

# Rhine, FRP with type-level clocks

## Functional Reactive Programming for Zurihac '24

Manuel Bärenz

June 8, 2024

# Functional Reactive Programming with Rhine

What's this now?

- I'm Manuel Bärenz (he/him)

Plan for this session

# Functional Reactive Programming with Rhine

## What's this now?

- I'm Manuel Bärenz (he/him)
- We'll do <https://github.com/turion/rhine-koans/>

## Plan for this session

# Functional Reactive Programming with Rhine

## What's this now?

- I'm Manuel Bärenz (he/him)
- We'll do <https://github.com/turion/rhine-koans/>

## Plan for this session

- 14:35 I'll briefly talk about FRP & Rhine (<15 minutes)

# Functional Reactive Programming with Rhine

## What's this now?

- I'm Manuel Bärenz (he/him)
- We'll do <https://github.com/turion/rhine-koans/>

## Plan for this session

- 14:35 I'll briefly talk about FRP & Rhine (<15 minutes)
- 14:50 If you haven't already, you'll clone the rhine-koans repo  
(Or find someone to pair program with!)

# Functional Reactive Programming with Rhine

## What's this now?

- I'm Manuel Bärenz (he/him)
- We'll do <https://github.com/turion/rhine-koans/>

## Plan for this session

- 14:35 I'll briefly talk about FRP & Rhine (<15 minutes)
- 14:50 If you haven't already, you'll clone the rhine-koans repo (Or find someone to pair program with!)
- 14:50 I'll show you how it works & walk you through the first koan

# Functional Reactive Programming with Rhine

## What's this now?

- I'm Manuel Bärenz (he/him)
- We'll do <https://github.com/turion/rhine-koans/>

## Plan for this session

- 14:35 I'll briefly talk about FRP & Rhine (<15 minutes)
- 14:50 If you haven't already, you'll clone the rhine-koans repo (Or find someone to pair program with!)
- 14:50 I'll show you how it works & walk you through the first koan
- 14:55 You'll solve the basic track, I'll come around and answer your questions

# Functional Reactive Programming with Rhine

## What's this now?

- I'm Manuel Bärenz (he/him)
- We'll do <https://github.com/turion/rhine-koans/>

## Plan for this session

- 14:35 I'll briefly talk about FRP & Rhine (<15 minutes)
- 14:50 If you haven't already, you'll clone the rhine-koans repo (Or find someone to pair program with!)
- 14:50 I'll show you how it works & walk you through the first koan
- 14:55 You'll solve the basic track, I'll come around and answer your questions
- 15:30 We'll collect & discuss the biggest questions & hardest problems that occurred so far



# Functional Reactive Programming with Rhine

## What's this now?

- I'm Manuel Bärenz (he/him)
- We'll do <https://github.com/turion/rhine-koans/>

## Plan for this session

- 14:35 I'll briefly talk about FRP & Rhine (<15 minutes)
- 14:50 If you haven't already, you'll clone the rhine-koans repo (Or find someone to pair program with!)
- 14:50 I'll show you how it works & walk you through the first koan
- 14:55 You'll solve the basic track, I'll come around and answer your questions
- 15:30 We'll collect & discuss the biggest questions & hardest problems that occurred so far
- 15:40 You'll start on the UI track, or on your own project, I'll come around and answer questions

Let me tell you a tale...

...but don't worry!

You don't need to memorise everything. Lean back & relax :)

# About Functional Reactive Programming

## What is Functional Reactive Programming?

- Ivan Perez/Conal Elliot: FRP is about time.

## Is this here Functional Reactive Programming?

# About Functional Reactive Programming

## What is Functional Reactive Programming?

- Ivan Perez/Conal Elliot: FRP is about time.
- Use awareness of time in the program.

## Is this here Functional Reactive Programming?

# About Functional Reactive Programming

## What is Functional Reactive Programming?

- Ivan Perez/Conal Elliot: FRP is about time.
- Use awareness of time in the program.
- *When* do computations & effects happen?

