Functional Reactive Programming with Events and Behaviours - Part 1

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Introduction

“True” FRP means:

- Events and behaviours

- Denotational semantics

- The ability to handle continuous time

What does it give us?

Composable systems of time-varying state and logic.

We are looking at `reactive-banana` today.

Part 2 will cover `reflex`.

Worth looking at `sodium` if you want this goodness in an other-than-Haskell flavour.

Events

```haskell
data Event a = ...

instance Functor Event
```

Events fire at infinitely-thin logical points in time.

```
Event a ~ [(Time,a)]
```

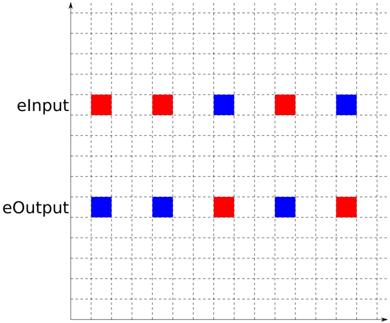
Events are push-based.

Each firing of an event is a new logical point in time.

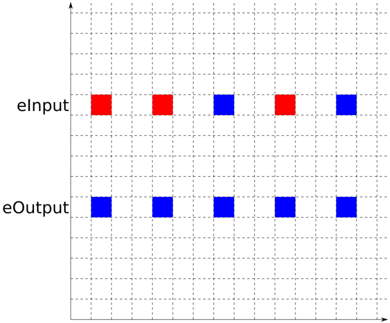
There can be multiple different events active at the same logical point in time.

The `Functor` instance demonstrates this - the output of `fmap` is active at the same points in time as the input.

```
flipper :: Event Colour
        -> Event Colour
flipper eInput =
  let
    eOutput =
      flip <$> eInput
  in
    eOutput
```



```haskell
blue :: Event Colour
     -> Event Colour
blue eInput =
  let
    eOutput =
      Blue <$ eInput
  in
    eOutput
```

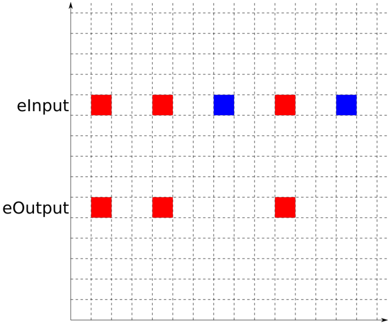


There are functions to filter and split events.

The outputs are active at the same points in time as the inputs - when the outputs are active at all.

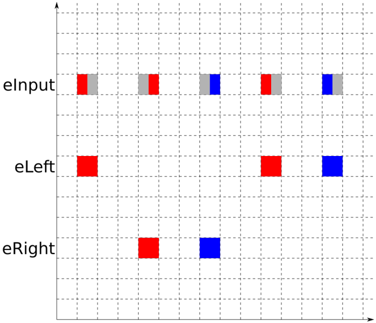
```haskell
filterE :: (a -> Bool) -> Event a -> Event a
```

```haskell
red :: Event Colour
    -> Event Colour
red eInput =
  let
    eOutput =
      filterE isRed eInput
  in
    eOutput
```



```haskell
split :: Event (Either a b) -> (Event a, Event b)
```

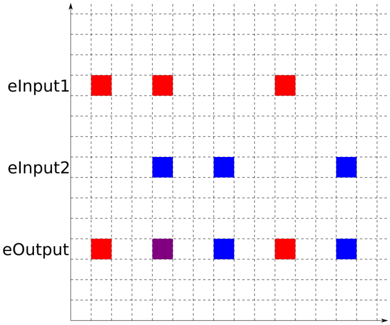
```haskell
type C = Colour
splitter :: Event (Either C C)
         -> (Event C, Event C)
splitter eInput =
  let
    (eLeft, eRight) =
      split eInput
  in
    (eLeft, eRight)
```



We need to be aware of the potential for simultaneous events when we combine them.

```haskell
unionWith :: (a -> a -> a)
          -> Event a -> Event a -> Event a
```

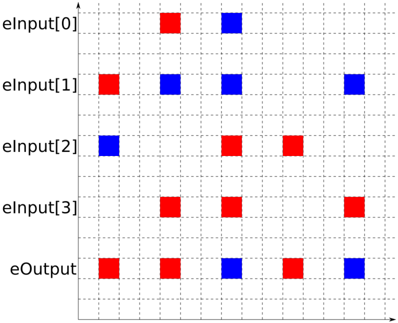
```haskell
mixer :: Event Colour
      -> Event Colour
      -> Event Colour
mixer eInput1 eInput2 =
  let
    eOutput =
      unionWith
        mix
        eInput1
        eInput2
  in
    eOutput
```



We can build a useful helper from this if you know you're not dealing with simultaneous events or if there is a clear priority between them.

```haskell
leftmost :: [Event a] -> Event a
leftmost = foldl (unionWith const) never
```

```haskell
lister :: [Event Colour]
       -> Event Colour
lister eInput =
  let
    eOutput =
      leftmost
        eInput
  in
    eOutput
```



There are other options for composing events:

```
unions :: [Event (a -> a)] -> Event (a -> a)
```

which we'll look at later.

Let's do something significant with this.

```haskell
multiple :: Int -> Event Int -> Event Int
multiple m =
  filterE (\x -> x `mod` m == 0)
```

```haskell
multiple :: Int -> Event Int -> Event Int
multiple m =
  filterE (\x -> x `mod` m == 0)

importantWork :: Event Int -> Event String
importantWork eCount =
  let




  in
    ???
```

```haskell
multiple :: Int -> Event Int -> Event Int
multiple m =
  filterE (\x -> x `mod` m == 0)

importantWork :: Event Int -> Event String
importantWork eCount =
  let
    eFizz = "Fizz" <$ multiple 3 eCount


  in
    ???
```

```haskell
multiple :: Int -> Event Int -> Event Int
multiple m =
  filterE (\x -> x `mod` m == 0)

importantWork :: Event Int -> Event String
importantWork eCount =
  let
    eFizz = "Fizz" <$ multiple 3 eCount
    eBuzz = "Buzz" <$ multiple 5 eCount

  in
    ???
```

```haskell
multiple :: Int -> Event Int -> Event Int
multiple m =
  filterE (\x -> x `mod` m == 0)

importantWork :: Event Int -> Event String
importantWork eCount =
  let
    eFizz = "Fizz" <$ multiple 3 eCount
    eBuzz = "Buzz" <$ multiple 5 eCount
    eFizzBuzz = unionWith (++) eFizz eBuzz
  in
    ???
```

```haskell
multiple :: Int -> Event Int -> Event Int
multiple m =
  filterE (\x -> x `mod` m == 0)

importantWork :: Event Int -> Event String
importantWork eCount =
  let
    eFizz = "Fizz" <$ multiple 3 eCount
    eBuzz = "Buzz" <$ multiple 5 eCount
    eFizzBuzz = unionWith (++) eFizz eBuzz
  in
    eFizzBuzz
```

We need a way to build a bridge between the ‘inside’ and ‘outside’ of an event network.

```haskell
newAddHandler :: IO (AddHandler a, a -> IO ())
```

```haskell
data EventSource a = EventSource {
    addHandler :: AddHandler a
  , fire       :: a -> IO ()
  }

mkEventSource :: IO (EventSource a)
mkEventSource =
  uncurry EventSource <$> newAddHandler
```

How do we get *new* logical points in time?

They come from outside the event network.

There are as many observable logical points in time as there are calls to the various `fire` functions.

How do we know we're dealing with something that effects something other than the current logical point in time?

You'll see a `Moment` or `MomentIO` context in the type signature.

`Moment`/`MomentIO` is a builder monad for the event network.

These ‘moments’ are referred to as ‘transactions’ in the `sodium` literature.

From inside the event network, we can register an event handler:

```
fromAddHandler :: AddHandler a -> MomentIO (Event a)
```

From inside the event network, we can do some `IO` when an event occurs:

```
reactimate :: Event (IO ()) -> MomentIO ()
```

Now we can put together an event network.

```haskell
networkDescription :: EventSource Int -> MomentIO ()
networkDescription c = do


  let
    eFizz = "Fizz" <$ multiple 3 eCount
    eBuzz = "Buzz" <$ multiple 5 eCount
    eWrite = unionWith (++) eFizz eBuzz
    showCount x =
      putStrLn $ "count: " ++ show x
```

```haskell
networkDescription :: EventSource Int -> MomentIO ()
networkDescription c = do
  eCount <- fromAddHandler . addHandler $ c

  let
    eFizz = "Fizz" <$ multiple 3 eCount
    eBuzz = "Buzz" <$ multiple 5 eCount
    eWrite = unionWith (++) eFizz eBuzz
    showCount x =
      putStrLn $ "count: " ++ show x
```

```haskell
networkDescription :: EventSource Int -> MomentIO ()
networkDescription c = do
  eCount <- fromAddHandler . addHandler $ c

  let
    eFizz = "Fizz" <$ multiple 3 eCount
    eBuzz = "Buzz" <$ multiple 5 eCount
    eWrite = unionWith (++) eFizz eBuzz
    showCount x =
      putStrLn $ "count: " ++ show x

  reactimate $ showCount <$> eCount
  reactimate $ putStrLn  <$> eWrite
```

We need an event loop to fire events from outside of the event network.

```haskell
eventStep :: EventSource Int -> Int -> IO ()
eventStep e i = do
  fire e i
  threadDelay 1000000
```

```haskell
eventStep :: EventSource Int -> Int -> IO ()
eventStep e i = do
  fire e i
  threadDelay 1000000

eventLoop :: EventSource Int -> IO ()
eventLoop e =
  traverse_ (eventStep e) [0..]
```

```haskell
go :: IO ()
go = do
  input <- mkEventSource
  network <- compile $ networkDescription input
  actuate network
  eventLoop input
```

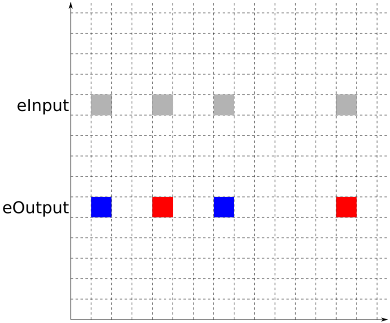
Some of the logic is outside of the event network. . .

