무료 전자 책

배우기

Haskell Language

#haskell

145

1:

[Haskell](#) .

:

- **:** . ( ) . .
- : . , ( ) .
- **:** GHC .
- **:** . .
- **:** .
- **:** Haskell .

Haskell Haskell 2010. 2016 5 Haskell 2020 .

. , , , ,

2010	2012-07-10
98	2002-12-01

Examples

, !

"Hello, World!" Haskell :

```
main :: IO ()
main = putStrLn "Hello, World!"
```

`main` `IO ()` "" I / O , `()` ("") ( ). `main` .

`helloworld.hs` GHC :

```
ghc helloworld.hs
```

`"Hello, World!"` :

```
./helloworld
Hello, World!
```

`runhaskell` `runghc` .

```
runhaskell helloworld.hs
```

REPL . GHC `ghci` Haskell .

```
ghci> putStrLn "Hello World!"
Hello, World!
ghci>
```

`load` (`:l`) ghci `load` .

```
ghci> :load helloworld
```

`:reload` (`:r`) ghci .

```
Prelude> :l helloworld.hs
[1 of 1] Compiling Main             ( helloworld.hs, interpreted )

<some time later after some edits>

*Main> :r
Ok, modules loaded: Main.
```

:

`main` .

```
main :: IO ()
```

`IO ()` .

Hindley-Milner , : `main :: IO ()` . `main` . . .

- Haskell . . "" GHCi . .
- . . . .

.

```
main = putStrLn "Hello, World!"
```

, :

```
main = do {
   putStrLn "Hello, World!" ;
   return ()
   }
```

(Haskell ,) :

```
main = do
    putStrLn "Hello, World!"
    return ()
```

do (I / O) do (I / O).

do IO return .

main = putStrLn "Hello, World!" main = putStrLn "Hello, World!" putStrLn "Hello, World!" putStrLn "Hello, World!" IO () . "" putStrLn "Hello, World!" , putStrLn "Hello, World!" main .

putStrLn .

```
putStrLn :: String -> IO ()
-- thus,
putStrLn (v :: String) :: IO ()
```

putStrLn I / O-action ( ) . main putStrLn "Hello, World!" putStrLn "Hello, World!" .

"Hello World!". ( ) .

1

```
fac :: (Integral a) => a -> a
fac n = product [1..n]
```

- Integral . Int Integer .
- (Integral a) => a
- fac :: a -> a fac a a a
- product .
- [1..n] enumFromTo 1 n 1 ≤ x ≤ n .

2

```
fac :: (Integral a) => a -> a
fac 0 = 1
fac n = n * fac (n - 1)
```

. 0 ( ) ( ) . fac .

---

fac GHC . .

,

Haskell .

.

```
f (0)  <-  0
f (1)  <-  1
f (n)  <-  f (n-1) + f (n-2)
```

. .

```
fibs !! n  <-  f (n)
```

```
                  ┌──────┐   ┌──────┐   ┌──────┐
                  │ f(0) │   │ f(1) │   │ f(2) │
fibs  ->  0 : 1 : │  +   │ : │  +   │ : │  +   │ :  .....
                  │ f(1) │   │ f(2) │   │ f(3) │
                  └──────┘   └──────┘   └──────┘

                  ┌────────────────────────────────────┐
                  │ f(0)   :   f(1)   :   f(2)   :  .....  │
                  └────────────────────────────────────┘
      ->  0 : 1 :               +
                  ┌────────────────────────────────────┐
                  │ f(1)   :   f(2)   :   f(3)   :  .....  │
                  └────────────────────────────────────┘
```

:

```
fibn n = fibs !! n
    where
    fibs = 0 : 1 : map f [2..]
    f n = fibs !! (n-1) + fibs !! (n-2)
```

```
GHCi> let fibs = 0 : 1 : zipWith (+) fibs (tail fibs)
GHCi> take 10 fibs
[0, 1, 1, 2, 3, 5, 8, 13, 21, 34]
```

`zipWith` . `zipWith (+) [x1, x2, ...] [y1, y2, ...]` `[x1 + y1, x2 + y2, ...]` .

`fibs` [`scanl`] :

```
GHCi> let fibs = 0 : scanl (+) 1 fibs
GHCi> take 10 fibs
[0, 1, 1, 2, 3, 5, 8, 13, 21, 34]
```

`scanl` `foldl` ., `scanl f z0 [x1, x2, ...]` `[z0, z1, z2, ...] where z1 = f z0 x1; z2 = f z1 x2; ...` `[z0, z1, z2, ...] where z1 = f z0 x1; z2 = f z1 x2; ...`

., `fib` . n .

```
GHCi> let fib n = fibs !! n  -- (!!) being the list subscript operator
-- or in point-free style:
```

```
GHCi> let fib = (fibs !!)
GHCi> fib 9
34
```

REPL

Haskell Haskell Haskell REPL (read-eval-print-loop) . REPL IO . `help` . .

GHC (i)

Glorious / Glasgow Haskell *GHCi* . *GHC* . *Cabal* *Stack* . Unix *Stack* .

```
curl -sSL https://get.haskellstack.org/ | sh
```

GHC . `stack` . Haskell Platform . .

1. *GHC* () *Cabal / Stack* ( )
2. , . .

( ).

- , , :

  ```
  sudo apt-get install haskell-platform
  ```

- :

  ```
  sudo dnf install haskell-platform
  ```

- :

  ```
  sudo yum install haskell-platform
  ```

- :

  ```
  sudo pacman -S ghc cabal-install haskell-haddock-api \
                 haskell-haddock-library happy alex
  ```

- :

  ```
  sudo layman -a haskell
  sudo emerge haskell-platform
  ```

- OSX :

```
brew cask install haskell-platform
```

- MacPorts OSX :

```
sudo port install haskell-platform
```

, *GHCi* `ghci` . .

```
me@notebook:~$ ghci
GHCi, version 6.12.1: http://www.haskell.org/ghc/  :? for help
Prelude>
```

`Prelude>` . , Haskell REPL REPL Haskell . `:q` `:quit` . *GHCi* `:?` .

. `.hs` `:l` `:load` REPL .

GHCi *GHC* . Haskell `.hs` . `.hs` `main` . `.test.hs` .

```
ghc test.hs
```

`main` .

1. .
   - *GHC* ( )
   -
   -
   -
   -
2. IHaskell IPython haskell markdown ( ) .

:

100

```
import Data.List ( (\\) )

ps100 = ((([2..100] \\ [4,6..100]) \\ [6,9..100]) \\ [10,15..100]) \\ [14,21..100]

   -- = (((2:[3,5..100]) \\ [9,15..100]) \\ [25,35..100]) \\ [49,63..100]

   -- = (2:[3,5..100]) \\ ([9,15..100] ++ [25,35..100] ++ [49,63..100])
```

Eratosthenes , data-ordlist :

```
import qualified Data.List.Ordered

ps   = 2 : _Y ((3:) . minus [5,7..] . unionAll . map (\p -> [p*p, p*p+2*p..]))
```

```
_Y g = g (_Y g)   -- = g (g (_Y g)) = g (g (g (g (...)))) = g . g . g . g . ...
```

( )

```
ps = sieve [2..]
     where
     sieve (x:xs) = [x] ++ sieve [y | y <- xs, rem y x > 0]

-- = map head ( iterate (\(x:xs) -> filter ((> 0).(`rem` x)) xs) [2..] )
```

```
ps = 2 : [n | n <- [3..], all ((> 0).rem n) $ takeWhile ((<= n).(^2)) ps]

-- = 2 : [n | n <- [3..], foldr (\p r-> p*p > n || (rem n p > 0 && r)) True ps]
```

:

```
[n | n <- [2..], []==[i | i <- [2..n-1], j <- [0,i..n], j==n]]
```

```
nubBy (((>1).).gcd) [2..]          -- i.e., nubBy (\a b -> gcd a b > 1) [2..]
```

`nubBy` `Data.List` `(\\)` .

REPL .

```
Prelude> let x = 5
Prelude> let y = 2 * 5 + x
Prelude> let result = y * 10
Prelude> x
5
Prelude> y
15
Prelude> result
150
```

.

```
-- demo.hs

module Demo where
-- We declare the name of our module so
-- it can be imported by name in a project.

x = 5

y = 2 * 5 + x

result = y * 10
```

.

: https://riptutorial.com/ko/haskell/topic/251/--

2: Attoparsec

Attoparsec " / " .

Attoparsec .

API Parsec API .

`ByteString` , `Text` `Char8` . `OverloadedStrings` .

`Parser ia`	. `i` (: `ByteString` .
`IResult ir`	`Fail i [String] String` , `Partial (i -> IResult ir)` `Done ir` .

Examples

 .

:

 : 0800 1600.

"" : - ""- "0800"- "1600".

.

```
data Day = Day String

day :: Parser Day
day = do
  name <- takeWhile1 (/= ':')
  skipMany1 (char ':')
  skipSpace
  return $ Day name
```

.

```
data TimePortion = TimePortion String String

time = do
    start <- takeWhile1 isDigit
    skipSpace
    end <- takeWhile1 isDigit
    return $ TimePortion start end
```

. " " .

```
data WorkPeriod = WorkPeriod Day TimePortion
```

```
work = do
    d <- day
    t <- time
    return $ WorkPeriod d t
```

.

```
parseOnly work "Monday: 0800 1600"
```

-

Attoparsec . .

```
import           Data.Attoparsec.ByteString (Parser, eitherResult, parse, take)
import           Data.Binary.Get            (getWord32le, runGet)
import           Data.ByteString            (ByteString, readFile)
import           Data.ByteString.Char8      (unpack)
import           Data.ByteString.Lazy       (fromStrict)
import           Prelude                    hiding (readFile, take)

-- The DIB section from a bitmap header
data DIB = BM | BA | CI | CP | IC | PT
           deriving (Show, Read)

type Reserved = ByteString

-- The entire bitmap header
data Header = Header DIB Int Reserved Reserved Int
              deriving (Show)
```

. 4 .

, DIB 2

```
dibP :: Parser DIB
dibP = read . unpack <$> take 2
```

, .

```
sizeP :: Parser Int
sizeP = fromIntegral . runGet getWord32le . fromStrict <$> take 4

reservedP :: Parser Reserved
reservedP = take 2

addressP :: Parser Int
addressP = fromIntegral . runGet getWord32le . fromStrict <$> take 4
```

.

```
bitmapHeader :: Parser Header
```

```
bitmapHeader = do
    dib <- dibP
    sz <- sizeP
    reservedP
    reservedP
    offset <- addressP
    return $ Header dib sz "" "" offset
```

Attoparsec : https://riptutorial.com/ko/haskell/topic/9681/attoparsec

3: cofree comonads

Examples

~~

```
data Empty a
```

.

```
data Cofree Empty a
   --  = a :< ...  not possible!
```

Cofree (Const c) ~ Writer c

```
data Const c a = Const c
```

.

```
data Cofree (Const c) a
     = a :< Const c
```

```
data Writer c a = Writer c a
```

~~

```
data Identity a = Identity a
```

.

```
data Cofree Identity a
     = a :< Identity (Cofree Identity a)
```

```
data Stream a = Stream a (Stream a)
```

Cofree Maybe ~ ~ NonEmpty

```
data Maybe a = Just a
             | Nothing
```

.

```
data Cofree Maybe a
     = a :< Just (Cofree Maybe a)
```

```
    | a :< Nothing
```

```
data NonEmpty a
    = NECons a (NonEmpty a)
    | NESingle a
```

Cofree (w) ~ WriterT w

```
data Writer w a = Writer w a
```

.

```
data Cofree (Writer w) a
    = a :< (w, Cofree (Writer w) a)
```

```
data Stream (w,a)
    = Stream (w,a) (Stream (w,a))
```

`WriterT w Stream` .

```
data WriterT w m a = WriterT (m (w,a))
```

Cofree (Either e) ~~ NonEmptyT (Writer e)

```
data Either e a = Left e
                | Right a
```

.

```
data Cofree (Either e) a
    = a :< Left e
    | a :< Right (Cofree (Either e) a)
```

```
data Hospitable e a
    = Sorry_AllIHaveIsThis_Here'sWhy a e
    | EatThis a (Hospitable e a)
```

`NonEmptyT (Writer e) a`

```
data NonEmptyT (Writer e) a = NonEmptyT (e,a,[a])
```

Cofree (Reader x) ~ x

```
data Reader x a = Reader (x -> a)
```

.

```
data Cofree (Reader x) a
     = a :< (x -> Cofree (Reader x) a)
```

```
data Plant x a
     = Plant a (x -> Plant x a)
```

.

cofree comonads : https://riptutorial.com/ko/haskell/topic/8258/cofree-comonads---

4: Data.Aeson - JSON

Examples

Aeson JSON .

```
{-# LANGUAGE DeriveGeneric #-}

import GHC.Generics
import Data.Text
import Data.Aeson
import Data.ByteString.Lazy
```

Person .

```
data Person = Person { firstName :: Text
                     , lastName  :: Text
                     , age       :: Int
                     } deriving (Show, Generic)
```

`Data.Aeson` `encode` `decode` `Person` `ToJSON` `FromJSON` `FromJSON` . `Generic` for `Person` `Generic` . `Generic` .

```
instance ToJSON Person
instance FromJSON Person
```

! `ToJSON` .

```
instance ToJSON Person where
    toEncoding = genericToEncoding defaultOptions
```

`encode` `Person` () Bytestring .

```
encodeNewPerson :: Text -> Text -> Int -> ByteString
encodeNewPerson first last age = encode $ Person first last age
```

`decode` :

```
> encodeNewPerson "Hans" "Wurst" 30
"{\"lastName\":\"Wurst\",\"age\":30,\"firstName\":\"Hans\"}"


> decode $ encodeNewPerson "Hans" "Wurst" 30
Just (Person {firstName = "Hans", lastName = "Wurst", age = 30})
```

Data.Aeson.Value

```
{-# LANGUAGE OverloadedStrings #-}
```

```
module Main where

import Data.Aeson

main :: IO ()
main = do
  let example = Data.Aeson.object [ "key" .= (5 :: Integer), "somethingElse" .= (2 :: Integer)
] :: Value
  print . encode $ example
```

JSON . ,

```
data Person = Person { firstName :: Text
                     , lastName  :: Text
                     , age       :: Maybe Int
                     }
```

.

```
import Data.Aeson.TH

$(deriveJSON defaultOptions{omitNothingFields = True} ''Person)
```

Data.Aeson - JSON : https://riptutorial.com/ko/haskell/topic/4525/data-aeson----json

5: Data.Text

Text Haskell String . String :

```
type String = [Char]
```

Text . .

Text String . String API , Text String .

OverloadedStrings .

Examples

OverloadedStrings Text Text .

```
{-# LANGUAGE OverloadedStrings #-}

import qualified Data.Text as T

myText :: T.Text
myText = "overloaded"
```

```
{-# LANGUAGE OverloadedStrings #-}

import qualified Data.Text as T

myText :: T.Text
myText = "\n\r\t   leading and trailing whitespace   \t\r\n"
```

strip Text .

```
ghci> T.strip myText
"leading and trailing whitespace"
```

stripStart .

```
ghci> T.stripStart myText
"leading and trailing whitespace   \t\r\n"
```

stripEnd .

```
ghci> T.stripEnd myText
"\n\r\t   leading and trailing whitespace"
```

filter .

```
ghci> T.filter /=' ' "spaces in the middle of a text string"
```

```
"spacesinthemiddleofatextstring"
```

```
{-# LANGUAGE OverloadedStrings #-}

import qualified Data.Text as T

myText :: T.Text
myText = "mississippi"
```

`splitOn` `Text` `Texts` .

```
ghci> T.splitOn "ss" myText
["mi","i","ippi"]
```

`splitOn` `intercalate` .

```
ghci> intercalate "ss" (splitOn "ss" "mississippi")
"mississippi"
```

`split` `Text` .

```
ghci> T.split (== 'i') myText
["m","ss","ss","pp",""]
```

`Data.Text.Encoding` .

```
ghci> import Data.Text.Encoding
ghci> decodeUtf8 (encodeUtf8 "my text")
"my text"
```

`decodeUtf8` . UTF-8 `decodeUtf8With` `decodeUtf8With` .

```
ghci> decodeUtf8With (\errorDescription input -> Nothing) messyOutsideData
```

```
ghci> :set -XOverloadedStrings
ghci> import Data.Text as T
```

`isInfixOf :: Text -> Text -> Bool` `Text` `Text` .

```
ghci> "rum" `T.isInfixOf` "crumble"
True
```

`isPrefixOf :: Text -> Text -> Bool` `Text` `Text` .

```
ghci> "crumb" `T.isPrefixOf` "crumble"
True
```

`isSuffixOf :: Text -> Text -> Bool` `Text` `Text` .

```
ghci> "rumble" `T.isSuffixOf` "crumble"
True
```

```
{-# LANGUAGE OverloadedStrings #-}

import qualified Data.Text as T

myText :: T.Text

myText = "mississippi"
```

`index` .

```
ghci> T.index myText 2
's'
```

`findIndex` `(Char -> Bool)` Text Nothing .

```
ghci> T.findIndex ('s'==) myText
Just 2
ghci> T.findIndex ('c'==) myText
Nothing
```

`count` `Text` `Text` .

```
ghci> count ("miss"::T.Text) myText
1
```

Data.Text : https://riptutorial.com/ko/haskell/topic/3406/data-text

6: GHCi

GHCI GHC REPL.

Examples

GHCi

`ghci` GHCI .

```
$ ghci
GHCi, version 8.0.1: http://www.haskell.org/ghc/  :? for help
Prelude>
```

GHCi

GHCI . .

```
Prelude Data.List Control.Monad> -- etc
```

`:set prompt` .

```
Prelude Data.List Control.Monad> :set prompt "foo> "
foo>
```

`:set prompt "foo> "` GHCi .

GHCi

GHCi `~/.ghci` . GHCi .

```
$ echo ":set prompt \"foo> \"" > ~/.ghci
$ ghci
GHCi, version 8.0.1: http://www.haskell.org/ghc/  :? for help
Loaded GHCi configuration from ~/.ghci
foo>
```

`:l` `:load` - .

```
$ echo "f = putStrLn \"example\"" > example.hs
$ ghci
GHCi, version 8.0.1: http://www.haskell.org/ghc/  :? for help
ghci> :l example.hs
[1 of 1] Compiling Main               ( example.hs, interpreted )
Ok, modules loaded: Main.
ghci> f
example
```

GHCi

`:q` GHCi `:q` `:quit`

```
ghci> :q
Leaving GHCi.

ghci> :quit
Leaving GHCi.
```

`CTRL` + `D` (OSX `Cmd` + `D`) `:q` .

GHCi (`:l filename.hs`) GHCi `:r` `:reload` `:reload` .

```
ghci> :r
OK, modules loaded: Main.

ghci> :reload
OK, modules loaded: Main.
```

GHCi

GHCi (`:loaded`) .

:

```
-- mySum.hs
doSum n = do
  putStrLn ("Counting to " ++ (show n))
  let v = sum [1..n]
  putStrLn ("sum to " ++ (show n) ++ " = " ++ (show v))
```

GHCi :

```
Prelude> :load mySum.hs
[1 of 1] Compiling Main             ( mySum.hs, interpreted )
Ok, modules loaded: Main.
*Main>
```

.

```
*Main> :break 2
Breakpoint 0 activated at mySum.hs:2:3-39
```

GHCi :

```
*Main> doSum 12
Stopped at mySum.hs:2:3-39
_result :: IO () = _
n :: Integer = 12
[mySum.hs:2:3-39] *Main>
```

`:list` `:list` :

```
[mySum.hs:2:3-39] *Main> :list
1  doSum n = do
2    putStrLn ("Counting to " ++ (show n))   -- GHCi will emphasise this line, as that's where
we've stopped
3    let v = sum [1..n]
```

.

```
[mySum.hs:2:3-39] *Main> n
12
:continue
Counting to 12
sum to 12 = 78
*Main>
```

`:{` `:}` . GHCi .

```
ghci> :{
ghci| myFoldr f z [] = z
ghci| myFoldr f z (y:ys) = f y (myFoldr f z ys)
ghci| :}
ghci> :t myFoldr
myFoldr :: (a -> b -> b) -> b -> [a] -> b
```

GHCi : https://riptutorial.com/ko/haskell/topic/3407/ghci-

7: GHCJS

GHCJS GHC API JavaScript   Haskell.

Examples

"Hello World!" Node.js

`ghcjs` `ghc`   .   Node.js SpiderMonkey jsshell   . :

```
$ ghcjs -o helloWorld helloWorld.hs
$ node helloWorld.jsexe/all.js
Hello world!
```

GHCJS : https://riptutorial.com/ko/haskell/topic/9260/ghcjs

8: Google

Haskell `htprotoc` :

1. Github
2.

`$HOME/.local/bin/ hprotoc` .

Examples

.proto ,

`.proto` `person.proto`

```
package Protocol;

message Person {
    required string firstName = 1;
    required string lastName  = 2;
    optional int32  age       = 3;
}
```

.

```
$HOME/.local/bin/hprotoc --proto_path=. --haskell_out=. person.proto
```

.

```
Loading filepath: "/<path-to-project>/person.proto"
All proto files loaded
Haskell name mangling done
Recursive modules resolved
./Protocol/Person.hs
./Protocol.hs
Processing complete, have a nice day.
```

`hprotoc` haskell `Person.hs` `Protocol` :

```
import Protocol (Person)
```

Stack add

```
  protocol-buffers
, protocol-buffers-descriptor
```

`build-depends:`

```
Protocol
```

.cabal exposed-modules .

ByteString ByteString .

ByteString ("Person") Haskell , import messageGet .

```
import Text.ProtocolBuffers (messageGet)
```

Person .

```
transformRawPerson :: ByteString -> Maybe Person
transformRawPerson raw = case messageGet raw of
    Left   _           -> Nothing
    Right  (person, _)  -> Just person
```

Google : https://riptutorial.com/ko/haskell/topic/5018/google--

9: Gtk3

- obj <- <widgetName> New - (: Windows, Buttons, Grids)
- <widget> [<attributes>] - Attr self (: buttonLabel)
- on <widget> <event> <IO action> - IO (: buttonActivated)

Haskell Gtk3 (: Ubuntu APT `libghc-gtk` . `stack` , Gtk3 `cabal` . `gtk2hs-buildtools` . `gtk` , `gtk3` Gtk `cabal install gtk2hs-buildtools` . `cabal install gtk2hs-buildtools build-depends` .

Examples

Gtk Hello World

Gtk3 "Hello World" . .

```
module Main (Main.main) where

import Graphics.UI.Gtk

main :: IO ()
main = do
  initGUI
  window <- windowNew
  on window objectDestroy mainQuit
  set window [ containerBorderWidth := 10, windowTitle := "Hello World" ]
  button <- buttonNew
  set button [ buttonLabel := "Hello World" ]
  on button buttonActivated $ do
    putStrLn "A \"clicked\"-handler to say \"destroy\""
    widgetDestroy window
  set window [ containerChild := button ]
  widgetShowAll window
  mainGUI -- main loop
```

Gtk3 : https://riptutorial.com/ko/haskell/topic/7342/gtk3

10: IO

Examples

IO

`io-streams` IO . :

- `InputStream` :
- `OutputStream` :

`makeInputStream :: IO (Maybe a) -> IO (InputStream a)` . `read :: InputStream a -> IO (Maybe a)` . `Nothing` EOF .

```
import Control.Monad (forever)
import qualified System.IO.Streams as S
import System.Random (randomRIO)

main :: IO ()
main = do
  is <- S.makeInputStream $ randomInt  -- create an InputStream
  forever $ printStream =<< S.read is  -- forever read from that stream
  return ()

randomInt :: IO (Maybe Int)
randomInt = do
  r <- randomRIO (1, 100)
  return $ Just r

printStream :: Maybe Int -> IO ()
printStream Nothing  = print "Nada!"
printStream (Just a) = putStrLn $ show a
```

IO : https://riptutorial.com/ko/haskell/topic/4984/io-

11: RankNTypes

GHC `Rank2Types` `RankNTypes` .

- `Rank2Types` `RankNTypes` .
- `forall` .

Examples

RankNTypes

StackOverflow . .

RankNTypes : https://riptutorial.com/ko/haskell/topic/8984/rankntypes----

12: XML

XML

Examples

`xml`

```
{-# LANGUAGE RecordWildCards #-}
import Text.XML.Light

data Package = Package
  { pOrderNo  :: String
  , pOrderPos :: String
  , pBarcode  :: String
  , pNumber   :: String
  }

-- | Create XML from a Package
instance Node Package where
  node qn Package {..} =
    node qn
      [ unode "package_number" pNumber
      , unode "package_barcode" pBarcode
      , unode "order_number" pOrderNo
      , unode "order_position" pOrderPos
      ]
```

XML : https://riptutorial.com/ko/haskell/topic/9264/xml

13: zipWithM

`zipWithM` `zipWith` `mapM` `map` : .

`Control.Monad`

- zipWithM :: m => (a -> b -> mc) -> [a] -> [b] -> m [c]

Examples

.

5 . , .

. `Nothing` .

```
calculateOne :: Double -> Double -> Maybe Double
calculateOne price percent = let newPrice = price*(percent/100)
                             in if newPrice < 5 then Nothing else Just newPrice
```

`zipWithM` .

```
calculateAllPrices :: [Double] -> [Double] -> Maybe [Double]
calculateAllPrices prices percents = zipWithM calculateOne prices percents
```

$ 5 `Nothing` .

zipWithM : https://riptutorial.com/ko/haskell/topic/9685/zipwithm

14:

`Traversable` `mapM :: Monad m => (a -> mb) -> [a] -> m [b]` `Applicative` `Applicative` .

Examples

Traversable Functor Foldable

```
import Data.Traversable as Traversable

data MyType a =  -- ...
instance Traversable MyType where
    traverse = -- ...
```

`Traversable` `Foldable` `Functor` USING `fmapDefault` `foldMapDefault` `Data.Traversable` .

```
instance Functor MyType where
    fmap = Traversable.fmapDefault

instance Foldable MyType where
    foldMap = Traversable.foldMapDefault
```

`fmapDefault` `Identity` applicative functor `traverse` .

```
newtype Identity a = Identity { runIdentity :: a }

instance Applicative Identity where
    pure = Identity
    Identity f <*> Identity x = Identity (f x)

fmapDefault :: Traversable t => (a -> b) -> t a -> t b
fmapDefault f = runIdentity . traverse (Identity . f)
```

`foldMapDefault` `Const` applicative functor , monoidal .

```
newtype Const c a = Const { getConst :: c }

instance Monoid m => Applicative (Const m) where
    pure _ = Const mempty
    Const x <*> Const y = Const (x `mappend` y)

foldMapDefault :: (Traversable t, Monoid m) => (a -> m) -> t a -> m
foldMapDefault f = getConst . traverse (Const . f)
```

Traversable

`traverse` `Applicative` `fmap` .

```
data Tree a = Leaf
            | Node (Tree a) a (Tree a)
```

```
instance Traversable Tree where
    traverse f Leaf = pure Leaf
    traverse f (Node l x r) = Node <$> traverse f l <*> f x <*> traverse f r
```

.

```
ghci> let myTree = Node (Node Leaf 'a' Leaf) 'b' (Node Leaf 'c' Leaf)

--    +--'b'--+
--    |       |
-- +-'a'-+ +-'c'-+
-- |     | |     |
-- *     * *     *

ghci> traverse print myTree
'a'
'b'
'c'
```

`DeriveTraversable` GHC `Traversable` . `Node` .

```
data Inorder a = ILeaf
               | INode (Inorder a) a (Inorder a)  -- as before
               deriving (Functor, Foldable, Traversable)  -- also using DeriveFunctor and
DeriveFoldable

data Preorder a = PrLeaf
                | PrNode a (Preorder a) (Preorder a)
                deriving (Functor, Foldable, Traversable)

data Postorder a = PoLeaf
                 | PoNode (Postorder a) (Postorder a) a
                 deriving (Functor, Foldable, Traversable)

-- injections from the earlier Tree type
inorder :: Tree a -> Inorder a
inorder Leaf = ILeaf
inorder (Node l x r) = INode (inorder l) x (inorder r)

preorder :: Tree a -> Preorder a
preorder Leaf = PrLeaf
preorder (Node l x r) = PrNode x (preorder l) (preorder r)

postorder :: Tree a -> Postorder a
postorder Leaf = PoLeaf
postorder (Node l x r) = PoNode (postorder l) (postorder r) x

ghci> traverse print (inorder myTree)
'a'
'b'
'c'
ghci> traverse print (preorder myTree)
'b'
'a'
'c'
ghci> traverse print (postorder myTree)
'a'
'c'
```

```
'b'
```

.