## Is this here Functional Reactive Programming?

# About Functional Reactive Programming

## What is Functional Reactive Programming?

- Ivan Perez/Conal Elliot: FRP is about time.
- Use awareness of time in the program.
- *When* do computations & effects happen?

## Is this here Functional Reactive Programming?

- It's a workshop on one specific, opinionated framework (<https://github.com/turion/rhine>)

# About Functional Reactive Programming

## What is Functional Reactive Programming?

- Ivan Perez/Conal Elliot: FRP is about time.
- Use awareness of time in the program.
- *When* do computations & effects happen?

## Is this here Functional Reactive Programming?

- It's a workshop on one specific, opinionated framework (<https://github.com/turion/rhine>)
- There are many other frameworks around that work similarly or quite differently

## Monadic/effectful streaming

- Centered around a “main loop” which constantly consumes & produces data, and performs side effects



## Monadic/effectful streaming

- Centered around a “main loop” which constantly consumes & produces data, and performs side effects
- “Synchronous”: One output per input

# Monadic/effectful streaming

- Centered around a “main loop” which constantly consumes & produces data, and performs side effects
- “Synchronous”: One output per input
  - dunai, automaton, essence-of-live-coding, machines, varying, netwire, . . .

# Monadic/effectful streaming

- Centered around a “main loop” which constantly consumes & produces data, and performs side effects
- “Synchronous”: One output per input
  - dunai, automaton, essence-of-live-coding, machines, varying, netwire, . . .
  - **Monadic stream function:**  
`data MSF m a b = MSF (a -> m (b, MSF m a b))`

# Monadic/effectful streaming

- Centered around a “main loop” which constantly consumes & produces data, and performs side effects
- “Synchronous”: One output per input
  - dunai, automaton, essence-of-live-coding, machines, varying, netwire, . . .
  - **Monadic stream function:**  
`data MSF m a b = MSF (a -> m (b, MSF m a b))`
- “Asynchronous”: Many outputs per many inputs

# Monadic/effectful streaming

- Centered around a “main loop” which constantly consumes & produces data, and performs side effects
- “Synchronous”: One output per input
  - dunai, automaton, essence-of-live-coding, machines, varying, netwire, ...
  - **Monadic stream function:**  
`data MSF m a b = MSF (a -> m (b, MSF m a b))`
- “Asynchronous”: Many outputs per many inputs
  - pipes, conduit, streamly, streaming, machines, ...

# Functional reactive programming paradigms

- “Classic” FRP: **Behaviours & events**

# Functional reactive programming paradigms

- “Classic” FRP: **Behaviours & events**
  - Morally type Behaviour  $a = \text{Time} \rightarrow a$

# Functional reactive programming paradigms

- “Classic” FRP: **Behaviours & events**
  - Morally type Behaviour  $a = \text{Time} \rightarrow a$ 
    - Computations happen all the time!



# Functional reactive programming paradigms

- “Classic” FRP: **Behaviours & events**
  - Morally type Behaviour  $a = \text{Time} \rightarrow a$ 
    - Computations happen all the time!
  - Morally type Event  $a = [(\text{Time}, a)]$

# Functional reactive programming paradigms

- “Classic” FRP: **Behaviours & events**
  - Morally type Behaviour  $a = \text{Time} \rightarrow a$ 
    - Computations happen all the time!
  - Morally type Event  $a = [(\text{Time}, a)]$ 
    - A computation happens on every event

# Functional reactive programming paradigms

- “Classic” FRP: **Behaviours & events**
  - Morally type Behaviour  $a = \text{Time} \rightarrow a$ 
    - Computations happen all the time!
  - Morally type Event  $a = [(\text{Time}, a)]$ 
    - A computation happens on every event
  - FRAN, frpnow, reactive-banana, reflex, ...

