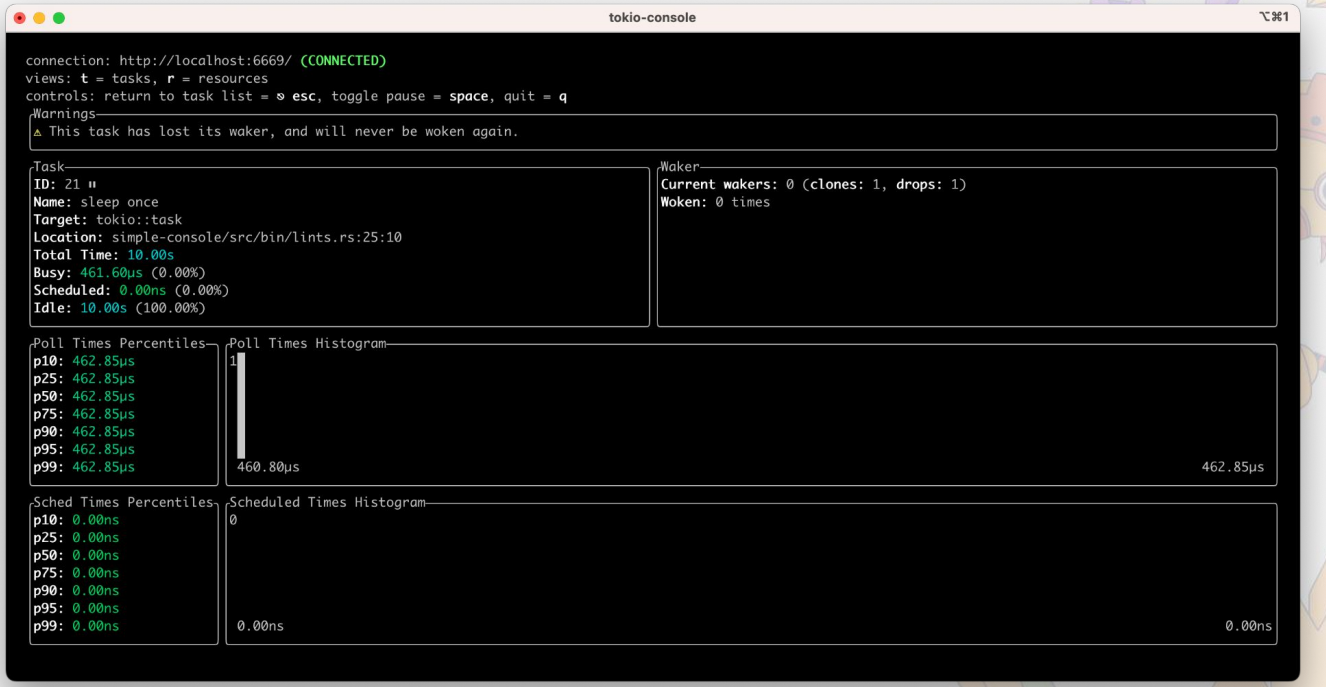


Lost waker - what could it be?

```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(())
}
```

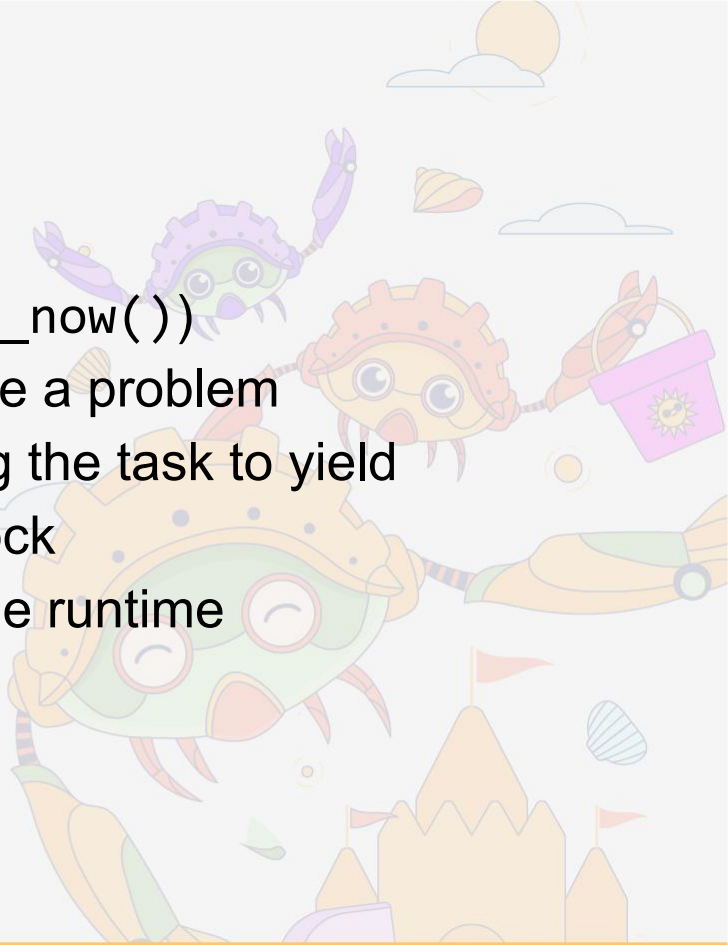
We're not keeping `sleep` anywhere!