. Backwards applicator .

```
newtype Backwards f a = Backwards { forwards :: f a }

instance Applicative f => Applicative (Backwards f) where
    pure = Backwards . pure
    Backwards ff <*> Backwards fx = Backwards ((\x f -> f x) <$> fx <*> ff)
```

Backwards "traverse" . traverse Backwards) .

```
newtype Reverse t a = Reverse { getReverse :: t a }

instance Traversable t => Traversable (Reverse t) where
    traverse f = fmap Reverse . forwards . traverse (Backwards . f) . getReverse

ghci> traverse print (Reverse "abc")
'c'
'b'
'a'
```

Reverse newtype Data.Functor.Reverse .

Traversable

```
class (Functor t, Foldable t) => Traversable t where
    {-# MINIMAL traverse | sequenceA #-}

    traverse :: Applicative f => (a -> f b) -> t a -> f (t b)
    traverse f = sequenceA . fmap f

    sequenceA :: Applicative f => t (f a) -> f (t a)
    sequenceA = traverse id

    mapM :: Monad m => (a -> m b) -> t a -> m (t b)
    mapM = traverse

    sequence :: Monad m => t (m a) -> m (t a)
    sequence = sequenceA
```

Traversable t "" a . f :: a -> fb traverse Applicative . sequenceA Traversable Applicative .

Traversable

mapAccum .

```
--                                                          A Traversable structure
--                                                                      |
--                                                        A seed value  |
```

```
--                                                              |     |
--                                                             |-|  |---|
mapAccumL, mapAccumR :: Traversable t => (a -> b -> (a, c)) -> a -> t b -> (a, t c)
--                                       |------------------|              |--------|
--                                                |                             |
--                       A folding function which produces a new mapped        |
--                         element 'c' and a new accumulator value 'a'          |
--                                                                              |
--                                                             Final accumulator value
--                                                              and mapped structure
```

fmap . foldl / foldr .

, tails mapAccumR inits mapAccumL .

```
tails, inits :: [a] -> [[a]]
tails = uncurry (:) . mapAccumR (\xs x -> (x:xs, xs)) []
inits = uncurry snoc . mapAccumL (\xs x -> (x `snoc` xs, xs)) []
    where snoc x xs = xs ++ [x]

ghci> tails "abc"
["abc", "bc", "c", ""]
ghci> inits "abc"
["", "a", "ab", "abc"]
```

mapAccumL State applicator .

```
{-# LANGUAGE DeriveFunctor #-}

newtype State s a = State { runState :: s -> (s, a) } deriving Functor
instance Applicative (State s) where
    pure x = State $ \s -> (s, x)
    State ff <*> State fx = State $ \s -> let (t, f) = ff s
                                              (u, x) = fx t
                                          in (u, f x)

mapAccumL f z t = runState (traverse (State . flip f) t) z
```

mapAccumR mapAccumL .

```
mapAccumR f z = fmap getReverse . mapAccumL f z . Reverse
```

t Traversable , ta : "" "":

```
data Traversed t a = Traversed { shape :: t (), contents :: [a] }
```

"" Foldable "" .

, ta Traversed ta Functor Foldable .

```
break :: (Functor t, Foldable t) => t a -> Traversed t a
break ta = Traversed (fmap (const ()) ta) (toList ta)
```

traverse

.

```
import Control.Monad.State

-- invariant: state is non-empty
pop :: State [a] a
pop = state $ \(a:as) -> (a, as)

recombine :: Traversable t => Traversed t a -> t a
recombine (Traversed s c) = evalState (traverse (const pop) s) c
```

Traversable break . recombine break . recombine recombine . break . contents shape .

Traversed t Traversable . traverse , Traversable , .

```
instance Traversable (Traversed t) where
    traverse f (Traversed s c) = fmap (Traversed s) (traverse f c)
```

zip ,

```
ghci> uncurry zip ([1,2],[3,4])
[(1,3), (2,4)]
```

transpose sequenceA ,

```
-- transpose exchanges the inner list with the outer list
--           +---+-->--+-+
--           |   |     | |
transpose :: [[a]] -> [[a]]
--            | |     |   |
--            +-+-->--+---+

-- sequenceA exchanges the inner Applicative with the outer Traversable
--                                               +------>------+
--                                               |             |
sequenceA :: (Traversable t, Applicative f) => t (f a) -> f (t a)
--                                                  |       |
--                                                  +--->---+
```

[] Traversable and Applicative sequenceA *n-ary* *zip* .

[] " " Applicative - "" Applicative . Control.Applicative ZipList newtype .

```
newtype ZipList a = ZipList { getZipList :: [a] }

instance Applicative ZipList where
    pure x = ZipList (repeat x)
    ZipList fs <*> ZipList xs = ZipList (zipWith ($) fs xs)
```

ZipList Applicative transpose .

```
transpose :: [[a]] -> [[a]]
transpose = getZipList . traverse ZipList
```

```
ghci> let myMatrix = [[1,2,3],[4,5,6],[7,8,9]]
ghci> transpose myMatrix
[[1,4,7],[2,5,8],[3,6,9]]
```

: https://riptutorial.com/ko/haskell/topic/754/-

15:

Higher Order Function .

Examples

.

Haskell .

.

```
map       :: (a -> b) -> [a] -> [b]
filter    :: (a -> Bool) -> [a] -> [a]
takeWhile :: (a -> Bool) -> [a] -> [a]
dropWhile :: (a -> Bool) -> [a] -> [a]
iterate   :: (a -> a) -> a -> [a]
zipWith   :: (a -> b -> c) -> [a] -> [b] -> [c]
scanr     :: (a -> b -> b) -> b -> [a] -> [b]
scanl     :: (b -> a -> b) -> b -> [a] -> [b]
```

. , .

:

```
Prelude> :t (map (+3))
(map (+3)) :: Num b => [b] -> [b]

Prelude> :t (map (=='c'))
(map (=='c')) :: [Char] -> [Bool]

Prelude> :t (map zipWith)
(map zipWith) :: [a -> b -> c] -> [[a] -> [b] -> [c]]
```

(:) . , .

```
aligned :: [a] ->  [a] -> Int
aligned xs ys = length (filter id (zipWith (==) xs ys))
```

.

. ( ) λ . , .

.

```
\x -> let {y = ...x...} in y
```

.

.

```
f(x) = x^2
```

```
f    x =  x^2

f = \x -> x^2
```

f `\x -> x^2` .

`map` , `a -> b` `a -> b` . `map` , . ,

```
\x -> let {y = ...x...} in y
```

`x` `a` `a` , `...x...` `x` `y` `b` `b` . .

```
map (\x -> x + 3)

map (\(x,y) -> x * y)

map (\xs -> 'c':xs) ["apples", "oranges", "mangos"]

map (\f -> zipWith f [1..5] [1..5]) [(+), (*), (-)]
```

Haskell . , .

`div` .

```
div :: Int -> Int -> Int
```

6 2 3 .

```
Prelude> div 6 2
3
```

. `div 6` `Int -> Int` . 2 3.

, " `Int` " " `Int` `Int` " . . `div` .

```
div :: Int -> (Int -> Int)
```

. , " ( )."

: https://riptutorial.com/ko/haskell/topic/4539/-

16:

Examples

Cabal . Cabal , Gloss `cabal install gloss` .

Hackage GitHub .

1. `gloss/gloss-rendering/` `cabal install`
2. `gloss/gloss/` `cabal install`

Gloss `display` .

`import Graphics.Gloss` . .

```
main :: IO ()
main = display window background drawing
```

`window` `Display` .

```
-- Defines window as an actual window with a given name and size
window = InWindow name (width, height) (0,0)

-- Defines window as a fullscreen window
window = FullScreen
```

`InWindow` `(0,0)` .

1.11 : Gloss `FullScreen` . `FullScreen (1024,768)` `FullScreen (1024,768)` `FullScreen (1024,768)`

`background` `Color` . .

```
background = white
```

. . ([1]).) 80 .

```
drawing = Circle 80
```

Hackage .

```
import Graphics.Gloss

main :: IO ()
main = display window background drawing
    where
      window = InWindow "Nice Window" (200, 200) (0, 0)
      background = white
```

```
    drawing = Circle 80
```

: https://riptutorial.com/ko/haskell/topic/5570/-

17:

`Profunctor` `Profunctor` `profunctors` `Data.Profunctor` .

"" .

- dimap :: Profunctor p => (a -> b) -> (c -> d) -> pbc -> pad
- lmap :: Profunctor p => (a -> b) -> pbc -> pac
- rmap :: Profunctor p => (b -> c) -> pab -> pac
- dimap id id = id
- lmap id = id
- rmap id = id
- dimap fg = lmap f. g
- lmap f = dimap f id
- rmap f = dimap id f

Profunctor Hackage " bifunctor."

? , bifunctor functor . `fmap` .

" (covariant)" profunctor . (`rmap`) `Profunctor p => (b -> c) -> pab -> pac` `Profunctor p => (b -> c) -> pab -> pac` . .

" " . (`lmap`) `Profunctor p => (a -> b) -> pbc -> pac` `Profunctor p => (a -> b) -> pbc -> pac` . . `a -> b` `a -> b` `a` .

: . `Functor` typeclass "" `Data.Functor.Contravariant` `Contravariant` `Data.Functor.Contravariant` ( ) `Cofunctor` `Data.Cofunctor` .

Examples

(->)

(->) profunctor . , .

```
instance Profunctor (->) where
    lmap f g = g . f
    rmap f g = g . g
```

: https://riptutorial.com/ko/haskell/topic/9694/

18:

(.) .

```
(.) :: (b -> c) -> (a -> b) ->  (a -> c)
(.)       f           g          x =  f (g x)     -- or, equivalently,

(.)       f           g     =   \x -> f (g x)
(.)       f     =    \g     ->  \x -> f (g x)
(.) =    \f     ->   \g     ->  \x -> f (g x)
(.) =    \f     ->  (\g     -> (\x -> f (g x) ) )
```

(b -> c) -> (a -> b) -> (a -> c) (b -> c) -> (a -> b) -> a -> c -> ""

```
 f g x y z ...    ==    (((f g) x) y) z ...
```

" " . x g f .

```
(.)       f           g          x =  r
                                      where r = f (g x)
-- g :: a -> b
-- f ::      b -> c
-- x :: a
-- r ::           c

(.)       f           g     =   q
                                where q = \x -> f (g x)
-- g :: a -> b
-- f ::      b -> c
-- q :: a      -> c

....
```

, .

```
(.) f g x  =  (f . g) x  =  (f .) g x  =  (. g) f x
```

" " " " .

```
(.) f g    =  (f . g)    =  (f .) g    =  (. g) f
--         1             2             3
```

x . η-shrinkment.

```
(f . g) x   =   f (g x)
```

"" x ; x (f . g) point-free .

Examples

`(.)` .

```
(f . g) x = f (g x)
```

, , .

```
((^2) . succ) 1        --    4
```

`(.)` `(<<<)` . ,

```
(+ 1) <<< sqrt $ 25    --    6
```

`Control.Category` `(>>>)` .

```
-- (>>>) :: Category cat => cat a b -> cat b c -> cat a c
-- (>>>) :: (->) a b -> (->) b c -> (->) a c
-- (>>>) :: (a -> b) -> (b -> c) -> (a -> c)
( f >>> g ) x = g (f x)
```

:

```
sqrt >>> (+ 1) $ 25    --    6.0
```

. ,

```
(f .: g) x y = f (g x y)           -- which is also
             = f ((g x) y)
             = (f . g x) y         -- by definition of (.)
             = (f .) (g x) y
             = ((f .) . g) x y
```

, η - `(f .: g) = ((f .) . g)`

```
(.:) f g    = ((f .) . g)
            = (.) (f .) g
            = (.) ((.) f) g
            = ((.) . (.)) f g
```

so `(.:) = ((.) . (.))` , .

:

```
(map (+1) .: filter) even [1..5]      --   [3,5]
(length   .: filter) even [1..5]      --   2
```

: https://riptutorial.com/ko/haskell/topic/4430/-

19:

1. `[] :: [a]`
2. `(:) :: a -> [a] -> [a]`
3. head - .

   `head :: [a] -> a`
4. - .

   `last :: [a] -> a`
5. tail - .

   `tail :: [a] -> [a]`
6. init - .

   `init :: [a] -> [a]`
7. xs !! i - xs i .

   `(!!) :: Int -> [a] -> a`
8. n xs - n . xs

   `take :: Int -> [a] -> [a]`
9. map :: (a -> b) -> [a] -> [b]
10. filter :: (a -> Bool) -> [a] -> [a]
11. (++) :: [a] -> [a]
12. concat :: [[a]] -> [a]

1. `[a]` `[]` `a` .
2. `[]` .
3. `[]` LHS `f [] = ...` , .
4. `x:xs` `x` `xs` `xs`
5. `f (x:xs) = ...` . `x` `xs` .
6. `f (a:b:cs) = ...` `f (a:(b:cs)) = ...` . `a` `b` `cs` .
7. `f ((a:as):bs) = ...` `f (a:(as:bs)) = ...` . `a` , `as` , `bs` .
8. `f (x:[]) = ...` `f [x] = ...` . .
9. `f (a:b:[]) = ...` `f [a,b] = ...` . .
10. `f [a:b] = ...` . `a` `b` .
11. `[a,b,c]` `(a:b:c:[])` . `(:)` `[]` .
12. `all@(x:y:ys)` `all` ( ) `(x:y:ys)` .

Examples

```
emptyList     = []

singletonList = [0]               -- = 0 : []

listOfNums    = [1, 2, 3]         -- = 1 : 2 : [3]

listOfStrings = ["A", "B", "C"]
```

```
listA      = [1, 2, 3]

listB      = [4, 5, 6]

listAThenB = listA ++ listB       -- [1, 2, 3, 4, 5, 6]

(++) xs     [] = xs
(++) []     ys = ys
(++) (x:xs) ys = x : (xs ++ ys)
```

Haskell Prelude `[]` . `Int` , .

```
xs :: [Int]    -- or equivalently, but less conveniently,
xs :: [] Int
```

Haskell . .

```
[1,2,3]   :: [Int]
[1,2,3,4] :: [Int]
```

.

- `[]` .
- `(:)` "cons" , . Consing `x` ( ) `a` `xs` (`a`) ( ) `x` ( ) `xs` .

.

```
ys :: [a]
ys = []

xs :: [Int]
xs = 12 : (99 : (37 : []))
-- or  = 12 : 99 : 37 : []     -- ((:) is right-associative)
-- or  = [12, 99, 37]          -- (syntactic sugar for lists)
```

`(++)` `(:)` `[]` .

.

```
listSum :: [Int] -> Int
```

```
listSum []          = 0
listSum (x:xs) = x + listSum xs
```

.

```
sumTwoPer :: [Int] -> Int
sumTwoPer [] = 0
sumTwoPer (x1:x2:xs) = x1 + x2 + sumTwoPer xs
sumTwoPer (x:xs) = x + sumTwoPer xs
```

.

Haskell Prelude `map` , `filter` . .

n (0).

```
list = [1 .. 10]

firstElement = list !! 0           -- 1
```

`!!` .

```
list !! (-1)     -- *** Exception: Prelude.!!: negative index

list !! 1000     -- *** Exception: Prelude.!!: index too large
```

`Data.List.genericIndex` `!!` `Integral` .

```
import Data.List (genericIndex)

list `genericIndex` 4              -- 5
```

O (n) . `Data.Vector` .

1 10 .

```
[1..10]    -- [1,2,3,4,5,6,7,8,9,10]
```

start .

```
[1,3..10]  -- [1,3,5,7,9]
```

Haskell , .

```
[1,3,5..10] -- error
[1,3,9..20] -- error
```

.

```
[5..1]     -- []

[5,4..1]   -- [5,4,3,2,1]
```

. [1..] [1..] . .

```
take 5 [1..]   -- returns [1,2,3,4,5] even though [1..] is infinite
```

.

```
[1.0,1.5..2.4]    -- [1.0,1.5,2.0,2.5] , though 2.5 > 2.4

[1.0,1.1..1.2]    -- [1.0,1.1,1.2000000000000002] , though 1.2000000000000002 > 1.2
```

`Enum` typeclass . `a` , `b` , `c` `Enum` .

```
[a..]    == enumFrom a
[a..c]   == enumFromTo a c
[a,b..]  == enumFromThen a b
[a,b..c] == enumFromThenTo a b c
```

`Bool`

```
 [False ..]      -- [False,True]
```

`False` (, `False..` . `False`).

```
head [1..10]       --    1

last [1..20]       --    20

tail [1..5]        --    [2, 3, 4, 5]

init [1..5]        --    [1, 2, 3, 4]

length [1 .. 10]   --    10

reverse [1 .. 10]  --    [10, 9 .. 1]

take 5 [1, 2 .. ]  --    [1, 2, 3, 4, 5]

drop 5 [1 .. 10]   --    [6, 7, 8, 9, 10]

concat [[1,2], [], [4]]   --    [1,2,4]
```

. step `foldr` ( ) .

```
foldl :: (b -> a -> b) -> b -> [a] -> b
foldl f acc []     =  acc
foldl f acc (x:xs) =  foldl f (f acc x) xs         -- = foldl f (acc `f` x) xs
```

`foldl` .:

```
foldl (+) 0 [1, 2, 3]     -- is equivalent to ((0 + 1) + 2) + 3
```

foldl (foldl).

```
foldl (+) 0 [1, 2, 3]                       --  foldl (+)    0    [ 1,   2,   3 ]
foldl (+) ((+) 0 1) [2, 3]                  --  foldl (+)   (0 + 1)    [ 2,   3 ]
foldl (+) ((+) ((+) 0 1) 2) [3]             --  foldl (+)  ((0 + 1) + 2)   [ 3 ]
foldl (+) ((+) ((+) ((+) 0 1) 2) 3) []      --  foldl (+) (((0 + 1) + 2) + 3) []
((+) ((+) ((+) 0 1) 2) 3)                   --            (((0 + 1) + 2) + 3)
```

((0 + 1) + 2) + 3 . (fab) (a `f` b) ((+) 0 1) (0 + 1) .

.

```
foldr :: (a -> b -> b) -> b -> [a] -> b
foldr f z []     = z
foldr f z (x:xs) = f x (foldr f z xs)            -- = x `f` foldr f z xs
```

foldr .:

```
foldr (+) 0 [1, 2, 3]      -- is equivalent to 1 + (2 + (3 + 0))
```

foldr (foldr).

```
foldr (+) 0 [1, 2, 3]                       --          foldr (+) 0  [1,2,3]
(+) 1 (foldr (+) 0 [2, 3])                  -- 1 +        foldr (+) 0  [2,3]
(+) 1 ((+) 2 (foldr (+) 0 [3]))             -- 1 + (2 +     foldr (+) 0  [3])
(+) 1 ((+) 2 ((+) 3 (foldr (+) 0 [])))      -- 1 + (2 + (3 +  foldr (+) 0 []))
(+) 1 ((+) 2 ((+) 3 0))                     -- 1 + (2 + (3 +            0   ))
```

1 + (2 + (3 + 0)) , ((+) 3 0) (3 + 0) .

`map`

( ) . map map :

```
-- Simple add 1
map (+ 1) [1,2,3]
[2,3,4]

map odd [1,2,3]
[True,False,True]

data Gender = Male | Female deriving Show
data Person = Person String Gender Int deriving Show

-- Extract just the age from a list of people
map (\(Person n g a) -> a) [(Person "Alex" Male 31),(Person "Ellie" Female 29)]
[31,29]
```

`filter`

:

```
li = [1,2,3,4,5]
```

`filter :: (a -> Bool) -> [a] -> [a]` .

```
filter (== 1) li       -- [1]

filter (even) li       -- [2,4]

filter (odd) li        -- [1,3,5]

-- Something slightly more complicated
comfy i = notTooLarge && isEven
  where
     notTooLarge = (i + 1) < 5
     isEven = even i

filter comfy li        -- [2]
```

.

```
data Gender = Male | Female deriving Show
data Person = Person String Gender Int deriving Show

onlyLadies :: [Person] -> Person
onlyLadies x = filter isFemale x
  where
    isFemale (Person _ Female _) = True
    isFemale _ = False

onlyLadies [(Person "Alex" Male 31),(Person "Ellie" Female 29)]
-- [Person "Ellie" Female 29]
```

zip .

```
zip []     _      = []
zip _      []     = []
zip (a:as) (b:bs) = (a,b) : zip as bs

> zip [1,3,5] [2,4,6]
> [(1,2),(3,4),(5,6)]
```

:

```
zipWith f  []     _      = []
zipWith f  _      []     = []
zipWith f  (a:as) (b:bs) = f a b : zipWith f as bs

> zipWith (+) [1,3,5] [2,4,6]
> [3,7,11]
```

:

```
unzip = foldr (\(a,b) ~(as,bs) -> (a:as,b:bs)) ([],[])

> unzip [(1,2),(3,4),(5,6)]
> ([1,3,5],[2,4,6])
```

: https://riptutorial.com/ko/haskell/topic/2281/

20:

- addDays :: -> ->
- diffDays :: Day -> Day -> Integer
- fromGregorian :: -> Int -> Int -> Day

  ```
  convert from proleptic Gregorian calendar. First argument is year, second month number
  (1-12), third day (1-31). Invalid values will be clipped to the correct range, month
  first, then day.
  ```

- getCurrentTime :: IO UTCTime

`time` `Data.Time` .

Examples

`getCurrentTime` .

```
import Data.Time

print =<< getCurrentTime
-- 2016-08-02 12:05:08.937169 UTC
```

`fromGregorian` .

```
fromGregorian 1984 11 17  -- yields a Day
```

,

`Day` .

```
import Data.Time

addDays 1 (fromGregorian 2000 1 1)
-- 2000-01-02
addDays 1 (fromGregorian 2000 12 31)
-- 2001-01-01
```

:

```
addDays (-1) (fromGregorian 2000 1 1)
-- 1999-12-31

addDays (-1) (fromGregorian 0 1 1)
-- -0001-12-31
-- wat
```

.

```
diffDays (fromGregorian 2000 12 31) (fromGregorian 2000 1 1)
365
```

.

```
diffDays (fromGregorian 2000 1 1) (fromGregorian 2000 12 31)
-365
```

: https://riptutorial.com/ko/haskell/topic/4950/-

21: (GHC)

Examples

@Viclib typeclass .

.

```
class ListIsomorphic l where
    toList    :: l a -> [a]
    fromList  :: [a] -> l a
```

`toList . fromList == id` `toList . fromList == id` . GHC ?

GHC . GHC (`fromList :: Seq a -> [a]` `Seq$fromList`).

`fromList` `fromList` - - `toList` .

```
{-# RULES
  "protect toList"   toList = toList';
  "protect fromList" fromList = fromList';
  "fromList/toList"  forall x . fromList' (toList' x) = x; #-}

{-# NOINLINE [0] fromList' #-}
fromList' :: (ListIsomorphic l) => [a] -> l a
fromList' = fromList

{-# NOINLINE [0] toList' #-}
toList' :: (ListIsomorphic l) => l a -> [a]
toList' = toList
```

(GHC) : https://riptutorial.com/ko/haskell/topic/4914/----ghc-

22:

Examples

PostgreSQL-simple PostgreSQL . DB / API .

.

```
{-# LANGUAGE OverloadedStrings #-}

import Database.PostgreSQL.Simple

main :: IO ()
main = do
  -- Connect using libpq strings
  conn <- connectPostgreSQL "host='my.dbhost' port=5432 user=bob pass=bob"
  [Only i] <- query_ conn "select 2 + 2"  -- execute with no parameter substitution
  print i
```

PostreSQL-Simple `query` .

```
main :: IO ()
main = do
  -- Connect using libpq strings
  conn <- connectPostgreSQL "host='my.dbhost' port=5432 user=bob pass=bob"
  [Only i] <- query conn "select ? + ?" [1, 1]
  print i
```

`execute` insert / update SQL `execute` .

```
main :: IO ()
main = do
  -- Connect using libpq strings
  conn <- connectPostgreSQL "host='my.dbhost' port=5432 user=bob pass=bob"
  execute conn "insert into people (name, age) values (?, ?)" ["Alex", 31]
```

: https://riptutorial.com/ko/haskell/topic/4444/

23:

.

-
-

Examples

`forkIO`

`forkIO` `forkIO` .

`forkIO :: IO () -> IO ThreadId` `IO` `ThreadId` .

`ghci` .

```
Prelude Control.Concurrent> forkIO $ (print . sum) [1..100000000]
ThreadId 290
Prelude Control.Concurrent> forkIO $ print "hi!"
"hi!"
-- some time later....
Prelude Control.Concurrent> 50000005000000
```

!

`MVar '

`MVar a` `Control.Concurrent` .

- `newEmptyMVar :: IO (MVar a)` - `MVar a` . `MVar a`
- `newMVar :: a -> IO (MVar a)` - `MVar` .
- `takeMVar :: MVar a -> IO a` - `MVar` .
- `putMVar :: MVar a -> a -> IO ()` - `MVar` `MVar` .

1 1 .

```
import Control.Concurrent
main = do
  m <- newEmptyMVar
  forkIO $ putMVar m $ sum [1..10000000]
  print =<< takeMVar m  -- takeMVar will block 'til m is non-empty!
```

.

```
main2 = loop
  where
    loop = do
```

```
        m <- newEmptyMVar
        n <- getLine
        putStrLn "Calculating. Please wait"
        -- In another thread, parse the user input and sum
        forkIO $ putMVar m $ sum [1..(read n :: Int)]
        -- In another thread, wait 'til the sum's complete then print it
        forkIO $ print =<< takeMVar m
        loop
```

takeMVar MVar MVar . putMVar putMVar . , .

.

```
concurrent ma mb = do
  a <- takeMVar ma
  b <- takeMVar mb
  putMVar ma a
  putMVar mb b
```

MVar .

```
concurrent ma mb     -- new thread 1
concurrent mb ma     -- new thread 2
```

.

1. 1 ma ma
2. 2 mb mb .

1 mb . 2 2 1 ma . !

(Software Transactional Memory), TVar a .

TVar a STM . MVar MVar STM .

atomically :: STM a -> IO a

STM .

readTVar :: TVar a -> STM a

TVar . :

```
value <- readTVar t
```

writeTVar :: TVar a -> a -> STM ()

TVar TVar .

```
t <- newTVar Nothing
writeTVar t (Just "Hello")
```

:

```
import Control.Monad
import Control.Concurrent
import Control.Concurrent.STM

main = do
  -- Initialise a new TVar
  shared <- atomically $ newTVar 0
  -- Read the value
  before <- atomRead shared
  putStrLn $ "Before: " ++ show before
  forkIO $ 25 `timesDo` (dispVar shared >> milliSleep 20)
  forkIO $ 10 `timesDo` (appV ((+) 2) shared >> milliSleep 50)
  forkIO $ 20 `timesDo` (appV pred shared >> milliSleep 25)
  milliSleep 800
  after <- atomRead shared
  putStrLn $ "After: " ++ show after
  where timesDo = replicateM_
        milliSleep = threadDelay . (*) 1000

atomRead = atomically . readTVar
dispVar x = atomRead x >>= print
appV fn x = atomically $ readTVar x >>= writeTVar x . fn
```

: https://riptutorial.com/ko/haskell/topic/4426/

24:

Examples

sum algebraic `data` .

```
data StandardType = StandardType String Int Bool --standard way to create a sum type

data RecordType = RecordType { -- the same sum type with record syntax
    aString :: String
  , aNumber :: Int
  , isTrue  :: Bool
  }
```

```
> let r = RecordType {aString = "Foobar", aNumber= 42, isTrue = True}
> :t r
  r :: RecordType
> :t aString
  aString :: RecordType -> String
> aString r
  "Foobar"
```

.

```
case r of
  RecordType{aNumber = x, aString=str} -> ... -- x = 42, str = "Foobar"
```

.

( )

```
r  = RecordType {aString = "Foobar", aNumber= 42, isTrue = True}
r' = RecordType  "Foobar" 42 True
```

`undefined` .

```
> let r = RecordType {aString = "Foobar", aNumber= 42}
  <interactive>:1:9: Warning:
     Fields of RecordType not initialized: isTrue
> isTrue r
  Error 'undefined'
```

. .

```
> let r = RecordType {aString = "Foobar", aNumber= 42, isTrue = True}
> let r' = r{aNumber=117}
    -- r'{aString = "Foobar", aNumber= 117, isTrue = True}
```

.