What we really want:

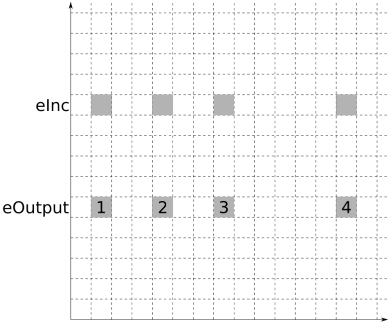
```
eventLoop :: EventSource () -> IO ()
eventLoop e =
  forever $ do
    threadDelay 1000000
    fire e ()
```

```haskell
accumE :: MonadMoment m
       => a
       -> Event (a -> a)
       -> m (Event a)
```

```haskell
toggler :: MonadMoment m
        => Event ()
        -> m (Event Colour)
toggler eInput = do
  eOutput <-
    accumE Red (flip <$ eInput)
  return eOutput
```

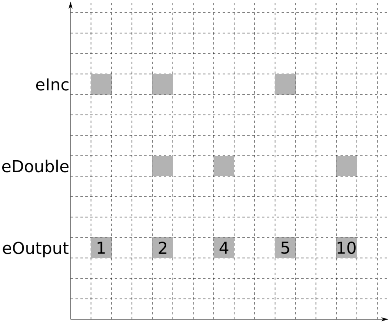


```haskell
counter :: MonadMoment m
        => Event ()
        -> m (Event Int)
counter eInc = do
  eOutput <-
    accumE 0 ((+ 1) <$ eInc)
  return eOutput
```

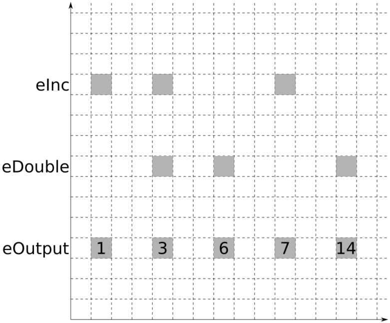


This is a good place to compare `leftmost` and `unions`.

```
counter2 :: MonadMoment m
         => Event ()
         -> Event ()
         -> m (Event Int)
counter2 eInc eDouble = do
  eOutput <-
    accumE 0 $ leftmost [
        (+ 1) <$ eInc
      , (* 2) <$ eDouble
      ]
  return eOutput
```



```haskell
counter3 :: MonadMoment m
         => Event ()
         -> Event ()
         -> m (Event Int)
counter3 eInc eDouble = do
  eOutput <-
    accumE 0 $ unions [
        (+ 1) <$ eInc
      , (* 2) <$ eDouble
      ]
  return eOutput
```



Let's put that counter to use.

```haskell
networkDescription :: EventSource Int -> MomentIO ()
networkDescription c = do
  eCount <- fromAddHandler . addHandler $ c




  let
    eFizz = "Fizz" <$ multiple 3 eCount
    eBuzz = "Buzz" <$ multiple 5 eCount
    eWrite = unionWith (++) eFizz eBuzz
    showCount x =
      putStrLn $ "count: " ++ show x

  reactimate $ showCount <$> eCount
  reactimate $ putStrLn  <$> eWrite
```

```haskell
networkDescription :: EventSource ()  -> MomentIO ()
networkDescription t = do
  eTick  <- fromAddHandler . addHandler $ t




  let
    eFizz = "Fizz" <$ multiple 3 eCount
    eBuzz = "Buzz" <$ multiple 5 eCount
    eWrite = unionWith (++) eFizz eBuzz
    showCount x =
      putStrLn $ "count: " ++ show x

  reactimate $ showCount <$> eCount
  reactimate $ putStrLn  <$> eWrite
```

```haskell
networkDescription :: EventSource ()  -> MomentIO ()
networkDescription t = do
  eTick  <- fromAddHandler . addHandler $ t

  eCount <- accumE 0 ((+ 1) <$ eTick)

  let
    eFizz = "Fizz" <$ multiple 3 eCount
    eBuzz = "Buzz" <$ multiple 5 eCount
    eWrite = unionWith (++) eFizz eBuzz
    showCount x =
      putStrLn $ "count: " ++ show x

  reactimate $ showCount <$> eCount
  reactimate $ putStrLn  <$> eWrite
```

A simple command line application

We're going to incrementally put together a program that echoes the input from the user.

```haskell
eventLoop :: EventSource String -> IO ()
eventLoop i =
  forever $ do
    x <- getLine
    fire i x
```

```haskell
networkDescription :: EventSource String -> MomentIO ()
networkDescription i = do
  eRead <- fromAddHandler . addHandler $ i

  let
    eWrite = eRead

  reactimate $ putStrLn <$> eWrite
```

Variant: Add the ability to quit

```haskell
networkDescription :: EventSource String -> MomentIO ()
networkDescription i = do
  eRead <- fromAddHandler . addHandler $ i

  let
    eMessage =                                eRead


  reactimate $ putStrLn    <$> eMessage
```

```haskell
networkDescription :: EventSource String -> MomentIO ()
networkDescription i = do
  eRead <- fromAddHandler . addHandler $ i

  let
    eMessage =       filterE (/= "/quit") eRead


  reactimate $ putStrLn    <$> eMessage
```

```haskell
networkDescription :: EventSource String -> MomentIO ()
networkDescription i = do
  eRead <- fromAddHandler . addHandler $ i

  let
    eMessage =       filterE (/= "/quit") eRead
    eQuit    = () <$ filterE (== "/quit") eRead

  reactimate $ putStrLn    <$> eMessage
```

```haskell
import System.Exit (exitSuccess)

networkDescription :: EventSource String -> MomentIO ()
networkDescription i = do
  eRead <- fromAddHandler . addHandler $ i

  let
    eMessage =       filterE (/= "/quit") eRead
    eQuit    = () <$ filterE (== "/quit") eRead

  reactimate $ putStrLn    <$> eMessage
  reactimate $ exitSuccess <$  eQuit
```

Variant: Add a parting message

```haskell
networkDescription :: EventSource String -> MomentIO ()
networkDescription i = do
  eRead <- fromAddHandler . addHandler $ i

  let
    eMessage =       filterE (/= "/quit") eRead
    eQuit    = () <$ filterE (== "/quit") eRead





  reactimate $ putStrLn    <$> eMessage
  reactimate $ exitSuccess <$  eQuit
```

```haskell
networkDescription :: EventSource String -> MomentIO ()
networkDescription i = do
  eRead <- fromAddHandler . addHandler $ i

  let
    eMessage =       filterE (/= "/quit") eRead
    eQuit    = () <$ filterE (== "/quit") eRead
    eWrite =
                 eMessage




  reactimate $ putStrLn    <$> eMessage
  reactimate $ exitSuccess <$  eQuit
```

```haskell
networkDescription :: EventSource String -> MomentIO ()
networkDescription i = do
  eRead <- fromAddHandler . addHandler $ i

  let
    eMessage =       filterE (/= "/quit") eRead
    eQuit    = () <$ filterE (== "/quit") eRead
    eWrite =
                 eMessage



  reactimate $ putStrLn    <$> eWrite
  reactimate $ exitSuccess <$  eQuit
```

```haskell
networkDescription :: EventSource String -> MomentIO ()
networkDescription i = do
  eRead <- fromAddHandler . addHandler $ i

  let
    eMessage =       filterE (/= "/quit") eRead
    eQuit    = () <$ filterE (== "/quit") eRead
    eWrite = leftmost [
                 eMessage
      , "Bye" <$ eQuit
      ]

  reactimate $ putStrLn    <$> eWrite
  reactimate $ exitSuccess <$  eQuit
```

Variant: Add a greeting message

```haskell
data InputSources = InputSources {
    isOpen :: EventSource ()
  , isRead :: EventSource String
  }

mkInputSources :: IO InputSources
mkInputSources =
  InputSources <$> mkEventSource <*> mkEventSource
```

```haskell
eventLoop :: InputSources -> IO ()
eventLoop (InputSources o r) = do
  fire o ()
  forever $ do
    x <- getLine
    fire r x
```

```haskell
networkDescription :: EventSource String -> MomentIO ()
networkDescription i                     = do

  eRead <- fromAddHandler . addHandler $ i

  let
    eMessage =       filterE (/= "/quit") eRead
    eQuit    = () <$ filterE (== "/quit") eRead
    eWrite = leftmost [

                  eMessage
      , "Bye" <$ eQuit
      ]

  reactimate $ putStrLn    <$> eWrite
  reactimate $ exitSuccess <$  eQuit
```

```haskell
networkDescription :: InputSources       -> MomentIO ()
networkDescription (InputSources o r) = do

  eRead <- fromAddHandler . addHandler $ i

  let
    eMessage =       filterE (/= "/quit") eRead
    eQuit    = () <$ filterE (== "/quit") eRead
    eWrite = leftmost [

                eMessage
      , "Bye" <$ eQuit
      ]

  reactimate $ putStrLn    <$> eWrite
  reactimate $ exitSuccess <$  eQuit
```

```haskell
networkDescription :: InputSources       -> MomentIO ()
networkDescription (InputSources o r) = do

  eRead <- fromAddHandler . addHandler $ r

  let
    eMessage =       filterE (/= "/quit") eRead
    eQuit    = () <$ filterE (== "/quit") eRead
    eWrite = leftmost [

                eMessage
      , "Bye" <$ eQuit
      ]

  reactimate $ putStrLn    <$> eWrite
  reactimate $ exitSuccess <$  eQuit
```

```haskell
networkDescription :: InputSources       -> MomentIO ()
networkDescription (InputSources o r) = do
  eOpen <- fromAddHandler . addHandler $ o
  eRead <- fromAddHandler . addHandler $ r

  let
    eMessage =       filterE (/= "/quit") eRead
    eQuit    = () <$ filterE (== "/quit") eRead
    eWrite = leftmost [

                eMessage
      , "Bye" <$ eQuit
      ]

  reactimate $ putStrLn    <$> eWrite
  reactimate $ exitSuccess <$  eQuit
```

```haskell
networkDescription :: InputSources       -> MomentIO ()
networkDescription (InputSources o r) = do
  eOpen <- fromAddHandler . addHandler $ o
  eRead <- fromAddHandler . addHandler $ r

  let
    eMessage =       filterE (/= "/quit") eRead
    eQuit    = () <$ filterE (== "/quit") eRead
    eWrite = leftmost [
        "Hi"  <$ eOpen
      ,          eMessage
      , "Bye" <$ eQuit
      ]

  reactimate $ putStrLn    <$> eWrite
  reactimate $ exitSuccess <$  eQuit
```

Variant: Add a help command

```haskell
helpMessage :: String
helpMessage =
  "/help              - displays this message\n" ++
  "/quit              - exits the program"
```

```haskell
let
  eMessage =        filterE (/= "/quit") eRead

  eQuit    = () <$ filterE (== "/quit") eRead
  eWrite = leftmost [
      "Hi"         <$ eOpen
    ,                 eMessage

    , "Bye"        <$ eQuit
    ]
```

```haskell
let
  eMessage =  filterE (/= "/" . take 1) eRead

  eQuit    = () <$ filterE (== "/quit") eRead
  eWrite = leftmost [
      "Hi"         <$ eOpen
    ,                 eMessage

    , "Bye"        <$ eQuit
    ]
```

```haskell
let
  eMessage =  filterE (/= "/" . take 1) eRead
  eHelp    = () <$ filterE (== "/help") eRead
  eQuit    = () <$ filterE (== "/quit") eRead
  eWrite = leftmost [
      "Hi"        <$ eOpen
    ,                eMessage

    , "Bye"       <$ eQuit
    ]
```

```haskell
let
  eMessage =  filterE (/= "/" . take 1) eRead
  eHelp    = () <$ filterE (== "/help") eRead
  eQuit    = () <$ filterE (== "/quit") eRead
  eWrite = leftmost [
      "Hi"        <$ eOpen
    ,                eMessage
    , helpMessage <$ eHelp
    , "Bye"       <$ eQuit
    ]
```

