Deep dive into Context Propagation

Jacob Wang

London Scala User Group, 2024 March

This talk

- Mechanisms for context propagation
- **otel4s** and **OpenTelemetry**

Hello

- Work at 

- Maintainer of Doobie and author of Difflicious + other libs
- https://mas.to/@jatcwang

Context Propagation - Large and Small

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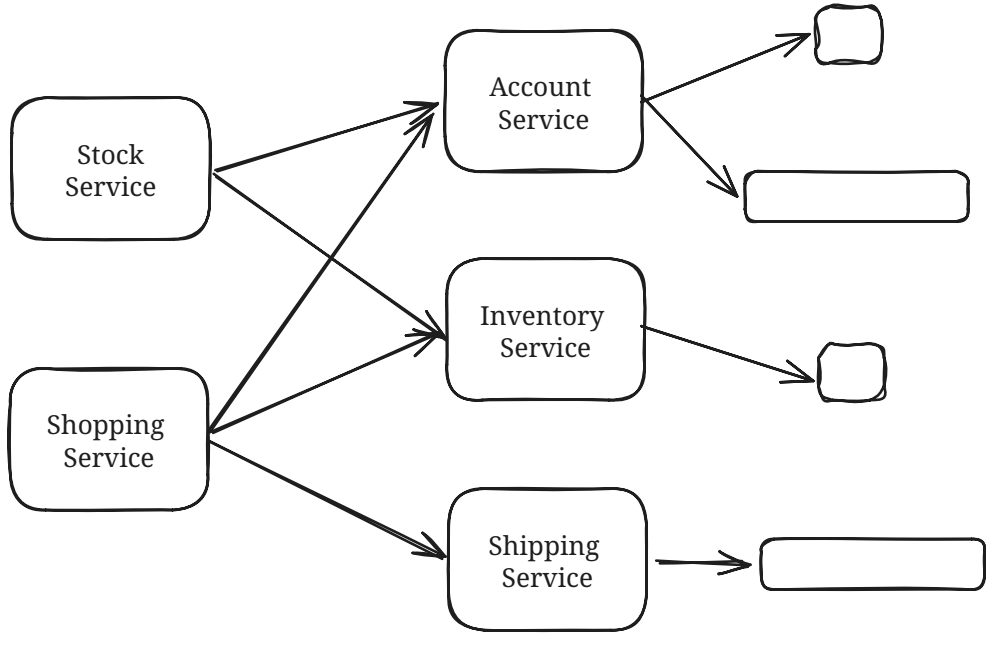

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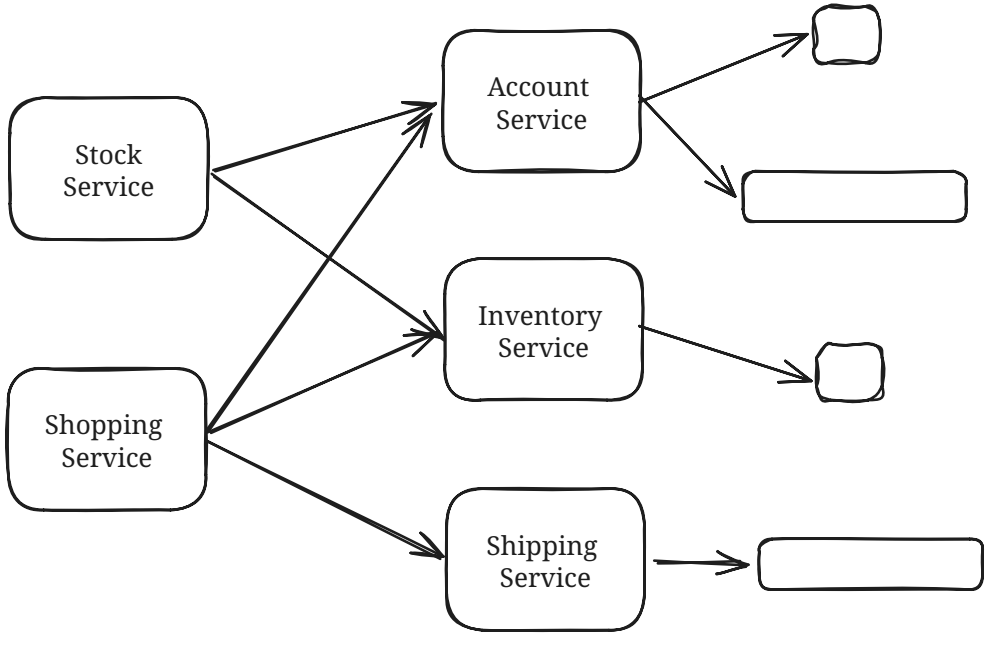