.

```
data Person = Person { name :: String, age:: Int } deriving (Show, Eq)
```

:

```
alex = Person { name = "Alex", age = 21 }
jenny = Person { name = "Jenny", age = 36 }
```

`alex` `Person` .

```
anotherAlex = alex { age = 31 }
```

`alex` `anotherAlex` `anotherAlex` .

```
Person {name = "Alex", age = 21}

Person {name = "Alex", age = 31}
```

newtype

`newtype` . newtype . monads `run` monoid `get` , `un` .

```
newtype State s a = State { runState :: s -> (s, a) }

newtype Product a = Product { getProduct :: a }

newtype Fancy = Fancy { unfancy :: String }
  -- a fancy string that wants to avoid concatenation with ordinary strings
```

```
getProduct $ mconcat [Product 7, Product 9, Product 12]
-- > 756
```

RecordWildCards

```
{-# LANGUAGE RecordWildCards #-}

data Client = Client { firstName     :: String
                     , lastName      :: String
                     , clientID      :: String
                     } deriving (Show)

printClientName :: Client -> IO ()
printClientName Client{..} = do
    putStrLn firstName
    putStrLn lastName
    putStrLn clientID
```

`Client{..}` `Client`

```
Client{ firstName = firstName, lastName = lastName, clientID = clientID }
```

matcher .

```
Client { firstName = "Joe", .. }
```

```
Client{ firstName = "Joe", lastName = lastName, clientID = clientID }
```

.

```
data Person = Person { age :: Int, name :: String }
```

.

`age` `name` `age` `name` .

```
age :: Person -> Int
name :: Person -> String
```

. , .

.

```
lowerCaseName :: Person -> String
lowerCaseName (Person { name = x }) = map toLower x
```

RHS (`x`) .

NamedFieldPuns NamedFieldPuns

```
lowerCaseName :: Person -> String
lowerCaseName (Person { name }) = map toLower name
```

`NamedFieldPuns` . RHS `name` .

RecordWildcards RecordWildcards

```
lowerCaseName :: Person -> String
lowerCaseName (Person { .. }) = map toLower name
```

`RecordWildCards` `RecordWildCards` . (`name` `age`)

`Person` .

```
setName :: String -> Person -> Person
setName newName person = person { name = newName }
```

.

: https://riptutorial.com/ko/haskell/topic/1950/-

25:

Lens Haskell , , , , , getter setter Java .

?

( ) . . `lens` . .

. . , `_1` .

. `Lens sa s a` ,

1. `a`
2. `a` .

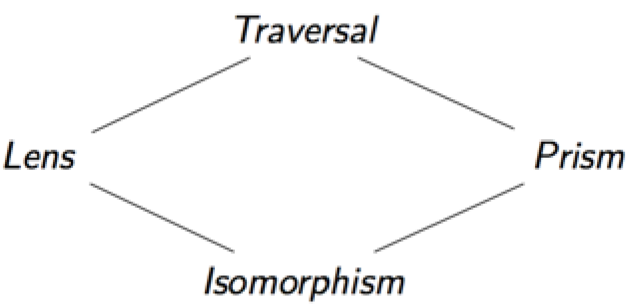
`get` `set` .

.

	...
0	
	...

. .

. , .



. () , . 0 1 . (affine traversal).

. . . ., .

Examples

```
("a", 1) ^. _1 -- returns "a"
("a", 1) ^. _2 -- returns 1
```

```
("a", 1) & _1 .~ "b" -- returns ("b", 1)
```

```
("a", 1) & _2 %~ (+1) -- returns ("a", 2)
```

both

```
(1, 2) & both *~ 2 -- returns (2, 4)
```

```
{-# LANGUAGE TemplateHaskell #-}
import Control.Lens

data Point = Point {
    _x :: Float,
    _y :: Float
}
makeLenses ''Point
```

x y .

```
let p = Point 5.0 6.0
p ^. x     -- returns 5.0
set x 10 p -- returns Point { _x = 10.0, _y = 6.0 }
p & x +~ 1 -- returns Point { _x = 6.0, _y = 6.0 }
```

```
data Person = Person { _personName :: String }
makeFields ''Person
```

HasName , Person name Person HasName HasName . .

```
data Entity = Entity { _entityName :: String }
makeFields ''Entity
```

makeFields Template Haskell . , .

. ~ = .

```
(+~) :: Num a => ASetter s t a a -> a -> s -> t
(+=) :: (MonadState s m, Num a) => ASetter' s a -> a -> m ()
```

: Lens' Simple Lens' .

&

- .

```
change :: A -> A
change a = a & lensA %~ operationA
             & lensB %~ operationB
             & lensC %~ operationC
```

& . .

```
change a = flip execState a $ do
    lensA %= operationA
    lensB %= operationB
    lensC %= operationC
```

lensX id lensX modify .

.

```
data Point = Point { _x :: Float, _y :: Float }
data Entity = Entity { _position :: Point, _direction :: Float }
data World = World { _entities :: [Entity] }

makeLenses ''Point
makeLenses ''Entity
makeLenses ''World
```

.

```
updateWorld :: MonadState World m => m ()
updateWorld = do
    -- move the first entity
    entities . ix 0 . position . x += 1

    -- do some operation on all of them
    entities . traversed . position %= \p -> p `pointAdd` ...

    -- or only on a subset
    entities . traversed . filtered (\e -> e ^. position.x > 100) %= ...
```

Template Haskell .

Template Haskell demystify ,

```
data Example a = Example { _foo :: Int, _bar :: a }
```

```
makeLenses 'Example
```

()

```
foo :: Lens' (Example a) Int
bar :: Lens (Example a) (Example b) a b
```

. .

```
foo :: Lens' (Example a) Int
--  :: Functor f => (Int -> f Int) -> (Example a -> f (Example a))    ;; expand the alias
foo wrap (Example foo bar) = fmap (\newFoo -> Example newFoo bar) (wrap foo)

bar :: Lens (Example a) (Example b) a b
--  :: Functor f => (a -> f b) -> (Example a -> f (Example b))    ;; expand the alias
bar wrap (Example foo bar) = fmap (\newBar -> Example foo newBar) (wrap bar)
```

, `wrap` "" "" "".

`Lens' sa` `a` `s` . `Prism' sa` `s` . `a`

(tuple) `_1 :: Lens' (a, b) a` . `_Just :: Prism' (Maybe a) a` `Maybe a` `a` `Just` `Nothing` .

- `view :: Lens' sa -> (s -> a)` " `s` " `a` .
- `set :: Lens' sa -> (a -> s -> s)` `s` `a` "" `a`
- `review :: Prism' sa -> (a -> s)` `a` `s` ""
- `preview :: Prism' sa -> (s -> Maybe a)` "" `s` . `a`

`Lens' sa` `s` `r` `(r, a)` . , `Prism' sa` `s` `Either ra` `r` . .

```
-- `Lens' s a` is no longer supplied, instead we just *know* that `s ~ (r, a)`

view :: (r, a) -> a
view (r, a) = a

set :: a -> (r, a) -> (r, a)
set a (r, _) = (r, a)

-- `Prism' s a` is no longer supplied, instead we just *know* that `s ~ Either r a`

review :: a -> Either r a
review a = Right a

preview :: Either r a -> Maybe a
preview (Left _) = Nothing
preview (Right a) = Just a
```

`Traversal' sa` `s` 0 . `a`

```
toListOf :: Traversal' s a -> (s -> [a])
```

`Traversable` `t` `traverse :: Traversal (ta) a` .

Traversal a

```
> set traverse 1 [1..10]
[1,1,1,1,1,1,1,1,1,1]

> over traverse (+1) [1..10]
[2,3,4,5,6,7,8,9,10,11]
```

f :: Lens' sa a s . g :: Prism' ab 0 1 b a . f . g Traversal' sb f g 0 1 b S s .

f :: Lens' ab a g :: Lens' bc f . g f f . g Lens' ac g g . :

- ( )
- Lens view " " . . , . OO .

Lens Lens , (.) " Lens -like" . lens . x . y x y .

makeLenses Lens ES Control.Lens.TH makeClassy . makeClassy makeLenses makeLenses .
.

```
data Foo = Foo { _fooX, _fooY :: Int }
  makeClassy ''Foo
```

.

```
class HasFoo t where
   foo :: Simple Lens t Foo

instance HasFoo Foo where foo = id

fooX, fooY :: HasFoo t => Simple Lens t Int
```

makeFields

(StackOverflow)

, capacity . makeFields .

```
{-# LANGUAGE FunctionalDependencies
           , MultiParamTypeClasses
           , TemplateHaskell
  #-}

module Foo
where

import Control.Lens

data Foo
  = Foo { fooCapacity :: Int }
  deriving (Eq, Show)
$(makeFields ''Foo)
```

```
data Bar
  = Bar { barCapacity :: Double }
  deriving (Eq, Show)
$(makeFields ''Bar)
```

ghci :

```
*Foo
λ let f = Foo 3
|     b = Bar 7
|
b :: Bar
f :: Foo

*Foo
λ fooCapacity f
3
it :: Int

*Foo
λ barCapacity b
7.0
it :: Double

*Foo
λ f ^. capacity
3
it :: Int

*Foo
λ b ^. capacity
7.0
it :: Double

λ :info HasCapacity
class HasCapacity s a | s -> a where
  capacity :: Lens' s a
    -- Defined at Foo.hs:14:3
instance HasCapacity Foo Int -- Defined at Foo.hs:14:3
instance HasCapacity Bar Double -- Defined at Foo.hs:19:3
```

`HasCapacity sa` , `Lens' s` (`a a`). () "" . . . makeFieldsWith lensRules .

, ghci -ddump-splices . Foo.hs :

```
[1 of 1] Compiling Foo              ( Foo.hs, interpreted )
Foo.hs:14:3-18: Splicing declarations
    makeFields ''Foo
  ======>
    class HasCapacity s a | s -> a where
      capacity :: Lens' s a
    instance HasCapacity Foo Int where
      {-# INLINE capacity #-}
      capacity = iso (\ (Foo x_a7fG) -> x_a7fG) Foo
Foo.hs:19:3-18: Splicing declarations
    makeFields ''Bar
  ======>
    instance HasCapacity Bar Double where
```

```
    {-# INLINE capacity #-}
    capacity = iso (\ (Bar x_a7ne) -> x_a7ne) Bar
Ok, modules loaded: Foo.
```

`HasCapcity` `HasCapcity` Foo . Bar .

`HasCapcity` . `makeFields` . .

: https://riptutorial.com/ko/haskell/topic/891/

26: /

Reader . http://adit.io/posts/2013-06-10-three-useful-monads.html .

Examples

`ask` (https://hackage.haskell.org/package/mtl-2.2.1/docs/Control-Monad-Reader.html#v:ask) . .
:

```
import Control.Monad.Trans.Reader hiding (ask)
import Control.Monad.Trans

ask :: Monad m => ReaderT r m r
ask = reader id

main :: IO ()
main = do
  let f = (runReaderT $ readerExample) :: Integer -> IO String
  x <- f 100
  print x
  --
  let fIO = (runReaderT $ readerExampleIO) :: Integer -> IO String
  y <- fIO 200
  print y

readerExample :: ReaderT Integer IO String
readerExample = do
  x <- ask
  return $ "The value is: " ++ show x

liftAnnotated :: IO a -> ReaderT Integer IO a
liftAnnotated = lift

readerExampleIO :: ReaderT Integer IO String
readerExampleIO = do
  x <- reader id
  lift $ print "Hello from within"
  liftAnnotated $ print "Hello from within..."
  return $ "The value is: " ++ show x
```

:

```
"The value is: 100"
"Hello from within"
"Hello from within..."
"The value is: 200"
```

/ : https://riptutorial.com/ko/haskell/topic/9320/---

27:

Examples

SmallCheck, QuickCheck HUnit

```
import Test.Tasty
import Test.Tasty.SmallCheck as SC
import Test.Tasty.QuickCheck as QC
import Test.Tasty.HUnit


main :: IO ()
main = defaultMain tests

tests :: TestTree
tests = testGroup "Tests" [smallCheckTests, quickCheckTests, unitTests]

smallCheckTests :: TestTree
smallCheckTests = testGroup "SmallCheck Tests"
  [ SC.testProperty "String length <= 3" $
      \s -> length (take 3 (s :: String)) <= 3
  , SC.testProperty "String length <= 2" $  -- should fail
      \s -> length (take 3 (s :: String)) <= 2
  ]

quickCheckTests :: TestTree
quickCheckTests = testGroup "QuickCheck Tests"
  [ QC.testProperty "String length <= 5" $
      \s -> length (take 5 (s :: String)) <= 5
  , QC.testProperty "String length <= 4" $  -- should fail
      \s -> length (take 5 (s :: String)) <= 4
  ]

unitTests :: TestTree
unitTests = testGroup "Unit Tests"
  [ testCase "String comparison 1" $
      assertEqual "description" "OK" "OK"

  , testCase "String comparison 2" $  -- should fail
      assertEqual "description" "fail" "fail!"
  ]
```

:

```
cabal install tasty-smallcheck tasty-quickcheck tasty-hunit
```

Cabal   :

```
cabal exec runhaskell test.hs
```

: https://riptutorial.com/ko/haskell/topic/3816/-

28:

. Monad . IO . IO a a " a ".

m (: [] Maybe) instance Monad m . " a " ma .

Examples

Maybe - null . .

.

```
halve :: Int -> Maybe Int
halve x
  | even x = Just (x `div` 2)
  | odd x  = Nothing
```

halve Int .

halve ?

```
takeOneEighth :: Int -> Maybe Int              -- (after you read the 'do' sub-section:)
takeOneEighth x =
  case halve x of                                 --  do {
    Nothing -> Nothing
    Just oneHalf ->                               --      oneHalf    <- halve x
      case halve oneHalf of
        Nothing -> Nothing
        Just oneQuarter ->                        --      oneQuarter <- halve oneHalf
          case halve oneQuarter of
            Nothing -> Nothing                    --      oneEighth  <- halve oneQuarter
            Just oneEighth ->
              Just oneEighth                      --      return oneEighth }
```

- takeOneEighth halve .
- halve , takeOneEighth .
- halve .

```
instance Monad Maybe where
  -- (>>=) :: Maybe a -> (a -> Maybe b) -> Maybe b
  Nothing >>= f  = Nothing                            -- infixl 1 >>=
  Just x  >>= f  = Just (f x)                         -- also, f =<< m = m >>= f

  -- return :: a -> Maybe a
  return x       = Just x
```

.

```
takeOneEighth :: Int -> Maybe Int
takeOneEighth x = halve x >>= halve >>= halve             -- or,
    -- return x >>= halve >>= halve >>= halve             -- which is parsed as
```

```
    -- (((return x) >>= halve) >>= halve) >>= halve        -- which can also be written as
    -- (halve =<<) . (halve =<<) . (halve =<<) $ return x     -- or, equivalently, as
    --  halve <=<     halve <=<     halve      $        x
```

`<=<` `(g <=< f) x = g =<< fx` `(f >=> g) x = fx >>= g` .

```
takeOneEighth :: Int -> Maybe Int
takeOneEighth = halve <=< halve <=< halve               -- infixr 1 <=<
        -- or, equivalently,
        --      halve >=> halve >=> halve               -- infixr 1 >=>
```

`Monad` typeclass .

```
1.  return x >>= f  =  f x
2.    m >>= return  =  m
3. (m >>= g) >>= h  =  m >>= (\y -> g y >>= h)
```

`m` , `f` `a -> mb` `g` `b -> mc` .

, `>=>` Kleisli .

```
1.    return >=> g  =  g                        -- do { y <- return x ; g y } == g x
2.    f >=> return  =  f                        -- do { y <- f x ; return y } == f x
3. (f >=> g) >=> h  =  f >=> (g >=> h)       -- do { z <- do { y <- f x; g y } ; h z }
                                                --  == do { y <- f x ; do { z <- g y; h z } }
```

. .

`Maybe` .

1. - `return x >>= f = fx`

```
return z >>= f
= (Just z) >>= f
= f z
```

2. - `m >>= return = m`

- `Just`

```
Just z >>= return
= return z
= Just z
```

- `Nothing`

```
Nothing >>= return
= Nothing
```

3. - `(m >>= f) >>= g = m >>= (\x -> fx >>= g)`

- Just

```
-- Left-hand side
((Just z) >>= f) >>= g
= f z >>= g

-- Right-hand side
(Just z) >>= (\x -> f x >>= g)
(\x -> f x >>= g) z
= f z >>= g
```

- Nothing

```
-- Left-hand side
(Nothing >>= f) >>= g
= Nothing >>= g
= Nothing

-- Right-hand side
Nothing >>= (\x -> f x >>= g)
= Nothing
```

IO

`IO a` `a` . `IO` .

`IO a` , `a` . , `getLine :: IO String` `getLine` - `getLine` .

, `main :: IO ()` Haskell / .

`IO` `IO a` :

- `(>>)` , .

    ```
    -- print the lines "Hello" then "World" to stdout
    putStrLn "Hello" >> putStrLn "World"
    ```

- . . `>>=` . `IO` , `(>>=) :: IO a -> (a -> IO b) -> IO b` .

    ```
    -- get a line from stdin and print it back out
    getLine >>= putStrLn
    ```

- . `do` notation .

    ```
    -- make an action that just returns 5
    return 5
    ```

IO .

. :

```
instance Monad [] where
```

```
  return x = [x]
  xs >>= f = concat (map f xs)
```

. xs >>= f , f :: a -> [b] xs f xs , . **do notation** . . .

```
sumnd xs ys = do
  x <- xs
  y <- ys
  return (x + y)
```

, Control.Monad liftM2 .

```
sumnd = liftM2 (+)
```

:

```
> sumnd [1,2,3] [0,10]
[1,11,2,12,3,13]
```

GHC 7.10, Applicative Monad (, Monad Applicative). Applicative (pure , <*>) Monad (return , >>=) .

pure return pure = return . <*> .

```
mf <*> mx = do { f <- mf; x <- mx; return (f x) }
       -- = mf >>= (\f -> mx >>= (\x -> return (f x)))
       -- = [r   | f <- mf, x <- mx, r <- return (f x)]   -- with MonadComprehensions
       -- = [f x | f <- mf, x <- mx]
```

ap .

Monad "" Applicative

```
instance Applicative < type > where
    pure  = return
    (<*>) = ap
```

.

▪

.

```
return :: Monad m => a -> m a
(>>=)  :: Monad m => m a -> (a -> m b) -> m b
```

Monad Monad m => ma -> a .

, (: "unwrap"). .

```
extract :: Maybe a -> a
extract (Just x) = x          -- Sure, this works, but...
extract Nothing  = undefined  -- We can’t extract a value from failure.
```

, `IO a -> a` . .

`do` -notation . .

```
do x <- mx                                    do x <- mx
   y <- my       is equivalent to                do y <- my
   ...                                              ...
```

```
do let a = b                                  let a = b in
   ...           is equivalent to               do ...
```

```
do m                                          m >> (
   e             is equivalent to               e)
```

```
do x <- m                                     m >>= (\x ->
   e             is equivalent to               e)
```

```
do m             is equivalent to             m
```

, .

```
example :: IO Integer
example =
  putStrLn "What's your name?" >> (
    getLine >>= (\name ->
      putStrLn ("Hello, " ++ name ++ ".") >> (
        putStrLn "What should we return?" >> (
          getLine >>= (\line ->
            let n = (read line :: Integer) in
              return (n + n))))))
```

```
example :: IO Integer
example = do
  putStrLn "What's your name?"
  name <- getLine
  putStrLn ("Hello, " ++ name ++ ".")
  putStrLn "What should we return?"
  line <- getLine
  let n = (read line :: Integer)
  return (n + n)
```

Monad

```
class Monad m where
    return :: a -> m a
    (>>=) :: m a -> (a -> m b) -> m b
```

>>= :

```
(>>=) :: m a -> (a -> m b) -> m b
```

- `ma` " ". *a*
- `a -> mb` " *a* *b* " .

`>>=` .

`Monad` .

```
return :: a -> m a
```

. `return` `return` .

`return x` **x** . (:)

```
return x >>= f        ≡  f x      --  “left identity” monad law
       x >>= return   ≡  x        -- “right identity” monad law
```

: https://riptutorial.com/ko/haskell/topic/2968/

29:

Examples

, . .

.

.

```
newtype Counter = MkCounter {cValue :: Int}
  deriving (Show)

-- | 'inc c n' increments the counter by 'n' units.
inc :: Counter -> Int -> Counter
inc (MkCounter c) n = MkCounter (c + n)
```

.

- 0 .
- 3
- 3 .
- 5
- 2 .

. .

```
-- | CounterS is a monad.
type CounterS = State Counter

-- | Increment the counter by 'n' units.
incS :: Int-> CounterS ()
incS n = modify (\c -> inc c n)
```

:

```
-- | The computation we want to run, with the state monad.
mComputationS :: CounterS ()
mComputationS = do
  incS 3
  incS 3
  incS 3
  incS 5
  incS 5
```

. .

. OO *(dependency injection*) .

.

- (, , `r`)
- ( ). `a`

  ra

. `ReaderT` .

```
newtype ReaderT r m a :: * -> (* -> *) -> * -> *
```

`ReaderT` .

```
type CounterRS = ReaderT Int CounterS
```

`incR` (`ask`), `CounterS` `lift` ( ).

```
-- | Increment the counter by the amount of units specified by the environment.
incR :: CounterRS ()
incR = ask >>= lift . incS
```

.

```
-- | The computation we want to run, using reader and state monads.
mComputationRS :: CounterRS ()
mComputationRS = do
  local (const 3) $ do
    incR
    incR
    incR
    local (const 5) $ do
      incR
      incR
```

: !

.

. , .

```
newtype WriterT w m a :: * -> (* -> *) -> * -> *
```

`w` ( ) , `m` . `a`

, .

```
type CounterWRS = WriterT [Int] CounterRS
```

lift .

```
incW :: CounterWRS ()
incW = lift incR >> get >>= tell . (:[]) . cValue
```

.

```
mComputationWRS :: CounterWRS ()
mComputationWRS = do
  local (const 3) $ do
    incW
    incW
    incW
    local (const 5) $ do
      incW
      incW
```

. (,) .

:

```
inc' :: (MonadReader Int m, MonadState Counter m, MonadWriter [Int] m) => m ()
inc' = ask >>= modify . (flip inc) >> get >>= tell . (:[]) . cValue
```

. .

```
mComputation' :: (MonadReader Int m, MonadState Counter m, MonadWriter [Int] m) => m ()
```

inc . '

ghci REPL ghci .

```
runState ( runReaderT ( runWriterT mComputation' ) 15 )  (MkCounter 0)
```

: https://riptutorial.com/ko/haskell/topic/7752/-

30:

Examples

Monoid

```
instance Monoid [a] where
    mempty  = []
    mappend = (++)
```

`Monoid` :

```
mempty `mappend` x = x   <->   [] ++ xs = xs  -- prepending an empty list is a no-op

x `mappend` mempty = x   <->   xs ++ [] = xs  -- appending an empty list is a no-op

x `mappend` (y `mappend` z) = (x `mappend` y) `mappend` z
    <->
xs ++ (ys ++ zs) = (xs ++ ys) ++ zs           -- appending lists is associative
```

Monoids

`mconcat :: [a] -> a` `Monoid` typeclass :

```
ghci> mconcat [Sum 1, Sum 2, Sum 3]
Sum {getSum = 6}
ghci> mconcat ["concat", "enate"]
"concatenate"
```

`mconcat = foldr mappend mempty` .

Monoids

monoidal : 1 0 . . `newtypes` , `Sum` `Product` .

```
newtype Sum n = Sum { getSum :: n }

instance Num n => Monoid (Sum n) where
    mempty = Sum 0
    Sum x `mappend` Sum y = Sum (x + y)

newtype Product n = Product { getProduct :: n }

instance Num n => Monoid (Product n) where
    mempty = Product 1
    Product x `mappend` Product y = Product (x * y)
```

`newtype` .

```
Sum 3     <> Sum 5     == Sum 8
Product 3 <> Product 5 == Product 15
```

Monoid for ()

`()` `Monoid` . type `()` `mempty` `mappend` .

```
instance Monoid () where
    mempty = ()
    () `mappend` () = ()
```

: https://riptutorial.com/ko/haskell/topic/2211/-

31:

- module Name - .
- module Name (functionOne, Type (..)) - functionOne, Type Type .
- import Module -
- MN -
- import (justThisFunction) -
- import (functionName, Type) - functionName Type

Haskell :

- .
- " "

.

-
-

haskell.org .

Examples

`Business.hs` , `import Business` :

```
module Business (
    Person (..), -- ^ Export the Person type and all its constructors and field names
    employees   -- ^ Export the employees function
) where
-- begin types, function definitions, etc
```

. Hierarchical .

.

```
module X (Person (..)) where
```

`People.hs` .

```
data Person = Friend String | Foe deriving (Show, Eq, Ord)

isFoe Foe = True
isFoe _   = False
```

:

```
module People (Person (..)) where
```

`Person` `Friend` `Foe` .

module .

```
module People where
```

`Person` , , `isFoe` export .

.

```
import qualified Data.Stream (map) as D
```

`Data.Stream` `map` `Data.Stream` `D.` .

```
D.map odd [1..]
```

`Prelude` `map` .

Prelude . .

`Data.Stream` `map` , `head` `tail` . Prelude . `hiding` :

```
import Data.Stream -- everything from Data.Stream
import Prelude hiding (map, head, tail, scan, foldl, foldr, filter, dropWhile, take) -- etc
```

, Prelude `Data.Stream` `qualified` .

. ( ) `qualified` .

```
import qualified Data.Stream as D
```

`Prelude` `Data.Stream` `map` .

```
map (== 1) [1,2,3] -- will use Prelude.map
D.map (odd) (fromList [1..]) -- will use Data.Stream.map
```

`import Data.Text as T` , `Text` `T.Text`

. .

```
Foo/
├── Baz/
│   └── Quux.hs
└── Bar.hs
Foo.hs
```

```
Bar.hs
```

.

```
-- file Foo.hs
module Foo where

-- file Bar.hs
module Bar where

-- file Foo/Bar.hs
module Foo.Bar where

-- file Foo/Baz/Quux.hs
module Foo.Baz.Quux where
```

:

- .
- .

: https://riptutorial.com/ko/haskell/topic/5234/

32:

Examples

Haskell comprehension . set comprehensions . .

```
[ x | x <- someList ]
```

```
[ x | x <- [1..4] ]    -- [1,2,3,4]
```

x .

```
[ f x | x <- someList ]
```

.

```
map f someList
```

:

```
[ x+1 | x <- [1..4]]    -- [2,3,4,5]
```

x . .

```
[x | Just x <- [Just 1, Nothing, Just 3]]     -- [1, 3]
```

x . x .

, .

```
[ x | x <- [1..4], even x] ==
[ x | x <- [1..4], () <- [() | even x]] ==
[ x | x <- [1..4], () <- if even x then [()] else []]
```

list comprehension guard. .

```
[x    | p x]   ===   if p x then [x] else []
```

. ,

```
[ f x | x <- list, pred1 x y, pred2 x]     -- `y` must be defined in outer scope
```

```
map f (filter pred2 (filter (\x -> pred1 x y) list))          -- or,

-- ($ list) (filter (`pred1` y) >>> filter pred2 >>> map f)
```

```
-- list >>= (\x-> [x | pred1 x y]) >>= (\x-> [x | pred2 x]) >>= (\x -> [f x])
```

(`>>=` `infixl 1` ,). :

```
[ x        | x <- [1..4], even x]            -- [2,4]

[ x^2 + 1 | x <- [1..100], even x ]          -- map (\x -> x^2 + 1) (filter even [1..100])
```

. . ,

```
[ (a,b) | a <- [1,2,3], b <- ['a','b'] ]

-- [(1,'a'), (1,'b'), (2,'a'), (2,'b'), (3,'a'), (3,'b')]
```

Parallel List Comprehensions ,

```
[(x,y) | x <- xs | y <- ys]
```

~ .

```
zip xs ys
```

:

```
[(x,y) | x <- [1,2,3] | y <- [10,20]]

-- [(1,10),(2,20)]
```

List comprehensions .

```
[(x,y) | x <- [1..4], let y=x*x+1, even y]     -- [(1,2),(3,10)]
```

.

```
[(x,y) | x <- [1..4], y <- [x*x+1], even y]    -- [(1,2),(3,10)]
```

`let` , . .

```
[x | x <- [1..4], x <- [x*x+1], even x]        -- [2,10]
```

`do` .

```
[f x | x <- xs]                f  <$> xs          do { x <- xs ; return (f x) }

[f x | f <- fs, x <- xs]       fs <*> xs          do { f <- fs ; x <- xs ; return (f x) }

[y   | x <- xs, y <- f x]      f  =<< xs          do { x <- xs ; y <- f x ; return y }
```

`Control.Monad.guard` :

```
[x   | x <- xs, even x]                    do { x <- xs ; guard (even x) ; return x }
```

: https://riptutorial.com/ko/haskell/topic/4970/-

33:

Examples

.