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

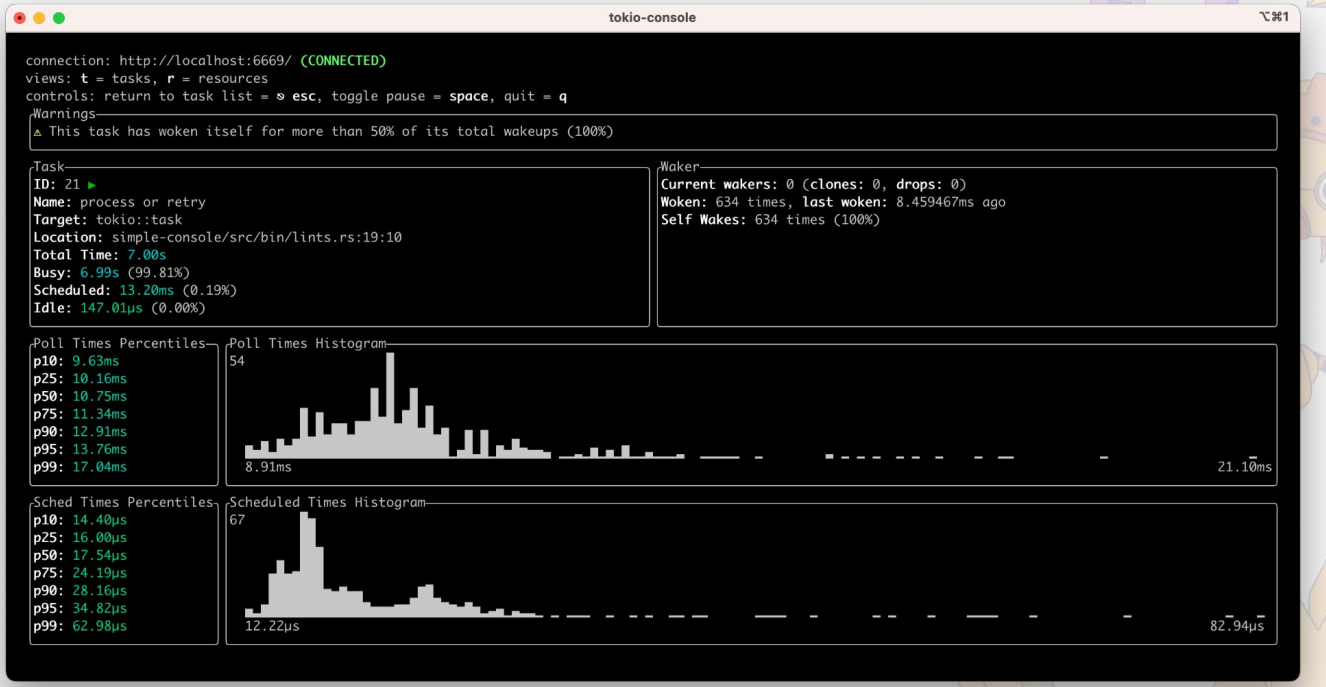


Self wakes - what could it be?