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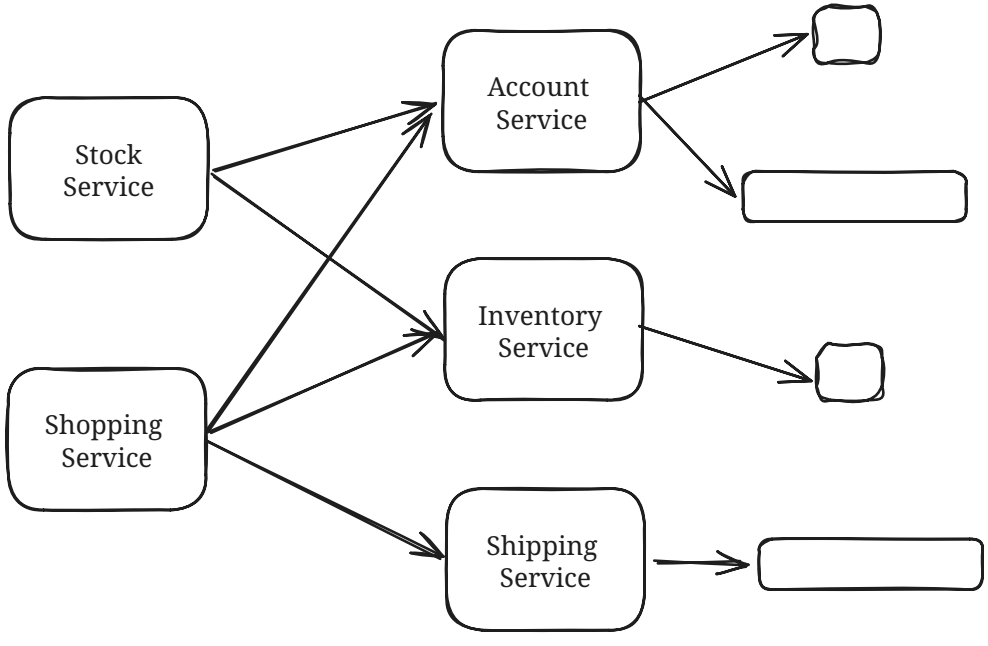

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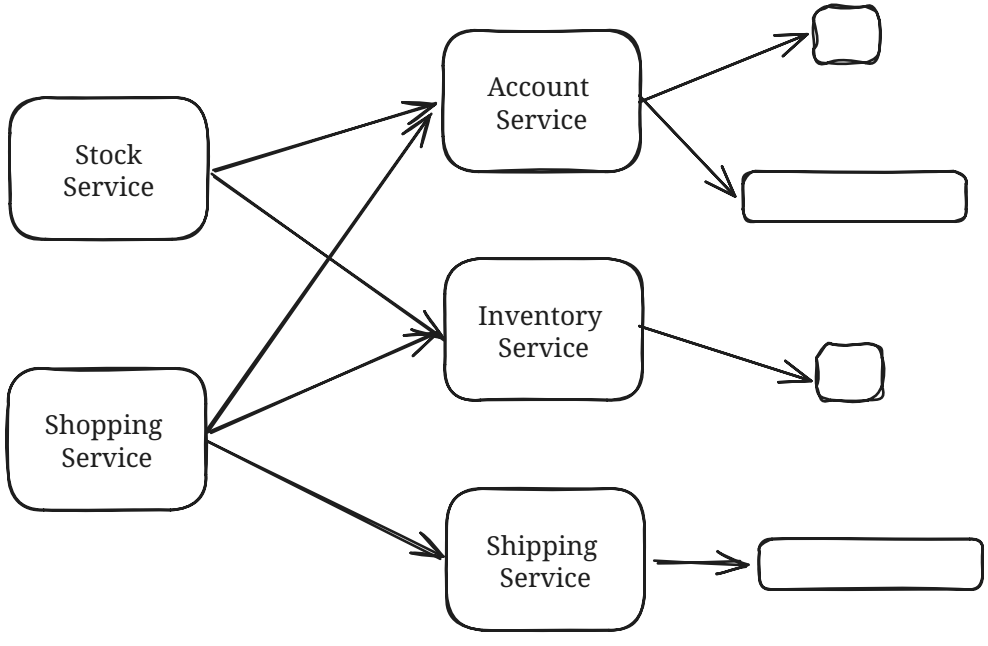