Variant: Deal with unknown commands

```haskell
type Message = String
type Command = String

command :: String -> Either Message Command
command ('/':xs) = Right xs
command xs       = Left xs
```

```haskell
unknownCommand :: Command -> String
unknownCommand cmd =
  let
    commandError = case cmd of
      "" ->
        "Command can not be an empty string."
      cmd ->
        "Unknown command: " ++ cmd ++ "."

    helpPrompt =
      "\nType /help for options."
  in
    commandError ++ helpPrompt
```

```haskell
let
  eMessage =       filterE (/= "/" . take 1) eRead

  eHelp    =   () <$ filterE (== "/help")    eRead
  eQuit    =   () <$ filterE (== "/quit")    eRead




  eWrite = leftmost [
      "Hi"            <$  eOpen
    ,                     eMessage
    , helpMessage     <$  eHelp

    , "Bye"           <$  eQuit
    ]
```

```haskell
let
  (eMessage, eCommand) = split $ command <$> eRead

  eHelp    =   () <$ filterE (== "/help")    eRead
  eQuit    =   () <$ filterE (== "/quit")    eRead




  eWrite = leftmost [
      "Hi"              <$  eOpen
    ,                       eMessage
    , helpMessage       <$  eHelp

    , "Bye"             <$  eQuit
    ]
```

```haskell
let
  (eMessage, eCommand) = split $ command <$> eRead

  eHelp    =   () <$ filterE (== "/help") eCommand
  eQuit    =   () <$ filterE (== "/quit") eCommand




  eWrite = leftmost [
      "Hi"           <$  eOpen
    ,                    eMessage
    , helpMessage    <$  eHelp

    , "Bye"          <$  eQuit
    ]
```

```haskell
let
  (eMessage, eCommand) = split $ command <$> eRead

  eHelp    =   () <$ filterE (== "help")  eCommand
  eQuit    =   () <$ filterE (== "quit")  eCommand




  eWrite = leftmost [
      "Hi"           <$  eOpen
    ,                    eMessage
    , helpMessage    <$  eHelp

    , "Bye"          <$  eQuit
    ]
```

```haskell
let
  (eMessage, eCommand) = split $ command <$> eRead

  eHelp    =   () <$ filterE (== "help")  eCommand
  eQuit    =   () <$ filterE (== "quit")  eCommand

  commands = ["help", "quit"]
  eUnknown = filterE (`notElem` commands) eCommand

  eWrite = leftmost [
      "Hi"              <$  eOpen
    ,                       eMessage
    , helpMessage       <$  eHelp

    , "Bye"             <$  eQuit
    ]
```

```haskell
let
  (eMessage, eCommand) = split $ command <$> eRead

  eHelp    =   () <$ filterE (== "help")  eCommand
  eQuit    =   () <$ filterE (== "quit")  eCommand

  commands = ["help", "quit"]
  eUnknown = filterE (`notElem` commands) eCommand

  eWrite = leftmost [
      "Hi"            <$  eOpen
    ,                     eMessage
    , helpMessage     <$  eHelp
    , unknownCommand  <$> eUnknown
    , "Bye"           <$  eQuit
    ]
```

Refactorings and API options

FRP code is usually pretty easy to refactor.

There isn't much information out there about what you should be refactoring towards.

Let’s look at some options.

Let's separate out the bits of the event network that deal with `IO` from the bits that don't.

```haskell
data InputIO = InputIO {
    ioeOpen :: Event ()
  , ioeRead :: Event String
  }

handleInput :: InputSources -> MomentIO InputIO
handleInput (InputSources iso isr) = do
  eOpen <- fromAddHandler . addHandler $ iso
  eRead <- fromAddHandler . addHandler $ isr
  return $ InputIO eOpen eRead
```

```haskell
data OutputIO = OutputIO {
    ioeWrite :: Event String
  , ioeClose :: Event ()
  }

handleOutput :: OutputIO -> MomentIO ()
handleOutput (OutputIO eWrite eClose) = do
  reactimate $ putStrLn <$> eWrite
  reactimate $ exitSuccess <$ eClose
```

```haskell
mkNetwork :: (InputIO -> Moment OutputIO)
          -> InputSources
          -> MomentIO ()
mkNetwork fn input = do
  i <- handleInput input
  o <- liftMoment $ fn i
  handleOutput o
```

```haskell
networkDescription :: InputSources -> MomentIO ()
networkDescription (InputSources o r)    = do
  eOpen <- fromAddHandler . addHandler $ o
  eRead <- fromAddHandler . addHandler $ r

  let
    eMessage =       filterE (/= "/quit") eRead
    eQuit    = () <$ filterE (== "/quit") eRead
    eWrite = leftmost [
        "Hi" <$ eOpen
      , eMessage
      , "Bye" <$ eQuit
      ]



  reactimate $ putStrLn    <$> eWrite
  reactimate $ exitSuccess <$  eQuit
```

```haskell
networkDescription :: InputIO      -> MomentIO ()
networkDescription (InputSources o r)    = do
  eOpen <- fromAddHandler . addHandler $ o
  eRead <- fromAddHandler . addHandler $ r

  let
    eMessage =       filterE (/= "/quit") eRead
    eQuit    = () <$ filterE (== "/quit") eRead
    eWrite = leftmost [
        "Hi" <$ eOpen
      , eMessage
      , "Bye" <$ eQuit
      ]



  reactimate $ putStrLn    <$> eWrite
  reactimate $ exitSuccess <$  eQuit
```

```haskell
networkDescription :: InputIO      -> MomentIO ()
networkDescription (InputIO eOpen eRead) = do
  eOpen <- fromAddHandler . addHandler $ o
  eRead <- fromAddHandler . addHandler $ r

  let
    eMessage =       filterE (/= "/quit") eRead
    eQuit    = () <$ filterE (== "/quit") eRead
    eWrite = leftmost [
        "Hi" <$ eOpen
      , eMessage
      , "Bye" <$ eQuit
      ]



  reactimate $ putStrLn    <$> eWrite
  reactimate $ exitSuccess <$  eQuit
```

```haskell
networkDescription :: InputIO      -> MomentIO ()
networkDescription (InputIO eOpen eRead) = do



  let
    eMessage =       filterE (/= "/quit") eRead
    eQuit    = () <$ filterE (== "/quit") eRead
    eWrite = leftmost [
        "Hi" <$ eOpen
      , eMessage
      , "Bye" <$ eQuit
      ]



  reactimate $ putStrLn    <$> eWrite
  reactimate $ exitSuccess <$  eQuit
```

```haskell
networkDescription :: InputIO      -> Moment OutputIO
networkDescription (InputIO eOpen eRead) = do



  let
    eMessage =       filterE (/= "/quit") eRead
    eQuit    = () <$ filterE (== "/quit") eRead
    eWrite = leftmost [
        "Hi" <$ eOpen
      , eMessage
      , "Bye" <$ eQuit
      ]



  reactimate $ putStrLn    <$> eWrite
  reactimate $ exitSuccess <$  eQuit
```

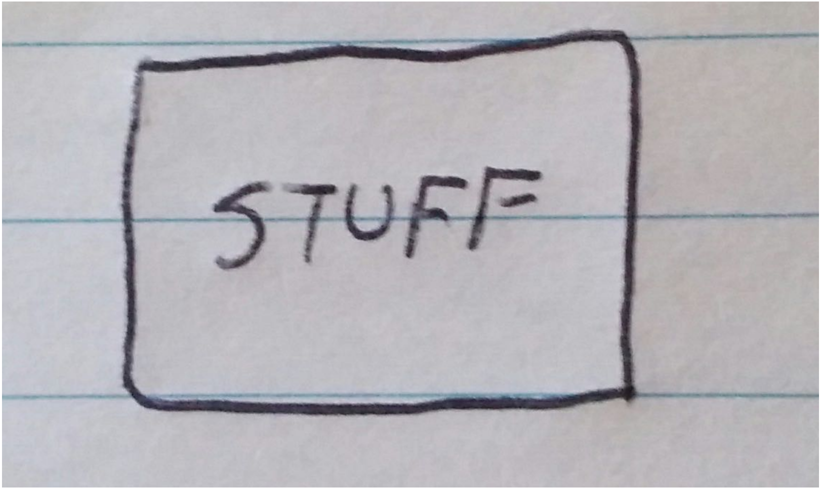
```haskell
networkDescription :: InputIO      -> Moment OutputIO
networkDescription (InputIO eOpen eRead) =




  let
    eMessage =       filterE (/= "/quit") eRead
    eQuit    = () <$ filterE (== "/quit") eRead
    eWrite = leftmost [
        "Hi" <$ eOpen
      , eMessage
      , "Bye" <$ eQuit
      ]
  in
    return $
      OutputIO
                                  eWrite
                                  eQuit
```

```
networkDescription  :: InputIO      -> Moment OutputIO
networkDescription  = ...
```

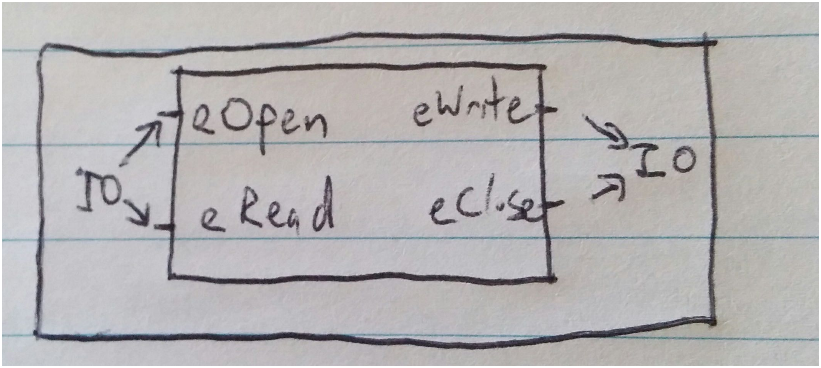
```haskell
networkDescription' :: InputIO      -> Moment OutputIO
networkDescription' = ...
```

```haskell
networkDescription :: InputSources -> MomentIO ()
networkDescription = mkNetwork networkDescription'

networkDescription' :: InputIO      -> Moment OutputIO
networkDescription' = ...
```

We have gone from:



To:



We're still dealing with things in terms of `IO`.

Let’s set up some domain specific input events.

```haskell
data Inputs = Inputs {
    ieOpen    :: Event ()
  , ieMessage :: Event String
  , ieHelp    :: Event ()
  , ieUnknown :: Event String
  , ieQuit    :: Event ()
  }
```

```haskell
fanOut :: InputIO -> Inputs
fanOut (InputIO eOpen eRead) =
  let
    (eMessage, eCommand) = split $ command <$> eRead

    eHelp    =   () <$ filterE (== "help")  eCommand
    eQuit    =   () <$ filterE (== "quit")  eCommand

    commands = ["help", "quit"]
    eUnknown = filterE (`notElem` commands) eCommand
  in
    Inputs eOpen eMessage eHelp eUnknown eQuit
```

We'll do something similar for the outputs.