```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
        }
    }
}
```

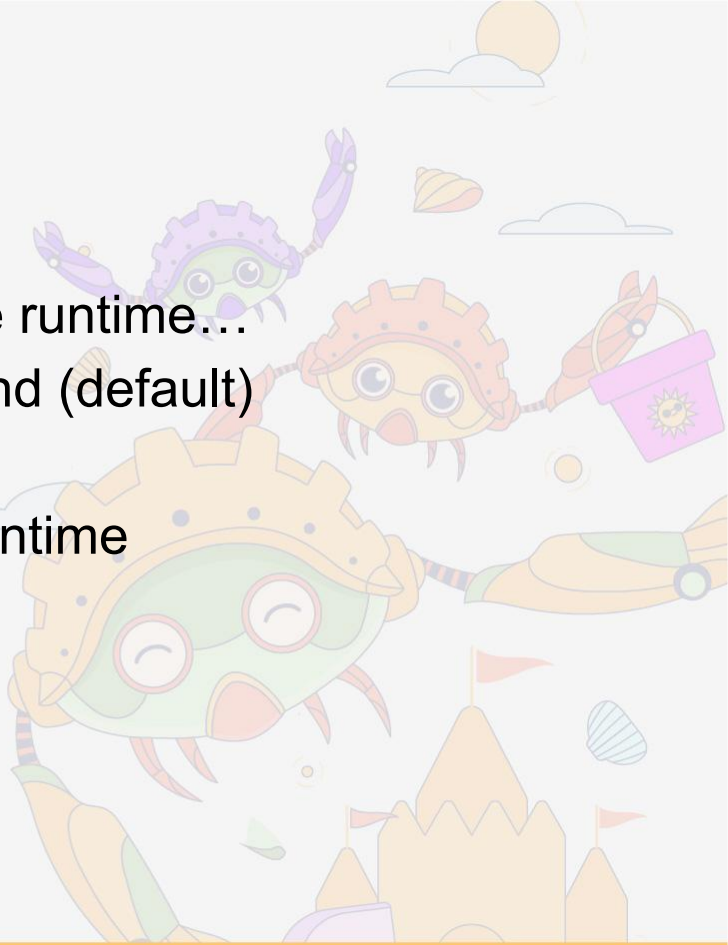
We might be keeping our queue “always ready”!

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

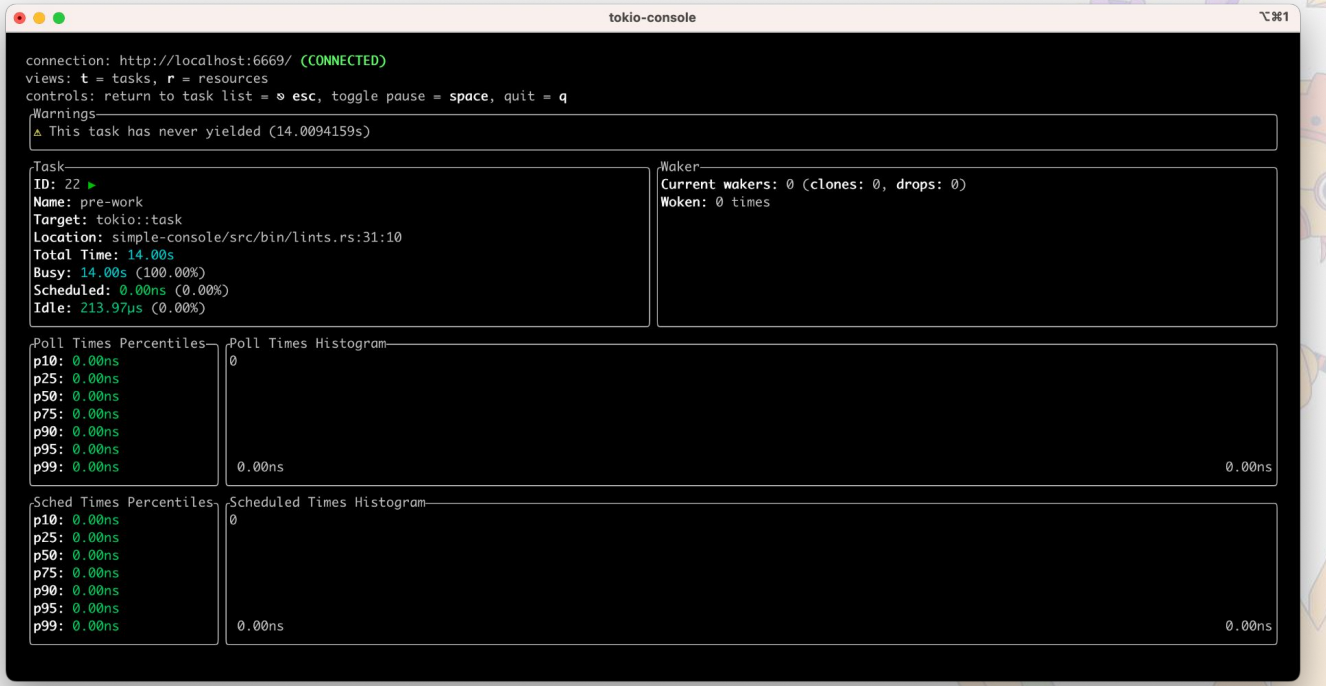


Never yielded - what could it be?