, :

"" Functor

```
{-# LANGUAGE DeriveFunctor #-}

data TeletypeF next
    = PrintLine String next
    | ReadLine (String -> next)
    deriving Functor
```

`Free` "Free Monad over `TeletypeF` " .

```
import Control.Monad.Free (Free, liftF, iterM)

type Teletype = Free TeletypeF

printLine :: String -> Teletype ()
printLine str = liftF (PrintLine str ())

readLine :: Teletype String
readLine = liftF (ReadLine id)
```

`f` `Functor` `Free f` `Monad` `Monad` (`do` notation) `Teletype` .

```
import Control.Monad -- we can use the standard combinators

echo :: Teletype ()
echo = readLine >>= printLine

mockingbird :: Teletype a
mockingbird = forever echo
```

`Teletype a` `Teletype a` "" `IO a` `IO a`

```
interpretTeletype :: Teletype a -> IO a
interpretTeletype = foldFree run where
  run :: TeletypeF a -> IO a
  run (PrintLine str x) = putStrLn *> return x
  run (ReadLine f) = fmap f getLine
```

`Teletype a` `IO` `Teletype a` "" .

```
> interpretTeletype mockingbird
hello
```

```
hello
goodbye
goodbye
this will go on forever
this will go on forever
```

.

Free Fix .

```
data Free f a = Return a
              | Free (f (Free f a))

newtype Fix f = Fix { unFix :: f (Fix f) }
```

, Free Fix . Free Fix , Free Return a .

foldFree iterM ?

Free m : iterM :: (Functor f, Monad m) => (f (ma) -> ma) -> (Free fa -> ma) foldFree :: Monad m => (forall x. fx -> mx) -> (Free fa -> ma) . ?

Teletype a IO . Free fa .

```
data Free f a
    = Pure a
    | Free (f (Free f a))
```

Pure .

```
interpretTeletype :: Teletype a -> IO a
interpretTeletype (Pure x) = return x
interpretTeletype (Free teletypeF) = _
```

Free Teletype ? teletypeF :: TeletypeF (Teletype a) IO a ., IO runIO :: TeletypeF a -> IO a a .

```
runIO :: TeletypeF a -> IO a
runIO (PrintLine msg x) = putStrLn msg *> return x
runIO (ReadLine k) = fmap k getLine
```

runIO interpretTeletype . teletypeF :: TeletypeF (Teletype a) Free TeletypeF . runIO (runIO teletypeF :: IO (Teletype a)). IO >>= combinator Teletype a .

```
interpretTeletype :: Teletype a -> IO a
interpretTeletype (Pure x) = return x
interpretTeletype (Free teletypeF) = runIO teletypeF >>= interpretTeletype
```

foldFree interpretTeletype , runIO . foldFree .

```
foldFree :: Monad m => (forall x. f x -> m x) -> Free f a -> m a
foldFree eta (Pure x) = return x
foldFree eta (Free fa) = eta fa >>= foldFree eta
```

foldFree rank-2 . eta . foldFree Monad m => (f (Free fa) -> m (Free fa)) -> Free fa -> ma ,
eta f Free eta . foldFree eta .

iterM . () f . iterM A *paramorphism* foldFree *catamorphism* .

```
iterM :: (Monad m, Functor f) => (f (m a) -> m a) -> Free f a -> m a
iterM phi (Pure x) = return x
iterM phi (Free fa) = phi (fmap (iterM phi) fa)
```

Freer (Prompt, Operational) . Functor .

Freer i :: * -> * . . , State .

```
data StateI s a where
    Get :: StateI s s  -- the Get instruction returns a value of type 's'
    Put :: s -> StateI s ()  -- the Put instruction contains an 's' as an argument and returns
()
```

:>>= . :>>= a ., a , a b , :>>= b .

```
data Freer i a where
    Return :: a -> Freer i a
    (:>>=) :: i a -> (a -> Freer i b) -> Freer i b
```

a :>>= . GADT i a .

: - Freer Free . CoYoneda functor CoYoneda .

```
data CoYoneda i b where
  CoYoneda :: i a -> (a -> b) -> CoYoneda i b
```

Freer i Free (CoYoneda i) . Free f ~ CoYoneda i .

```
Pure :: a -> Free (CoYoneda i) a
Free :: CoYoneda i (Free (CoYoneda i) b) -> Free (CoYonda i) b ~
        i a -> (a -> Free (CoYoneda i) b) -> Free (CoYoneda i) b
```

Freer i Freer i ~ Free (CoYoneda i) .

CoYoneda i A Functor i , Freer A Monad i , i Functor .

```
instance Monad (Freer i) where
    return = Return
    Return x >>= f = f x
    (i :>>= g) >>= f = i :>>= fmap (>>= f) g  -- using `(->) r`'s instance of Functor, so fmap
= (.)
```

`Freer` .

```
foldFreer :: Monad m => (forall x. i x -> m x) -> Freer i a -> m a
foldFreer eta (Return x) = return x
foldFreer eta (i :>>= f) = eta i >>= (foldFreer eta . f)
```

`State s` `Freer (StateI s)` .

```
runFreerState :: Freer (StateI s) a -> s -> (a, s)
runFreerState = State.runState . foldFreer toState
    where toState :: StateI s a -> State s a
          toState Get = State.get
          toState (Put x) = State.put x
```

: https://riptutorial.com/ko/haskell/topic/1290/-

34:

Examples

~~

```
data Empty a
```

.

```
data Free Empty a
     = Pure a
-- the Free constructor is impossible!
```

```
data Identity a
     = Identity a
```

~~ (Nat,) ~ Writer Nat

```
data Identity a = Identity a
```

.

```
data Free Identity a
     = Pure a
     | Free (Identity (Free Identity a))
```

```
data Deferred a
     = Now a
     | Later (Deferred a)
```

(fst) `(Nat, a)` , `Writer Nat a`

```
data Nat = Z | S Nat
data Writer Nat a = Writer Nat a
```

~~ MaybeT (Nat)

```
data Maybe a = Just a
             | Nothing
```

.

```
data Free Maybe a
     = Pure a
     | Free (Just (Free Maybe a))
```

```
     | Free Nothing
```

```
data Hopes a
     = Confirmed a
     | Possible (Hopes a)
     | Failed
```

(fst) (Nat, Maybe a) , MaybeT (Writer Nat) a

```
data Nat = Z | S Nat
data Writer Nat a = Writer Nat a
data MaybeT (Writer Nat) a = MaybeT (Nat, Maybe a)
```

(w) ~~ [w]

```
data Writer w a = Writer w a
```

.

```
data Free (Writer w) a
     = Pure a
     | Free (Writer w (Free (Writer w) a))
```

```
data ProgLog w a
     = Done a
     | After w (ProgLog w a)
```

( ) Writer [w] a .

(Const c) ~~ c

```
data Const c a = Const c
```

.

```
data Free (Const c) a
     = Pure a
     | Free (Const c)
```

```
data Either c a
     = Right a
     | Left c
```

(x) ~~ (x)

```
data Reader x a = Reader (x -> a)
```

.

```
data Free (Reader x) a
      = Pure a
      | Free (x -> Free (Reader x) a)
```

```
data Demand x a
      = Satisfied a
      | Hungry (x -> Demand x a)
```

`Stream x -> a`

```
data Stream x = Stream x (Stream x)
```

: https://riptutorial.com/ko/haskell/topic/8256/---

35: -

Examples

reactive-banana-wx GUI . `IO` FRP .

`Control.Event.Handler` `AddHandler a` `a -> IO ()` `addHandler` . `Event a` .

```
import Data.Char (toUpper)

import Control.Event.Handler
import Reactive.Banana

main = do
    (inputHandler, inputFire) <- newAddHandler
```

`a` `String` .

FRP `EventNetwork` . `compile` :

```
main = do
    (inputHandler, inputFire) <- newAddHandler
    compile $ do
        inputEvent <- fromAddHandler inputHandler
```

`fromAddHandler` `AddHandler a` `Event a` . .

" " .

```
main = do
    (inputHandler, inputFire) <- newAddHandler
    compile $ do
        ...
    forever $ do
        input <- getLine
        inputFire input
```

`Event` . `Event` . `Event` `Functor` typeclass . `Event` . `Event` [] `IO` .

`Event` s `fmap` .

```
main = do
    (inputHandler, inputFire) <- newAddHandler
    compile $ do
        inputEvent <- fromAddHandler inputHandler
        -- turn all characters in the signal to upper case
        let inputEvent' = fmap (map toUpper) inputEvent
```

`Event` . `a -> IO ()` `fmap` `reactimate` .

```
main = do
    (inputHandler, inputFire) <- newAddHandler
    compile $ do
        inputEvent <- fromAddHandler inputHandler
        -- turn all characters in the signal to upper case
        let inputEvent' = fmap (map toUpper) inputEvent
        let inputEventReaction = fmap putStrLn inputEvent' -- this has type `Event (IO ())
        reactimate inputEventReaction
```

inputFire "something" "SOMETHING" .

Behavior a . Event Behavior Applicative n Behavior (<$> <*>) n Behavior .

Event a Behavior a accumE .

```
main = do
    (inputHandler, inputFire) <- newAddHandler
    compile $ do
        ...
        inputBehavior <- accumE "" $ fmap (\oldValue newValue -> newValue) inputEvent
```

accumE Behavior Event .

Event fmap Behavior (<*>) .

```
main = do
    (inputHandler, inputFire) <- newAddHandler
    compile $ do
        ...
        inputBehavior  <- accumE "" $ fmap (\oldValue newValue -> newValue) inputEvent
        inputBehavior' <- accumE "" $ fmap (\oldValue newValue -> newValue) inputEvent
        let constantTrueBehavior = (==) <$> inputBehavior <*> inputBehavior'
```

Behavior changes :

```
main = do
    (inputHandler, inputFire) <- newAddHandler
    compile $ do
        ...
        inputBehavior  <- accumE "" $ fmap (\oldValue newValue -> newValue) inputEvent
        inputBehavior' <- accumE "" $ fmap (\oldValue newValue -> newValue) inputEvent
        let constantTrueBehavior = (==) <$> inputBehavior <*> inputBehavior'
        inputChanged <- changes inputBehavior
```

changes Event a Event (Future a) . reactimate' reactimate reactimate . .

EventNetwork compile EventNetwork .

```
main = do
    (inputHandler, inputFire) <- newAddHandler

    eventNetwork <- compile $ do
        inputEvent <- fromAddHandler inputHandler
        let inputEventReaction = fmap putStrLn inputEvent
```

```
        reactimate inputEventReaction

    inputFire "This will NOT be printed to the console!"
    actuate eventNetwork
    inputFire "This WILL be printed to the console!"
```

-   : https://riptutorial.com/ko/haskell/topic/4186/---

36:

IO "IO " .

: putStrLn (print), hslogger Debug.Trace .

Examples

hslogger

hslogger Python logging API , stdout stderr .

WARNING .

```
import           System.Log.Logger (Priority (DEBUG), debugM, infoM, setLevel,
                                   updateGlobalLogger, warningM)

main = do
  debugM "MyProgram.main" "This won't be seen"
  infoM "MyProgram.main" "This won't be seen either"
  warningM "MyProgram.main" "This will be seen"
```

updateGlobalLogger .

```
  updateGlobalLogger "MyProgram.main" (setLevel DEBUG)

  debugM "MyProgram.main" "This will now be seen"
```

MyProgram MyParent.Module .

: https://riptutorial.com/ko/haskell/topic/9628/-

37:

Examples

. . Haskell .

`Functor` typeclass Type `F` `Functor` (`Functor F`)

```
fmap :: (a -> b) -> (F a -> F b)
```

`F` "" . ( ) `F a` `a` `fmap` . `Maybe`

```
instance Functor Maybe where
  fmap f Nothing = Nothing     -- if there are no values contained, do nothing
  fmap f (Just a) = Just (f a) -- else, apply our transformation
```

, " `Mappable` `Functor` `Mappable` ?".

Functor `Functor` "Functor" .

. `a -> b` . . `F` `F a -> F b` .

Functor Haskell `a -> b` `F` - `F a -> F b` `F` . `fmap`

```
forall (x :: F a) . fmap id x == x

forall (f :: a -> b) (g :: b -> c) . fmap g . fmap f = fmap (g . f)
```

`Functor` " " `Functor` .

`C` .

- `Obj(C)` ;
- (`Hom(C)` `Hom(C)` . `a` `b` `Obj(C)` morphism `f` `Hom(C)` `f : a -> b` , morphism `a` `b` `hom(a,b)` ;
- (*identity* morphism) - `a : Obj(C)` . `id : a -> a` ;
- (. morphisms) `f : a -> b` , `g : b -> c` morphism `a -> c`

.

```
For all f : a -> x, g : x -> b, then id . f = f and g . id = g
```

```
For all f : a -> b, g : b -> c and h : c -> d, then h . (g . f) = (h . g) . f
```

, ( ) .

Haskell, `Category` Control.category typeclass .

```
-- | A class for categories.
--   id and (.) must form a monoid.
class Category cat where
    -- | the identity morphism
    id :: cat a a

    -- | morphism composition
    (.) :: cat b c -> cat a b -> cat a c
```

, `cat :: k -> k -> *` morphism - `cat ab` (,) `cat ab` . `a` , `b` `c` `Obj(C)` . `Obj(C)` `k` . `k ~ *` .

:

```
instance Category (->) where
  id = Prelude.id
  (.) = Prelude..
```

`Monad` `Kleisli` `Category` .

```
newtype Kleisli m a b = Kleisli (a -> m b)

class Monad m => Category (Kleisli m) where
  id = Kleisli return
  Kleisli f . Kleisli g = Kleisli (f >=> g)
```

.

(†) . () `a` () (`id :: a -> a`). (`(.) :: (b -> c) -> (a -> b) -> a -> c`)

```
f . id = f = id . f
h . (g . f) = (h . g) . f
```

Hask .

. , . **Hask** `f` , `g` :

```
 f . g == id == g . f
```

, .

`((),a)` `a` `a` . :

```
f :: ((),a) -> a
f ((),x) = x

g :: a -> ((),a)
g x = ((),x)
```

`f . g == id == g . f` .

, . , **Hask** , **Hask** **endofunctors Hask,** , . endofunctors :

```
F :: * -> *
```

( ) Haskell .

```
fmap (f . g) = (fmap f) . (fmap g)
fmap id = id
```

`[]` , `Maybe` `(-> r)` **Hask** .

. `F :: * -> *` (`forall a . F a -> G a` `forall a . F a -> G a`).

monoid monoidal , morphisms :

```
zero :: () -> M
mappend :: (M,M) -> M
```

Hask endofunctors :

```
return :: a -> m a
join :: m (m a) -> m a
```

.

, `undefined` . **Hask** ( ) . .

Hask

, **X** , **Y** **Z** : **π1 : Z → X** **π2 : Z → Y** ; . , **f1 : W → X** **f2 : W → Y** , **π1 → g = f1** **π2 → g = f2** **g : W → Z** .

Haskell **Hask** . `Z` `A` , `B` .

```
-- if there are two functions
f1 :: W -> A
f2 :: W -> B
-- we can construct a unique function
g  :: W -> Z
-- and we have two projections
p1 :: Z -> A
p2 :: Z -> B
-- such that the other two functions decompose using g
p1 . g == f1
p2 . g == f2
```

`A` , `B` `(A,B)` `fst` `snd` . `f1 :: W -> A` `f2 :: W -> B` . .

```
decompose :: (W -> A) -> (W -> B) -> (W -> (A,B))
```

```
decompose f1 f2 = (\x -> (f1 x, f2 x))
```

:

```
fst . (decompose f1 f2) = f1
snd . (decompose f1 f2) = f2
```

A B (A,B) . .

```
data Pair a b = Pair a b
```

, (B,A) (B,A,()) , .

```
decompose2 :: (W -> A) -> (W -> B) -> (W -> (B,A,()))
decompose2 f1 f2 = (\x -> (f2 x, f1 x, ()))
```

. A B . (A,B) (B,A,()) .

```
iso1 :: (A,B) -> (B,A,())
iso1 (x,y) = (y,x,())

iso2 :: (B,A,()) -> (A,B)
iso2 (y,x,()) = (x,y)
```

. . , (A,(B,Bool)) fst fst . snd fst . snd A B fst . snd :

```
decompose3 :: (W -> A) -> (W -> B) -> (W -> (A,(B,Bool)))
decompose3 f1 f2 = (\x -> (f1 x, (f2 x, True)))
```

:

```
fst          . (decompose3 f1 f2) = f1 x
(fst . snd) . (decompose3 f1 f2) = f2 x
```

.

```
decompose3' :: (W -> A) -> (W -> B) -> (W -> (A,(B,Bool)))
decompose3' f1 f2 = (\x -> (f1 x, (f2 x, False)))
```

, , (A,(B,Bool)) **Hask** A B

Coproduct

A B A B . Either ab . Either a (b,Bool) .

.

. . **X, Y Z i_1 : X → Z I_2 : Y → Z; X Y** . , **f1 : X → W f2 : Y → W** , **g → i1 =**

f1 , g → i2 = f2

Hask .

```
-- if there are two functions
f1 :: A -> W
f2 :: B -> W
-- and we have a coproduct with two inclusions
i1 :: A -> Z
i2 :: B -> Z
-- we can construct a unique function
g  :: Z -> W
-- such that the other two functions decompose using g
g . i1 == f1
g . i2 == f2
```

Hask `A` `B` coproduct `Either ab` .

```
-- Coproduct
-- The two inclusions are Left and Right
data Either a b = Left a | Right b

-- If we have those functions, we can decompose them through the coproduct
decompose :: (A -> W) -> (B -> W) -> (Either A B -> W)
decompose f1 f2 (Left x)  = f1 x
decompose f1 f2 (Right y) = f2 y
```

`Functor` `a` (**Hask**) `F a` `a -> b` (**Hask** morphism) `F a -> F b` . .

.

- (Hask)
- ()

.

```
class Functor f => Monoidal f where
    mcat :: f a -> f b -> f (a,b)
    munit :: f ()
```

`Applicative` `Monoidal` .

```
instance Monoidal f => Applicative f where
    pure x = fmap (const x) munit
    f <*> fa = (\(f, a) -> f a) <$> (mcat f fa)
```

: https://riptutorial.com/ko/haskell/topic/2261/-

38:

[Data.Vector] . , () . C Storable . Int .

Haskell Wiki .

:

- Data.Vector.Unboxed .
- Data.Vector .
- C Data.Vector.Storable .

;

- . Data.Vector.Generic

Examples

Data.Vector

Data.Vector .

`Data.Vector` `Vector` .

```
Prelude> import Data.Vector
Prelude Data.Vector> let a = fromList [2,3,4]

Prelude Data.Vector> a
fromList [2,3,4] :: Data.Vector.Vector

Prelude Data.Vector> :t a
a :: Vector Integer
```

.

```
Prelude Data.Vector> let x = fromList [ fromList [1 .. x] | x <- [1..10] ]

Prelude Data.Vector> :t x
x :: Vector (Vector Integer)
```

:

```
Prelude Data.Vector> Data.Vector.filter odd y
fromList [1,3,5,7,9,11] :: Data.Vector.Vector
```

(`map`) (`fold`)

`map` 'D `fold'd,` `'d and` zip`'d :

```
Prelude Data.Vector> Data.Vector.map (^2) y
fromList [0,1,4,9,16,25,36,49,64,81,100,121] :: Data.Vector.Vector
```

.

```
Prelude Data.Vector> Data.Vector.foldl (+) 0 y
66
```

.

```
Prelude Data.Vector> Data.Vector.zip y y
fromList [(0,0),(1,1),(2,2),(3,3),(4,4),(5,5),(6,6),(7,7),(8,8),(9,9),(10,10),(11,11)] ::
Data.Vector.Vector
```

: https://riptutorial.com/ko/haskell/topic/4738/

39:

/	
`data Eval a`	Eval Monad.
`type Strategy a = a -> Eval a`	. , .
`rpar :: Strategy a`	( )
`rseq :: Strategy a`	.
`force :: NFData a => a -> a`	. Control.DeepSeq .

(Simon Marlow) , . Haskell . PDF .

Simon Marlow .

(:) . .

. "". , . . .

. WHNF .

Examples

Monad

Haskell `rpar` `rseq` `Control.Parallel.Strategies` `Eval` Monad .

```
f1 :: [Int]
f1 = [1..100000000]

f2 :: [Int]
f2 = [1..200000000]

main = runEval $ do
  a <- rpar (f1) -- this'll take a while...
  b <- rpar (f2) -- this'll take a while and then some...
  return (a,b)
```

`main` "return", `a` `b` `rpar` .

: `-threaded` .

Rpar

`rpar :: Strategy a` (: `type Strategy a = a -> Eval a`).

```
import Control.Concurrent
import Control.DeepSeq
import Control.Parallel.Strategies
import Data.List.Ordered

main = loop
  where
    loop = do
      putStrLn "Enter a number"
      n <- getLine

      let lim = read n :: Int
          hf  = quot lim 2
          result = runEval $ do
            -- we split the computation in half, so we can concurrently calculate primes
            as <- rpar (force (primesBtwn 2 hf))
            bs <- rpar (force (primesBtwn (hf + 1) lim))
            return (as ++ bs)

      forkIO $ putStrLn ("\nPrimes are: " ++ (show result) ++ " for " ++ n ++ "\n")
      loop

-- Compute primes between two integers
-- Deliberately inefficient for demonstration purposes
primesBtwn n m = eratos [n..m]
  where
    eratos []     = []
    eratos (p:xs) = p : eratos (xs `minus` [p, p+p..])
```

.

```
Enter a number
12
Enter a number

Primes are: [2,3,5,7,8,9,10,11,12] for 12

100
Enter a number

Primes are:
[2,3,5,7,11,13,17,19,23,29,31,37,41,43,47,51,52,53,54,55,56,57,58,59,60,61,62,63,64,65,66,67,68,69,70,7
for 100

200000000
Enter a number
-- waiting for 200000000
200
Enter a number

Primes are:
[2,3,5,7,11,13,17,19,23,29,31,37,41,43,47,53,59,61,67,71,73,79,83,89,97,101,102,103,104,105,106,107,108
for 200

-- still waiting for 200000000
```

rseq

`rseq :: Strategy a` Weak Head Normal Form .

```
f1 :: [Int]
f1 = [1..100000000]

f2 :: [Int]
f2 = [1..200000000]

main = runEval $ do
  a <- rpar (f1) -- this'll take a while...
  b <- rpar (f2) -- this'll take a while and then some...
  rseq a
  return (a,b)
```

`rpar` . , `a` WHNF .

: https://riptutorial.com/ko/haskell/topic/6887/

40:

.

.

```
max :: (Ord a) => a -> a -> a
max m n
  | m >= n = m
  | otherwise = n
```

max :: (Ord a) => a -> a -> a a a () a a . max a a a -> a a -> a . a a a .

max max :: (Ord a) => a -> (a -> a) .

max .

```
Prelude> :t max
max :: Ord a => a -> a -> a

Prelude> :t (max 75)
(max 75) :: (Num a, Ord a) => a -> a

Prelude> :t (max "Fury Road")
(max "Fury Road") :: [Char] -> [Char]

Prelude> :t (max "Fury Road" "Furiosa")
(max "Fury Road" "Furiosa") :: [Char]
```

max 75 max "Fury Road" .

. Haskell a a -> a .

Examples

"". .

```
(+) :: Int -> Int -> Int

addOne :: Int -> Int
addOne = (+) 1
```

addOne Int .

```
> addOne 5
6
> map addOne [1,2,3]
[2,3,4]
```

.

```
add :: Int -> Int -> Int
add x = (+x)

add 5 2
```

(+ x) . add .

`add 5 2` 7.

Sectioning .

, "ing" .

```
> (++ "ing") "laugh"
"laughing"
```

. .

.

```
> ("re" ++) "do"
"redo"
```

.

```
> ((++) "re") "do"
"redo"
```

.

```
> map (-1) [1,2,3]
***error: Could not deduce...
```

`-1` `-1` `- 1` . `subtract` .

```
> map (subtract 1) [1,2,3]
[0,1,2]
```

: https://riptutorial.com/ko/haskell/topic/1954/-

41:

Examples

Bool .

```
prop_reverseDoesNotChangeLength xs = length (reverse xs) == length xs
```

. QuickCheck 100 True .

prop_ .

quickCheck 100 .

```
ghci> quickCheck prop_reverseDoesNotChangeLength
+++ OK, passed 100 tests.
```

quickCheck .

```
prop_reverseIsAlwaysEmpty xs = reverse xs == []  -- plainly not true for all xs

ghci> quickCheck prop_reverseIsAlwaysEmpty
*** Failed! Falsifiable (after 2 tests):
[()]
```

quickCheckAll prop_ quickCheckAll Template Haskell .

```
{-# LANGUAGE TemplateHaskell #-}

import Test.QuickCheck (quickCheckAll)
import Data.List (sort)

idempotent :: Eq a => (a -> a) -> a -> Bool
idempotent f x = f (f x) == f x

prop_sortIdempotent = idempotent sort

-- does not begin with prop_, will not be picked up by the test runner
sortDoesNotChangeLength xs = length (sort xs) == length xs


return []
main = $quickCheckAll
```

return [] . Template Haskell .

```
$ runhaskell QuickCheckAllExample.hs
=== prop_sortIdempotent from tree.hs:7 ===
+++ OK, passed 100 tests.
```

`Arbitrary` QuickCheck .

`Arbitrary` `Arbitrary` `Gen` `arbitrary` .

`Arbitrary` .

```
import Test.QuickCheck.Arbitrary (Arbitrary(..))
import Test.QuickCheck.Gen (oneof)
import Control.Applicative ((<$>), (<*>))

data NonEmpty a = End a | Cons a (NonEmpty a)

instance Arbitrary a => Arbitrary (NonEmpty a) where
    arbitrary = oneof [  -- randomly select one of the cases from the list
        End <$> arbitrary,  -- call a's instance of Arbitrary
        Cons <$>
            arbitrary <*>  -- call a's instance of Arbitrary
            arbitrary  -- recursively call NonEmpty's instance of Arbitrary
        ]
```

(==>) .

```
prop_evenNumberPlusOneIsOdd :: Integer -> Property
prop_evenNumberPlusOneIsOdd x = even x ==> odd (x + 1)
```

`==>` . QuickCheck .

```
prop_overlySpecific x y = x == 0 ==> x * y == 0

ghci> quickCheck prop_overlySpecific
*** Gave up! Passed only 31 tests.
```

quickcheck . .

```
import Data.List(permutations)
import Test.QuickCheck

longRunningFunction :: [a] -> Int
longRunningFunction xs = length (permutations xs)

factorial :: Integral a => a -> a
factorial n = product [1..n]

prop_numberOfPermutations xs =
    longRunningFunction xs == factorial (length xs)

ghci> quickCheckWith (stdArgs { maxSize = 10}) prop_numberOfPermutations
```

`quickCheckWith` `stdArgs` (10) , , , 10 .

: https://riptutorial.com/ko/haskell/topic/1156/-

42:

Examples

data .

```
data Foo = Bar | Biz
```

data = . After = | . . :

Foo . Bar Biz .

```
let x = Bar
```

. Foo x . .

```
:t x
```

```
x :: Foo
```

. .

```
data Foo = Bar String Int | Biz String
```

Bar .

```
:t Bar
```

```
Bar :: String -> Int -> Foo
```

Bar .

```
let x = Bar "Hello" 10
let y = Biz "Goodbye"
```

:

```
data Foo a b = Bar a b | Biz a b
```

Haskell . . . a b .

```
let x = Bar "Hello" 10      -- x :: Foo [Char] Integer
let y = Biz "Goodbye" 6.0   -- y :: Fractional b => Foo [Char] b
let z = Biz True False      -- z :: Foo Bool Bool
```

, , , , Person .