Option 1:

```haskell
data Outputs = Outputs {
    oeOpenWrite    :: Event String
  , oeMessageWrite :: Event String
  , oeHelpWrite    :: Event String
  , oeQuitWrite    :: Event String
  , oeUnknownWrite :: Event String
  , oeClose        :: Event ()
  }
```

Option 2:

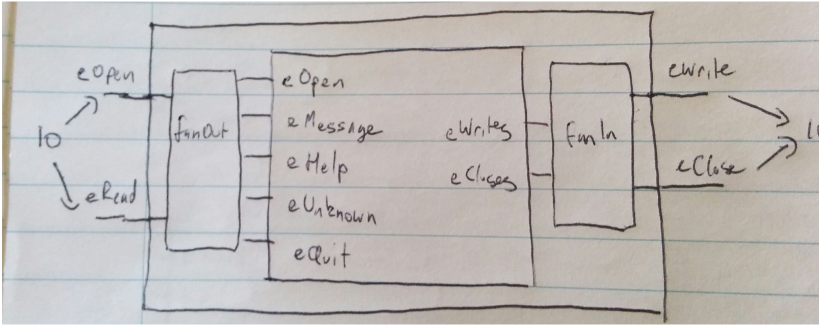
```haskell
data Outputs = Outputs {
    oeWrite :: [Event String]
  , oeClose :: [Event ()]
  }
```

```haskell
fanIn :: Outputs -> OutputIO
fanIn (Outputs eWrites eCloses) =
  let
    addLine x y =
      x ++ '\n' : y
    eCombinedWrites =
      foldr (unionWith addLine) never eWrites
    eCombinedCloses =
      () <$ leftmost eCloses
  in
    OutputIO eCombinedWrites eCombinedCloses
```

```haskell
networkDescription'' :: Inputs -> Moment Outputs
networkDescription'' (Inputs eO eM eH eU eQ) =
  let
    eWrite = leftmost [
        "Hi"             <$  eO
      ,                      eM
      , helpMessage    <$  eH
      , unknownCommand <$> eU
      , "Bye"            <$  eQ
      ]
    eQuits = [eQ]
  in
    return $ Outputs eWrites eQuits
```

```
networkDescription‘ :: InputIO -> Moment OutputIO
networkDescription‘ i = do
  o <- networkDescription'' . fanOut $ i
  return $ fanIn o
```

Now we have something like:



Instead of working with a product of domain events, we could work with a single event of a sum type.

```
data InputsCmd =
    ICOpen
  | ICMessage String
  | ICHelp
  | ICQuit
  | ICUnknown String
  deriving (Eq, Ord, Show)

fanOut :: InputIO -> Event InputsCmd
```

We can convert back and forth between these two approaches.

```
collapse :: Inputs -> Event InputsCmd
expand   :: Event InputsCmd -> Inputs
```

Using a single event is great for testing.

```
interpret :: (Event a -> Moment (Event b))
          -> [Maybe a]
          -> IO [Maybe b]
```

```haskell
> output <- testNetwork networkDescription’ [
    Just (IORead "one")
  , Nothing
  , Just (IORead "two")
  , Just (IORead "/quit")
  ]
> output
[ Just [IOWrite "one"]
, Nothing
, Just [IOWrite "two"]
, Just [IOWrite "Bye", IOClose]
]
```

```
> output <- testNetwork networkDescription'' [
    Just Open
  , Just (Message "testing...")
  , Just Quit
  ]
> output
[ Just [Write "Hi"]
, Just [Write "testing..."]
, Just [Write "Bye", Close]
]
```

Using a product of events is good for decomposing problems into independent components.

On that note: we still have a big ball of mud in the middle.

```haskell
data OpenInput =
  OpenInput  { oieOpen  :: Event () }
data OpenOutput =
  OpenOutput { ooeWrite :: Event String }

handleOpen :: OpenInput -> Moment OpenOutput
handleOpen (OpenInput eOpen) =
  let
    eWrite = "Hi" <$ eOpen
  in
    return $ OpenOutput eWrite
```

```haskell
data MessageInput =
  MessageInput  { mieRead  :: Event String }
data MessageOutput =
  MessageOutput { moeWrite :: Event String }

handleMessage :: MessageInput -> Moment MessageOutput
handleMessage (MessageInput eMessage) =
  return $ MessageOutput eMessage
```

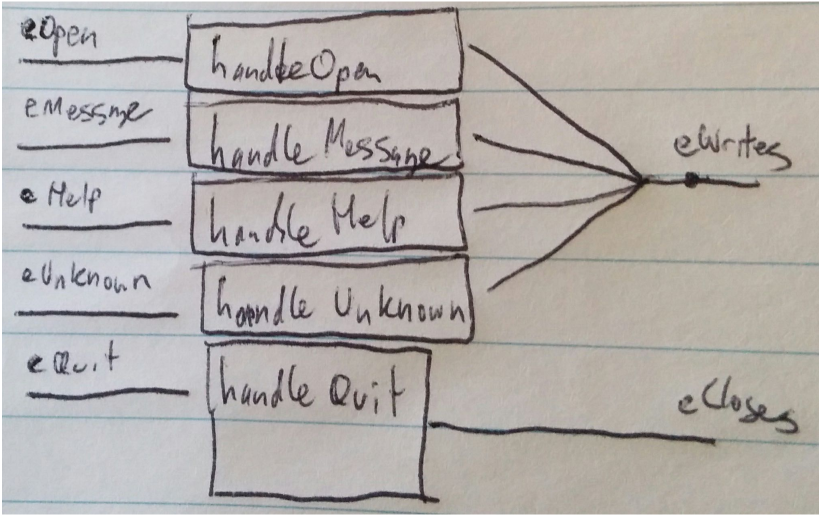
```haskell
data HelpInput =
  HelpInput  { hieHelp  :: Event () }
data HelpOutput =
  HelpOutput { hoeWrite :: Event String }

handleHelp :: HelpInput -> Moment HelpOutput
handleHelp (HelpInput eHelp) =
  let
    eWrite = helpMessage <$ eHelp
  in
    return $ HelpOutput eWrite
```

```haskell
data QuitInput =
  QuitInput { qieQuit :: Event () }

data QuitOutput = QuitOutput {
    qoeWrite :: Event String
  , qoeQuit  :: Event ()
  }

handleQuit :: QuitInput -> Moment QuitOutput
handleQuit (QuitInput eQuit) =
  let
    eWrite = "Bye" <$ eQuit
  in
    return $ QuitOutput eWrite eQuit
```

```haskell
data UnknownInput =
  UnknownInput  { ucieCommand :: Event String }
data UnknownOutput =
  UnknownOutput { ucoeWrite   :: Event String }

handleUnknown :: UnknownInput -> Moment UnknownOutput
handleUnknown (UnknownInput eUnknown) =
  return . UnknownOutput $ unknownCommand <$> eUnknown
```

```haskell
networkDescription'' :: Inputs -> Moment Outputs
networkDescription'' (Inputs eO eM eH eU eQ) = do
  OpenOutput ewO         <- handleOpen    $ OpenInput eO
  MessageOutput ewM      <- handleMessage $ MessageInput eM
  HelpOutput ewH         <- handleHelp    $ HelpInput eH
  UnknownOutput ewU      <- handleUnknown $ UnknownInput eU
  QuitOutput ewQ eqQuit <- handleQuit    $ QuitInput eQ

  return $ Outputs
    [ewO, ewM, ewH, ewU, ewQ] [eqQuit]
```

Which stands out in the block diagram:



Behaviors

```haskell
data Behavior a = ...

instance Functor Behavior
instance Applicative Behavior
```

Behaviors have a value at every point in time.

```
Behavior a ~ (Time -> a)
```

If you squint, it looks a bit like `State a`.

Behaviors are pull-based.

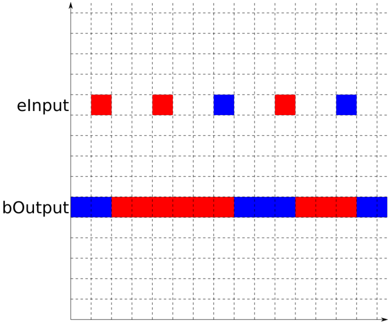
Some of the time you'll use `Behavior` to model `State`.

Some of the time you'll use `Behavior` to pass around values that could be changed by parts of the program you don't care about.

We build `Behaviors` with `Events`.

```
stepper :: MonadMoment m
        => a
        -> Event a
        -> m (Behavior a)
```

```haskell
holder :: MonadMoment m
       => Event Colour
       -> m (Behavior Colour)
holder eInput = do
  eOutput <-
    stepper Blue eInput
  return eOutput
```

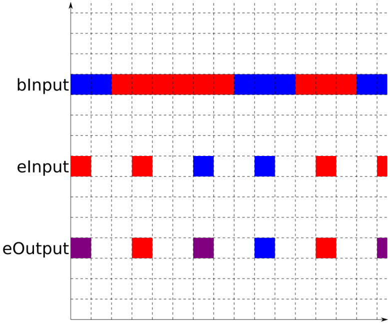


We sample `Behavior`s with `Event`s:

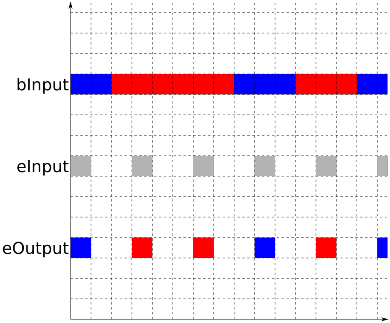
```
(<@>) :: Behavior (a -> b) -> Event a -> Event b
(<@)  :: Behavior b        -> Event a -> Event b
```

```
threeArgFn <$> bBehavior1 <*> bBehavior2 <@> eEvent
twoArgFn   <$> bBehavior1 <*> bBehavior2 <@ eTrigger
```

```haskell
mixer :: Behavior Colour
      -> Event Colour
      -> Event Colour
mixer bInput eInput =
  let
    eOutput =
      mix <$>
        bInput <@>
        eInput
  in
    eOutput
```



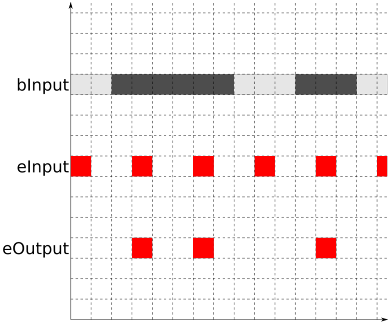
```haskell
tagger :: Behavior Colour
       -> Event ()
       -> Event Colour
tagger bInput eInput =
  let
    eOutput =
      bInput <@ eInput
  in
    eOutput
```



We can filter `Events` with `Behaviors`:

```
whenE       :: Behavior Bool -> Event a -> Event a
filterApply :: Behavior (a -> Bool) -> Event a -> Event a
```

```
sifter :: Behavior Bool
       -> Event Colour
       -> Event Colour
sifter bInput eInput =
  let
    eOutput =
      whenE bInput eInput
  in
    eOutput
```



Let’s look at a little example.

```haskell
logInHandler :: Event ()
             -> Event ()
             -> Moment (Behavior LogInState)
logInHandler eLogIn eLogOut =
  stepper LoggedOut . leftmost $ [
      LoggedIn  <$ eLogIn
    , LoggedOut <$ eLogOut
    ]
```