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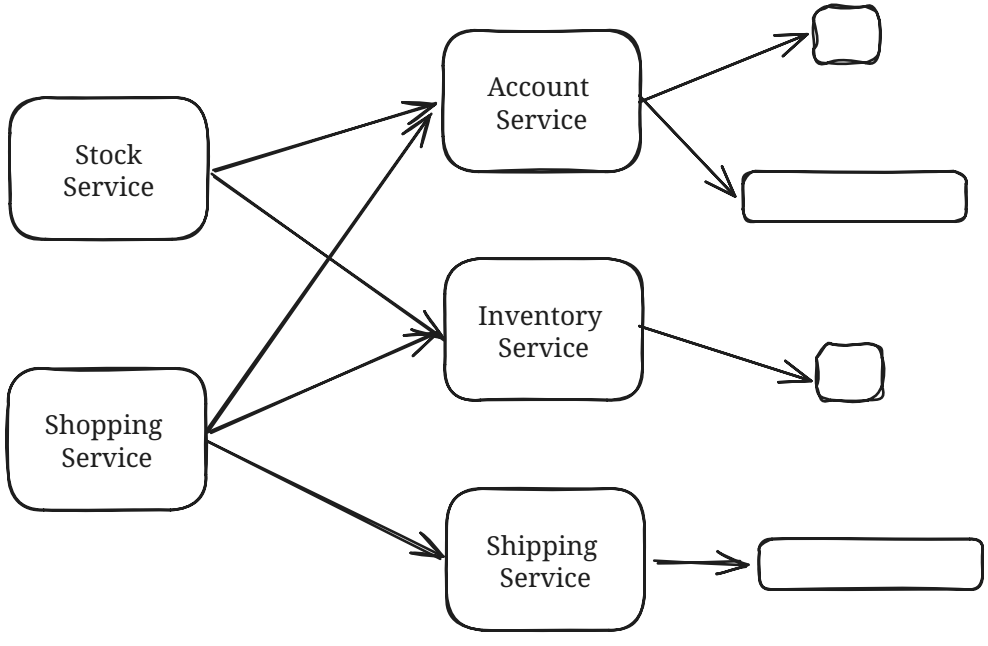

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- This talk: Passing context *within* an application
- Invisible / Non-local mechanisms only

java.lang.ThreadLocal

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```
1  val TL_FOO: ThreadLocal[Int] = ThreadLocal.withInitial(() => 0)
2  val TL_BAR: ThreadLocal[Int] = ThreadLocal.withInitial(() => 0)
3
4  TL_FOO.set(5)
5
6  TL_FOO.get() // == 5
7  TL_BAR.get() // == 0, because TL_BAR is a different "key" from TL_FOO
8
9  TL_FOO.remove()
10
11 TL_FOO.get() // == 0
```

```
1  val t1 = new Thread(() => {
2    TL_FOO.get()   // == 0
3    TL_FOO.set(1)
4    TL_FOO.get()   // == 1
5  }, "t1").start()
6
7  val t2 = new Thread(() => {
8    TL_FOO.get()   // == 0
9    TL_FOO.set(3)
10   TL_FOO.get()   // == 3
11 }, "t2").start()
```

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  - e.g. background tasks

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- Threads are often blocked
- CPU cores switching between threads (“context switching”) are expensive

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- "Async"
- Java/Scala Futures and Effect runtimes (Cats-effect, ZIO) are all built on top of threadpools

```
1  trait Runnable {
2    def run(): Unit
3  }
4
5  trait Executor { // The threadpool interface
6    def execute(task: Runnable): Unit
7  }
```

```scala
val threadpool = Executors.newFixedThreadPool(4)
val httpClient = ...
val finishCallback: Result => Unit = ...