.

```
data Person = Person String String Int Int String String String
```

, .

```
getPhone :: Person -> Int
getPhone (Person _ _ _ phone _ _ _) = phone
```

, . .

```
data Person' = Person' { firstName     :: String
                       , lastName      :: String
                       , age           :: Int
                       , phone         :: Int
                       , street        :: String
                       , code          :: String
                       , town          :: String }
```

phone .

```
:t phone
phone :: Person' -> Int
```

. :

```
printPhone :: Person' -> IO ()
printPhone = putStrLn . show . phone
```

.

```
getPhone' :: Person' -> Int
getPhone' (Person {phone = p}) = p
```

RecordWildCards

: https://riptutorial.com/ko/haskell/topic/4057/----

43:

( ) . . " " .

`Num` typeclass . (Prelude `Data.Complex`).

```
λ> :i Num
class Num a where
  (+) :: a -> a -> a
  (-) :: a -> a -> a
  (*) :: a -> a -> a
  negate :: a -> a
  abs :: a -> a
  signum :: a -> a
  fromInteger :: Integer -> a
  {-# MINIMAL (+), (*), abs, signum, fromInteger, (negate | (-)) #-}
      -- Defined in 'GHC.Num'
instance RealFloat a => Num (Complex a) -- Defined in 'Data.Complex'
instance Num Word -- Defined in 'GHC.Num'
instance Num Integer -- Defined in 'GHC.Num'
instance Num Int -- Defined in 'GHC.Num'
instance Num Float -- Defined in 'GHC.Float'
instance Num Double -- Defined in 'GHC.Float'
```

`Num` "" `(/)` `Fractional` .

```
λ> :i Fractional
class Num a => Fractional a where
  (/) :: a -> a -> a
  recip :: a -> a
  fromRational :: Rational -> a
  {-# MINIMAL fromRational, (recip | (/)) #-}
      -- Defined in 'GHC.Real'
instance RealFloat a => Fractional (Complex a) -- Defined in 'Data.Complex'
instance Fractional Float -- Defined in 'GHC.Float'
instance Fractional Double -- Defined in 'GHC.Float'
```

`Real` . `Num` `Ord` , . , ( ).

```
λ> :i Real
class (Num a, Ord a) => Real a where
  toRational :: a -> Rational
  {-# MINIMAL toRational #-}
      -- Defined in 'GHC.Real'
instance Real Word -- Defined in 'GHC.Real'
instance Real Integer -- Defined in 'GHC.Real'
instance Real Int -- Defined in 'GHC.Real'
instance Real Float -- Defined in 'GHC.Float'
instance Real Double -- Defined in 'GHC.Float'
```

`RealFrac` .

```
λ> :i RealFrac
class (Real a, Fractional a) => RealFrac a where
  properFraction :: Integral b => a -> (b, a)
  truncate :: Integral b => a -> b
  round :: Integral b => a -> b
  ceiling :: Integral b => a -> b
  floor :: Integral b => a -> b
  {-# MINIMAL properFraction #-}
      -- Defined in ‘GHC.Real’
instance RealFrac Float -- Defined in ‘GHC.Float’
instance RealFrac Double -- Defined in ‘GHC.Float’
```

`Floating` (`Fractional`) .

```
λ> :i Floating
class Fractional a => Floating a where
  pi :: a
  exp :: a -> a
  log :: a -> a
  sqrt :: a -> a
  (**) :: a -> a -> a
  logBase :: a -> a -> a
  sin :: a -> a
  cos :: a -> a
  tan :: a -> a
  asin :: a -> a
  acos :: a -> a
  atan :: a -> a
  sinh :: a -> a
  cosh :: a -> a
  tanh :: a -> a
  asinh :: a -> a
  acosh :: a -> a
  atanh :: a -> a
  GHC.Float.log1p :: a -> a
  GHC.Float.expm1 :: a -> a
  GHC.Float.log1pexp :: a -> a
  GHC.Float.log1mexp :: a -> a
  {-# MINIMAL pi, exp, log, sin, cos, asin, acos, atan, sinh, cosh,
              asinh, acosh, atanh #-}
      -- Defined in ‘GHC.Float’
instance RealFloat a => Floating (Complex a) -- Defined in ‘Data.Complex’
instance Floating Float -- Defined in ‘GHC.Float’
instance Floating Double -- Defined in ‘GHC.Float’
```

: `sqrt . negate :: Floating a => a -> a` `sqrt . negate :: Floating a => a -> a` `NaN` ("not-a-number") . ( ) .

Examples

```
λ> :t 1
1 :: Num t => t

λ> :t pi
pi :: Floating a => a
```

. Haskell `Num` ( ), `pi` 0 .

```
list0 :: [Integer]
list0 = [1, 2, 3]

list1 :: [Double]
list1 = [1, 2, pi]
```

GHC . `list0 :: Num a => [a]` (: `Num` `Num` `Double`).

`Fractional Int ... '

. .

. :

```
averageOfList ll = sum ll / length ll
```

`(/)` . `(/) :: Fractional a => a -> a -> a` (`length :: Foldable t => ta -> Int`) `Int` (`Int Fractional`) , .

`fromIntegral :: (Num b, Integral a) => a -> b` . `Integral` `Num` :

```
averageOfList' :: (Foldable t, Fractional a) => t a -> a
averageOfList' ll = sum ll / fromIntegral (length ll)
```

`(+)` ?

```
λ> :t (+)
(+) :: Num a => a -> a -> a
```

`sqrt` ?

```
λ> :t sqrt
sqrt :: Floating a => a -> a
```

`sqrt . fromIntegral` ? `sqrt . fromIntegral` ?

```
sqrt . fromIntegral :: (Integral a, Floating c) => a -> c
```

: https://riptutorial.com/ko/haskell/topic/8616/

44:

Examples

OS X

:

```
brew install haskell-stack
```

helloworld :

```
stack new helloworld simple
```

`helloworld` .

.

```
➜ helloworld ls
LICENSE          Setup.hs          helloworld.cabal src            stack.yaml
```

`src` `Main.hs` `Main.hs` . `helloworld` "". `Main.hs` "Hello, World!" .

Main.hs

```
module Main where

main :: IO ()
main = do
  putStrLn "hello world"
```

`helloworld` .

```
stack build # Compile the program
stack exec helloworld # Run the program
# prints "hello world"
```

LTS ()

Stackage Haskell . .

.

`stack.yaml` `stack.yaml` . `stack.yaml` .

```
resolver: lts-6.8
```

Stackage `lts` . `lts-6.8` . .

```
https://www.stackage.org/lts-6.8 # if a different version is used, change 6.8 to the correct
resolver number.
```

Lens-4.13 .

`helloworld.cabal` .

```
  build-depends: base >= 4.7 && < 5
```

:

```
  build-depends: base >= 4.7 && 5,
                 lens == 4.13
```

LTS ( ), resolver number . :

```
resolver: lts-6.9
```

`stack build` LTS 6.9 .

`stack new helloworld simple` "helloworld".

`stack build` .

```
stack exec helloworld-exe
```

```
stack install
```

.

```
/Users/<yourusername>/.local/bin/
```

`stack` . `--profile` .

```
stack build --profile
```

GHC (`-prof`) . `stack` . `+RTS` .

```
stack exec -- my-bin +RTS -p
```

.

```
stack list-dependencies
```

.

. .

```
stack dot --external | grep template-haskell
```

`stack dot` . .

```
stack dot --external | dot -Tpng -o my-project.png
```

.

```
stack dot --external --depth 3 | dot -Tpng -o my-project.png
```

: https://riptutorial.com/ko/haskell/topic/2970/

45:

. State sa s a , " " . mtl transformers .

State . , State ? .

- .
- State .

action :: State sa .

- action .
- s action s s ;
- runState :: State sa -> s -> (a, s) stateful "" .

State . s runState " " . (. .

Examples

.

```
data Tree a = Tree a [Tree a] deriving Show
```

.

```
tag :: Tree a -> Tree (a, Int)
```

State .

```
import Control.Monad.State

-- Function that numbers the nodes of a `Tree`.
tag :: Tree a -> Tree (a, Int)
tag tree =
    -- tagStep is where the action happens.  This just gets the ball
    -- rolling, with `0` as the initial counter value.
    evalState (tagStep tree) 0

-- This is one monadic "step" of the calculation.  It assumes that
-- it has access to the current counter value implicitly.
tagStep :: Tree a -> State Int (Tree (a, Int))
tagStep (Tree a subtrees) = do
    -- The `get :: State s s` action accesses the implicit state
    -- parameter of the State monad.  Here we bind that value to
    -- the variable `counter`.
    counter <- get

    -- The `put :: s -> State s ()` sets the implicit state parameter
    -- of the `State` monad.  The next `get` that we execute will see
```

```
    -- the value of `counter + 1` (assuming no other puts in between).
    put (counter + 1)

    -- Recurse into the subtrees.  `mapM` is a utility function
    -- for executing a monadic actions (like `tagStep`) on a list of
    -- elements, and producing the list of results.  Each execution of
    -- `tagStep` will be executed with the counter value that resulted
    -- from the previous list element's execution.
    subtrees' <- mapM tagStep subtrees

    return $ Tree (a, counter) subtrees'
```

postIncrement .

get put + 1 postIncrement C :

```
postIncrement :: Enum s => State s s
postIncrement = do
    result <- get
    modify succ
    return result
```

.

.

```
mapTreeM :: Monad m => (a -> m b) -> Tree a -> m (Tree b)
mapTreeM action (Tree a subtrees) = do
    a' <- action a
    subtrees' <- mapM (mapTreeM action) subtrees
    return $ Tree a' subtrees'
```

postIncrement tagStep :

```
tagStep :: Tree a -> State Int (Tree (a, Int))
tagStep = mapTreeM step
    where step :: a -> State Int (a, Int)
          step a = do
              counter <- postIncrement
              return (a, counter)
```

Traversable

mapTreeM Traversable .

```
instance Traversable Tree where
    traverse action (Tree a subtrees) =
        Tree <$> action a <*> traverse action subtrees
```

Monad

`Applicative` (`<*>`) .

`tag` .

```
tag :: Traversable t => t a -> t (a, Int)
tag init t = evalState (traverse step t) 0
    where step a = do tag <- postIncrement
                      return (a, tag)
```

`Tree` `Traversable` .

`Traversable`

GHC `DeriveTraversable` .

```
{-# LANGUAGE DeriveFunctor, DeriveFoldable, DeriveTraversable #-}

data Tree a = Tree a [Tree a]
            deriving (Show, Functor, Foldable, Traversable)
```

: https://riptutorial.com/ko/haskell/topic/5740/-

46:

Examples

(!) .

```
foo (!x, y) !z = [x, y, z]
```

x z weak head normal form . :

```
foo (x, y) z = x `seq` z `seq` [x, y, z]
```

Bang Haskell 2010 BangPatterns .

. .

(,) . ( ) (: - \x -> ..). .

, ( ) . , .

.

(: let x = 1:x in x) . [1,1, ...] . let y = 1+y in y undefined .

RNF . (WHNF) . e e Con e1 e2 .. en Con . \x -> e1 ; f e1 e2 .. en , f n (, e). , e1..en e1..en . undefined .

Haskell WHNF . - e , WHNF , .

seq WHNF . seq xy y (seq xy y). y WHNF x WHNF . -XBangPatterns bang WHNF .

```
f !x y = ...
```

f x WHNF y () . .

```
data X = Con A !B C .. N
```

Con B , (, 2) B WHNF .

(~pat) . , . .

.

```
f1 :: Either e Int -> Int
```

```
f1 ~(Right 1) = 42
```

```
λ» f1 (Right 1)
42
λ» f1 (Right 2)
42
λ» f1 (Left "foo")
42
λ» f1 (error "oops!")
42
λ» f1 "oops!"
*** type mismatch ***
```

`Left` .

```
f2 :: Either e Int -> Int
f2 ~(Right x) = x + 1

λ» f2 (Right 1)
2
λ» f2 (Right 2)
3
λ» f2 (Right (error "oops!"))
*** Exception: oops!
λ» f2 (Left "foo")
*** Exception: lazypat.hs:5:1-21: Irrefutable pattern failed for pattern (Right x)
λ» f2 (error "oops!")
*** Exception: oops!
```

`let` , :

```
act1 :: IO ()
act1 = do
    ss <- readLn
    let [s1, s2] = ss :: [String]
    putStrLn "Done"

act2 :: IO ()
act2 = do
    ss <- readLn
    let [s1, s2] = ss
    putStrLn s1
```

`act1` , `act2` `putStrLn s1` `[s1, s2]` `s1` .

```
λ» act1
> ["foo"]
Done
λ» act2
> ["foo"]
*** readIO: no parse ***
```

`data` (`!`) . .

.

```
data User = User
    { identifier :: !Int
    , firstName :: !Text
    , lastName :: !Text
    }

data T = MkT !Int !Int
```

: https://riptutorial.com/ko/haskell/topic/3798/

47:

TypeFamilies . GADT . GeneralizedNewTypeDeriving . Haskell .

SafeNewtypeDeriving .

Examples

Haskell Wiki :

```
type family Inspect x
type instance Inspect Age = Int
type instance Inspect Int = Bool
```

x Inspect . x .

, x . RoleAnnotations .

```
type role Inspect nominal
```

.

```
data List a = Nil | Cons a (List a)

type family DoNotInspect x
type instance DoNotInspect x = List x
```

DoNotInspect x x .

, X . RoleAnnotations .

```
type role DoNotInspect representational
```

. .

: https://riptutorial.com/ko/haskell/topic/8753/

48:

, 0 , 1 , 42 , ...

Num fromInteger Num a => a . , Num

.

: 0.0 , -0.1111 , ...

fromRational Fractional a => a - Fractional

GHC OverloadedStrings String fromString . Data.String.IsString Data.String.IsString Data.String.IsString .

String Text ByteString .

[1, 2, 3] . GHC 7.8 OverloadedLists .

[] .

```
> :t []
[] :: [t]
```

OverloadedLists .

```
[] :: GHC.Exts.IsList l => l
```

Examples

```
Prelude> :t 1
1 :: Num a => a
```

Num .

```
Prelude> 1 :: Int
1
it :: Int
Prelude> 1 :: Double
1.0
it :: Double
Prelude> 1 :: Word
1
it :: Word
```

.

Prelude> 1 :: String

```
<interactive>:
    No instance for (Num String) arising from the literal `1'
    In the expression: 1 :: String
    In an equation for `it': it = 1 :: String
```

```
Prelude> :t 1.0
1.0 :: Fractional a => a
```

. Fractional .

```
Prelude> 1.0 :: Double
1.0
it :: Double
Prelude> 1.0 :: Data.Ratio.Ratio Int
1 % 1
it :: GHC.Real.Ratio Int
```

.

```
Prelude> 1.0 :: Int
<interactive>:
    No instance for (Fractional Int) arising from the literal `1.0'
    In the expression: 1.0 :: Int
    In an equation for `it': it = 1.0 :: Int
```

(,) . .

```
Prelude> :t "foo"
"foo" :: [Char]
```

OverloadedStrings .

```
Prelude> :set -XOverloadedStrings
Prelude> :t "foo"
"foo" :: Data.String.IsString t => t
```

. OverloadedStrings fromString String Text .

```
{-# LANGUAGE OverloadedStrings #-}

import Data.Text (Text, pack)
import Data.ByteString (ByteString, pack)


withString :: String
withString = "Hello String"

-- The following two examples are only allowed with OverloadedStrings

withText :: Text
```

```
withText = "Hello Text"      -- instead of: withText = Data.Text.pack "Hello Text"

withBS :: ByteString
withBS = "Hello ByteString"  -- instead of: withBS = Data.ByteString.pack "Hello ByteString"
```

`pack` `String` (`[Char]`) `Text` `ByteString` .

`OverloadedStrings` .

GHC OverloadedLists .

Data.Map .

```
> :set -XOverloadedLists
> import qualified Data.Map as M
> M.lookup "foo" [("foo", 1), ("bar", 2)]
Just 1
```

(M.fromList) :

```
> import Data.Map as M
> M.lookup "foo" (M.fromList [("foo", 1), ("bar", 2)])
Just 1
```

: https://riptutorial.com/ko/haskell/topic/369/--

49:

- foreign import ccall unsafe "foo"hFoo :: Int32 -> IO Int32 {- `foo` Haskell `hFoo` . -}

Cabal C C ++ . , `ao` `bo` ( ) `C-sources: ac, bc` cabal . # 12152 . Cabal `C-sources C-sources: bc, ac` `C-sources` . `C-sources: bc, ac` . `C-sources` .

(.h) C ++ `#ifdef __cplusplus` guard `#ifdef __cplusplus` . GHC C ++ . C ++ .

`ccall` . `ccall` `stdcall` ( ) . `unsafe` . , 1 .

Examples

C

C C . C .

foo.c :

```
#include <inttypes.h>

int32_t foo(int32_t a) {
  return a+1;
}
```

Foo.hs :

```
import Data.Int

main :: IO ()
main = print =<< hFoo 41

foreign import ccall unsafe "foo" hFoo :: Int32 -> IO Int32
```

`unsafe` 'safe' , C Haskell . `foo` C Haskell `unsafe` .

C cabal .

foo.cabal :

```
name:                 foo
version:              0.0.0.1
build-type:           Simple
extra-source-files:   *.c
cabal-version:        >= 1.10

executable foo
  default-language: Haskell2010
  main-is:        Foo.hs
  C-sources:      foo.c
  build-depends:  base
```

.

```
> cabal configure
> cabal build foo
> ./dist/build/foo/foo
42
```

Haskell C .

C . GUI . C .

C :

```
void event_callback_add (Object *obj, Object_Event_Cb func, const void *data)
```

Haskell .

```
foreign import ccall "header.h event_callback_add"
    callbackAdd :: Ptr () -> FunPtr Callback -> Ptr () -> IO ()
```

`Object_Event_Cb` C `Object_Event_Cb` Haskell `Callback` .

```
type Callback = Ptr () -> Ptr () -> IO ()
```

, `Callback` . `FunPtr Callback` :

```
foreign import ccall "wrapper"
    mkCallback :: Callback -> IO (FunPtr Callback)
```

C .

```
cbPtr <- mkCallback $ \objPtr dataPtr -> do
    -- callback code
    return ()
callbackAdd cpPtr
```

`FunPtr` .

```
freeHaskellFunPtr cbPtr
```

: https://riptutorial.com/ko/haskell/topic/7256/--

50:

Examples

Servant API .

- ( )
- (haskell) .
- ,
-
- ...

Servant API . API .

```
{-# LANGUAGE DataKinds #-}
{-# LANGUAGE TypeOperators #-}

import Data.Text
import Data.Aeson.Types
import GHC.Generics
import Servant.API

data SortBy = Age | Name

data User = User {
  name :: String,
  age :: Int
} deriving (Eq, Show, Generic)

instance ToJSON User  -- automatically convert User to JSON
```

API .

```
type UserAPI = "users" :> QueryParam "sortby" SortBy :> Get '[JSON] [User]
```

`/users` `SortBy` `sortby` `/users` `GET` `User` JSON .

.

```
-- This is where we'd return our user data, or e.g. do a database lookup
server :: Server UserAPI
server = return [User "Alex" 31]

userAPI :: Proxy UserAPI
userAPI = Proxy

app1 :: Application
app1 = serve userAPI server
```

`8081` API .

```
main :: IO ()
main = run 8081 app1
```

Stack Servant API . .

Yesod

Yesod `stack new` .

- `yesod-minimal` . Yesod .
- `yesod-mongo` . MongoDB DB .
- `yesod-mysql` . MySQL DB .
- `yesod-postgres` . PostgreSQL DB .
- `yesod-postgres-fay` . PostgreSQL DB . Fay .
- `yesod-simple` . .
- `yesod-sqlite` . SQlite DB .

`yesod-bin` `yesod` . `yesod` .

`Application.hs` . .

`Foundation.hs` `App` . `HandlerT` `getYesod` `getYesod` .

`Import.hs` `Import.hs` .

`Model.hs` DB Template Haskell . DB .

`config/models` DB . `Model.hs` .

`config/routes` URI . HTTP `{method}{RouteR}` .

`static/` . `Settings/StaticFiles.hs` .

`templates/` .

, `Handler/` .

IO `HandlerT` . , , `runDB` DB , IO , . HTML `defaultLayout` .

: https://riptutorial.com/ko/haskell/topic/4721/-

51:

Examples

. 3 .

-

- : :

```
{-# LANGUAGE TypeFamilies #-}
type family Vanquisher a where
    Vanquisher Rock = Paper
    Vanquisher Paper = Scissors
    Vanquisher Scissors = Rock

data Rock=Rock; data Paper=Paper; data Scissors=Scissors
```

-

typeclass . .

```
type family DoubledSize w

type instance DoubledSize Word16 = Word32
type instance DoubledSize Word32 = Word64
-- Other instances might appear in other modules, but two instances cannot overlap
-- in a way that would produce different results.
```

. . `VectorSpace` .

```
class VectorSpace v where
  type Scalar v :: *
  (*^) :: Scalar v -> v -> v

instance VectorSpace Double where
  type Scalar Double = Double
  μ *^ n = μ * n

instance VectorSpace (Double,Double) where
  type Scalar (Double,Double) = Double
  μ *^ (n,m) = (μ*n, μ*m)

instance VectorSpace (Complex Double) where
  type Scalar (Complex Double) = Complex Double
  μ *^ n = μ*n
```

Scalar . . , .

, . , typecheck :

```
class Foo a where
  type Bar a :: *
  bar :: a -> Bar a
instance Foo Int where
  type Bar Int = String
  bar = show
instance Foo Double where
  type Bar Double = Bool
  bar = (>0)

main = putStrLn (bar 1)
```

, bar Num Literal, . Bar "inverse direction" . injective † invertible (Bar a = String).

---

† .

.

```
{-# LANGUAGE TypeFamilies #-}
data family List a
data instance List Char = Nil | Cons Char (List Char)
data instance List () = UnitList Int
```

Nil :: List Char UnitList :: Int -> List ()

---

typeclasses . typeclass " " . , .

```
class Container f where
  data Location f
  get :: Location f -> f a -> Maybe a

instance Container [] where
  data Location [] = ListLoc Int
  get (ListLoc i) xs
    | i < length xs  = Just $ xs!!i
    | otherwise      = Nothing

instance Container Tree where
  data Location Tree = ThisNode | NodePath Int (Location Tree)
  get ThisNode (Node x _) = Just x
  get (NodePath i path) (Node _ sfo) = get path =<< get i sfo
```

. . , servant Server a a . Proxy . , servant serve ... Proxy a -> Server a -> ... a Proxy a Proxy data .

: https://riptutorial.com/ko/haskell/topic/2955/-

52:

Examples

. .

. :

```
type Color = Red | Yellow | Green
```

3 . `Bool` **2** .

```
type Bool = True | False
```

. . `f` `g` .

```
f :: a -> b
g :: b -> a

f . g == id == g . f
```

. .

, 2 .

```
type Bit  = I    | O
type Bool = True | False

bitValue :: Bit -> Bool
bitValue I = True
bitValue O = False

booleanBit :: Bool -> Bit
booleanBit True  = I
booleanBit False = O
```

`bitValue . booleanBit == id == booleanBit . bitValue` `bitValue . booleanBit == id == booleanBit . bitValue`

1 0

1 . Haskell, unit `()` type `()` . `()` .

0 . Haskell **Void** , `Data.Void` `Data.Void` . .

```
data Void
```

.   .

```
data Sum a b = A a | B b
data Prod a b = Prod a b
```

.

,   `Either` `(,)`   .   .

```
type Sum' a b = Either a b
type Prod' a b = (a,b)
```

. , 1 + 2, 2 + 1 3   . 1 + 2 = 3 = 2 + 1.

```
data Color = Red | Green | Blue

f :: Sum () Bool -> Color
f (Left ())     = Red
f (Right True)  = Green
f (Right False) = Blue

g :: Color -> Sum () Bool
g Red   = Left ()
g Green = Right True
g Blue  = Right False

f' :: Sum Bool () -> Color
f' (Right ())   = Red
f' (Left True)  = Green
f' (Left False) = Blue

g' :: Color -> Sum Bool ()
g' Red   = Right ()
g' Green = Left True
g' Blue  = Left False
```

commutativity, associativity distributivity   .

```
-- Commutativity
Sum a b           <=> Sum b a
Prod a b          <=> Prod b a
-- Associativity
Sum (Sum a b) c   <=> Sum a (Sum b c)
Prod (Prod a b) c <=> Prod a (Prod b c)
-- Distributivity
Prod a (Sum b c)  <=> Sum (Prod a b) (Prod a c)
```

.

```
data List a = Nil | Cons a (List a)
```

,

(a) = 1 + a * (a)

List (a) .

(a) = 1 + a + a * a + a * a * a + a * a * a * a + ...

`[]` . `[x]` `a` ; `[x,y]` `a` ; . List .

```
-- Not working Haskell code!
data List a = Nil
            | One a
            | Two a a
            | Three a a a
            ...
```

. :

```
data Tree a = Empty | Node a (Tree a) (Tree a)
```

.

(a) = 1 + a * (a) * (a)

.

(a) = 1 + a + 2 (a * a) +5 (a * a * a) + 14 (a * a * a * a) + ...

, n n .

. .

`(a,a,a)` .

```
data OneHoleContextsOfTriple = (a,a,()) | (a,(),a) | ((),a,a)
```

.

d / da (a * a * a) = 3 * a * a

.

. , `a` n `b` m , `a -> b` n m .

, `Bool -> Bool` `(Bool,Bool)` , $2 * 2 = 2^2$.

```
iso1 :: (Bool -> Bool) -> (Bool,Bool)
iso1 f = (f True,f False)

iso2 :: (Bool,Bool) -> (Bool -> Bool)
```

```
iso2 (x,y) = (\p -> if p then x else y)
```

: https://riptutorial.com/ko/haskell/topic/4905/-

53:

TypeApplications .

TypeApplications .

{-# LANGUAGE TypeApplications #-} .

Examples

. .

```
x :: Num a => a
x = 5

main :: IO ()
main = print x
```

. a Num , Show . , , a Int

```
main = print (x :: Int)
```

.

```
main = print @Int x
```

print .

```
print :: Show a => a -> IO ()
```

a a . .

. ? ! TypeApplications TypeApplications . .

```
print :: Show a => a -> IO ()
print @Int :: Int -> IO ()
print @Int x :: IO ()
```

.

Java, C # C ++ generics / templates .

C # .

```
public static T DoNothing<T>(T in) { return in; }
```

float DoNothing(5.0f) DoNothing<float>(5.0f) . .

Haskell .

```
doNothing :: a -> a
doNothing x = x
```

`ScopedTypeVariables` , `Rank2Types` `RankNTypes` .

```
doNothing :: forall a. a -> a
doNothing x = x
```

`doNothing 5.0` `doNothing @Float 5.0` .

. ?

```
const :: a -> b -> a
```

`const @Int` `a` `Int` , `b` ? `const :: forall a b. a -> b -> a` `forall` `const :: forall a b. a -> b -> a` . `a` , `b` .

. , .

? .

```
const @_ @Int
```

.

```
const @_ @Int :: a -> Int -> a
```

.

```
class SizeOf a where
    sizeOf :: a -> Int
```

. `sizeOf` `a` `sizeOf` , .

`Proxy` .

```
data Proxy a = Proxy
```

. .

```
class SizeOf a where
    sizeOf :: Proxy a -> Int
```

. ? `sizeOf :: Int` , `sizeOf :: SizeOf a => Int` `sizeOf :: forall a. SizeOf a => Int` `sizeOf :: forall a. SizeOf a => Int` .

. `sizeOf` , `Int` . `a` . `{-# LANGUAGE AllowAmbiguousTypes #-}` . .

, ! `sizeOf @Int` . `a` `Int` `a` . !