Now let's add some error handling.

```haskell
logIn :: LogInState -> Either LogInError LogInState
logIn LoggedIn  = Left AlreadyLoggedIn
logIn LoggedOut = Right LoggedIn

logOut :: LogInState -> Either LogInError LogInState
logOut LoggedOut = Left NotLoggedIn
logOut LoggedIn  = Right LoggedOut
```

```
{-# LANGUAGE RecursiveDo #-}
```

```haskell
logIn  :: LogInState -> Either LogInError LogInState
logOut :: LogInState -> Either LogInError LogInState

logInHandler :: Event ()
             -> Event ()
             -> Moment ( Behavior LogInState
                       , Event    LogInError
                       )
logInHandler eLogIn eLogOut = mdo




  return (???        , ???        )
```

```haskell
logIn  :: LogInState -> Either LogInError LogInState
logOut :: LogInState -> Either LogInError LogInState

logInHandler :: Event ()
             -> Event ()
             -> Moment ( Behavior LogInState
                       , Event    LogInError
                       )
logInHandler eLogIn eLogOut = mdo
  bLogInState <- stepper LoggedOut ???




  return (???       , ???        )
```

```haskell
logIn  :: LogInState -> Either LogInError LogInState
logOut :: LogInState -> Either LogInError LogInState

logInHandler :: Event ()
             -> Event ()
             -> Moment ( Behavior LogInState
                       , Event    LogInError
                       )
logInHandler eLogIn eLogOut = mdo
  bLogInState <- stepper LoggedOut ???




  return (bLogInState, ???        )
```

```haskell
logIn  :: LogInState -> Either LogInError LogInState
logOut :: LogInState -> Either LogInError LogInState

logInHandler :: Event ()
             -> Event ()
             -> Moment ( Behavior LogInState
                       , Event    LogInError
                       )
logInHandler eLogIn eLogOut = mdo
  bLogInState <- stepper LoggedOut ???
  (eLogInError, eLogInState) = split . leftmost $ [
      logIn  <$> bLogInState <@ eLogIn
      logOut <$> bLogInState <@ eLogOut
    ]
  return (bLogInState, ???        )
```

```haskell
logIn  :: LogInState -> Either LogInError LogInState
logOut :: LogInState -> Either LogInError LogInState

logInHandler :: Event ()
             -> Event ()
             -> Moment ( Behavior LogInState
                       , Event    LogInError
                       )
logInHandler eLogIn eLogOut = mdo
  bLogInState <- stepper LoggedOut ???
  (eLogInError, eLogInState) = split . leftmost $ [
      logIn  <$> bLogInState <@ eLogIn
      logOut <$> bLogInState <@ eLogOut
    ]
  return (bLogInState, eLogInError)
```

```haskell
logIn  :: LogInState -> Either LogInError LogInState
logOut :: LogInState -> Either LogInError LogInState

logInHandler :: Event ()
             -> Event ()
             -> Moment ( Behavior LogInState
                       , Event    LogInError
                       )
logInHandler eLogIn eLogOut = mdo
  bLogInState <- stepper LoggedOut eLogInState
  (eLogInError, eLogInState) = split . leftmost $ [
      logIn  <$> bLogInState <@ eLogIn
      logOut <$> bLogInState <@ eLogOut
    ]
  return (bLogInState, eLogInError)
```

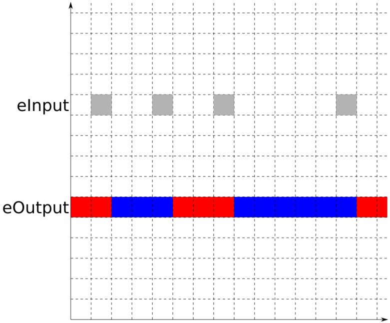
Let's use behaviors in our echo application to keep track of message history.

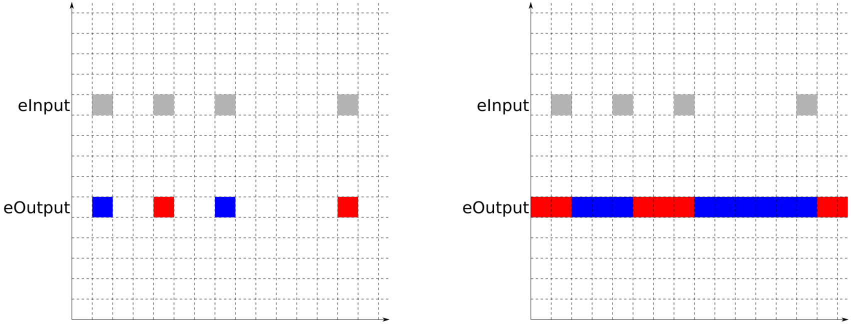
```haskell
handleMessage :: MessageInput -> Moment MessageOutput
handleMessage (MessageInput eMessage) = do
  bMessages <- stepper "" eMessage
  let
    format l m = m ++ " (last message: " ++ l ++ ")"
    eOut = format <$> bMessages <@> eMessage
  return $ MessageOutput eOut
```

One message isn't all that interesting.

```haskell
accumB :: MonadMoment m
       => a
       -> Event (a -> a)
       -> m (Behavior a)
```

```haskell
toggler :: MonadMoment m
        => Event ()
        -> m (Behavior Colour)
toggler eInput = do
  eOutput <-
    accumB Red (flip <$ eInput)
  return eOutput
```




eInput
eOutput
eInput
eOutput

```haskell
handleMessage :: MessageInput -> Moment MessageOutput
handleMessage (MessageInput eMessage) = do
  bMessages <- stepper ""
                         eMessage

  let
    format l  m =
      m ++
      " (last message: "      ++ l       ++ ")"
    eOut =
        format <$> bMessages <@> eMessage

  return $ MessageOutput eOut
```

```haskell
handleMessage :: MessageInput -> Moment MessageOutput
handleMessage (MessageInput eMessage) = do
  bMessages <- accumB [] $
    (\x xs -> x : xs) <$> eMessage

  let
    format l  m =
      m ++
      " (last message: "      ++ l        ++ ")"
    eOut =
        format <$> bMessages <@> eMessage

  return $ MessageOutput eOut
```

```haskell
handleMessage :: MessageInput -> Moment MessageOutput
handleMessage (MessageInput eMessage) = do
  bMessages <- accumB [] $
    (\x xs -> x : xs) <$> eMessage

  let
    format ls m =
      m ++
      " (previous messages: " ++ show ls ++ ")"
    eOut =
        format <$> bMessages <@> eMessage

  return $ MessageOutput eOut
```

That prints a weird message when the message history is empty.

```haskell
handleMessage :: MessageInput -> Moment MessageOutput
handleMessage (MessageInput eMessage) = do
  bMessages <- accumB [] $
    (\x xs -> x : xs) <$> eMessage

  let
    format ls m =
      m ++
      " (previous messages: " ++ show ls ++ ")"


    eOut =
        format <$> bMessages <@> eMessage



  return $ MessageOutput eOut
```

```haskell
handleMessage :: MessageInput -> Moment MessageOutput
handleMessage (MessageInput eMessage) = do
  bMessages <- accumB [] $
    (\x xs -> x : xs) <$> eMessage

  let
    format ls m =
      m ++
      " (previous messages: " ++ show ls ++ ")"
    bHasMessages = (not . null) <$> bMessages

    eOut =
        format <$> bMessages <@> eMessage



  return $ MessageOutput eOut
```

```haskell
handleMessage :: MessageInput -> Moment MessageOutput
handleMessage (MessageInput eMessage) = do
  bMessages <- accumB [] $
    (\x xs -> x : xs) <$> eMessage

  let
    format ls m =
      m ++
      " (previous messages: " ++ show ls ++ ")"
    bHasMessages = (not . null) <$> bMessages
    eMessageWithHistory = whenE bHasMessage eMessage
    eOut =
        format <$> bMessages <@> eMessage



  return $ MessageOutput eOut
```

```haskell
handleMessage :: MessageInput -> Moment MessageOutput
handleMessage (MessageInput eMessage) = do
  bMessages <- accumB [] $
    (\x xs -> x : xs) <$> eMessage

  let
    format ls m =
      m ++
      " (previous messages: " ++ show ls ++ ")"
    bHasMessages = (not . null) <$> bMessages
    eMessageWithHistory = whenE bHasMessage eMessage
    eOut =
        format <$> bMessages <@> eMessageWithHistory



  return $ MessageOutput eOut
```

```haskell
handleMessage :: MessageInput -> Moment MessageOutput
handleMessage (MessageInput eMessage) = do
  bMessages <- accumB [] $
    (\x xs -> x : xs) <$> eMessage

  let
    format ls m =
      m ++
      " (previous messages: " ++ show ls ++ ")"
    bHasMessages = (not . null) <$> bMessages
    eMessageWithHistory = whenE bHasMessage eMessage
    eOut = leftmost [
        format <$> bMessages <@> eMessageWithHistory
      , eMessage
      ]

  return $ MessageOutput eOut
```

We should trim that history a little.

```haskell
handleMessage :: MessageInput -> Moment MessageOutput
handleMessage (MessageInput eMessage) = do
  bMessages <- accumB [] $
    (\x xs ->         x : xs ) <$> eMessage

  let
    format ls m =
      m ++
      " (previous messages: " ++ show ls ++ ")"
    bHasMessages = (not . null) <$> bMessages
    eMessageWithHistory = whenE bHasMessage eMessage
    eOut = leftmost [
        format <$> bMessages <@> eMessageWithHistory
      , eMessage
      ]

  return $ MessageOutput eOut
```

```haskell
handleMessage :: MessageInput -> Moment MessageOutput
handleMessage (MessageInput eMessage) = do
  bMessages <- accumB [] $
    (\x xs -> take 3 (x : xs)) <$> eMessage

  let
    format ls m =
      m ++
      " (previous messages: " ++ show ls ++ ")"
    bHasMessages = (not . null) <$> bMessages
    eMessageWithHistory = whenE bHasMessage eMessage
    eOut = leftmost [
        format <$> bMessages <@> eMessageWithHistory
      , eMessage
      ]

  return $ MessageOutput eOut
```

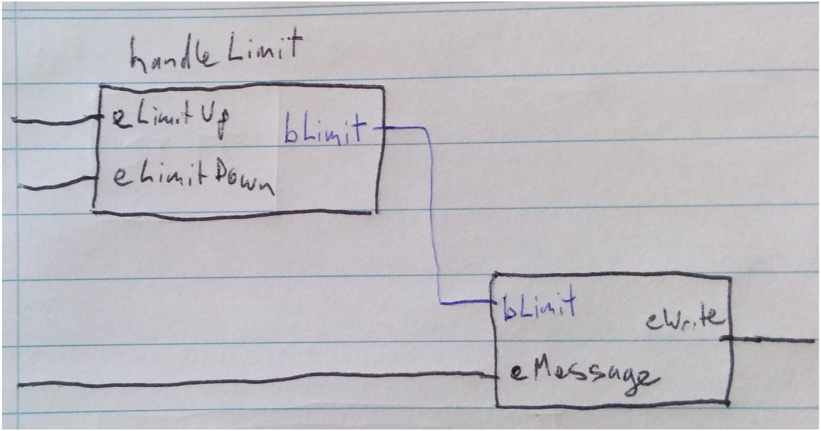
We do the trimming while creating the `Behavior`, to keep the storage size bounded.

Hard-coding that 3 should make us a bit queasy.