threadpool.execute(() => {
  println(s"step 1")
  val httpRequest = ...

  httpClient.send(httpRequest, onResponse = response => {
    // Callback will submit next task to threadpool
    threadpool.execute(() => {
      val result = doWork(response)
      finishCallback(result)
    })

  })
})
```


I think I forgot something.
If you forgot, then it wasn't important.
Yeah, you're right.
ThreadLocal
imgflip.com

Losing Context

```
1    val threadpool = Executors.newFixedThreadPool(4) // 4 threads in pool
2    val CONTEXT = ThreadLocal.withInitial(() => "no user")
3
4    threadpool.execute(() => {
5      CONTEXT.set("user1")
6      println(s"${Thread.currentThread().getName}: step 1 for $
XT.get()}")
7
8      threadpool.execute(() => {
9        println(s"${Thread.currentThread().getName}: step 2 for $
XT.get()}")
10
11       threadpool.execute(() => {
12         println(s"${Thread.currentThread().getName}: complete for $
XT.get()}")
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15     })
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- Worse, another unrelated task executing on thread 1 now has “user 1” as its context!

Making ThreadLocal work with threadpools

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4      val wrappedTask = wrap(task, toAttach)                // T1
5      delegate.execute(wrappedTask)                         // T1
6
7    def wrap(task: Runnable, toAttach: Context): Runnable =
8      () =>
9        try                                                 //   T2
10         CONTEXT.set(toAttach)                             //   T2
11         task.run()                                        //   T2
12       finally                                             //   T2
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  - Set the context we want to pass on (Line 10)
  - Remove the ThreadLocal value (Line 13)

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cats.effect.IOLocal

- With Cats-Effect, *can* use `ThreadLocal` + task wrapping trick we just learned
- But we have a nicer solution: `IOLocal`
- `IOLocal` allow us to pass context through the executing fiber
- On fork, child fibers inherit a copy of the parent's context

cats.effect.IOLocal Example

```
1  for
2    // Create the IOLocal "key"
3    CONTEXT <- IOLocal(default = 0)
4
5    _ <- CONTEXT.get                    // == 0
6    _ <- CONTEXT.set(5)
7
8    // fork!
9    fiber1 <- (for {
10     _ <- CONTEXT.get                  // == 5
11     _ <- CONTEXT.set(6)
12     _ <- CONTEXT.get                  // == 6
13   } yield ()).start
14
15   _ <- CONTEXT.get                    // == 5
16   _ <- CONTEXT.set(10)
17   _ <- fiber1.joinWithNever
18   _ <- CONTEXT.get                    // == 10
19 yield ()
```

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- **ThreadLocal**
- **Thread pools** and how ThreadLocal can work with them
- `IOLocal` for cats-effect
- Now, let's apply what we've learned