```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

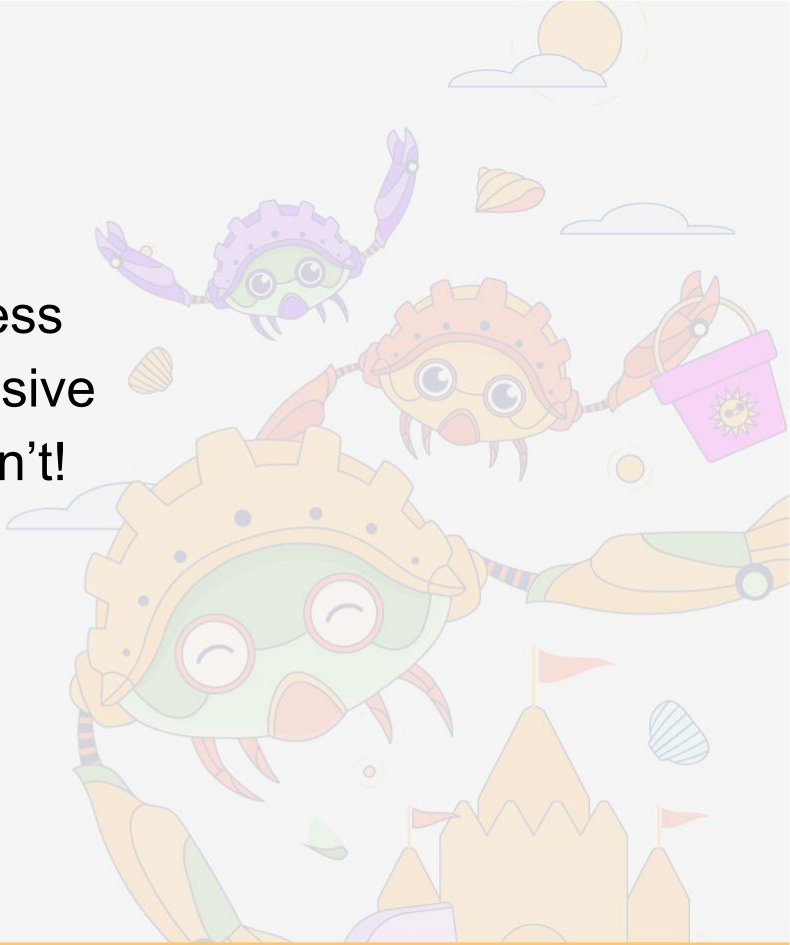
```rust
let barrier = Arc::new(Barrier::new(2));
let (_tx, mut rx) = mpsc::channel::<u64>(2);