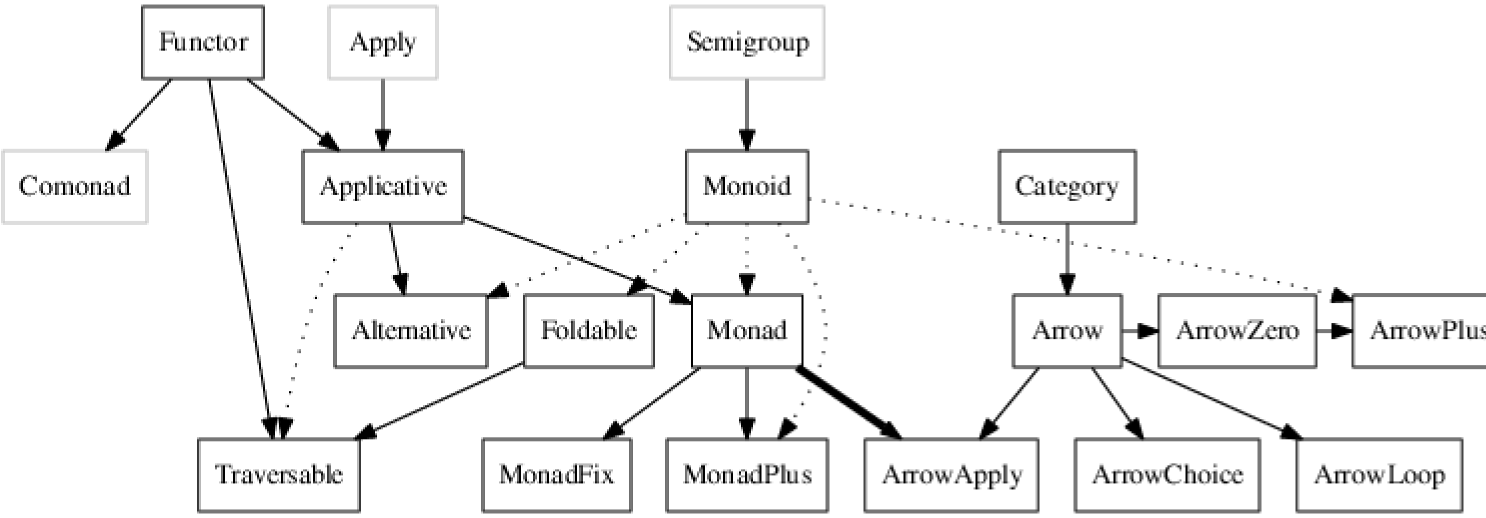
: https://riptutorial.com/ko/haskell/topic/10767/-

54:

. , , .

Haskell `base` . .

Typeclassopedia .



Examples

Haskell . `Maybe` .

`Maybe` . , `Maybe` . `Maybe` .

.

```
Maybe a = Just a | Nothing
```

`Maybe` `Just` `Nothing` . `Just` `Maybe` , `Nothing` . `Just "foo"` `Maybe String` . `Maybe` . `Nothing` `Maybe a` `a` .

`Maybe` . `Either` , `IO` List . . .

. , .

Haskell `Functor` typeclass . .

```
class Functor f where
  fmap :: (a -> b) -> f a -> f b
```

`fmap` `fmap` . , , , a b . ( ) a . b ( ) .

, `fmap` functor . `Functor` , . `Applicative` `Monad` .

Type : Ord

Haskell . , `Ord` `Eq` `Ordering` `compare` . `Ord` `min` `max` .

`=>` `Ord` `Eq` `a` .

```
data Ordering = EQ | LT | GT

class Eq a => Ord a where
    compare :: Ord a => a -> a -> Ordering
    (<)     :: Ord a => a -> a -> Bool
    (<=)    :: Ord a => a -> a -> Bool
    (>)     :: Ord a => a -> a -> Bool
    (>=)    :: Ord a => a -> a -> Bool
    min     :: Ord a => a -> a -> a
    max     :: Ord a => a -> a -> a
```

`compare` .

```
x < y   = compare x y == LT
x <= y  = x < y || x == y -- Note the use of (==) inherited from Eq
x > y   = not (x <= y)
x >= y  = not (x < y)

min x y = case compare x y of
               EQ -> x
               LT -> x
               GT -> y

max x y = case compare x y of
               EQ -> x
               LT -> y
               GT -> x
```

`Ord` `compare` `(<=)` , .

Eq

Prelude `IO` (`Int` , `String` , `Eq a => [a]`) `Eq` . `Eq` .

```
> 3 == 2
False
> 3 == 3
True
```

- `(==) :: Eq a => a -> a -> Boolean` `(/=) :: Eq a => a -> a -> Boolean` ( )

- `(==) :: Eq a => a -> a -> Boolean`
- `(/=) :: Eq a => a -> a -> Boolean`

---

* Ord

Ord

`Ord` `Int` , `String` `[a]` (: `Ord a` `Ord a`) . `Ord` "" . , "" `Ord` .

`Ord` `(<=)` , `(<)` , `(>)` , `(>=)`

```
data Ordering = LT | EQ | GT

compare :: Ord a => a -> a -> Ordering
```

* `compare :: Ord a => a -> a -> Ordering` `(<=) :: Ord a => a -> a -> Boolean` (`compare` `(<=)`)

* `compare :: Ord a => a -> a -> Ordering`
* `(<=) :: Ord a => a -> a -> Boolean`
* `(<) :: Ord a => a -> a -> Boolean`
* `(>=) :: Ord a => a -> a -> Boolean`
* `(>) :: Ord a => a -> a -> Boolean`
* `min :: Ord a => a -> a -> a`
* `max :: Ord a => a -> a -> a`

* Eq

Monoid `Monoid` , . `Monoid` (`mappend` `(<>)`) , "" (`mempty`) , :

```
mempty  <>  x == x
x <>  mempty  == x

x <> (y <> z) == (x <> y) <> z
```

`Monoid` " ". `Monoid` . , `Monoid` `Monoid` (`Foldable` `Traversable`).

* `mempty :: Monoid m => m`
* `mappend :: Monoid m => m -> m -> m`

. , , .

`Integer` (`Int` , `Integer` , `Word32`) (`Double` , `Rational` ,) . , , † .

. .

* `fromInteger :: Num a => Integer -> a` . ( ). Haskell `Integer` `Int` `Complex` `Double` 5 .

- `(+) :: Num a => a -> a -> a` . , associative commutative , ,

```
a + (b + c) ≡ (a + b) + c
a + b ≡ b + a
```

- `(-) :: Num a => a -> a -> a` . ( ) :

```
(a - b) + b ≡ (a + b) - b ≡ a
```

- `(*) :: Num a => a -> a -> a` . (multiplication), :

```
a * (b * c) ≡ (a * b) * c
a * (b + c) ≡ a * b + a * c
```

.

- `negate :: Num a => a -> a` . . `-1` `negate 1` .

```
-a ≡ negate a ≡ 0 - a
```

- `abs :: Num a => a -> a` . .

```
abs (-a) ≡ abs a
abs (abs a) ≡ abs a
```

`abs a ≡ 0` `a ≡ 0` .

. `abs a >= 0` . , `abs` (,) ‡ .

- `signum :: Num a => a -> a` . sign `-1` `1` . 0 . `signum` .

```
abs (signum a) ≡ 1   -- unless a≡0
signum a * abs a ≡ a -- This is required to be true for all Num instances
```

Haskell 2010 6.4.4 `Num` .

, hmatrix `Num` . . `+` `-` , `*` . , `*` ?
- . `VectorSpace` .

---

† , "" `(-4 :: Word32) == 4294967292` : `(-4 :: Word32) == 4294967292` .

‡ : . `Num` `abs` `signum` . .

: https://riptutorial.com/ko/haskell/topic/1879/-

55:

- cabal <command> <command> .
- **[]**
    -
        -
    -
        -
    -
        -
    -
        -
    -
        -
    -
        -
    -
        - Cabal .
- **[]**
    -
        - / ()
    -
        - .cabal ( )
    -
        - .
    -
        - /
    -
        -
    -
        - .
    - repl
        -
    -
        - /
    -
        - /
    -
        - .
    - sdist
        - (.tar.gz)
    -
        - Hackage .
    -
        -
    -
        -
    -
        -
    -
        - Haddock HTML
    -
        - HsColour HTML .
    -
        - .
    -
        - .
- **[ ]**
    -
        - / /
            - cabal [FLAGS]
            - [FLAGS]
            - Cabal [FLAGS] PATHS
            - [FLAGS] PATHS
            - cabal [FLAGS]
            - cabal hc-pkg [] [-] [-] [ARGS]
    -
        -
    - repl
        -

Examples

: aeson :

```
cabal install aeson
```

Haskell . (: Haskell).

Haskell :

```
cabal sandbox init
```

`cabal install` .

:

```
cabal sandbox hc-pkg list
```

:

```
cabal sandbox delete
```

:

```
cabal sandbox add-source /path/to/dependency
```

: https://riptutorial.com/ko/haskell/topic/4740/

56:

Applicative f :: * -> * .

```
class Functor f => Applicative f where
    pure  :: a -> f a
    (<*>) :: f (a -> b) -> f a -> f b
```

f Functor . pure Applicative . <*> ("") Applicative fmap .

Applicative .

```
pure id <*> a = a                              -- identity
pure (.) <*> a <*> b <*> c = a <*> (b <*> c)   -- composition
pure f <*> pure a = pure (f a)                 -- homomorphism
a <*> pure b = pure ($ b) <*> a                -- interchange
```

Examples

Applicative Functor Functor fmap . Applicative .

```
class Functor f => PairingFunctor f where
  funit :: f ()                  -- create a context, carrying nothing of import
  fpair :: (f a,f b) -> f (a,b)  -- collapse a pair of contexts into a pair-carrying context
```

Applicative .

```
pure a = const a <$> funit = a <$ funit

fa <*> fb = (\(a,b) -> a b) <$> fpair (fa, fb) = uncurry ($) <$> fpair (fa, fb)
```

,

```
funit = pure ()

fpair (fa, fb) = (,) <$> fa <*> fb
```

Maybe (functor) .

```
instance Applicative Maybe where
    pure = Just

    Just f <*> Just x = Just $ f x
    _ <*> _ = Nothing
```

pure Just Maybe Maybe . (<*>) Maybe A Maybe . (Just) . Nothing .

`<*> :: [a -> b] -> [a] -> [b]` Cartesian :

```
fs <*> xs = [f x | f <- fs, x <- xs]
         -- = do { f <- fs; x <- xs; return (f x) }

pure x = [x]
```

, , . 2 2 :

```
ghci> [(+1),(+2)] <*> [3,30,300]
[4,31,301,5,32,302]
```

"" `Applicative` . .

```
data Stream a = Stream { headS :: a, tailS :: Stream a }
```

`Stream` `Applicative` . `pure` - .

```
instance Applicative Stream where
    pure x = let s = Stream x s in s
    Stream f fs <*> Stream x xs = Stream (f x) (fs <*> xs)
```

`ZipList` newtype "zippy" `Applicative` .

```
newtype ZipList a = ZipList { getZipList :: [a] }

instance Applicative ZipList where
    ZipList xs <*> ZipList ys = ZipList $ zipWith ($) xs ys
```

`zip` `Applicative` `pure` .

```
    pure a = ZipList (repeat a)   -- ZipList (fix (a:)) = ZipList [a,a,a,a,...
```

:

```
ghci> getZipList $ ZipList [(+1),(+2)] <*> ZipList [3,30,300]
[4,32]
```

. `nx 1` (`nx 1`) 1 (`1 xm`) `nxm` (,); 1 1 ( ).

`(->) r` `pure` `<*>` `K` `S` .

```
pure :: a -> (r -> a)
<*> :: (r -> (a -> b)) -> (r -> a) -> (r -> b)
```

`pure` `const` `<*>` .

```
instance Applicative ((->) r) where
    pure = const
    f <*> g = \x -> f x (g x)
```

"" . , `(->) Nat` , isomorphic ...

```
-- | Index into a stream
to :: Stream a -> (Nat -> a)
to (Stream x xs) Zero = x
to (Stream x xs) (Suc n) = to xs n

-- | List all the return values of the function in order
from :: (Nat -> a) -> Stream a
from f = from' Zero
    where from' n = Stream (f n) (from' (Suc n))
```

`Applicative` .

: https://riptutorial.com/ko/haskell/topic/8162/-

57:

- bimap :: (a -> b) -> (c -> d) -> pac -> pbd
- :: (a -> b) -> pac -> pbc
- : (b -> c) -> pab -> pac

`Functor` . , `f` A `Functor` , `fa` `a -> b` `fb` (`fmap`).

`Bifunctor` . `f` `Bifunctor` , `fab` , `a -> c` `b -> d` `bimap` `fcd` .

`first` int `fmap` , 1 `second` int `fmap` , `bimap` 1 2 covariantly .

Examples

Bifunctor

2

`(,)` `Bifunctor` .

```
instance Bifunctor (,) where
    bimap f g (x, y) = (f x, g y)
```

`bimap` .

```
bimap (+ 2) (++ "nie") (3, "john") --> (5,"johnnie")
bimap ceiling length (3.5 :: Double, "john" :: String) --> (4,4)
```

`Either`

`Either` `Bifunctor` `Left` `Right` .

```
instance Bifunctor Either where
    bimap f g (Left x)  = Left (f x)
    bimap f g (Right y) = Right (g y)
```

`first` `second` (`bimap`).

```
first :: Bifunctor f => (a -> c) -> f a b -> f c b
first f = bimap f id

second :: Bifunctor f => (b -> d) -> f a b -> f a d
second g = bimap id g
```

,

```
ghci> second (+ 2) (Right 40)
Right 42
ghci> second (+ 2) (Left "uh oh")
Left "uh oh"
```

Bifunctor

`Bifunctor` (`f :: * -> * -> *`) , .

```
class Bifunctor f where
    bimap :: (a -> c) -> (b -> d) -> f a b -> f c d
```

`bimap` `fmap` .

`f` `Bifunctor` *functor* *bifunctor* .

```
bimap id id = id  -- identity
bimap (f . g) (h . i) = bimap f h . bimap g i  -- composition
```

`Bifunctor` `Data.Bifunctor` . GHC 7.10 . `bifunctors` .

: https://riptutorial.com/ko/haskell/topic/8020/-

58: GHC

Glasgow Haskell (GHC) Haskell 2010 . `module` `LANGUAGE` programa . GCH 7 .

`LANGUAGE` `{-# LANGUAGE ExtensionOne, ExtensionTwo ... #-}` . `{-# LANGUAGE` `#-}` . `LANGUAGE` .

Examples

MultiParamTypeClasses

. MPTC .

```
{-# LANGUAGE MultiParamTypeClasses #-}

class Convertable a b where
    convert :: a -> b

instance Convertable Int Float where
    convert i = fromIntegral i
```

.

MPTC .

FlexibleInstances

.

```
All instance types must be of the form (T a1 ... an)
where a1 ... an are *distinct type variables*,
and each type variable appears at most once in the instance head.
```

, `[a]` `[Int]` . `FlexibleInstances` .

```
class C a where

-- works out of the box
instance C [a] where

-- requires FlexibleInstances
instance C [Int] where
```

Haskell `String` . `String` `[Char]` . `Text` `ByteString` .

`OverloadedStrings`

```
"test" :: Data.String.IsString a => a
```

. `[Char]` Data.Text Data.ByteString .

SQL SQL Postgresql-simple `OverloadedStrings` .

`IsString` `fromString` . † :

```
data Foo = A | B | Other String deriving Show

instance IsString Foo where
  fromString "A" = A
  fromString "B" = B
  fromString xs  = Other xs

tests :: [ Foo ]
tests = [ "A", "B", "Testing" ]
```

---

† Lyndon Maydwell (GitHub `sordina`) .

TupleSections

() .

```
(a,b) == (,) a b

-- With TupleSections
(a,b) == (,) a b == (a,) b == (,b) a
```

N-

2 (arity)

```
(,2,) 1 3 == (1,2,3)
```

:

```
map (,"tag") [1,2,3] == [(1,"tag"), (2, "tag"), (3, "tag")]
```

.

```
map (\a -> (a, "tag")) [1,2,3]
```

UnicodeSyntax

.

ASCII		
`::`	∷	

ASCII		
->	→	, , case
=>	⇒	
forall	∀	
<-	←	do
*	★	( ) (: Int :: ★)
>-	⤚	Arrows proc
-<	⤙	Arrows proc
>>-	⤜	Arrows proc
-<<	⤛	Arrows proc

:

```
runST :: (forall s. ST s a) -> a
```

```
runST :: (∀ s. ST s a) → a
```

---

* ★ . * ★ * (*) . :

```
ghci> 2 ★ 3
6
ghci> let (*) = (+) in 2 ★ 3
5
ghci> let (★) = (-) in 2 * 3
-1
```

() 16 (0x 0X) (0o 0O). BinaryLiterals (0b 0B) .

```
0b1111 == 15     -- evaluates to: True
```

ExistentialQuantification

† , , , .

abstract-base-class : contains .

```
data S = forall a. Show a => S a
```

GADT .

```
{-# LANGUAGE GADTs #-}
data S where
   S :: Show a => a -> S
```

: , `S` , `show` , .

```
instance Show S where
    show (S a) = show a    -- we rely on (Show a) from the above
```

:

```
ss = [S 5, S "test", S 3.0]
```

(polymorphic) .

```
mapM_ print ss
```

Existentials , Haskell . `Show` . `S` . . .

, . , "". `S` (`Show`) " ". . `Couldn't match type 'a0' with '()' 'a0' is untouchable` `Couldn't match type 'a0' with '()' 'a0' is untouchable` .

---

† . ( ).

Existential Rank-N . . `show` ( ) . . , . . `{-# LANGUAGE Rank2Types #-}` .

```
genShowSs :: (∀ x . Show x => x -> String) -> [S] -> [String]
genShowSs f = map (\(S a) -> f a)
```

`\arg -> case arg of` `\arg -> case arg of` `\case` .

.

```
dayOfTheWeek :: Int -> String
dayOfTheWeek 0 = "Sunday"
dayOfTheWeek 1 = "Monday"
dayOfTheWeek 2 = "Tuesday"
dayOfTheWeek 3 = "Wednesday"
dayOfTheWeek 4 = "Thursday"
dayOfTheWeek 5 = "Friday"
dayOfTheWeek 6 = "Saturday"
```

.

```
dayOfTheWeek :: Int -> String
dayOfTheWeek i = case i of
    0 -> "Sunday"
    1 -> "Monday"
    2 -> "Tuesday"
```

```
    3 -> "Wednesday"
    4 -> "Thursday"
    5 -> "Friday"
    6 -> "Saturday"
```

LambdaCase .

```
{-# LANGUAGE LambdaCase #-}

dayOfTheWeek :: Int -> String
dayOfTheWeek = \case
    0 -> "Sunday"
    1 -> "Monday"
    2 -> "Tuesday"
    3 -> "Wednesday"
    4 -> "Thursday"
    5 -> "Friday"
    6 -> "Saturday"
```

RankNTypes

.

```
foo :: Show a => (a -> String) -> String -> Int -> IO ()
foo show' string int = do
   putStrLn (show' string)
   putStrLn (show' int)
```

String , int . ! .

, ! GHC `a` . , :

```
putStrLn (show' string)
```

GHC `show' :: String -> String` , `string` A `String` . `show' int` `show' int` .

`RankNTypes` `show'` .

```
foo :: (forall a. Show a => (a -> String)) -> String -> Int -> IO ()
```

`show'` , . `a`

`RankNTypes` `forall ...` . , N .

GHC 7.8 .

OverloadedLists, OverloadedStrings desugared :

```
[]          -- fromListN 0 []
[x]         -- fromListN 1 (x : [])
[x .. ]     -- fromList (enumFrom x)
```

Set , Vector Map .

```
['0' .. '9']             :: Set Char
[1 .. 10]                :: Vector Int
[("default",0), (k1,v1)] :: Map String Int
['a' .. 'z']             :: Text
```

IsList GHC.Exts .

IsList Item , fromList :: [Item l] -> l , toList :: l -> [Item l] fromListN :: Int -> [Item l] -> l . fromListN . .

```
instance IsList [a] where
  type Item [a] = a
  fromList = id
  toList   = id

instance (Ord a) => IsList (Set a) where
  type Item (Set a) = a
  fromList = Set.fromList
  toList   = Set.toList
```

- GHC .

a, b, c x x a, b c .

```
class SomeClass a b c x | a b c -> x where ...
```

. abc x .

.

```
class OtherClass a b c d | a b -> c d, a d -> b where ...
```

MTL .

```
class MonadReader r m| m -> r where ...
instance MonadReader r ((->) r) where ...
```

MonadReader a ((->) Foo) => a a ~ Foo . .

SomeClass x abc . .

GADT

. , ADT

```
data Expr a = IntLit Int
            | BoolLit Bool
            | If (Expr Bool) (Expr a) (Expr a)
```

, IntLit :: Int -> Expr a : universially , a Expr a . a ~ Bool IntLit :: Int -> Expr Bool If (IntLit 1) e1 e2 . If If .

Generalized Algebraic Data Types . Expr GADT .

```
data Expr a where
  IntLit :: Int -> Expr Int
  BoolLit :: Bool -> Expr Bool
  If :: Expr Bool -> Expr a -> Expr a -> Expr a
```

IntLit IntLit Int -> Expr Int IntLit 1 :: Expr Bool .

GADT . , Expr a Expr a .

```
crazyEval :: Expr a -> a
crazyEval (IntLit x) =
   -- Here we can use `(+)` because x :: Int
   x + 1
crazyEval (BoolLit b) =
   -- Here we can use `not` because b :: Bool
   not b
crazyEval (If b thn els) =
  -- Because b :: Expr Bool, we can use `crazyEval b :: Bool`.
  -- Also, because thn :: Expr a and els :: Expr a, we can pass either to
  -- the recursive call to `crazyEval` and get an a back
  crazyEval $ if crazyEval b then thn else els
```

, IntLit x a ~ Int (a ~ Bool not if_then_else_) (+) .

ScopedTypeVariables

ScopedTypeVariables . :

```
import Data.Monoid

foo :: forall a b c. (Monoid b, Monoid c) => (a, b, c) -> (b, c) -> (a, b, c)
foo (a, b, c) (b', c') = (a :: a, b'', c'')
    where (b'', c'') = (b <> b', c <> c') :: (b, c)
```

a , b c (where a . ScopedTypeVariables .

PatternSynonyms

.

Data.Sequence . Seq , O (1) (un) consing (un) snocing .

. Seq .

```
empty :: Seq a

(<|) :: a -> Seq a -> Seq a
data ViewL a = EmptyL | a :< (Seq a)
```

```
viewl :: Seq a -> ViewL a

(|>) :: Seq a -> a -> Seq a
data ViewR a = EmptyR | (Seq a) :> a
viewr :: Seq a -> ViewR a
```

.

```
uncons :: Seq a -> Maybe (a, Seq a)
uncons xs = case viewl xs of
    x :< xs' -> Just (x, xs')
    EmptyL -> Nothing
```

.

```
{-# LANGUAGE ViewPatterns #-}

uncons :: Seq a -> Maybe (a, Seq a)
uncons (viewl -> x :< xs) = Just (x, xs)
uncons _ = Nothing
```

`PatternSynonyms` snoc-list .

```
{-# LANGUAGE PatternSynonyms #-}
import Data.Sequence (Seq)
import qualified Data.Sequence as Seq

pattern Empty :: Seq a
pattern Empty <- (Seq.viewl -> Seq.EmptyL)

pattern (:<) :: a -> Seq a -> Seq a
pattern x :< xs <- (Seq.viewl -> x Seq.:< xs)

pattern (:>) :: Seq a -> a -> Seq a
pattern xs :> x <- (Seq.viewr -> xs Seq.:> x)
```

`uncons` :

```
uncons :: Seq a -> Maybe (a, Seq a)
uncons (x :< xs) = Just (x, xs)
uncons _ = Nothing
```

RecordWildCards

RecordWildCards .

GHC : https://riptutorial.com/ko/haskell/topic/1274/-ghc--

59:

Examples

GADTs .

```
data DataType a where
    Constr1 :: Int -> a -> Foo a -> DataType a
    Constr2 :: Show a => a -> DataType a
    Constr3 :: DataType Int
```

GADT . N-ary (nullary) .

DataType Constr1 , Constr2 Constr3 .

Constr1 . data DataType a = Constr1 Int a (Foo a) | ...

Constr2 a Show , . , a Show .

```
foo :: DataType a -> String
foo val = case val of
    Constr2 x -> show x
    ...
```

Show a , -> .

Constr3 DataType Int , DataType a A Constr3 , a ~ Int . .

: https://riptutorial.com/ko/haskell/topic/2971/----

60:

Examples

.

```
main = do
    input <- getContents
    putStr input
```

:

```
This is an example sentence.
And this one is, too!
```

:

```
This is an example sentence.
And this one is, too!
```

: . , 50MiB `getContents` Haskell ( ) . 50MiB .

```
main = do
    line <- getLine
    putStrLn line
```

:

```
This is an example.
```

:

```
This is an example.
```

```
readFloat :: IO Float
readFloat =
    fmap read getLine


main :: IO ()
main = do
    putStr "Type the first number: "
    first <- readFloat

    putStr "Type the second number: "
    second <- readFloat

    putStrLn $ show first ++ " + " ++ show second ++ " = " ++ show ( first + second )
```

:

```
Type the first number: 9.5
Type the second number: -2.02
```

:

```
9.5 + -2.02 = 7.48
```

I / O

`Handle` `System.IO` .. , `getLine :: IO String` `hGetLine :: Handle -> IO String` .

```
import System.IO( Handle, FilePath, IOMode( ReadMode ),
                  openFile, hGetLine, hPutStr, hClose, hIsEOF, stderr )

import Control.Monad( when )


dumpFile :: Handle -> FilePath -> Integer -> IO ()

dumpFile handle filename lineNumber = do      -- show file contents line by line
    end <- hIsEOF handle
    when ( not end ) $ do
        line <- hGetLine handle
        putStrLn $ filename ++ ":" ++ show lineNumber ++ ": " ++ line
        dumpFile handle filename $ lineNumber + 1


main :: IO ()

main = do
    hPutStr stderr "Type a filename: "
    filename <- getLine
    handle <- openFile filename ReadMode
    dumpFile handle filename 1
    hClose handle
```

`example.txt` :

```
This is an example.
Hello, world!
This is another example.
```

:

```
Type a filename: example.txt
```

:

```
example.txt:1: This is an example.
example.txt:2: Hello, world!
example.txt:3: This is another example
```

(end-of-file)

I / O `isEOF` Haskell `isEOF` EOF . .

```
import System.IO( isEOF )


eofTest :: Int -> IO ()
eofTest line = do
    end <- isEOF
    if end then
        putStrLn $ "End-of-file reached at line " ++ show line ++ "."
    else do
        getLine
        eofTest $ line + 1


main :: IO ()
main =
    eofTest 1
```

:

```
Line #1.
Line #2.
Line #3.
```

:

```
End-of-file reached at line 4.
```

, † / . IO .

```
-- | The interesting part of the program, which actually processes data
--   but doesn't do any IO!
reverseWords :: String -> [String]
reverseWords = reverse . words

-- | A simple wrapper that only fetches the data from disk, lets
--   'reverseWords' do its job, and puts the result to stdout.
main :: IO ()
main = do
   content <- readFile "loremipsum.txt"
   mapM_ putStrLn $ reverseWords content
```

`loremipsum.txt`

```
Lorem ipsum dolor sit amet,
consectetur adipiscing elit
```

.

```
elit
adipiscing
consectetur
amet,
```

```
sit
dolor
ipsum
Lorem
```

mapM_ putStrLn .

---

† , . , Haskell . . . readFile Data.Text Data.Text .

IO `main`

Haskell IO () main .

```
main :: IO ()
main = putStrLn "Hello world!"
```

IO . Hello world! .

main IO a IO a .

```
other :: IO ()
other = putStrLn "I won't get printed"

main :: IO ()
main = putStrLn "Hello world!"
```

. other .

other main . main IO . IO do -notation .

```
other :: IO ()
other = putStrLn "I will get printed... but only at the point where I'm composed into main"

main :: IO ()
main = do
  putStrLn "Hello world!"
  other
```

,

```
Hello world!
I will get printed... but only at the point where I'm composed into main
```

other main .

IO

. (:).

Haskell ( ) IO . , IO . , IO Int Int I / O . IO , IO (, sensical) IO IO .

x IO x main Haskell .

IO

IO . IO .

```
(>>=) :: IO a -> (a -> IO b) -> IO b
```

( ) IO IO , IO IO .

```
return :: a -> IO a
```

(,) IO IO . , I / O .

. , (>>) :: IO a -> IO b -> IO b (>>=) .

.

```
main :: IO ()
main =
  putStrLn "What is your name?" >>
  getLine >>= \name ->
  putStrLn ("Hello " ++ name ++ "!")
```

putStrLn :: String -> IO () getLine :: IO String .

: (>>= , >> return) .

IO

IO . , s1 ; s2 s1 , s2 , s1 >> s2 .