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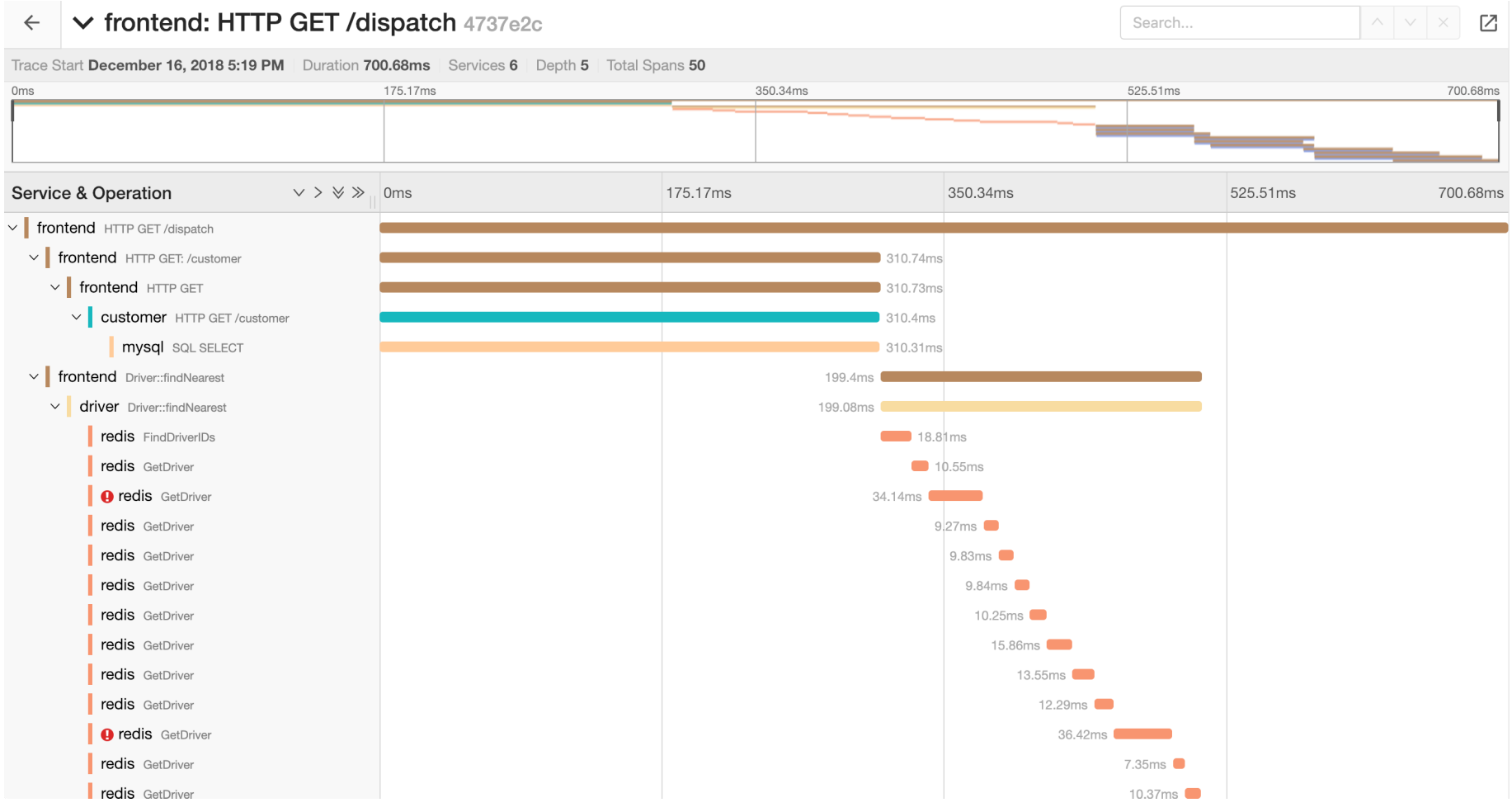
- **Span**: A recorded unit of work
  - Attributes include `traceId`, `parentSpanId`, `isError` and `duration`
- **Trace**: Links together a set of spans (same `traceId`), so we can track the execution trace from start to finish across services.


frontend: HTTP GET /dispatch 4737e2c
Search...
Trace Start December 16, 2018 5:19 PM
Duration 700.68ms
Services 6
Depth 5
Total Spans 50
0ms
175.17ms
350.34ms
525.51ms
700.68ms
Service & Operation
frontend HTTP GET /dispatch
frontend HTTP GET: /customer
frontend HTTP GET
customer HTTP GET /customer
mysql SQL SELECT
frontend Driver::findNearest
driver Driver::findNearest
redis FindDriverIDs
redis GetDriver
redis GetDriver
redis GetDriver
redis GetDriver
redis GetDriver
redis GetDriver
redis GetDriver
redis GetDriver
redis GetDriver
redis GetDriver
redis GetDriver
redis GetDriver
redis GetDriver
310.74ms
310.73ms
310.4ms
310.31ms
199.4ms
199.08ms
18.81ms
10.55ms
34.14ms
9.27ms
9.83ms
9.84ms
10.25ms
15.86ms
13.55ms
12.29ms
36.42ms
7.35ms
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- Typelevel ecosystem
- Follows OTel terminology and specification, but does not directly use OpenTelemetry-Java types
- Uses OpenTelemetry-Java as backend (e.g. reporting spans)