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
```

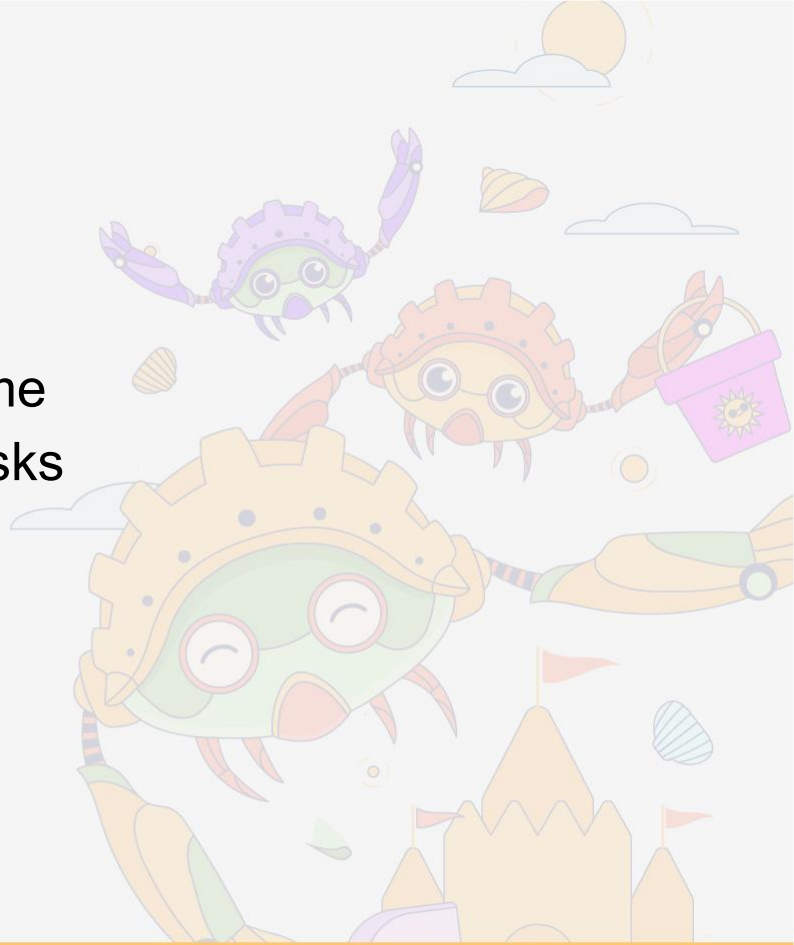
Caveats

- 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

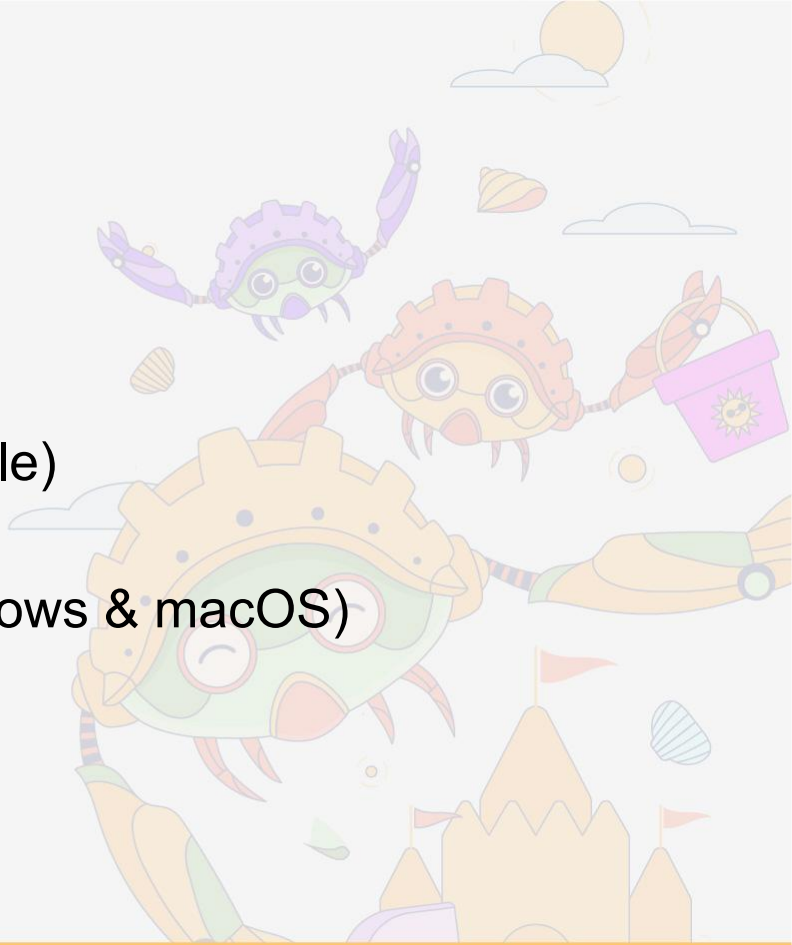
- Additional metrics