IO . return . IO . , return () >> putStrLn "boom" "boom" .

IO .

```
return x >>= f ≡ f x, ∀ f x
y >>= return ≡ return y, ∀ y
(m >>= f) >>= g ≡ m >>= (\x -> (f x >>= g)), ∀ m f g
```

ID, ID . .

```
(>=>) :: (a -> IO b) -> (b -> IO c) -> a -> IO c
(f >=> g) x = (f x) >>= g
```

```
return >=> f ≡ f, ∀ f
f >=> return ≡ f, ∀ f
(f >=> g) >=> h ≡ f >=> (g >=> h), ∀ f g h
```

I / O . , . . putStrLn "X" >> putStrLn "Y" "XY" . lazily I / O . , I / O . getContents readFile . Lazy I / O Haskell .

IO do

Haskell IO IO . do notation * >>= , >> return .

do notation . .

```
main = do
  putStrLn "What is your name?"
  name <- getLine
  putStrLn ("Hello " ++ name ++ "!")


main = do {
  putStrLn "What is your name?" ;
  name <- getLine ;
  putStrLn ("Hello " ++ name ++ "!")
  }
```

.

---

* do .

'a' "IO" " "

" IO a , ? : " a (:) ?

. ! IO a " (a) " a main (b) . , " ". a

, , IO , . a IO , do -notation :

```
-- assuming
myComputation :: IO Int

getMessage :: Int -> String
getMessage int = "My computation resulted in: " ++ show int

newComputation :: IO ()
newComputation = do
  int <- myComputation       -- we "bind" the result of myComputation to a name, 'int'
  putStrLn $ getMessage int  -- 'int' holds a value of type Int
```

(getMessage) Int String , () IO myComputation do notation . IO , newComputation . .

stdout

Haskell 2010 Prelude IO .

`putChar :: Char -> IO ()` - char stdout .

```
Prelude> putChar 'a'
aPrelude>  -- Note, no new line
```

`putStr :: String -> IO ()` - String stdout .

```
Prelude> putStr "This is a string!"
This is a string!Prelude>  -- Note, no new line
```

`putStrLn :: String -> IO ()` - stdout String .

```
Prelude> putStrLn "Hi there, this is another String!"
Hi there, this is another String!
```

`print :: Show a => a -> IO ()` - Show stdout a

```
Prelude> print "hi"
"hi"
Prelude> print 1
1
Prelude> print 'a'
'a'
Prelude> print (Just 'a')  -- Maybe is an instance of the `Show` type class
Just 'a'
Prelude> print Nothing
Nothing
```

`deriving` `Show` .

```
-- In ex.hs
data Person = Person { name :: String } deriving Show
main = print (Person "Alex")  -- Person is an instance of `Show`, thanks to `deriving`
```

GHCi :

```
Prelude> :load ex.hs
[1 of 1] Compiling ex             ( ex.hs, interpreted )
Ok, modules loaded: ex.
*Main> main  -- from ex.hs
Person {name = "Alex"}
*Main>
```

`stdin`

Haskell 2010 Prelude IO .

getChar :: IO Char - stdin Char

```
-- MyChar.hs
main = do
  myChar <- getChar
  print myChar

-- In your shell

runhaskell MyChar.hs
a -- you enter a and press enter
'a'  -- the program prints 'a'
```

getLine :: IO String - stdin String . .

```
Prelude> getLine
Hello there!  -- user enters some text and presses enter
"Hello there!"
```

read :: Read a => String -> a -

```
Prelude> read "1" :: Int
1
Prelude> read "1" :: Float
1.0
Prelude> read "True" :: Bool
True
```

.

- `getContents :: IO String` - . .
- `interact :: (String -> String) -> IO ()` - String -> String . .

: https://riptutorial.com/ko/haskell/topic/1904/

61:

(: data-fix recursion-schemes ( )). Hayoo .

Examples

Fix "" .

```
newtype Fix f = Fix { unFix :: f (Fix f) }
```

Fix f f . f Fix f Fix f . f Fix f .

. r .

```
{-# LANGUAGE DeriveFunctor #-}

-- natural numbers
-- data Nat = Zero | Suc Nat
data NatF r = Zero_ | Suc_ r deriving Functor
type Nat = Fix NatF

zero :: Nat
zero = Fix Zero_
suc :: Nat -> Nat
suc n = Fix (Suc_ n)


-- lists: note the additional type parameter a
-- data List a = Nil | Cons a (List a)
data ListF a r = Nil_ | Cons_ a r deriving Functor
type List a = Fix (ListF a)

nil :: List a
nil = Fix Nil_
cons :: a -> List a -> List a
cons x xs = Fix (Cons_ x xs)


-- binary trees: note two recursive occurrences
-- data Tree a = Leaf | Node (Tree a) a (Tree a)
data TreeF a r = Leaf_ | Node_ r a r deriving Functor
type Tree a = Fix (TreeF a)

leaf :: Tree a
leaf = Fix Leaf_
node :: Tree a -> a -> Tree a -> Tree a
node l x r = Fix (Node_ l x r)
```

Catamorphisms , . cata (*)* fixpoint . cata f Functor .

```
cata :: Functor f => (f a -> a) -> Fix f -> a
cata f = f . fmap (cata f) . unFix
```

```
-- list example
foldr :: (a -> b -> b) -> b -> List a -> b
foldr f z = cata alg
    where alg Nil_ = z
          alg (Cons_ x acc) = f x acc
```

(anamorphisms), , . `ana` ( ) *coalgebra* fixpoint . `ana` `f` `Functor` .

```
ana :: Functor f => (a -> f a) -> a -> Fix f
ana f = Fix . fmap (ana f) . f

-- list example
unfoldr :: (b -> Maybe (a, b)) -> b -> List a
unfoldr f = ana coalg
    where coalg x = case f x of
                         Nothing -> Nil_
                         Just (x, y) -> Cons_ x y
```

`ana` `cata` . .

,

. . .

```
hylo :: Functor f => (a -> f a) -> (f b -> b) -> a -> b
hylo f g = g . fmap (hylo f g) . f  -- no mention of Fix!
```

:

```
hylo f g = cata g . ana f
         = g . fmap (cata g) . unFix . Fix . fmap (ana f) . f  -- definition of cata and ana
         = g . fmap (cata g) . fmap (ana f) . f  -- unfix . Fix = id
         = g . fmap (cata g . ana f) . f  -- Functor law
         = g . fmap (hylo f g) . f  -- definition of hylo
```

Paramorphisms . .

```
para :: Functor f => (f (Fix f, a) -> a) -> Fix f -> a
para f = f . fmap (\x -> (x, para f x)) . unFix
```

Prelude `tails` paramorphism .

```
tails :: List a -> List (List a)
tails = para alg
    where alg Nil_ = cons nil nil  -- [[]]
          alg (Cons_ x (xs, xss)) = cons (cons x xs) xss  -- (x:xs):xss
```

Apomorphisms corecursion. .

```
apo :: Functor f => (a -> f (Either (Fix f) a)) -> a -> Fix f
apo f = Fix . fmap (either id (apo f)) . f
```

`apo` `para` *dual* . . `para` `apo` `Either` , .

: https://riptutorial.com/ko/haskell/topic/2984/-

62:

Foldable t :: * -> * . fold .

t Foldable ta a "" ta . foldMap :: Monoid m => (a -> m) -> (ta -> m) : foldMap :: Monoid m => (a -> m) -> (ta -> m) . Monoid Monoid ( ).

Examples

Foldable

length a ta .

```
ghci> length [7, 2, 9]  -- t ~ []
3
ghci> length (Right 'a')  -- t ~ Either e
1  -- 'Either e a' may contain zero or one 'a'
ghci> length (Left "foo")  -- t ~ Either String
0
ghci> length (3, True)  -- t ~ (,) Int
1  -- '(c, a)' always contains exactly one 'a'
```

length .

```
class Foldable t where
    -- ...
    length :: t a -> Int
    length = foldl' (\c _ -> c+1) 0
```

Int length . fromIntegral .

Dual . Dual .

```
newtype Dual a = Dual { getDual :: a }

instance Monoid m => Monoid (Dual m) where
    mempty = Dual mempty
    (Dual x) `mappend` (Dual y) = Dual (y `mappend` x)
```

foldMap foldMap Dual . Reverse Data.Functor.Reverse .

```
newtype Reverse t a = Reverse { getReverse :: t a }

instance Foldable t => Foldable (Reverse t) where
    foldMap f = getDual . foldMap (Dual . f) . getReverse
```

reverse :

```
reverse :: [a] -> [a]
```

```
reverse = toList . Reverse
```

Foldable

Foldable foldMap foldr .

```
data Tree a = Leaf
            | Node (Tree a) a (Tree a)

instance Foldable Tree where
    foldMap f Leaf = mempty
    foldMap f (Node l x r) = foldMap f l `mappend` f x `mappend` foldMap f r

    foldr f acc Leaf = acc
    foldr f acc (Node l x r) = foldr f (f x (foldr f acc r)) l
```

.

```
ghci> let myTree = Node (Node Leaf 'a' Leaf) 'b' (Node Leaf 'c' Leaf)

--    +--'b'--+
--    |       |
-- +-'a'-+ +-'c'-+
-- |     | |     |
-- *     * *     *

ghci> toList myTree
"abc"
```

DeriveFoldable GHC Foldable . Node .

```
data Inorder a = ILeaf
               | INode (Inorder a) a (Inorder a)  -- as before
               deriving Foldable

data Preorder a = PrLeaf
                | PrNode a (Preorder a) (Preorder a)
                deriving Foldable

data Postorder a = PoLeaf
                 | PoNode (Postorder a) (Postorder a) a
                 deriving Foldable

-- injections from the earlier Tree type
inorder :: Tree a -> Inorder a
inorder Leaf = ILeaf
inorder (Node l x r) = INode (inorder l) x (inorder r)

preorder :: Tree a -> Preorder a
preorder Leaf = PrLeaf
preorder (Node l x r) = PrNode x (preorder l) (preorder r)

postorder :: Tree a -> Postorder a
postorder Leaf = PoLeaf
postorder (Node l x r) = PoNode (postorder l) (postorder r) x
```

```
ghci> toList (inorder myTree)
"abc"
ghci> toList (preorder myTree)
"bac"
ghci> toList (postorder myTree)
"acb"
```

toList Foldable ta S. a

```
ghci> toList [7, 2, 9]  -- t ~ []
[7, 2, 9]
ghci> toList (Right 'a')  -- t ~ Either e
"a"
ghci> toList (Left "foo")  -- t ~ Either String
[]
ghci> toList (3, True)  -- t ~ (,) Int
[True]
```

toList .

```
class Foldable t where
    -- ...
    toList :: t a -> [a]
    toList = foldr (:) []
```

Foldable

traverse_ Foldable Applicative . . Traversable .

```
-- using the Writer applicative functor (and the Sum monoid)
ghci> runWriter $ traverse_ (\x -> tell (Sum x)) [1,2,3]
((),Sum {getSum = 6})
-- using the IO applicative functor
ghci> traverse_ putStrLn (Right "traversing")
traversing
ghci> traverse_ putStrLn (Left False)
-- nothing printed
```

for_ traverse_ . foreach .

```
ghci> let greetings = ["Hello", "Bonjour", "Hola"]
ghci> :{
ghci|     for_ greetings $ \greeting -> do
ghci|         print (greeting ++ " Stack Overflow!")
ghci| :}
"Hello Stack Overflow!"
"Bonjour Stack Overflow!"
"Hola Stack Overflow!"
```

sequenceA_ Applicative Foldable .

```
ghci> let actions = [putStrLn "one", putStLn "two"]
ghci> sequenceA_ actions
one
```

```
two
```

traverse_ .

```
traverse_ :: (Foldable t, Applicative f) => (a -> f b) -> t a -> f ()
traverse_ f = foldr (\x action -> f x *> action) (pure ())
```

sequenceA_ .

```
sequenceA_ :: (Foldable t, Applicative f) -> t (f a) -> f ()
sequenceA_ = traverse_ id
```

Foldable Functor traverse_ sequenceA_ .

```
traverse_ f = sequenceA_ . fmap f
```

Foldable Monoid

foldMap (A) Monoid .

foldMap foldr . , Foldable .

```
class Foldable t where
    foldMap :: Monoid m => (a -> m) -> t a -> m
    foldMap f = foldr (mappend . f) mempty
```

Product :

```
product :: (Num n, Foldable t) => t n -> n
product = getProduct . foldMap Product
```

Foldable

```
class Foldable t where
    {-# MINIMAL foldMap | foldr #-}

    foldMap :: Monoid m => (a -> m) -> t a -> m
    foldMap f = foldr (mappend . f) mempty

    foldr :: (a -> b -> b) -> b -> t a -> b
    foldr f z t = appEndo (foldMap (Endo #. f) t) z

    -- and a number of optional methods
```

( ) Foldable a a . foldMap Monoid Monoid .

Foldable

null foldable ta a True , False . null True length 0.

```
ghci> null []
True
ghci> null [14, 29]
False
ghci> null Nothing
True
ghci> null (Right 'a')
False
ghci> null ('x', 3)
False
```

`null` .

```
class Foldable t where
    -- ...
    null :: t a -> Bool
    null = foldr (\_ _ -> False) True
```

: https://riptutorial.com/ko/haskell/topic/753/-

63:

Examples

```
insert :: Ord a => a -> [a] -> [a]
insert x [] = [x]
insert x (y:ys) | x < y     = x:y:ys
                | otherwise = y:(insert x ys)

isort :: Ord a => [a] -> [a]
isort [] = []
isort (x:xs) = insert x (isort xs)
```

:

```
> isort [5,4,3,2,1]
```

:

```
[1,2,3,4,5]
```

:

```
merge :: Ord a => [a] -> [a] -> [a]
merge xs [] = xs
merge [] ys = ys
merge (x:xs) (y:ys) | x <= y    = x:merge xs (y:ys)
                    | otherwise = y:merge (x:xs) ys
```

:

```
msort :: Ord a => [a] -> [a]
msort [] = []
msort [a] = [a]
msort xs = merge (msort (firstHalf xs)) (msort (secondHalf xs))

firstHalf  xs = let { n = length xs } in take (div n 2) xs
secondHalf xs = let { n = length xs } in drop (div n 2) xs
```

.

:

```
> msort [3,1,4,5,2]
```

:

```
[1,2,3,4,5]
```

:

```
msort [] = []
msort xs = go [[x] | x <- xs]
    where
    go [a] = a
    go xs = go (pairs xs)
    pairs (a:b:t) = merge a b : pairs t
    pairs t = t
```

```
qsort :: (Ord a) => [a] -> [a]
qsort [] = []
qsort (x:xs) = qsort [a | a <- xs, a < x]
                      ++ [x] ++
               qsort [b | b <- xs, b >= x]
```

```
bsort :: Ord a => [a] -> [a]
bsort s = case bsort' s of
               t | t == s    -> t
                 | otherwise -> bsort t
  where bsort' (x:x2:xs) | x > x2    = x2:(bsort' (x:xs))
                         | otherwise = x:(bsort' (x2:xs))
        bsort' s = s
```

bogosort .

```
import Data.List (permutations)

sorted :: Ord a => [a] -> Bool
sorted (x:y:xs) = x <= y && sorted (y:xs)
sorted _        = True

psort :: Ord a => [a] -> [a]
psort = head . filter sorted . permutations
```

( ).

.

```
import Data.List (minimum, delete)

ssort :: Ord t => [t] -> [t]
ssort [] = []
ssort xs = let { x = minimum xs }
           in  x : ssort (delete x xs)
```

: https://riptutorial.com/ko/haskell/topic/2300/-

64:

( ) . (+) , ().

Examples

`&&` AND, `||` OR.

`==` , `/=` , `<` / `<=` `>` / `>=` .

`+` , `-` `/` . (- `quot` `div`). .

- `^` . ( ) . :

  ```
  4^5  ≡  (4*4)*(4*4)*4
  ```

- `^^` . :

  ```
  3^^(-2)  ≡  1 / (2*2)
  ```

  `^` (: `4^^5 :: Int` `4^5 :: Int` `4^^5 :: Rational`).

- `**` . `^` `^^` .

  ```
  2**pi  ≡  exp (pi * log 2)
  ```

.

- `:` (cons cons pron) . (" ") .

- `++` .

  ```
  [1,2] ++ [3,4]  ≡  1 : 2 : [3,4]  ≡  1 : [2,3,4]  ≡  [1,2,3,4]
  ```

`!!` .

```
[0, 10, 20, 30, 40] !! 3  ≡  30
```

($O(1)$ N $O()$ $O(N)$); .

- `$` .

```
f $ x  ≡  f x
       ≡  f(x)  -- disapproved style
```

. $! .

- . .

```
(f . g) x  ≡  f (g x)  ≡  f $ g x
```

- `>>` . : `writeFile "foo.txt" "bla" >> putStrLn "Done."` .
- `>>=` . `readLn >>= \x -> print (x^2)` .

Haskell . , .

```
(>+<) :: [a] -> [a] -> [a]
env >+< l = env ++ l ++ env

GHCi> "**">+<"emphasis"
"**emphasis**"
```

.

```
infixr 5 >+<
```

(`>+<` `++` `:` do) .

Haskell . .

- Hayoo Hoogle . .
- GHCi IHaskell `:i` `:t` (**i** nfo **t** ype) . ,

```
Prelude> :i +
class Num a where
  (+) :: a -> a -> a
  ...
        -- Defined in 'GHC.Num'
infixl 6 +
Prelude> :i ^^
(^^) :: (Fractional a, Integral b) => a -> b -> a
        -- Defined in 'GHC.Real'
infixr 8 ^^
```

`^^` `+` , , `^^` .

`:t` .

```
Prelude> :t (==)
(==) :: Eq a => a -> a -> Bool
```

: https://riptutorial.com/ko/haskell/topic/6792/-

65:

Examples

GHC .

`-prof -fprof-auto` .

.

```
main = print (fib 30)
fib n = if n < 2 then 1 else fib (n-1) + fib (n-2)
```

:

```
ghc -prof -fprof-auto -rtsopts Main.hs
```

.

```
./Main +RTS -p
```

`main.prof` , :

```
    Wed Oct 12 16:14 2011 Time and Allocation Profiling Report  (Final)

           Main +RTS -p -RTS

        total time  =        0.68 secs   (34 ticks @ 20 ms)
        total alloc = 204,677,844 bytes  (excludes profiling overheads)

COST CENTRE MODULE  %time %alloc

fib         Main    100.0  100.0


                                                      individual     inherited
COST CENTRE MODULE                  no.      entries  %time %alloc   %time %alloc

MAIN        MAIN                    102           0    0.0    0.0   100.0  100.0
 CAF        GHC.IO.Handle.FD        128           0    0.0    0.0     0.0    0.0
 CAF        GHC.IO.Encoding.Iconv   120           0    0.0    0.0     0.0    0.0
 CAF        GHC.Conc.Signal         110           0    0.0    0.0     0.0    0.0
 CAF        Main                    108           0    0.0    0.0   100.0  100.0
  main      Main                    204           1    0.0    0.0   100.0  100.0
   fib      Main                    205     2692537  100.0  100.0   100.0  100.0
```

GHC (`-fprot-auto`) `{-# SCC "name" #-} <expression>` Haskell . "name" `<expression>` .

```
-- Main.hs
main :: IO ()
main = do let l = [1..9999999]
```

```
        print $ {-# SCC "print_list" #-} (length l)
```

-fprof +RTS -p ghc -prof -rtsopts Main.hs && ./Main.hs +RTS -p Main.prof .

: https://riptutorial.com/ko/haskell/topic/4342/

66: - .

Examples

Map .

```
Map.fromList [("Alex", 31), ("Bob", 22)]
```

Map .

```
> Map.singleton "Alex" 31
fromList [("Alex",31)]
```

`empty` .

```
empty :: Map k a
```

Data.Map `union` , `difference` `intersection` `intersection` .

`null` Map .

```
> Map.null $ Map.fromList [("Alex", 31), ("Bob", 22)]
False

> Map.null $ Map.empty
True
```

.

`member :: Ord k => k -> Map ka -> Bool` `k` `Map ka` `True` .

```
> Map.member "Alex" $ Map.singleton "Alex" 31
True
> Map.member "Jenny" $ Map.empty
False
```

`notMember` .

```
> Map.notMember "Alex" $ Map.singleton "Alex" 31
False
> Map.notMember "Jenny" $ Map.empty
True
```

key `findWithDefault :: Ord k => a -> k -> Map ka -> a` .

```
Map.findWithDefault 'x' 1 (fromList [(5,'a'), (3,'b')]) == 'x'
Map.findWithDefault 'x' 5 (fromList [(5,'a'), (3,'b')]) == 'a'
```

.

```
> let m = Map.singleton "Alex" 31
fromList [("Alex",31)]

> Map.insert "Bob" 99 m
fromList [("Alex",31),("Bob",99)]
```

```
> let m = Map.fromList [("Alex", 31), ("Bob", 99)]
fromList [("Alex",31),("Bob",99)]

> Map.delete "Bob" m
fromList [("Alex",31)]
```

`containers` `Data.Map` `Map` .

`Data.Map` Prelude .

```
import qualified Data.Map as Map
```

`Map` `Map` `Map.` , .

```
Map.empty -- give me an empty Map
```

Monoid

`Map kv` Monotype :

- `mempty` `Map` , `Map.empty` `Map.empty`
- `m1 <> m2` `m1` `m2` , , `m1` `m2` , `m1` `m1 <> m2` . `Monoid` `Map.union` .

- . : https://riptutorial.com/ko/haskell/topic/4591/-----

67:

. . (,) " . GHC 7.8 . . .

Haskell .

GHC .

Examples

(_) . .

. . (GHC trac).

> GHC .
>
> `-fdefer-type-errors` `-fdefer-typed-holes` .
>
> `-fwarn-typed-holes` . `-fdefer-type-errors` `-fdefer-typed-holes` `-fdefer-typed-holes` . ( ) `-fno-warn-typed-holes` . .

`undefined` `undefined` , . ( ) , ( ) . :

```
Prelude> \x -> _var + length (drop 1 x)

<interactive>:19:7: Warning:
    Found hole `_var' with type: Int
    Relevant bindings include
      x :: [a] (bound at <interactive>:19:2)
      it :: [a] -> Int (bound at <interactive>:19:1)
    In the first argument of `(+)', namely `_var'
    In the expression: _var + length (drop 1 x)
    In the expression: \ x -> _var + length (drop 1 x)
```

GHCi repl `it` (`[a] -> Int`).

.

`Foo` `Bar` (`Foo` `Bar`) . `Foo` , , . !

.

```
instance Foo Bar where
```

.

```
Bar.hs:13:10: Warning:
No explicit implementation for
  'foom' and 'quun'
```

```
In the instance declaration for ‘Foo Bar’
```

, `foom` `foom` `Bar` . ? . :

```
instance Foo Bar where
  foom = _
```

" " .

```
Bar.hs:14:10:
    Found hole ‘_’ with type: Bar -> Gronk Bar
    Relevant bindings include
      foom :: Bar -> Gronk Bar (bound at Foo.hs:4:28)
    In the expression: _
    In an equation for ‘foom’: foom = _
    In the instance declaration for ‘Foo Bar’
```

`Bar` . . .

`Gronk` `Gronk` ? [Hayoo](https://hayoo.fh-wedel.de/) . : , . , `Gronk a` .

```
instance Foo Bar where
  foom bar = _ Gronk
```

, `Gronk` ,

```
    Found hole ‘_’
      with type: (Int -> [(Int, b0)] -> Gronk b0) -> Gronk Bar
    Where: ‘b0’ is an ambiguous type variable
```

. . `Gronk` .

```
instance Foo Bar where
  foom bar = Gronk _ _
```

.

```
    Found hole ‘_’ with type: [(Int, Bar)]
    Relevant bindings include
      bar :: Bar (bound at Bar.hs:14:29)
      foom :: Bar -> Gronk Bar (bound at Foo.hs:15:24)
    In the second argument of ‘Gronk’, namely ‘_’
    In the expression: Gronk _ _
    In an equation for ‘foom’: foom bar = Gronk _ _
```

`bar` (`Relevant bindings`). . . .

(: haskell-mode Emacs). IDE .

: https://riptutorial.com/ko/haskell/topic/4913/--

68: HTML

Examples

div ID .

Taggy-lens HTML .

```
#!/usr/bin/env stack
-- stack --resolver lts-7.0 --install-ghc runghc --package text --package lens --package
taggy-lens

{-# LANGUAGE OverloadedStrings #-}

import qualified Data.Text.Lazy as TL
import qualified Data.Text.IO as T
import Text.Taggy.Lens
import Control.Lens

someHtml :: TL.Text
someHtml =
    "\
    \<!doctype html><html><body>\
    \<div>first div</div>\
    \<div id=\"thediv\">second div</div>\
    \<div id=\"not-thediv\">third div</div>"

main :: IO ()
main = do
    T.putStrLn
        (someHtml ^. html . allAttributed (ix "id" . only "thediv") . contents)
```

`id="article"` div .

```
#!/usr/bin/env stack
-- stack --resolver lts-7.1 --install-ghc runghc --package text --package lens --package
taggy-lens --package string-class --package classy-prelude
{-# LANGUAGE NoImplicitPrelude #-}
{-# LANGUAGE OverloadedStrings #-}

import ClassyPrelude
import Control.Lens hiding (children, element)
import Data.String.Class (toText, fromText, toString)
import Data.Text (Text)
import Text.Taggy.Lens
import qualified Text.Taggy.Lens as Taggy
import qualified Text.Taggy.Renderer as Renderer

somehtmlSmall :: Text
somehtmlSmall =
    "<!doctype html><html><body>\
    \<div id=\"article\"><div>first</div><div>second</div><script>this should be
removed</script><div>third</div></div>\
    \</body></html>"
```

```
renderWithoutScriptTag :: Text
renderWithoutScriptTag =
    let mArticle :: Maybe Taggy.Element
        mArticle =
            (fromText somehtmlSmall) ^? html .
            allAttributed (ix "id" . only "article")
        mArticleFiltered =
            fmap
                (transform
                     (children %~
                      filter (\n -> n ^? element . name /= Just "script")))
                mArticle
    in maybe "" (toText . Renderer.render) mArticleFiltered

main :: IO ()
main = print renderWithoutScriptTag
-- outputs:
-- "<div id=\"article\"><div>first</div><div>second</div><div>third</div></div>"
```

@ duplode SO

HTML : https://riptutorial.com/ko/haskell/topic/6962/----html--

69: &

?

GHC . .

? (?)

. Template Haskell . "" 0 1 .

0 1 . ( ) .

( ) 0 1. .

1 `Q Exp` , `Q Type` 0 . . `Q Exp` (0) 1 ,

1 . . *n* *m*> *n* . 1 .

```
>:t [| \x -> $x |]

<interactive>:1:10: error:
    * Stage error: `x' is bound at stage 2 but used at stage 1
    * In the untyped splice: $x
      In the Template Haskell quotation [| \ x -> $x |]
```

Template Haskell ?

, Haskell . , . Template Haskell . TH .

Examples

Q

`Language.Haskell.TH.Syntax` `Q :: * -> *` constructor, abstract . `Q` TH ( ). `x` `QX` .

.

- ,
    -
    -
    - (,)
- (, , ,)
- (GHC 7.10)
- GHC (GHC 8.0)

`Q` `newName :: String -> Q Name` . .

`Q` `Functor,Monad,Applicative` `Language.Haskell.TH.Lib` `Q` . TH ast .

```
LitE :: Lit -> Exp
litE :: Lit -> ExpQ

AppE :: Exp -> Exp -> Exp
appE :: ExpQ -> ExpQ -> ExpQ
```

`ExpQ` , `TypeQ` , `DecsQ` `PatQ` `Q` AST .

TH `runQ :: Quasi m => Q a -> ma` `Quasi IO` `Q` `IO` . `runQ :: Q a -> IO a` `IO` . `Q` . `IO` .

```
curry :: ((a,b) -> c) -> a -> b -> c
curry = \f a b -> f (a,b)
```

. .

```
curry3 :: ((a, b, c) -> d) -> a -> b -> c -> d
curry4 :: ((a, b, c, d) -> e) -> a -> b -> c -> d -> e
```

2 (:) 20 (20).