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  - e.g. `Span` object is stored in `Context`
  - ```
    val context = Map(
      SPAN_KEY -> Span(traceId, spanId, ...),
      BAGGAGE_KEY -> Baggage(..)
    )
    ```
    ```

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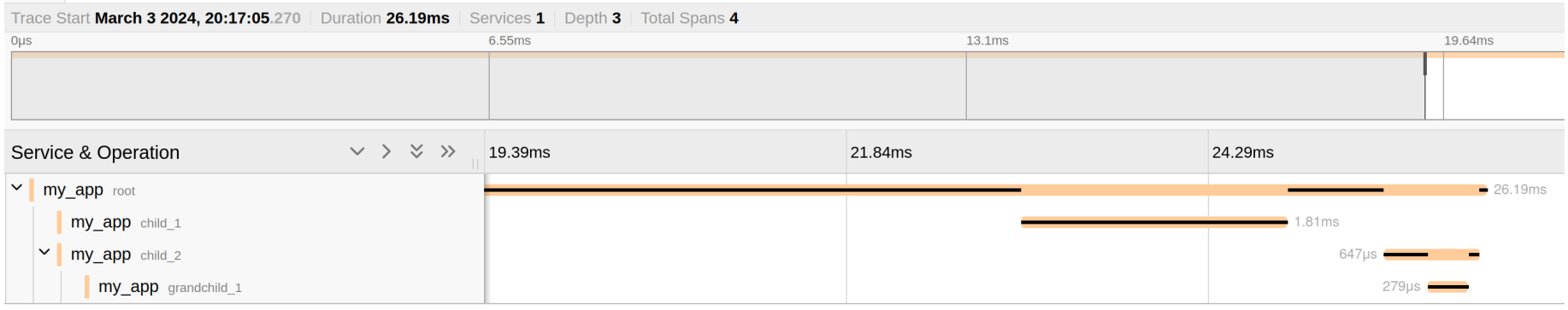
    ```
- `OpenTelemetry`/`Otel4s`: Central service for handling reporting spans and metrics
- `Tracer`: Use to create spans. Created from `OpenTelemetry` instance
    ```

Otel4s - Minimal Example

```scala
import cats.effect._
import cats.implicits.*
import org.typelevel.otel4s.oteljava.context.Context
import org.typelevel.otel4s.oteljava.OtelJava
import org.typelevel.otel4s.trace.Tracer
```

```scala
for
  otel4s <- OtelJava.global[IO] // Initialize otel-java backend of Otel4s
  given Tracer[IO] <- otel4s.tracerProvider.get("my_app")

  _ <- Tracer[IO].span("root").surround(      // Start a span,
nding an IO
    for
      _ <- Tracer[IO].span("child_1").surround(
        IO.println("work work")
      )
      _ <- Tracer[IO].span("child_2").surround(
        Tracer[IO].span("grandchild_1").surround(
          IO.println("more work done")
        )
      )
    yield ()
  )
yield ()
```


Trace Start March 3 2024, 20:17:05.270
Duration 26.19ms
Services 1
Depth 3
Total Spans 4
0µs
6.55ms
13.1ms
19.64ms
Service & Operation
19.39ms
21.84ms
24.29ms
my_app root
my_app child_1
my_app child_2
my_app grandchild_1
26.19ms
1.81ms
647µs
279µs

Integrating with Java libraries

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Integrating with Java libraries

- In Otel4s, we use IOLocal to propagate context, but Java libs use opentelemetry-java (`ThreadLocal`)
- 💡 Extract `Context` from IOLocal and set it up as ThreadLocal before calling the java code

```scala
import cats.mtl.Local
import io.opentelemetry.context.Context as JContext // Context type from Tel