- Simpler collector integration

The Future: Tokio Console

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

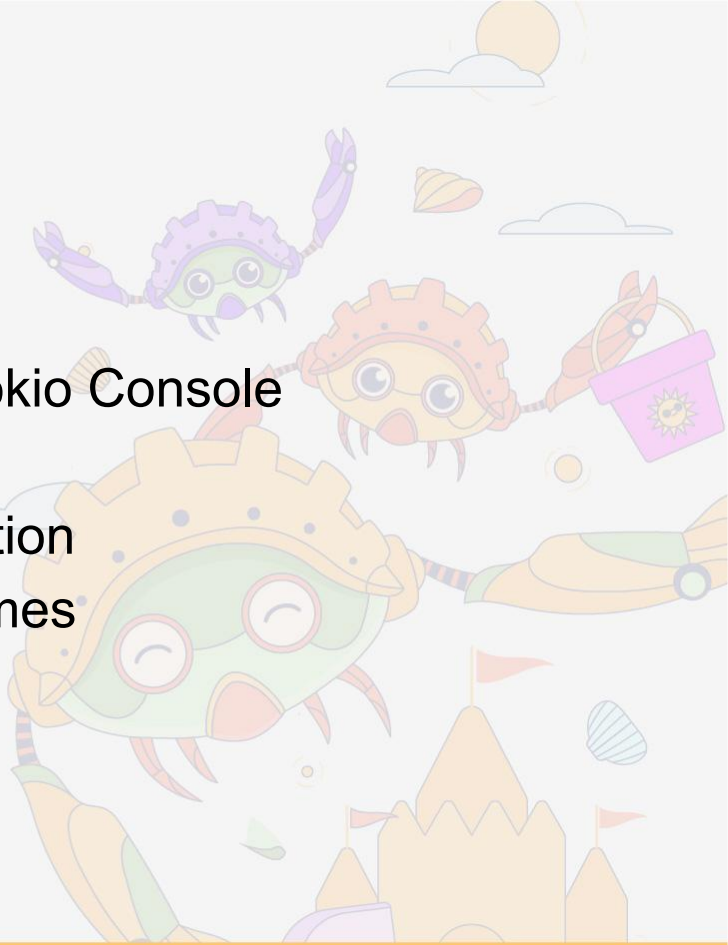
The Future: Task Dump

- 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