# Functional reactive programming paradigms

- “Classic” FRP: **Behaviours & events**
  - Morally type Behaviour  $a = \text{Time} \rightarrow a$ 
    - Computations happen all the time!
  - Morally type Event  $a = [(\text{Time}, a)]$ 
    - A computation happens on every event
  - FRAN, frpnow, reactive-banana, reflex, ...
- Arrowized FRP: **Signal functions**

# Functional reactive programming paradigms

- “Classic” FRP: **Behaviours & events**
  - Morally type Behaviour  $a = \text{Time} \rightarrow a$ 
    - Computations happen all the time!
  - Morally type Event  $a = [(\text{Time}, a)]$ 
    - A computation happens on every event
  - FRAN, frpnow, reactive-banana, reflex, ...
- Arrowized FRP: **Signal functions**
  - Morally type SF  $a \ b = \text{Behaviour } a \rightarrow \text{Behaviour } b$

# Functional reactive programming paradigms

- “Classic” FRP: **Behaviours & events**
  - Morally type Behaviour  $a = \text{Time} \rightarrow a$ 
    - Computations happen all the time!
  - Morally type Event  $a = [(\text{Time}, a)]$ 
    - A computation happens on every event
  - FRAN, frpnow, reactive-banana, reflex, ...
- Arrowized FRP: **Signal functions**
  - Morally type SF  $a \rightarrow b = \text{Behaviour } a \rightarrow \text{Behaviour } b$
  - Yampa, dunai, bearriver, Rhine

# Functional reactive programming paradigms

- “Classic” FRP: **Behaviours & events**
  - Morally type Behaviour  $a = \text{Time} \rightarrow a$ 
    - Computations happen all the time!
  - Morally type Event  $a = [(\text{Time}, a)]$ 
    - A computation happens on every event
  - FRAN, frpnow, reactive-banana, reflex, ...
- Arrowized FRP: **Signal functions**
  - Morally type SF  $a \ b = \text{Behaviour } a \rightarrow \text{Behaviour } b$
  - Yampa, dunai, bearriver, Rhine
- Effectful FRP: “Monadic signal functions”

# Functional reactive programming paradigms

- “Classic” FRP: **Behaviours & events**
  - Morally type Behaviour  $a = \text{Time} \rightarrow a$ 
    - Computations happen all the time!
  - Morally type Event  $a = [(\text{Time}, a)]$ 
    - A computation happens on every event
  - FRAN, frpnow, reactive-banana, reflex, ...
- Arrowized FRP: **Signal functions**
  - Morally type SF  $a \ b = \text{Behaviour } a \rightarrow \text{Behaviour } b$
  - Yampa, dunai, bearriver, Rhine
- Effectful FRP: “Monadic signal functions”
  - type SF  $m \ a \ b = \text{MSF } (\text{ReaderT Time } m) \ a \ b$



# Functional reactive programming paradigms

- “Classic” FRP: **Behaviours & events**
  - Morally type Behaviour  $a = \text{Time} \rightarrow a$ 
    - Computations happen all the time!
  - Morally type Event  $a = [(\text{Time}, a)]$ 
    - A computation happens on every event
  - FRAN, frpnow, reactive-banana, reflex, ...
- Arrowized FRP: **Signal functions**
  - Morally type SF  $a \ b = \text{Behaviour } a \rightarrow \text{Behaviour } b$
  - Yampa, dunai, bearriver, Rhine
- Effectful FRP: “Monadic signal functions”
  - type SF  $m \ a \ b = \text{MSF } (\text{ReaderT Time } m) \ a \ b$
  - bearriver, Rhine

## Rhine: Arrowized FRP with type level clocks

How to organize bigger FRP applications?