Digression: Let's build a component that will provide the message history limit.

```haskell
data LimitInput = LimitInput {
    lieLimitUp   :: Event ()
  , lieLimitDown :: Event ()
  }

data LimitOutput = LimitOutput {
    lobLimit :: Behavior Int
  }
```

We're aiming for something like this:



`unions` is handy when accumulating from multiple events:

```
accumE :: MonadMoment m
       => a
       -> Event (a -> a)
       -> m (Event a)

accumB :: MonadMoment m
       => a
       -> Event (a -> a)
       -> m (Behavior a)

unions :: [Event (a -> a)] -> Event (a -> a)
```

```haskell
handleLimit :: LimitInput -> Moment LimitOutput
handleLimit (LimitInput eUp eDown) = do
  let
    eChanges =
      unions [
          succ <$ eUp
        , (max 0 . pred) <$ eDown
        ]
  bLimit <- accumB 1 eChanges
  return $ LimitOutput bLimit
```

Or, with `RecursiveDo`:

```haskell
handleLimit :: LimitInput -> Moment LimitOutput
handleLimit (LimitInput eUp eDown) = mdo
  let


    eChanges = unions [
        succ <$ eUp
      , (max 0 . pred) <$ eDown
      ]
  bLimit <- accumB 1 eChanges
  return $ LimitOutput bLimit
```

```haskell
handleLimit :: LimitInput -> Moment LimitOutput
handleLimit (LimitInput eUp eDown) = mdo
  let
    eDownNonNegative =
      whenE ((> 0) <$> bLimit) eDown
    eChanges = unions [
        succ <$ eUp
      , (max 0 . pred) <$ eDown
      ]
  bLimit <- accumB 1 eChanges
  return $ LimitOutput bLimit
```

```haskell
handleLimit :: LimitInput -> Moment LimitOutput
handleLimit (LimitInput eUp eDown) = mdo
  let
    eDownNonNegative =
      whenE ((> 0) <$> bLimit) eDown
    eChanges = unions [
        succ <$ eUp
      , (max 0 . pred) <$ eDownNonNegative
      ]
  bLimit <- accumB 1 eChanges
  return $ LimitOutput bLimit
```

```haskell
handleLimit :: LimitInput -> Moment LimitOutput
handleLimit (LimitInput eUp eDown) = mdo
  let
    eDownNonNegative =
      whenE ((> 0) <$> bLimit) eDown
    eChanges = unions [
        succ <$ eUp
      , pred           <$ eDownNonNegative
      ]
  bLimit <- accumB 1 eChanges
  return $ LimitOutput bLimit
```

Or, with both an `Event` and a `Behavior` for the limit:

```haskell
data LimitOutput = LimitOutput {

    lobLimit :: Behavior Int
  }
```

```haskell
data LimitOutput = LimitOutput {
    loeLimit :: Event Int
  , lobLimit :: Behavior Int
  }
```

```haskell
handleLimit :: LimitInput -> Moment LimitOutput
handleLimit (LimitInput eUp eDown) = do
  let

    eChanges = unions [
        succ <$ eUp
      , (max 0 . pred) <$ eDown
      ]
  bLimit           <- accumB   1             eChanges
  return $ LimitOutput       bLimit
```

```haskell
handleLimit :: LimitInput -> Moment LimitOutput
handleLimit (LimitInput eUp eDown) = do
  let
    apBoth f x = (f x, f x)
    eChanges = unions [
        succ <$ eUp
      , (max 0 . pred) <$ eDown
      ]
  bLimit           <- accumB   1              eChanges
  return $ LimitOutput        bLimit
```

```haskell
handleLimit :: LimitInput -> Moment LimitOutput
handleLimit (LimitInput eUp eDown) = do
  let
    apBoth f x = (f x, f x)
    eChanges = unions [
        succ <$ eUp
      , (max 0 . pred) <$ eDown
      ]
  (eLimit, bLimit) <- mapAccum 1 $ apBoth <$> eChanges
  return $ LimitOutput        bLimit
```

```haskell
handleLimit :: LimitInput -> Moment LimitOutput
handleLimit (LimitInput eUp eDown) = do
  let
    apBoth f x = (f x, f x)
    eChanges = unions [
        succ <$ eUp
      , (max 0 . pred) <$ eDown
      ]
  (eLimit, bLimit) <- mapAccum 1 $ apBoth <$> eChanges
  return $ LimitOutput eLimit bLimit
```

Having both the `Event` and the the `Behavior` can lead to some efficiency wins.

Now we can make use of the `Behavior Int` that comes out of the limit component, without having to know any more about it.

```haskell
data MessageInput = MessageInput {
    mieRead  :: Event String

  }
```

```haskell
data MessageInput = MessageInput {
    mieRead  :: Event String
  , mibLimit :: Behavior Int
  }
```

```haskell
handleMessage :: MessageInput -> Moment MessageOutput
handleMessage (MessageInput eMessage        ) = do
  bMessages <- accumB [] $
    (\  x xs ->          x : xs ) <$>              eMessage

  let
    format ls m =
      m ++
      " (previous messages: " ++ show ls ++ ")"
    bHasMessages = (not . null) <$> bMessages
    eMessageWithHistory = whenE bHasMessage eMessage
    eOut = leftmost [
        format <$> bMessages <@> eMessageWithHistory
      , eMessage
      ]

  return $ MessageOutput eOut
```

```haskell
handleMessage :: MessageInput -> Moment MessageOutput
handleMessage (MessageInput eMessage bLimit) = do
  bMessages <- accumB [] $
    (\  x xs ->         x : xs ) <$>            eMessage

  let
    format ls m =
      m ++
      " (previous messages: " ++ show ls ++ ")"
    bHasMessages = (not . null) <$> bMessages
    eMessageWithHistory = whenE bHasMessage eMessage
    eOut = leftmost [
        format <$> bMessages <@> eMessageWithHistory
      , eMessage
      ]

  return $ MessageOutput eOut
```

```haskell
handleMessage :: MessageInput -> Moment MessageOutput
handleMessage (MessageInput eMessage bLimit) = do
  bMessages <- accumB [] $
    (\  x xs ->         x : xs ) <$> bLimit <@> eMessage

  let
    format ls m =
      m ++
      " (previous messages: " ++ show ls ++ ")"
    bHasMessages = (not . null) <$> bMessages
    eMessageWithHistory = whenE bHasMessage eMessage
    eOut = leftmost [
        format <$> bMessages <@> eMessageWithHistory
      , eMessage
      ]

  return $ MessageOutput eOut
```

```haskell
handleMessage :: MessageInput -> Moment MessageOutput
handleMessage (MessageInput eMessage bLimit) = do
  bMessages <- accumB [] $
    (\n x xs -> take n (x : xs)) <$> bLimit <@> eMessage

  let
    format ls m =
      m ++
      " (previous messages: " ++ show ls ++ ")"
    bHasMessages = (not . null) <$> bMessages
    eMessageWithHistory = whenE bHasMessage eMessage
    eOut = leftmost [
        format <$> bMessages <@> eMessageWithHistory
      , eMessage
      ]

  return $ MessageOutput eOut
```

Components for a chat server

We want to prompt the user for a nickname, and then start processing commands.

In both of these phases we have two kinds of outputs:

- notifications are broadcast to everyone

```haskell
data Notification =
    NJoin User
  | NMessage User Message
  | NTell User User Message
  | NKick User User
  | NQuit User
  deriving (Eq, Ord, Show)
```

- error and help messages are only sent to the user who triggered them

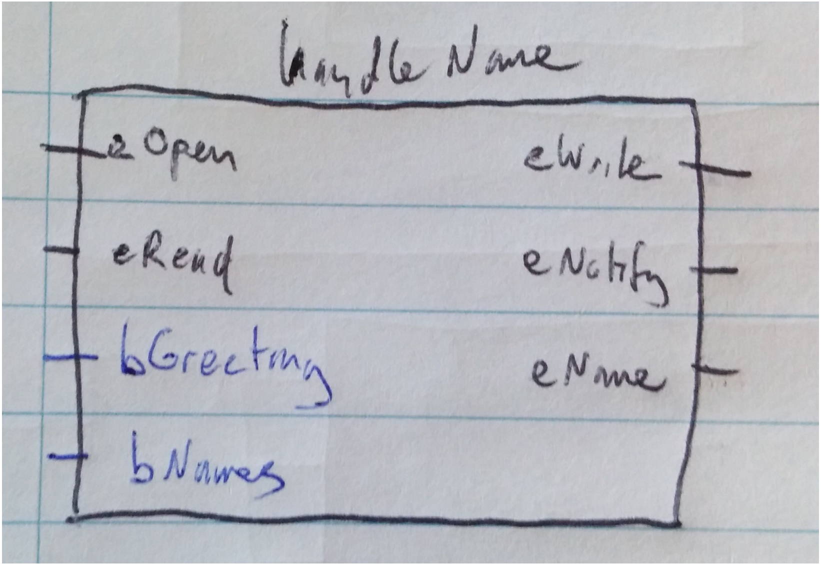
This is similar to `stdout` and `stderr`.

We want the option to either stream notifications to the display, or to gather them all up until the user asks for them.

We have a few restrictions on nicknames:

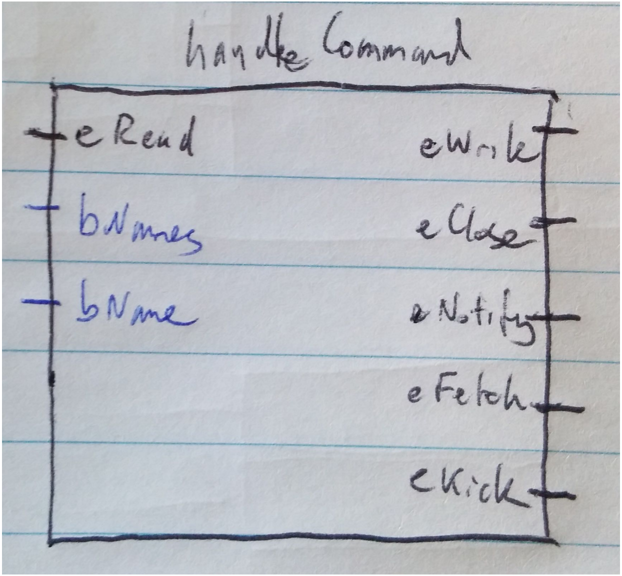
- they can't be empty
- they should be one word
- they should not contain a '/' character, since we're using those for commands
- they should not be the same as the nickname of any of the other users

```haskell
data NameInput = NameInput {
    nieOpen     :: Event ()
  , nieRead     :: Event String
  , nibGreeting :: Behavior String
  , nibNames    :: Behavior (S.Set String)
  }

data NameOutput = NameOutput {
    noeWrite  :: Event String
  , noeNotify :: Event Notification
  , noeName   :: Event String
  }
```



handleName
eOpen
eRead
bGreeting
bNames
eWrite
eNotify
eName

```haskell
data CommandInput = CommandInput {
    cieRead   :: Event String
  , cibNames  :: Behavior (S.Set User)
  , cibName   :: Behavior User
  }

data CommandOutput = CommandOutput {
    coeWrite  :: Event String
  , coeClose  :: Event ()
  , coeNotify :: Event Notification
  , coeFetch  :: Event ()
  , coeKick   :: Event User
  }
```