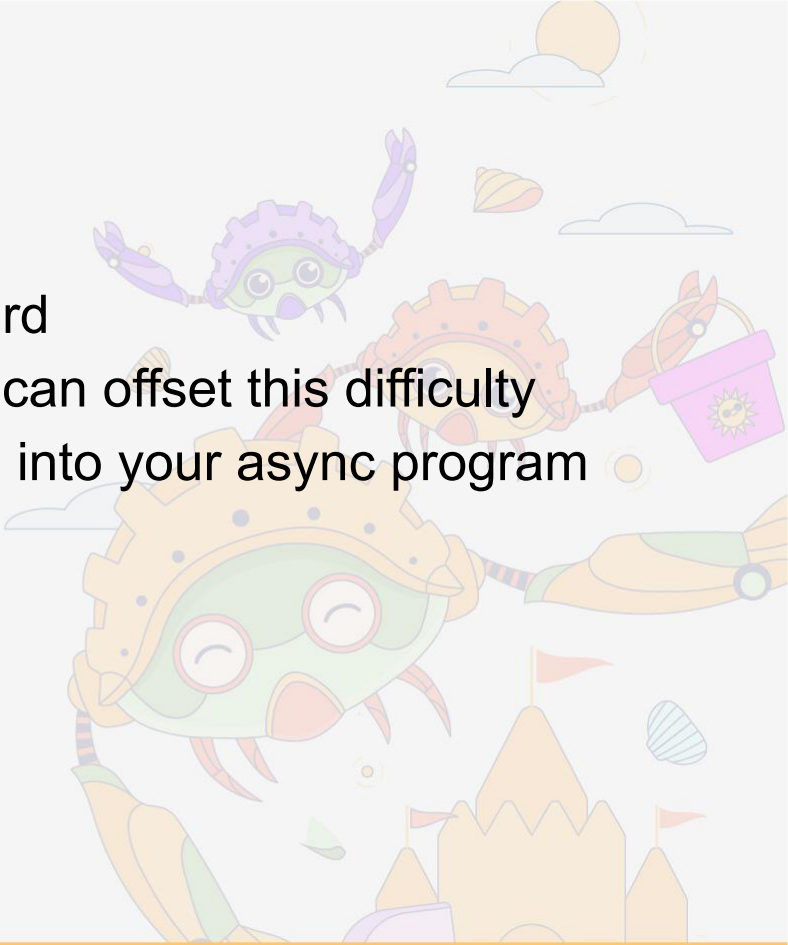


The Future: Ecosystem

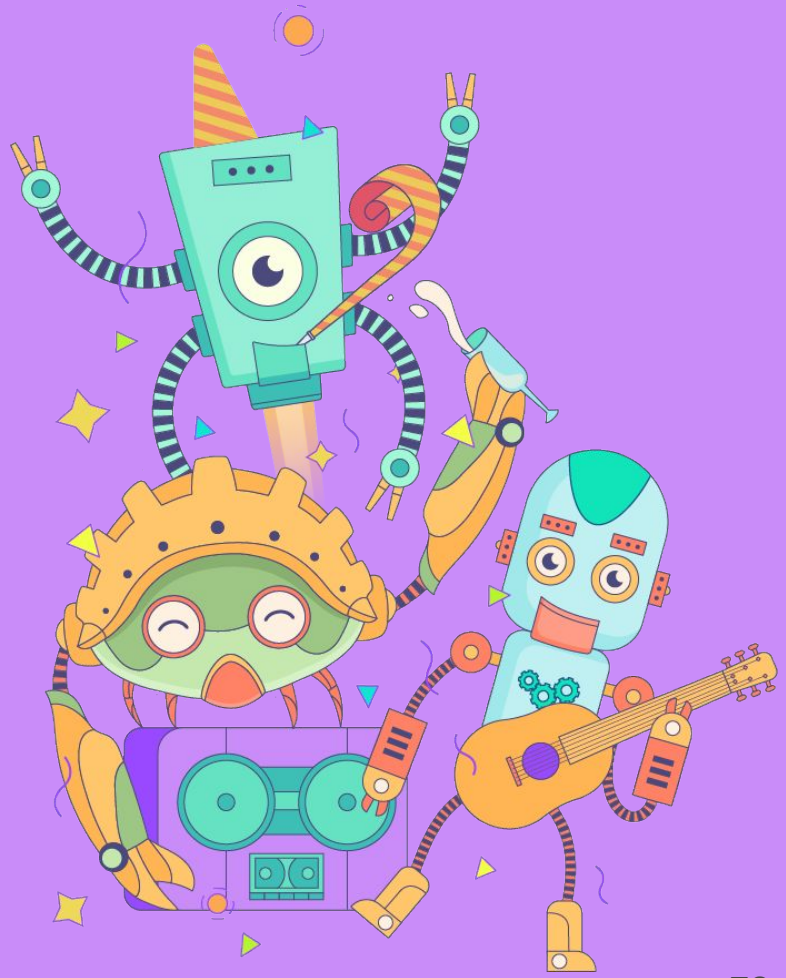
- You!
  - All these tools are open source
  - Many are developed in maintainer “free time”
  - Want to help?