Template Haskell `n` `curryN` .

```
{-# LANGUAGE TemplateHaskell #-}
import Control.Monad (replicateM)
import Language.Haskell.TH (ExpQ, newName, Exp(..), Pat(..))
import Numeric.Natural (Natural)

curryN :: Natural -> Q Exp
```

`curryN` (Haskell AST) `curryN` .

```
curryN n = do
  f  <- newName "f"
  xs <- replicateM (fromIntegral n) (newName "x")
```

. .

```
  let args = map VarP (f:xs)
```

`args` `f x1 x2 .. xn` . . , let LHS ( ) .

```
      ntup = TupE (map VarE xs)
```

. . (`VarP`) (`VarE`) .

```
  return $ LamE args (AppE (VarE f) ntup)
```

AST `\f x1 x2 .. xn -> f (x1, x2, .. , xn)` .

'' .

```
...
import Language.Haskell.TH.Lib

curryN' :: Natural -> ExpQ
curryN' n = do
  f  <- newName "f"
  xs <- replicateM (fromIntegral n) (newName "x")
  lamE (map varP (f:xs))
        [| $(varE f) $(tupE (map varE xs)) |]
```

`[| \ $(map varP (f:xs)) -> .. |]` Haskell 'list' `[| \ $(map varP (f:xs)) -> .. |]` . `\ var -> ..` `\ var -> ..` `PatQ` , .

GHCi TH .

```
>:set -XTemplateHaskell
>:t $(curryN 5)
$(curryN 5)
  :: ((t1, t2, t3, t4, t5) -> t) -> t1 -> t2 -> t3 -> t4 -> t5 -> t
>$(curryN 5) (\(a,b,c,d,e) -> a+b+c+d+e) 1 2 3 4 5
15
```

.

Template Haskell Quasiquotes

`-XTemplateHaskell` GHC . . Template Haskell .

- `$(...)` Template Haskell . `(...)` .
- `$` . Template Haskell `$` . , `f$g` `($)` `fg` . Template Haskell .
- `$` . .
- splice Haskell AST AST Haskell .
- , , . `Q Exp` , `Q Pat` , `Q Type` , `Q [Decl]` . , .

(: QuasiQuotation)

- .
  - `[e|..|]` `[|..|]` - `..` `Q Exp` .
  - `[p|..|]` - `..` `Q Pat` .

- [t|..|] - .. Q Type .
- [d|..|] - .. Q [Dec] .

- AST .
- (: `\x -> [| x |]`) `\x -> [| $(lift x) |]` , `lift :: Lift t => t -> Q Exp` .

```
class Lift t where
  lift :: t -> Q Exp
  default lift :: Data t => t -> Q Exp
```

- ( ) `$$(..)` `$$(..)` `(..)` .
- `e` `Q (TExp a)` `$$e` `a` `Q (TExp a)` .
- `[||..||]` `[||..||]` `..` `a` . `Q (TExp a)` .
- : `unType :: TExp a -> Exp` .

- QuasiQuotes - (`e,p,t,d`) QuasiQuotes . .
- `[iden|...|]` , `iden` `Language.Haskell.TH.Quote.QuasiQuoter` .
- `QuasiQuoter` .

```
data QuasiQuoter = QuasiQuoter { quoteExp  :: String -> Q Exp,
                                 quotePat  :: String -> Q Pat,
                                 quoteType :: String -> Q Type,
                                 quoteDec  :: String -> Q [Dec] }
```

- `Language.Haskell.TH.Syntax.Name` . Template Haskell Haskell .
- `'e` `'T` . `e` `T` ( ).

& : https://riptutorial.com/ko/haskell/topic/5216/---amp---

70: (, ...)

- Haskell .
- (written `()`) .
- . . .

Examples

.

. .

```
(1, 2)
```

.

```
(1, 2, 3)

(1, 2, 3, 4)
```

unsugared .

```
(,) 1 2     -- equivalent to (1,2)
(,,) 1 2 3  -- equivalent to (1,2,3)
```

.

```
("answer", 42, '?')
```

.

```
([1, 2, 3], "hello", ('A', 65))

(1, (2, (3, 4), 5), 6)
```

. .

```
(Int, Int)
```

.

```
(Int, Int, Int)

(Int, Int, Int, Int)
```

.

```
(String, Int, Char)
```

.

```
([Int], String, (Char, Int))

(Int, (Int, (Int, Int), Int), Int)
```

. (,) .

```
myFunction1 (a, b) = ...
```

.

```
myFunction2 (a, b, c) = ...

myFunction3 (a, b, c, d) = ...
```

.

```
myFunction4 ([a, b, c], d, e) = ...

myFunction5 (a, (b, (c, d), e), f) = ...
```

`Prelude` `Data.Tuple` `fst` `snd` .

```
fst (1, 2) -- evaluates to 1

snd (1, 2) -- evaluates to 2
```

.

```
case (1, 2) of (result, _) => result -- evaluates to 1

case (1, 2) of (_, result) => result -- evaluates to 2
```

.

```
case (1, 2, 3) of (result, _, _) => result -- evaluates to 1

case (1, 2, 3) of (_, result, _) => result -- evaluates to 2

case (1, 2, 3) of (_, _, result) => result -- evaluates to 3
```

Haskell `fst` `snd` . Hackage `tuple` `Data.Tuple.Select` .

(uncurrying).

uncurry (Prelude Data.Tuple) .

```
uncurry (+) (1, 2) -- computes 3

uncurry map (negate, [1, 2, 3]) -- computes [-1, -2, -3]

uncurry uncurry ((+), (1, 2)) -- computes 3

map (uncurry (+)) [(1, 2), (3, 4), (5, 6)] -- computes [3, 7, 11]

uncurry (curry f) -- computes the same as f
```

(currying)

Prelude Data.Tuple curry .

```
curry fst 1 2 -- computes 1

curry snd 1 2 -- computes 2

curry (uncurry f) -- computes the same as f

import Data.Tuple (swap)
curry swap 1 2 -- computes (2, 1)
```

swap (Data.Tuple) .

```
import Data.Tuple (swap)
swap (1, 2) -- evaluates to (2, 1)
```

.

```
case (1, 2) of (x, y) => (y, x) -- evaluates to (2, 1)
```

(p1, p2) . , (Data.Function.fix) .

```
fix $ \(x, y) -> (1, 2)
```

(x, y) . (1, 2) .

```
fix $ \ ~(x, y) -> (1, 2)
```

(, ...) : https://riptutorial.com/ko/haskell/topic/5342/---------

71:

hackage :

.

" " .

await :: Monad m => Consumer' ama

. a .

yield :: Monad m => a -> Producer' am ()

. a .

Pipes Producer , Consumer Effect Pipes.Tutorial .

Examples

Producer yield :

```
type Producer b = Proxy X () () b
yield :: Monad m => a -> Producer a m ()
```

:

```
naturals :: Monad m => Producer Int m ()
naturals = each [1..] -- each is a utility function exported by Pipes
```

Producer :

```
naturalsUntil :: Monad m => Int -> Producer Int m ()
naturalsUntil n = each [1..n]
```

Consumer await await .

```
type Consumer a = Proxy () a () X
await :: Monad m => Consumer a m a
```

:

```
fancyPrint :: MonadIO m => Consumer String m ()
fancyPrint = forever $ do
  numStr <- await
  liftIO $ putStrLn ("I received: " ++ numStr)
```

await yield await .

```
type Pipe a b = Proxy () a () b
```

Int String :

```
intToStr :: Monad m => Pipe Int String m ()
intToStr = forever $ await >>= (yield . show)
```

runEffect

runEffect Pipe :

```
main :: IO ()
main = do
  runEffect $ naturalsUntil 10 >-> intToStr >-> fancyPrint
```

runEffect Proxy Effect .

```
runEffect :: Monad m => Effect m r -> m r
type Effect = Proxy X () () X
```

(X Void).

>-> Producer , Consumer Pipe Pipe .

```
printNaturals :: MonadIO m => Effect m ()
printNaturals = naturalsUntil 10 >-> intToStr >-> fancyPrint
```

Producer , Consumer , Pipe Effect Proxy . >-> . .

```
(>->) :: Monad m => Producer b m r -> Consumer b   m r -> Effect       m r
(>->) :: Monad m => Producer b m r -> Pipe     b c m r -> Producer   c m r
(>->) :: Monad m => Pipe   a b m r -> Consumer b   m r -> Consumer a   m r
(>->) :: Monad m => Pipe   a b m r -> Pipe     b c m r -> Pipe     a c m r
```

pipes Proxy . Pipe , Producer , Consumer Proxy .

Proxy Pipe await yield , m .

.

:

1. FirstMessage .
2. DoSomething 0 .
3. DoNothing DoNothing
4. 2 3 .

:

```
-- Command.hs
{-# LANGUAGE DeriveGeneric #-}
module Command where
import Data.Binary
import GHC.Generics (Generic)

data Command = FirstMessage
           | DoNothing
           | DoSomething Int
           deriving (Show,Generic)

instance Binary Command
```

.

```
module Server where

import Pipes
import qualified Pipes.Binary as PipesBinary
import qualified Pipes.Network.TCP as PNT
import qualified Command as C
import qualified Pipes.Parse as PP
import qualified Pipes.Prelude as PipesPrelude

pageSize :: Int
pageSize = 4096

-- pure handler, to be used with PipesPrelude.map
pureHandler :: C.Command -> C.Command
pureHandler c = c  -- answers the same command that we have receveid

-- impure handler, to be used with PipesPremude.mapM
sideffectHandler :: MonadIO m => C.Command -> m C.Command
sideffectHandler c = do
  liftIO $ putStrLn $ "received message = " ++ (show c)
  return $ C.DoSomething 0
  -- whatever incoming command `c` from the client, answer DoSomething 0

main :: IO ()
main = PNT.serve (PNT.Host "127.0.0.1") "23456" $
  \(connectionSocket, remoteAddress) -> do
                 putStrLn $ "Remote connection from ip = " ++ (show remoteAddress)
                 _ <- runEffect $ do
                   let bytesReceiver = PNT.fromSocket connectionSocket pageSize
                   let commandDecoder = PP.parsed PipesBinary.decode bytesReceiver
                   commandDecoder >-> PipesPrelude.mapM sideffectHandler >-> for cat
PipesBinary.encode >-> PNT.toSocket connectionSocket
                   -- if we want to use the pureHandler
                   --commandDecoder >-> PipesPrelude.map pureHandler >-> for cat
PipesBinary.Encode >-> PNT.toSocket connectionSocket
                 return ()
```

.

```
module Client where

import Pipes
import qualified Pipes.Binary as PipesBinary
import qualified Pipes.Network.TCP as PNT
```

```
import qualified Pipes.Prelude as PipesPrelude
import qualified Pipes.Parse as PP
import qualified Command as C

pageSize :: Int
pageSize = 4096

-- pure handler, to be used with PipesPrelude.amp
pureHandler :: C.Command -> C.Command
pureHandler c = c  -- answer the same command received from the server

-- inpure handler, to be used with PipesPremude.mapM
sideffectHandler :: MonadIO m => C.Command -> m C.Command
sideffectHandler c = do
  liftIO $ putStrLn $ "Received: " ++ (show c)
  return C.DoNothing  -- whatever is received from server, answer DoNothing

main :: IO ()
main = PNT.connect ("127.0.0.1") "23456" $
  \(connectionSocket, remoteAddress) -> do
    putStrLn $ "Connected to distant server ip = " ++ (show remoteAddress)
    sendFirstMessage connectionSocket
    _ <- runEffect $ do
      let bytesReceiver = PNT.fromSocket connectionSocket pageSize
      let commandDecoder = PP.parsed PipesBinary.decode bytesReceiver
      commandDecoder >-> PipesPrelude.mapM sideffectHandler >-> for cat PipesBinary.encode >->
PNT.toSocket connectionSocket
    return ()

sendFirstMessage :: PNT.Socket -> IO ()
sendFirstMessage s = do
  _ <- runEffect $ do
    let encodedProducer = PipesBinary.encode C.FirstMessage
    encodedProducer >-> PNT.toSocket s
  return ()
```

: https://riptutorial.com/ko/haskell/topic/6768/

72:

Examples

:

.

. . 5.32€ + 2.94$? .

.

```
{-# LANGUAGE GeneralizedNewtypeDeriving #-}

data USD
data EUR

newtype Amount a = Amount Double
                 deriving (Show, Eq, Ord, Num)
```

`GeneralisedNewtypeDeriving` `Amount` `Num` . GHC `Double` `Num` .

`(5.0 :: Amount EUR)` . `(1.13 :: Amount EUR) + (5.30 :: Amount USD)` .

haskell .

: https://riptutorial.com/ko/haskell/topic/5227/-

73:

`Functor` covariantly `f :: * -> *` . .

Functor . `Maybe a` `[a]` . Typeclassopedia Functors .

Functor 2 .

```
fmap id == id
```

```
fmap (f . g) = (fmap f) . (fmap g)
```

Examples

Functor

`Maybe` `Functor` .

```
instance Functor Maybe where
    fmap f Nothing = Nothing
    fmap f (Just x) = Just (f x)
```

`Maybe` `Functor` `Just` . (, `Maybe` `Nothing`) `fmap` .

```
> fmap (+ 3) (Just 3)
Just 6
> fmap length (Just "mousetrap")
Just 9
> fmap sqrt Nothing
Nothing
```

. (identity law)

```
fmap id Nothing
Nothing  -- definition of fmap
id Nothing  -- definition of id

fmap id (Just x)
Just (id x)  -- definition of fmap
Just x  -- definition of id
id (Just x)  -- definition of id
```

,

```
(fmap f . fmap g) Nothing
fmap f (fmap g Nothing)  -- definition of (.)
fmap f Nothing  -- definition of fmap
```

```
Nothing  -- definition of fmap
fmap (f . g) Nothing  -- because Nothing = fmap f Nothing, for all f

(fmap f . fmap g) (Just x)
fmap f (fmap g (Just x))  -- definition of (.)
fmap f (Just (g x))  -- definition of fmap
Just (f (g x))  -- definition of fmap
Just ((f . g) x)  -- definition of (.)
fmap (f . g) (Just x)  -- definition of fmap
```

Functor .

```
instance Functor [] where
    fmap f [] = []
    fmap f (x:xs) = f x : fmap f xs
```

list comprehension : fmap f xs = [fx | x <- xs] .

fmap generalises map . map fmap Functor .

:

```
-- base case
fmap id []
[]  -- definition of fmap
id []  -- definition of id

-- inductive step
fmap id (x:xs)
id x : fmap id xs  -- definition of fmap
x : fmap id xs  -- definition of id
x : id xs  -- by the inductive hypothesis
x : xs  -- definition of id
id (x : xs)  -- definition of id
```

, :

```
-- base case
(fmap f . fmap g) []
fmap f (fmap g [])  -- definition of (.)
fmap f []  -- definition of fmap
[]  -- definition of fmap
fmap (f . g) []  -- because [] = fmap f [], for all f

-- inductive step
(fmap f . fmap g) (x:xs)
fmap f (fmap g (x:xs))  -- definition of (.)
fmap f (g x : fmap g xs)  -- definition of fmap
f (g x) : fmap f (fmap g xs)  -- definition of fmap
(f . g) x : fmap f (fmap g xs)  -- definition of (.)
(f . g) x : fmap (f . g) xs  -- by the inductive hypothesis
fmap (f . g) xs  -- definition of fmap
```

Functor . Functor .

```
instance Functor ((->) r) where
    fmap f g = \x -> f (g x)
```

fmap = (.) . fmap .

.

```
fmap id g
\x -> id (g x)  -- definition of fmap
\x -> g x  -- definition of id
g  -- eta-reduction
id g  -- definition of id
```

:

```
(fmap f . fmap g) h
fmap f (fmap g h)  -- definition of (.)
fmap f (\x -> g (h x))  -- definition of fmap
\y -> f ((\x -> g (h x)) y)  -- definition of fmap
\y -> f (g (h y))  -- beta-reduction
\y -> (f . g) (h y)  -- definition of (.)
fmap (f . g) h  -- definition of fmap
```

```
class Functor f where
    fmap :: (a -> b) -> f a -> f b
```

fmap f .

Functor , :

```
fmap id = id                    -- identity
fmap f . fmap g = fmap (f . g)  -- composition
```

<$> fmap fmap .

```
infixl 4 <$>
(<$>) :: Functor f => (a -> b) -> f a -> f b
(<$>) = fmap
```

Functor

Data.Functor , <$ $> .

```
infixl 4 <$, $>

<$ :: Functor f => a -> f b -> f a
(<$) = fmap . const

$> :: Functor f => f a -> b -> f b
```

```
($>) = flip (<$)
```

void .

```
void :: Functor f => f a -> f ()
void = (() <$)
```

Functor Functor . Functor , (functor) generic .

ID . SKI I .

```
newtype I a = I a

instance Functor I where
    fmap f (I x) = I (f x)
```

I , Identity Data.Functor.Identity .

. const SKI K .

```
newtype K c a = K c
```

K ca -values; a K () Proxy . K fmap !

```
instance Functor (K c) where
    fmap _ (K c) = K c
```

K Data.Functor.Const Const .

.

Functor Functor . , (,) :: * -> * -> * types * , (:*:) :: (* -> *) -> (* -> *) -> (* -> *) functors * -> * .

```
infixl 7 :*:
data (f :*: g) a = f a :*: g a

instance (Functor f, Functor g) => Functor (f :*: g) where
    fmap f (fx :*: gy) = fmap f fx :*: fmap f gy
```

Data.Functor.Product Product Product .

:*: (,) :+: Either Functor .

```
infixl 6 :+:
data (f :+: g) a = InL (f a) | InR (g a)

instance (Functor f, Functor g) => Functor (f :+: g) where
    fmap f (InL fx) = InL (fmap f fx)
    fmap f (InR gy) = InR (fmap f gy)
```

:+: Data.Functor.Sum Sum .

, :.: (.) .

```
infixr 9 :.:
newtype (f :.: g) a = Cmp (f (g a))

instance (Functor f, Functor g) => Functor (f :.: g) where
    fmap f (Cmp fgx) = Cmp (fmap (fmap f) fgx)
```

Compose Data.Functor.Compose .

I , K , :*: , :+: and :.: . . Functor Functor . I Fix .

	data Pair a = Pair aa	type Pair = I :*: I
2x2	type Grid a = Pair (Pair a)	type Grid = Pair :.: Pair
	data Nat = Zero | Succ Nat	type Nat = Fix (K () :+: I)
	data List a = Nil | Cons a (List a)	type List a = Fix (K () :+: K a :*: I)
	data Tree a = Leaf | Node (Tree a) a (Tree a)	type Tree a = Fix (K () :+: I :*: K a :*: I)
	data Rose a = Rose a (List (Rose a))	type Rose a = Fix (K a :*: List :.: I)

"" generics-sop . .

```
class Generic a where
    type Rep a  -- a generic representation built using a kit
    to :: a -> Rep a
    from :: Rep a -> a
```

Functor

Functor (") . () () .

(Hask) . **Hask Hask** .

Functor . f :: * -> * fmap :: (a -> b) -> (fa -> fb) . ,

```
class Functor (f :: * -> *) where
    fmap :: (a -> b) -> f a -> f b
```

`fmap` (morphism) `:: a -> b` `:: fa -> fb` . `Functor` **Hask** ( ) .

```
fmap (id {- :: a -> a -})  ==  id {- :: f a -> f a -}
fmap (h . g)               ==  fmap h . fmap g
```

`fmap` `:: a -> b` **Hask** .

`Functor` **Hask** *endo* . . .

```
class Category c where
    id  :: c i i
    (.) :: c j k -> c i j -> c i k

class (Category c1, Category c2) => CFunctor c1 c2 f where
    cfmap :: c1 a b -> c2 (f a) (f b)
```

Functor **Hask** . ,

```
instance Category (->) where        -- Hask
    id    = \x -> x
    f . g = \x -> f (g x)

instance CFunctor (->) (->) [] where
    cfmap = fmap
```

`DeriveFunctor` GHC `Functor` .

```
{-# LANGUAGE DeriveFunctor #-}

data List a = Nil | Cons a (List a) deriving Functor

-- instance Functor List where            -- automatically defined
--   fmap f Nil = Nil
--   fmap f (Cons x xs) = Cons (f x) (fmap f xs)

map :: (a -> b) -> List a -> List b
map = fmap
```

: https://riptutorial.com/ko/haskell/topic/3800/

74:

Examples

`Data.Proxy` `Proxy :: k -> *` (:) . .

```
{-# LANGUAGE PolyKinds #-}

data Proxy a = Proxy
```

`Proxy` `ScopedTypeVariables` `a` .

,

```
showread :: String -> String
showread = show . read
```

elaborator `Show` `Read` . `Proxy` :

```
{-# LANGUAGE ScopedTypeVariables #-}

import Data.Proxy

showread :: forall a. (Show a, Read a) => Proxy a -> String -> String
showread _ = (show :: a -> String) . read
```

`Proxy` `a` .

```
ghci> showread (Proxy :: Proxy Int) "3"
"3"
ghci> showread (Proxy :: Proxy Bool) "'m'"  -- attempt to parse a char literal as a Bool
"*** Exception: Prelude.read: no parse
```

" "

`Proxy` `Proxy` . `Proxy` .

```
showread :: forall proxy a. (Show a, Read a) => proxy a -> String -> String
showread _ = (show :: a -> String) . read
```

, `f` `fa` `Proxy :: Proxy a f` `Proxy :: Proxy a` .

```
ghci> let chars = "foo"  -- chars :: [Char]
ghci> showread chars "'a'"
"'a'"
```

() .

`Proxy` `f` `fa -> Proxy a` .

```
proxy :: f a -> Proxy a
proxy _ = Proxy
```

`()` .

```
unit :: a -> ()
unit _ = ()
```

, `Proxy` Functor . `()` .

: https://riptutorial.com/ko/haskell/topic/8025/

75:

Examples

.

.

```
absolute :: Int -> Int  -- definition restricted to Ints for simplicity
absolute n = if (n < 0) then (-n) else n
```

.

```
absolute :: Int -> Int
absolute n
  | n < 0 = -n
  | otherwise = n
```

`otherwise` `True` .

Haskell `case` .

case Haskell .

:

```
longName :: String -> String
longName name = case name of
                   "Alex"  -> "Alexander"
                   "Jenny" -> "Jennifer"
                   _       -> "Unknown"  -- the "default" case, if you like
```

`case` .

```
longName "Alex"  = "Alexander"
longName "Jenny" = "Jennifer"
longName _       = "Unknown"
```

`Maybe` .

```
data Person = Person { name :: String, petName :: (Maybe String) }

hasPet :: Person -> Bool
hasPet (Person _ Nothing) = False
hasPet _ = True  -- Maybe can only take `Just a` or `Nothing`, so this wildcard suffices
```

.

```
isEmptyList :: [a] -> Bool
```

```
isEmptyList [] = True
isEmptyList _  = False

addFirstTwoItems :: [Int] -> [Int]
addFirstTwoItems []        = []
addFirstTwoItems (x:[])    = [x]
addFirstTwoItems (x:y:ys)  = (x + y) : ys
```

. : : ,

:

```
annualSalaryCalc :: (RealFloat a) => a -> a -> String
annualSalaryCalc hourlyRate weekHoursOfWork
  | hourlyRate * (weekHoursOfWork * 52) <= 40000  = "Poor child, try to get another job"
  | hourlyRate * (weekHoursOfWork * 52) <= 120000 = "Money, Money, Money!"
  | hourlyRate * (weekHoursOfWork * 52) <= 200000 = "Ri¢hie Ri¢h"
  | otherwise = "Hello Elon Musk!"
```

`where` ., `where`:

```
annualSalaryCalc' :: (RealFloat a) => a -> a -> String
annualSalaryCalc' hourlyRate weekHoursOfWork
  | annualSalary <= smallSalary  = "Poor child, try to get another job"
  | annualSalary <= mediumSalary = "Money, Money, Money!"
  | annualSalary <= highSalary   = "Ri¢hie Ri¢h"
  | otherwise = "Hello Elon Musk!"
  where
      annualSalary = hourlyRate * (weekHoursOfWork * 52)
      (smallSalary, mediumSalary, highSalary)  = (40000, 120000, 200000)
```

, `where` (`hourlyRate * (weekHoursOfWork * 52)`) `where` .

`let` `let` `where` .

: https://riptutorial.com/ko/haskell/topic/3799/-

76:

C Haskell . C .

C Haskell , . C C .

, () .
.

Examples

C

```
plus(a, b); // Parentheses surrounding only the arguments, comma separated
```

```
(plus a b) -- Parentheses surrounding the function and the arguments, no commas
```

Haskell . .

```
plus a b -- no parentheses are needed here!
```

C

. , .
C :

```
plus(a, take(b, c));
```

Haskell :

```
(plus a (take b c))
-- or equivalently, omitting the outermost parentheses
plus a (take b c)
```

.

```
plus a take b c -- Not what we want!
```

`take` `b` `c` `plus` .
Haskell . `take` .

C .

```
plus(a, take, b, c); // Not what we want!
```

- 1

Haskell . . .

```
(((plus) 1) 2)
```

`(plus) 1 ((plus) 1)` , `2 (((plus) 1) 2)` . `plus 1 2` . .

`plus` .

`plus 1 1` .

`plus 1 2 1 2` , `3` .

- 2

, `map` .

```
map :: (a -> b) -> [a] -> [b]
```

. `map`

```
addOne x = plus 1 x
map addOne [1,2,3]
```

`addOne addOne` .

```
(addOne) x = ((plus) 1) x
```

`addOne x plus 1 x plus 1` . `addOne plus 1` , `addOne plus 1 plus 1`

```
map (plus 1) [1,2,3]
```

: https://riptutorial.com/ko/haskell/topic/9615/--

77:

Examples

`Arrow` , " " . , `Arrow (->)` . , :

```
spaceAround :: Double -> [Double] -> Double
spaceAround x ys = minimum greater - maximum smaller
 where (greater, smaller) = partition (>x) ys
```

.

```
spaceAround x = partition (>x) >>> minimum *** maximum >>> uncurry (-)
```

.

```
                        ──── minimum ────
                    ╱           *           ╲
──── partition (>x) >>>         *         >>>  uncurry (-) ───
                    ╲           *           ╱
                        ──── maximum ────
```

,

- `>>>` . composition (`<<<`). .
- ╱╲ "" . Haskell , :

  ```
  partition (>x) :: [Double] -> ([Double], [Double])
  ```

  `[Double]` ,

  ```
  uncurry (-) :: (Double,Double) -> Double
  ```

  `Double` .
- `***` † . `maximum` `minimum` . .

  ```
  (***) :: (b->c) -> (β->γ) -> (b,β)->(c,γ)
  ```

---

† **Hask** (, `Arrow (->)`) `f***g` `f` `g` . .

: https://riptutorial.com/ko/haskell/topic/4912/

78:

1. []
2. infixl []
3. []

`infixr`	.
`infixl`	.
`infix`	.
	(0 ~ 9, 9)
`op1, ... , opn`	

.

1. .
2. .
3. .

2 . .

, `1 + negate 5 * 2 - 3 * 4 ^ 2 ^ 1` `1 + negate 5 * 2 - 3 * 4 ^ 2 ^ 1` .

```
infixl 6 +
infixl 6 -
infixl 7 *
infixr 8 ^
```

1. `1 + (negate 5) * 2 - 3 * 4 ^ 2 ^ 1`
2. `1 + ((negate 5) * 2) - (3 * (4 ^ 2 ^ 1))`
3. `(1 + ((negate 5) * 2)) - (3 * (4 ^ (2 ^ 1)))`

Haskell 98 4.4.2 .

Examples

`infixl` `infixr` `infix` . , (base)

```
infixl 6 -
infixr 5 :
infix  4 ==
```

`infixl` `-` `1 - 2 - 3 - 4`

```
((1 - 2) - 3) - 4
```

`infixr` : `1 : 2 : 3 : []` ()

```
1 : (2 : (3 : []))
```

`infix ==` ., `True == False == True` . `True == (False == True)` `(True == False) == True` .

`infixl 9` .

. `0` `9` . . , (base)

```
infixl 6 +
infixl 7 *
```

`*` `+` `1 * 2 + 3` .

```
(1 * 2) + 3
```

, "".

- `fx `op` gy` (`fx `op` gy` `(fx)` op `(gy)` `` `op` `` .
- (: `infixl *!?`) `9` .

- `infixr 5 ++`
- `infixl 4 <*>, <*, *>, <**>`
- `infixl 8 `shift`, `rotate`, `shiftL`, `shiftR`, `rotateL`, `rotateR``
- `infix 4 ==, /=, <, <=, >=, >`
- `infix ??`

: https://riptutorial.com/ko/haskell/topic/4691/-

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