def blockingWithContext[A](use: => A)(using local: Local[IO, Context]): =
  for
    context <- local.ask
    result <- IO.blocking {
      val jContext: JContext = context.underlying
      val scope = jContext.makeCurrent()       // Set the ThreadLocal
      try
        use
      finally
        scope.close()                          // Unset the ThreadLocal
    }
  yield result
```

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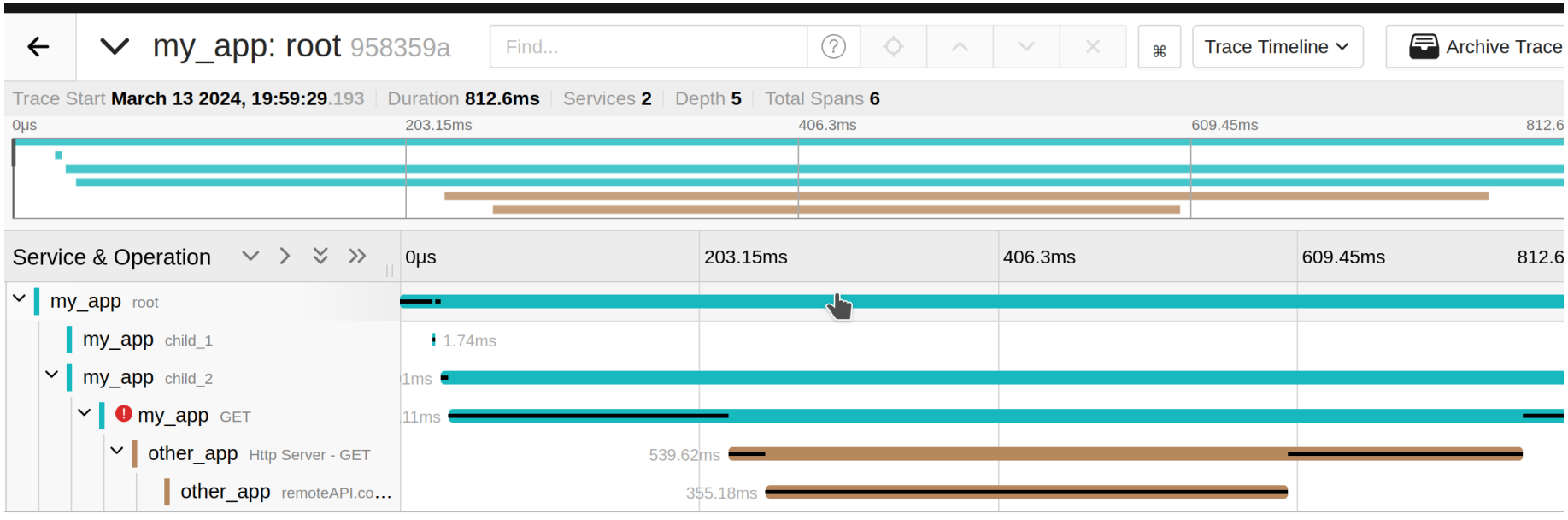
- **Expectations**: Downstream service continues the trace

```
      1  import
ntelemetry.instrumentation.httpclient.JavaHttpClientTelemetry
      2
      3  for
      4    otel4s <- OtelJava.global[IO]
      5    given Tracer[IO] <- otel4s.tracerProvider.get("my_app")
      6    given Local[IO, Context] = otel4s.localContext
      7
      8    httpClient = HttpClient.newBuilder().build()
      9    instrumentedHttpClient = JavaHttpClientTelemetry
     10            .builder(GlobalOpenTelemetry.get())
     11            .build()
     12            .newHttpClient(httpClient)
     13    myService = MyService(instrumentedHttpClient)
     14
     15    _ <- myService.doWorkAndMakeRequest
     16  yield ()
```

Integrating with Java libraries - Example

```
1  class MyService(javaHttpClient: HttpClient)(using Local[IO, Context],
[IO]):
2
3    def doWorkAndMakeRequest: IO[Unit] =
4      withSpan("root")(for
5        _ <- withSpan("child_1")(IO.println("work work"))
6
7        _ <- withSpan("child_2")(for
8          req <- IO(HttpRequest.newBuilder()
9            .uri(new URI("http://localhost:8080/example"))
10           .GET()
11           .build())
12
13         resp <- blockingWithContext {
14             javaHttpClient.send(req, BodyHandlers.ofString)
15           }
16         _ <- IO.println(resp.body())
17       yield ())
18
19     yield ())
20
21   def withSpan[F[_], A](name: String)(using tracer: Tracer[F])(io: F[A]):

22     tracer.span(name).surround(io)
```


my_app: root 958359a
Find...
Trace Timeline
Archive Trace
Trace Start March 13 2024, 19:59:29.193
Duration 812.6ms
Services 2
Depth 5
Total Spans 6
0µs
203.15ms
406.3ms
609.45ms
812.6
Service & Operation
my_app root
my_app child_1
1.74ms
my_app child_2
1ms
my_app GET
11ms
other_app Http Server - GET
539.62ms
other_app remoteAPI.co…
355.18ms

Final thoughts

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- Prefer Manual instrumentation? (Instead of using OTel Java agent)

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- Scala 3