- Different components are activated at different times

## Rhine: Arrowized FRP with type level clocks

### How to organize bigger FRP applications?

- Different components are activated at different times
  - E.g. game simulation at one frame rate, video and audio at other rates, user input as an event source

# Rhine: Arrowized FRP with type level clocks

## How to organize bigger FRP applications?

- Different components are activated at different times
  - E.g. game simulation at one frame rate, video and audio at other rates, user input as an event source
- Make these differences visible as *type level clocks*

# Rhine: Arrowized FRP with type level clocks

## How to organize bigger FRP applications?

- Different components are activated at different times
  - E.g. game simulation at one frame rate, video and audio at other rates, user input as an event source
- Make these differences visible as *type level clocks*
- Compose synchronous (1-1) and asynchronous (many-many) components safely

# Rhine: Arrowized FRP with type level clocks

## How to organize bigger FRP applications?

- Different components are activated at different times
  - E.g. game simulation at one frame rate, video and audio at other rates, user input as an event source
- Make these differences visible as *type level clocks*
- Compose synchronous (1-1) and asynchronous (many-many) components safely
- Accidental synchronisation becomes a type error

# Rhine: Arrowized FRP with type level clocks

## How to organize bigger FRP applications?

- Different components are activated at different times
  - E.g. game simulation at one frame rate, video and audio at other rates, user input as an event source
- Make these differences visible as *type level clocks*
- Compose synchronous (1-1) and asynchronous (many-many) components safely
- Accidental synchronisation becomes a type error
- Framework to answer the question “*When* do computations & effects happen?”

# Rhine concepts

## Clock types and values

```
class Clock m cl where
  type Time cl -- The type of timestamps
  type Tag cl  -- Additional info about the tick
  ...

-- Ticks every 10 milliseconds.
waitClock :: Millisecond 10
waitClock = ...
instance Clock IO (Millisecond 10) where ...

-- Ticks for every line entered on stdin. (An "event")
data StdinClock = StdinClock
instance Clock IO StdinClock where
  type Tag StdinClock = Text
  ...
```



# Rhine concepts

## Running example

[github.com/turion/rhine/blob/master/rhine-examples/src/Ball.hs](https://github.com/turion/rhine/blob/master/rhine-examples/src/Ball.hs)

## Clocked signal functions (ClSF)

```
type Ball = (Double, Double, Double)
type BallVel = (Double, Double, Double)

startVel :: ClSF IO StdinClock () BallVel
startVel = arrMC1 $ const $ do
  velX <- randomRIO (-10, 10)
  velY <- randomRIO (-10, 10)
  velZ <- randomRIO (3, 10)
  return (velX, velY, velZ)
```

# Rhine concepts

## Behaviours: Clock-independent signal functions

```
freeFall :: (Monad m) => BallVel ->
  BehaviourF m UTCTime () Ball
freeFall v0 =
  arr (const (0, 0, -9.81))
    >>> integralFrom v0
    >>> integral
```

## Arrow syntax

```
height :: (Monad m) => BallVel ->
  BehaviourF m UTCTime () Double
height v0 = proc _ -> do
  pos <- freeFall v0 -< ()
  let (_, _, height) = pos
  returnA -< height
```

# Rhine concepts

```
throwMaybe :: (Monad m) =>  
  ClSF (ExceptT e m) cl (Maybe e) (Maybe a)
```

## Throwing exceptions

```
falling :: (Monad m) => BallVel -> ClSF (ExceptT () m)  
  (Millisecond 10) (Maybe BallVel) Ball  
falling v0 = proc _ -> do  
  pos <- freeFall v0 -< ()  
  let (_, _, height) = pos  
  throwMaybe -< guard $ height < 0  
  returnA -< pos  
  
waiting :: (Monad m) => ClSF (ExceptT BallVel m)  
  (Millisecond 10) (Maybe BallVel) Ball  
waiting = throwMaybe >>> arr (const zeroVector)
```

# Rhine concepts

```
data ClSFEexcept clock input output monad exception
```

## Handling exceptions

```
ballModes :: ClSFEexcept (Millisecond 10)
```

```
  (Maybe BallVel) Ball IO void
```

```
ballModes = do
```

```
  v0 <- try waiting
```

```
  once_ $ putStrLn "Catch!"
```

```
  try $ falling v0
```

```
  once_ $ putStrLn "Caught!"
```

```
  ballModes
```

```
ball :: ClSF IO (Millisecond 10) (Maybe BallVel) Ball
```

```
ball = safely ballModes
```