handle Command
eRead
bNames
bName
eWrite
eClose
eNotify
eFetch
eKick

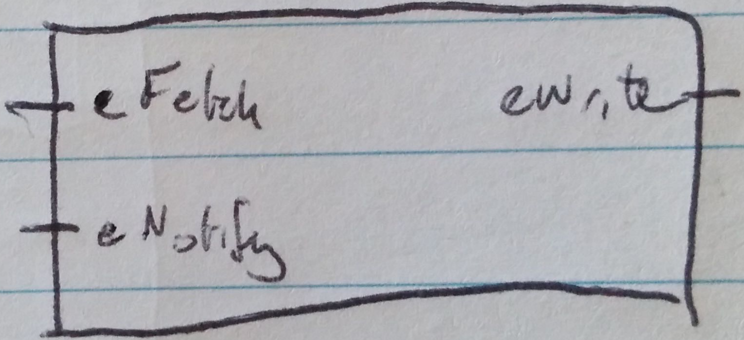
```haskell
data MessageInput = MessageInput {
    mibName    :: Behavior User
  , mieMessage :: Event String
  }

data MessageOutput = MessageOutput {
    moeNotify :: Event Notification
  }

handleMessage :: MessageInput -> Moment MessageOutput
handleMessage (MessageInput bName eMessage) = do
  let
    eNotify = NMessage <$> bName <@> eMessage
  return $ MessageOutput eNotify
```

```haskell
data NotifyType =
    Stream
  | Batch (Behavior Int)

data NotifyInput = NotifyInput {
    nieFetch  :: Event ()
  , nieNotify :: Event Notification
  }

data NotifyOutput = NotifyOutput {
    noeNotify :: Event String
  }
```

```haskell
handleNotifyStream :: NotifyInput
                   -> Moment (Event [Notification])
handleNotifyStream (NotifyInput _ eNotify) =
  return $ pure <$> eNotify
```

```haskell
addToBoundedList :: Int -> a -> [a] -> [a]
addToBoundedList limit x xs =
  take limit (x : xs)

handleNotifyBatch :: Behavior Int
                  -> NotifyInput
                  -> Moment (Event [Notification])
handleNotifyBatch bLimit (NotifyInput eFetch eNotify) = do
  bNotifys <- accumB [] . unions $ [
      addToBoundedList <$> bLimit <@> eNotify
    , const [] <$ eFetch
    ]
  return $ reverse <$> bNotifys <@ eFetch
```

handle Notify



```
handleBlock (Inputs eOpen eRead bGreet bNames eNotify) = do













  return $ Outputs eWrite eClose eNotifyOut eKick
```

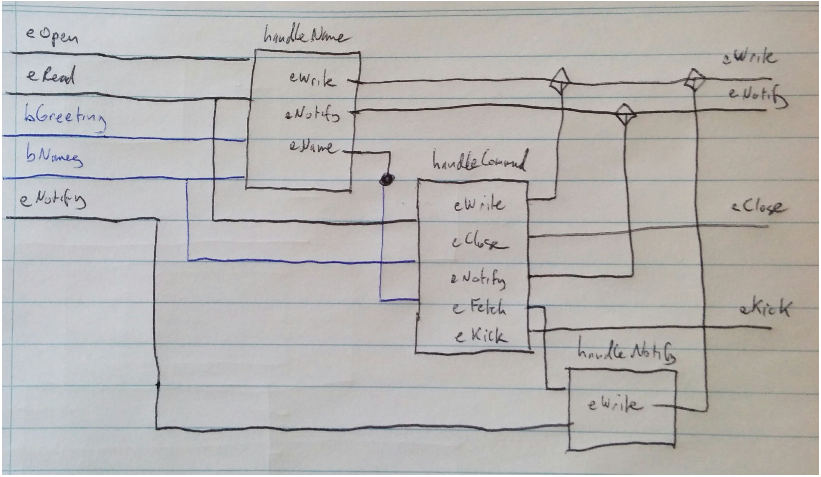
```haskell
handleBlock (Inputs eOpen eRead bGreet bNames eNotify) = do
  NameOutput enWrite enNotify eName <-
    handleName $ NameInput eOpen eRead bGreet bNames















  return $ Outputs eWrite eClose eNotifyOut eKick
```

```haskell
handleBlock (Inputs eOpen eRead bGreet bNames eNotify) = do
  NameOutput enWrite enNotify eName <-
    handleName $ NameInput eOpen eRead bGreet bNames

  bName <- stepper "" eName















  return $ Outputs eWrite eClose eNotifyOut eKick
```

```haskell
handleBlock (Inputs eOpen eRead bGreet bNames eNotify) = do
  NameOutput enWrite enNotify eName <-
    handleName $ NameInput eOpen eRead bGreet bNames

  bName <- stepper "" eName

  CommandOutput ecWrite eClose ecNotify eFetch eKick <-
    handleCommand $
      CommandInput eRead bNames bName









  return $ Outputs eWrite eClose eNotifyOut eKick
```

```haskell
handleBlock (Inputs eOpen eRead bGreet bNames eNotify) = do
  NameOutput enWrite enNotify eName <-
    handleName $ NameInput eOpen eRead bGreet bNames

  bName <- stepper "" eName

  CommandOutput ecWrite eClose ecNotify eFetch eKick <-
    handleCommand $
      CommandInput eRead bNames bName

  NotificationOutput enoWrite <-
    handleNotifyStream $
      NotificationInput eFetch eNotify




  return $ Outputs eWrite eClose eNotifyOut eKick
```

```haskell
handleBlock (Inputs eOpen eRead bGreet bNames eNotify) = do
  NameOutput enWrite enNotify eName <-
    handleName $ NameInput eOpen eRead bGreet bNames

  bName <- stepper "" eName

  CommandOutput ecWrite eClose ecNotify eFetch eKick <-
    handleCommand $
      CommandInput eRead bNames bName

  NotificationOutput enoWrite <-
    handleNotifyStream $
      NotificationInput eFetch eNotify

  let
    eWrite = leftmost [enWrite, ecWrite, enoWrite]
    eNotifyOut = leftmost [enNotify, ecNotify]

  return $ Outputs eWrite eClose eNotifyOut eKick
```


eOpen
eRead
bGreeting
bNames
eNotify
handleName
eWrite
eNotify
eName
handleCommand
eWrite
eClose
eNotify
eFetch
eKick
handleNotify
eWrite
eWrite
eNotify
eClose
eKick

Filtering and switching

First we use the name prompting component.

Then we use the command processing component.

The first way we can do this is to filter the input events.

```
...

  NameOutput enWrite enNotify eName <-
    handleName $ NameInput eOpen  eRead bGreeting bNames

  bName <- stepper "" eName

  CommandOutput ecWrite eClose ecNotify eFetch eKick <-
    handleCommand $
      CommandInput  eRead bNames bName
```

```
...



  NameOutput enWrite enNotify eName <-
    handleName $ NameInput eOpen  eRead bGreeting bNames

  bPhase <- stepper PreOpen . leftmost $ [
      NamePrompting <$ eOpen
    , CmdProcessing <$ eName
    ]

  bName <- stepper "" eName



  CommandOutput ecWrite eClose ecNotify eFetch eKick <-
    handleCommand $
      CommandInput  eRead bNames bName
```

```haskell
...
  let
    enRead = whenE ((== NamePrompting) <$> bPhase) eRead

  NameOutput enWrite enNotify eName <-
    handleName $ NameInput eOpen  eRead bGreeting bNames

  bPhase <- stepper PreOpen . leftmost $ [
      NamePrompting <$ eOpen
    , CmdProcessing <$ eName
    ]

  bName <- stepper "" eName



  CommandOutput ecWrite eClose ecNotify eKick <-
    handleCommand $
      CommandInput  eRead bNames bName
```

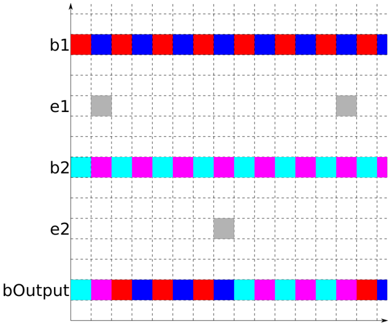
```haskell
...
  let
    enRead = whenE ((== NamePrompting) <$> bPhase) eRead

  NameOutput enWrite enNotify eName <-
    handleName $ NameInput eOpen enRead bGreeting bNames

  bPhase <- stepper PreOpen . leftmost $ [
      NamePrompting <$ eOpen
    , CmdProcessing <$ eName
    ]

  bName <- stepper "" eName



  CommandOutput ecWrite eClose ecNotify eKick <-
    handleCommand $
      CommandInput  eRead bNames bName
```

```haskell
...
  let
    enRead = whenE ((== NamePrompting) <$> bPhase) eRead

  NameOutput enWrite enNotify eName <-
    handleName $ NameInput eOpen enRead bGreeting bNames

  bPhase <- stepper PreOpen . leftmost $ [
      NamePrompting <$ eOpen
    , CmdProcessing <$ eName
    ]

  bName <- stepper "" eName

  let
    ecRead = whenE ((== CmdProcessing) <$> bPhase) eRead
  CommandOutput ecWrite eClose ecNotify eKick <-
    handleCommand $
      CommandInput  eRead bNames bName
```

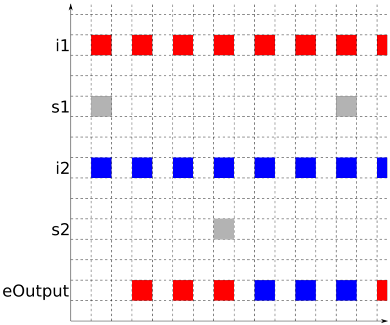
```haskell
...
  let
    enRead = whenE ((== NamePrompting) <$> bPhase) eRead

  NameOutput enWrite enNotify eName <-
    handleName $ NameInput eOpen enRead bGreeting bNames

  bPhase <- stepper PreOpen . leftmost $ [
        NamePrompting <$ eOpen
      , CmdProcessing <$ eName
      ]

  bName <- stepper "" eName

  let
    ecRead = whenE ((== CmdProcessing) <$> bPhase) eRead
  CommandOutput ecWrite eClose ecNotify eKick <-
    handleCommand $
      CommandInput ecRead bNames bName
```

The second way to manage the different phases is by ‘switching’ the outputs.

```haskell
switchB :: MonadMoment m
        => Behavior a
        -> Event (Behavior a)
        -> m (Behavior a)

switcher :: MonadMoment m
         => Behavior Colour
         -> Event ()
         -> Behavior Colour
         -> Event ()
         -> m (Behavior Colour)
switcher b1 e1 b2 e2 = do
  bOutput <-
    switchB b2 .
    leftmost $ [
        b1 <$ e1
      , b2 <$ e2
      ]
  return bOutput
```



```
switchE :: MonadMoment m
        => Event (Event a)
        -> m (Event a)

switcher :: MonadMoment m
         => Event Colour
         -> Event ()
         -> Even Colour
         -> Event ()
         -> m (Event Colour)
switcher i1 s1 i2 s2 = do
  eOutput <-
    switchE .
    leftmost $ [
        i1 <$ s1
      , i2 <$ s2
      ]
  return eOutput
```



Other libraries allow for an initial `Event` for `switchE`, or cover all of the combinations of nested `Events` and `Behaviors`.

```haskell
class Switch a where
  switch :: MonadMoment m => a -> Event a -> m a
```

```haskell
class Switch a where
  switch :: MonadMoment m => a -> Event a -> m a

instance Switch (Behavior a) where ...
instance Switch (Event a) where ...
```

```haskell
class Switch a where
  switch :: MonadMoment m => a -> Event a -> m a

instance Switch (Behavior a) where ...
instance Switch (Event a) where ...

switchAp :: (Switch b, MonadMoment m)
         => (a -> b)
         -> a
         -> Event a
         -> m b
switchAp f a e = switch (f a) (f <$> e)
```

```haskell
instance Switch OutputIO where
  switch e ee =
    OutputIO <$>
      switchAp ioeWrite e ee <*>
      switchAp ioeClose e ee
```

```haskell
...
let
  nameOut = OutputIO enWrite never
  cmdOut = OutputIO ecWrite ecClose

switch nameOut (cmdOut <$ eName)
```

Important to remember to switch out the event that does the switching if you aren't planning on switching back.

```haskell
once :: MonadMoment m => Event a -> m (Event a)
once e = switch e (never <$ e)
```

```haskell
...

let
  nameOut = OutputIO enWrite never
  cmdOut = OutputIO ecWrite ecClose

switch nameOut (cmdOut <$ eName)
```

```haskell
...
eSwitch <- once eName
let
  nameOut = OutputIO enWrite never
  cmdOut = OutputIO ecWrite ecClose

switch nameOut (cmdOut <$ eName)
```

```
...
eSwitch <- once eName
let
  nameOut = OutputIO enWrite never
  cmdOut = OutputIO ecWrite ecClose

switch nameOut (cmdOut <$ eSwitch)
```

A better option is to filter inputs *and* to switch the outputs.