    - Join us on the Tokio Discord

Final thoughts

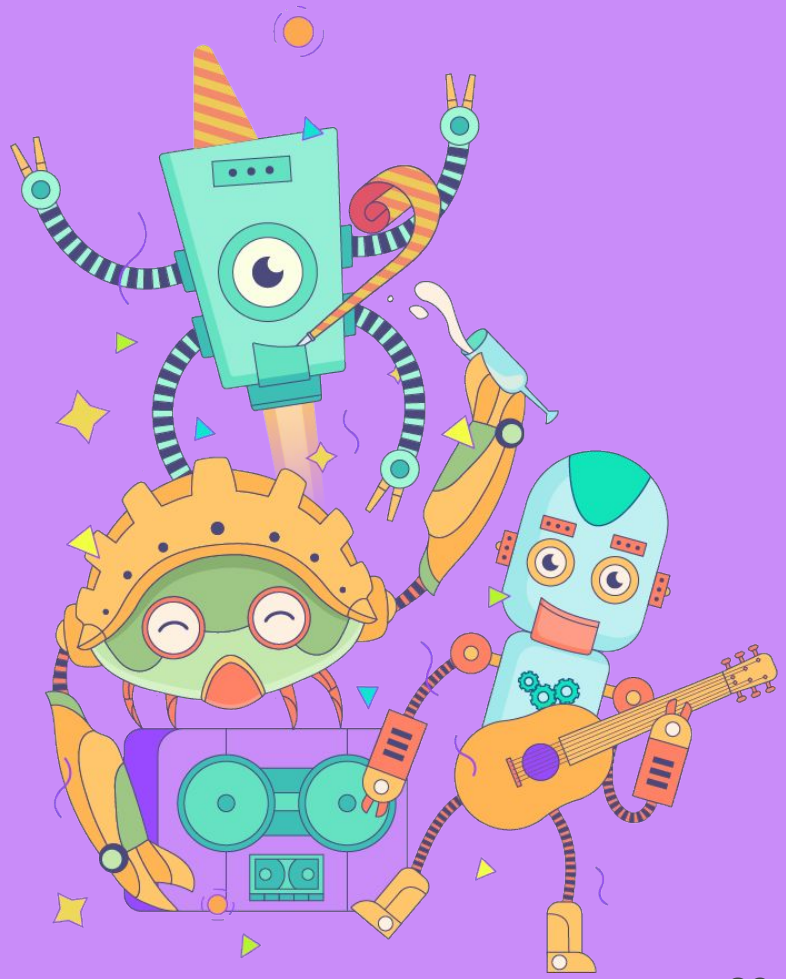
- Async programming can be hard
- Instrumentation of the runtime can offset this difficulty
- There are many options to see into your async program
- We're not there yet



Thank-you for listening



Questions?



Links

Tokio

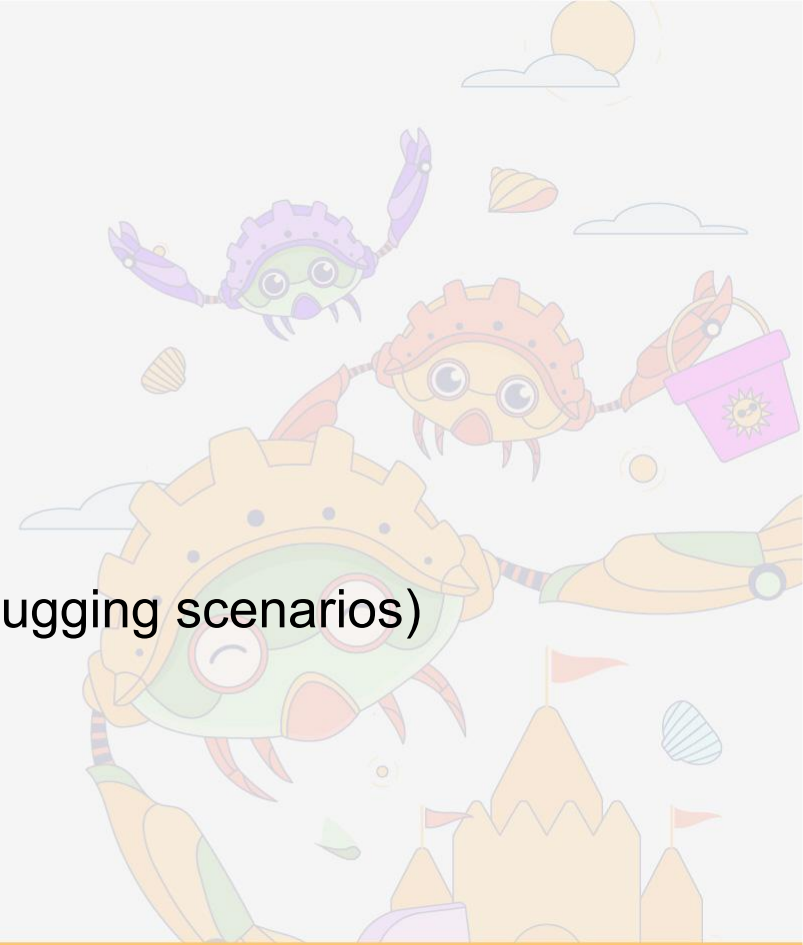
- Web-site
- Code
- docs.rs
- Discord server

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