# Rhine concepts

## Top level programs: Rhine

```
startVelRh :: Rhine IO StdinClock () BallVel
startVelRh = startVel @@ StdinClock
```

```
resample :: ResamplingBuffer IO
          StdinClock (Millisecond 10) BallVel (Maybe BallVel)
resample = fifoUnbounded
```

```
ballRh :: Rhine IO (Millisecond 10) (Maybe BallVel) Ball
ballRh = ball @@ waitClock
```

```
mainRhine :: Rhine IO
            (SeqClock StdinClock (Millisecond 10)) () ()
mainRhine = startVelRh >-- resample --> ballRh
```

```
main = flow mainRhine
```

## Basic track (until 14:00)

Let's get it off the ground!

```
git clone git@github.com:turion/rhine-koans.git
cabal update
cabal run basic-1-1-hello-rhine
cabal test basic-1-1-hello-rhine-test
```

Slides

[github.com/turion/rhine-koans/blob/main/presentation/presentation.pdf](https://github.com/turion/rhine-koans/blob/main/presentation/presentation.pdf)

Ask me anything :)

Manuel (he/him), turion on Discord/Discourse/Github/...,  
turion@types.pl on Mastodon

## Advanced track

Let's dive in!

```
cabal test ui-1-gloss-1-circle-test
```

Ask me anything :)

Manuel (he/him), turion on Discord/Discourse/Github/...,  
turion@types.pl on Mastodon

Some project ideas

- Websocket clock:  
<https://hackage.haskell.org/package/wuss>

# Advanced track

Let's dive in!

```
cabal test ui-1-gloss-1-circle-test
```

Ask me anything :)

Manuel (he/him), turion on Discord/Discourse/Github/...,  
turion@types.pl on Mastodon

Some project ideas

- Websocket clock:  
<https://hackage.haskell.org/package/wuss>
- Webserver: <https://hackage.haskell.org/package/wai>



## Advanced track

Let's dive in!

```
cabal test ui-1-gloss-1-circle-test
```

Ask me anything :)

Manuel (he/him), turion on Discord/Discourse/Github/...,  
turion@types.pl on Mastodon

Some project ideas

- Websocket clock:  
<https://hackage.haskell.org/package/wuss>
- Webserver: <https://hackage.haskell.org/package/wai>
- Machine learning:  
<https://hackage.haskell.org/package/rhine-bayes>

# Advanced track

Let's dive in!

```
cabal test ui-1-gloss-1-circle-test
```

Ask me anything :)

Manuel (he/him), turion on Discord/Discourse/Github/...,  
turion@types.pl on Mastodon

Some project ideas

- Websocket clock:  
<https://hackage.haskell.org/package/wuss>
- Webserver: <https://hackage.haskell.org/package/wai>
- Machine learning:  
<https://hackage.haskell.org/package/rhine-bayes>
- Port the snake to rhine-terminal

# Advanced track

Let's dive in!

```
cabal test ui-1-gloss-1-circle-test
```

Ask me anything :)

Manuel (he/him), turion on Discord/Discourse/Github/...,  
turion@types.pl on Mastodon

Some project ideas

- Websocket clock:  
<https://hackage.haskell.org/package/wuss>
- Webserver: <https://hackage.haskell.org/package/wai>
- Machine learning:  
<https://hackage.haskell.org/package/rhine-bayes>
- Port the snake to rhine-terminal
- Challenge: Rhine entry in <https://github.com/gelisam/frp-zoo>

# Thanks!

- Malte Ott: Alpha testing

# Thanks!

- Malte Ott: Alpha testing
- Alex Drake: Invitation to Zurihac, many `rhine-*` libraries

# Thanks!

- Malte Ott: Alpha testing
- Alex Drake: Invitation to Zurihac, many `rhine-*` libraries
- Jun Matsushita: `rhine-terminal`

# Thanks!

- Malte Ott: Alpha testing
- Alex Drake: Invitation to Zurihac, many `rhine-*` libraries
- Jun Matsushita: `rhine-terminal`
- Ivan Perez: Discussions on FRP, `dunai` & `Rhine`