This is often used when you are changing between implementations of an interface based on an event.

The third option involves an even bigger dynamic change to the event network.

```haskell
observeE :: Event (Moment   a) ->            Event a
execute  :: Event (MomentIO a) -> MomentIO (Event a)
```

```haskell
instance Switch a => Switch (Moment a) where
  switch e ee = do
    m <- liftMoment e
    return $ switch m (observeE ee)
```

```haskell
data OutputWrapper = OutputWrapper {
    owWrite  :: Event String
  , owClose  :: Event ()
  , owName   :: Event String
  , owNotify :: Event Notification
  , owFetch  :: Event ()
  , owKick   :: Event String
  }
```

```haskell
data OutputWrapper = OutputWrapper {
    owWrite  :: Event String
  , owClose  :: Event ()
  , owName   :: Event String
  , owNotify :: Event Notification
  , owFetch  :: Event ()
  , owKick   :: Event String
  }

instance Switch OutputWrapper where ...
```

```haskell
data OutputWrapper = OutputWrapper {
    owWrite  :: Event String
  , owClose  :: Event ()
  , owName   :: Event String
  , owNotify :: Event Notification
  , owFetch  :: Event ()
  , owKick   :: Event String
  }

instance Switch OutputWrapper where ...

wrapName :: NameOutput -> OutputWrapper
wrapCmd :: CommandOutput -> OutputWrapper
```

```haskell
let
  -- nameBlock, cmdBlock :: Moment OutputWrapper
  nameBlock =
    fmap wrapName .
    handleName $
    NameInput eOpen eRead bGreeting bNames
  cmdBlock =
    fmap wrapCmd .
    handleCommand $
    CommandInput eRead bNames bName
```

```haskell
eSwitch <- once ???

let
  -- nameBlock, cmdBlock :: Moment OutputWrapper
  nameBlock =
    fmap wrapName .
    handleName $
    NameInput eOpen eRead bGreeting bNames
  cmdBlock =
    fmap wrapCmd .
    handleCommand $
    CommandInput eRead bNames bName
```

```haskell
eSwitch <- once ???

let
  -- nameBlock, cmdBlock :: Moment OutputWrapper
  nameBlock =
    fmap wrapName .
    handleName $
    NameInput eOpen eRead bGreeting bNames
  cmdBlock =
    fmap wrapCmd .
    handleCommand $
    CommandInput eRead bNames bName

ow <-         switch nameBlock (cmdBlock <$ eSwitch)
```

```haskell
eSwitch <- once ???

let
  -- nameBlock, cmdBlock :: Moment OutputWrapper
  nameBlock =
    fmap wrapName .
    handleName $
    NameInput eOpen eRead bGreeting bNames
  cmdBlock =
    fmap wrapCmd .
    handleCommand $
    CommandInput eRead bNames bName

ow <- join $ switch nameBlock (cmdBlock <$ eSwitch)
```

```haskell
eSwitch <- once ???

let
  -- nameBlock, cmdBlock :: Moment OutputWrapper
  nameBlock =
    fmap wrapName .
    handleName $
    NameInput eOpen eRead bGreeting bNames
  cmdBlock =
    fmap wrapCmd .
    handleCommand $
    CommandInput eRead bNames bName

ow <- join $ switch nameBlock (cmdBlock <$ eSwitch)
let
  eName = owName ow
```

```haskell
eSwitch <- once eName

let
  -- nameBlock, cmdBlock :: Moment OutputWrapper
  nameBlock =
    fmap wrapName .
    handleName $
    NameInput eOpen eRead bGreeting bNames
  cmdBlock =
    fmap wrapCmd .
    handleCommand $
    CommandInput eRead bNames bName

ow <- join $ switch nameBlock (cmdBlock <$ eSwitch)
let
  eName = owName ow
```

This is particularly handy if you want to use multiple copies of an event network in a dynamically changing data structure.

FRP and garbage collection

The theory is that if you don't use it, you shouldn't pay for it.

Progress in the libraries is catching up / has caught up to that theory.

If a `Behavior` is never sampled, it shouldn't be created.

If an `Event` is part of a network that isn't connected to a `reactimate`, it shouldn't be created.

This is based on what can be statically determined when `compile` is applied to the network.

Switching makes this more interesting.

We could switch an `Event` to become `never`, but we need to be able to statically determine that it's not going to switch back.

That is why we use `once` on the event used to trigger those kind of switches.

Internally, reactive-banana uses weak references to have the GHC garbage collector enforce much of this.

How do we test these guidelines? Especially if being connected to IO can have an effect?

Allocate memory in fixed time-varying patterns, play with various options and profile the heap.

A socket based server

Will go into much more depth in this in Part 2.

```haskell
-- data ClientFns = ClientFns {
--     cfWrite :: String -> IO ()
--   , cfClose :: IO ()
--   }

mkServerNetwork (ServerIOInputs cl o r c) = mdo
  -- eNewClient :: Event (Int, ClientFns)
  eNewClient <- fromAddHandler . addHandler $ cl
  -- eOpens :: Event Int
  eOpens     <- fromAddHandler . addHandler $ o
  -- eReads :: Event (Int, String)
  eReads     <- fromAddHandler . addHandler $ r
  -- eCloses :: Event Int
  eCloses    <- fromAddHandler . addHandler $ c
  ...
```

```haskell
-- data ClientState = ClientState {
--     csName     :: String
--   , cseNotify :: Event Notification
--   }

  ...
  let
    -- mkClient :: (Int, ClientFns)
    --          -> MomentIO (Int, Behavior ClientState)
    mkClient (i, c) = do
      cn <- mkClientNetwork
        eOpens eReads eCloses bNames eNotify i c
      return (i, cn)

  -- eClient :: Event (Int, Behavior ClientState)
  eClient <- execute $ mkClient <$> eNewClient
  ...
```

```haskell
...
-- eClient :: Event (Int, Behavior ClientState)
eClient <- execute $ mkClient <$> eNewClient
```

```haskell
...
```

```haskell
...
-- eClient :: Event (Int, Behavior ClientState)
eClient <- execute $ mkClient <$> eNewClient

-- embClients ::
--   Event (M.Map Int (Behavior ClientState))
embClients <- accumE M.empty . unions $ [
    uncurry M.insert <$> eClient
  , M.delete         <$> eCloses
  ]
...
```

```haskell
...
-- eClient :: Event (Int, Behavior ClientState)
eClient <- execute $ mkClient <$> eNewClient

-- embClients ::
--   Event (M.Map Int (Behavior ClientState))
embClients <- accumE M.empty . unions $ [
    uncurry M.insert <$> eClient
  , M.delete         <$> eCloses
  ]

let
  -- ebmClients ::
  --   Event (Behavior (M.Map Int ClientState))
  ebmClients = sequenceA <$> eClients


...
```

```haskell
...
-- eClient :: Event (Int, Behavior ClientState)
eClient <- execute $ mkClient <$> eNewClient

-- embClients ::
--   Event (M.Map Int (Behavior ClientState))
embClients <- accumE M.empty . unions $ [
    uncurry M.insert <$> eClient
  , M.delete         <$> eCloses
  ]

let
  -- ebmClients ::
  --   Event (Behavior (M.Map Int ClientState))
  ebmClients = sequenceA <$> eClients

-- bClients :: Behavior (M.Map Int ClientState)
bClients <- switchB (pure M.empty) ebmClients
...
```

We just need to get hold of `bNames` and `eNotify`.

```haskell
let
  -- getNames :: M.Map Int ClientState
  --          -> S.Set String
  getNames =
    S.fromList . M.elems . fmap csName
  -- bNames :: Behavior (S.Set String)
  bNames = getNames <$> bClients
```

```haskell
let
  -- getENotify :: M.Map Int ClientState
  --            -> Event Notification
  getENotify =
    leftmost . M.elems . fmap cseNotify
```

```haskell
let
  -- getENotify :: M.Map Int ClientState
  --            -> Event Notification
  getENotify =
    leftmost . M.elems . fmap cseNotify

  -- beNotify :: Behavior (Event Notification)
  beNotify = getENotify <$> bClients
```

```haskell
let
  -- getENotify :: M.Map Int ClientState
  --            -> Event Notification
  getENotify =
    leftmost . M.elems . fmap cseNotify

  -- beNotify :: Behavior (Event Notification)
  beNotify = getENotify <$> bClients

  -- eTick :: Event ()
  eTick = leftmost [
      () <$ eOpens, () <$ eReads, () <$ eCloses
    ]
```

```haskell
let
  -- getENotify :: M.Map Int ClientState
  --            -> Event Notification
  getENotify =
    leftmost . M.elems . fmap cseNotify

  -- beNotify :: Behavior (Event Notification)
  beNotify = getENotify <$> bClients

  -- eTick :: Event ()
  eTick = leftmost [
      () <$ eOpens, () <$ eReads, () <$ eCloses
    ]

  -- eeNotify :: Event (Event Notification)
  eeNotify = beNotify <@ eTick
```

```haskell
let
  -- getENotify :: M.Map Int ClientState
  --            -> Event Notification
  getENotify =
    leftmost . M.elems . fmap cseNotify

  -- beNotify :: Behavior (Event Notification)
  beNotify = getENotify <$> bClients

  -- eTick :: Event ()
  eTick = leftmost [
      () <$ eOpens, () <$ eReads, () <$ eCloses
    ]

  -- eeNotify :: Event (Event Notification)
  eeNotify = beNotify <@ eTick

-- eNotify :: Event Notification
eNotify <- switchE eeNotify
```

Conclusion

Still lots more to cover:

- Plenty of testing goodness

- Using this event network for a webserver

- The differences between `reactive-banana` and `reflex`

- Using `reflex` and `reflex-dom` for the front-end.

Lots of other fun stuff as well:

- fun with serializing and deserializing `Behaviors`

- fun with event sourcing and friends

- what does an FRP implementation of Raft look like?

- what can you get up to with an FRP-based parser library?