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Functors, Applicatives, And Monads In Pictures

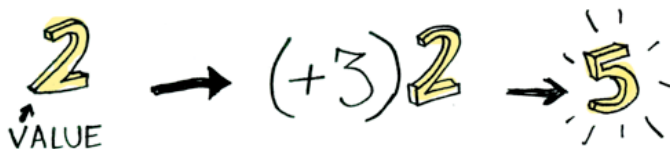
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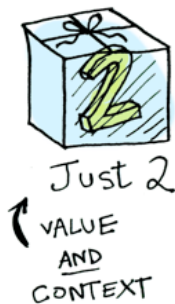
Here's a simple value:



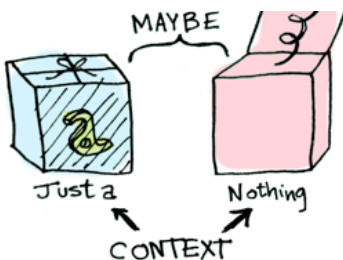
And we know how to apply a function to this value:



Simple enough. Lets extend this by saying that any value can be in a context. For now you can think of a context as a box that you can put a value in:



Now when you apply a function to this value, you'll get different results **depending on the context**. This is the idea that Functors, Applicatives, Monads, Arrows etc are all based on. The `Maybe` data type defines two related contexts:

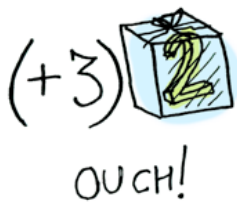


```
data Maybe a = Nothing | Just a
```

In a second we'll see how function application is different when something is a `Just a` versus a `Nothing`. First let's talk about Functors!

Functors

When a value is wrapped in a context, you can't apply a normal function to it:



This is where `fmap` comes in. `fmap` is from the street, `fmap` is hip to contexts. `fmap` knows how to apply functions to values that are wrapped in a context. For example, suppose you want to apply $(+3)$ to `Just 2`. Use `fmap`:

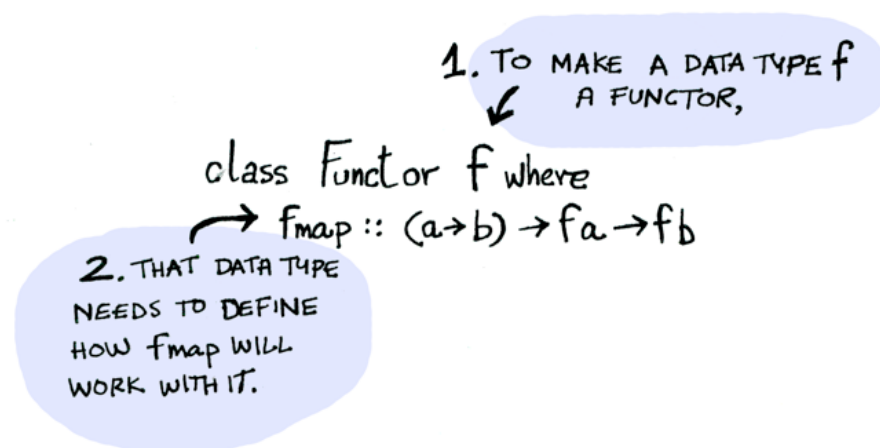
```
> fmap (+3) (Just 2)
Just 5
```



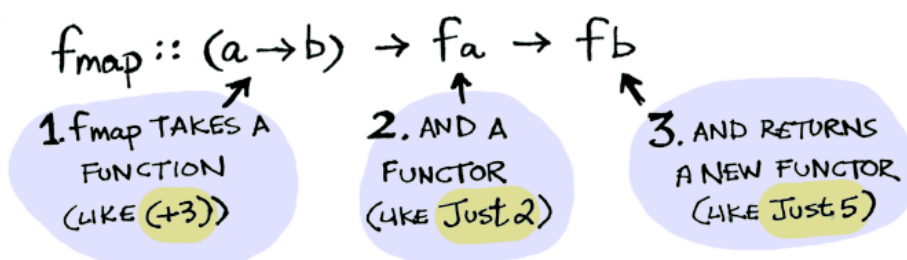
Bam! `fmap` shows us how it's done! But how does `fmap` know how to apply the function?

Just what is a Functor, really?

`Functor` is a [typeclass](#). Here's the definition:



A `Functor` is any data type that defines how `fmap` applies to it. Here's how `fmap` works:



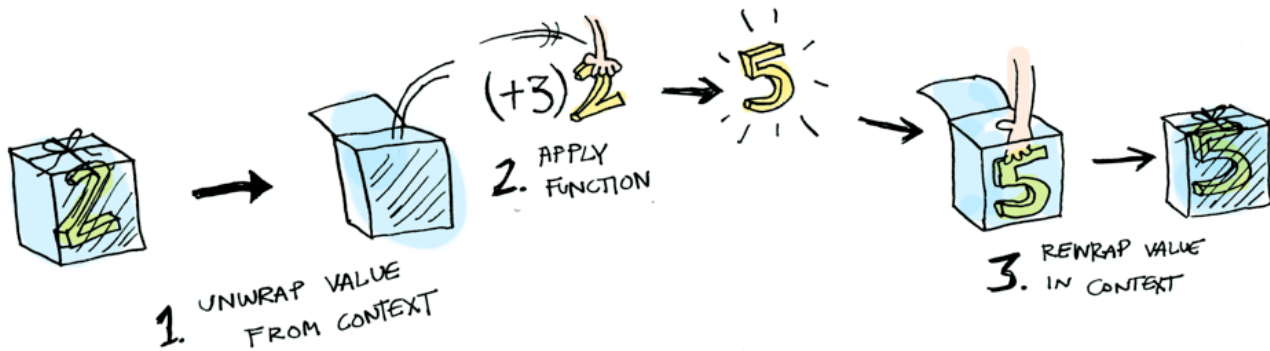
So we can do this:

```
> fmap (+3) (Just 2)
Just 5
```

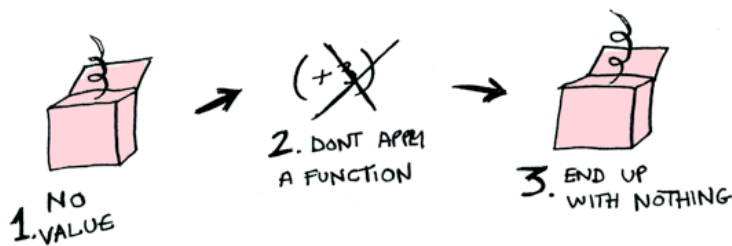
And `fmap` magically applies this function, because `Maybe` is a Functor. It specifies how `fmap` applies to `Just` s and `Nothing` s:

```
instance Functor Maybe where
  fmap func (Just val) = Just (func val)
  fmap func Nothing = Nothing
```

Here's what is happening behind the scenes when we write `fmap (+3) (Just 2)` :



So then you're like, alright `fmap`, please apply `(+3)` to a `Nothing` ?



```
> fmap (+3) Nothing
Nothing
```



Like Morpheus in the Matrix, `fmap` knows just what to do; you start with `Nothing`, and you end up with `Nothing` ! `fmap` is zen. Now it makes sense why the `Maybe` data type exists. For example, here's how you work with a database record in a language without `Maybe` :

```
post = Post.find_by_id(1)
if post
  return post.title
else
  return nil
end
```

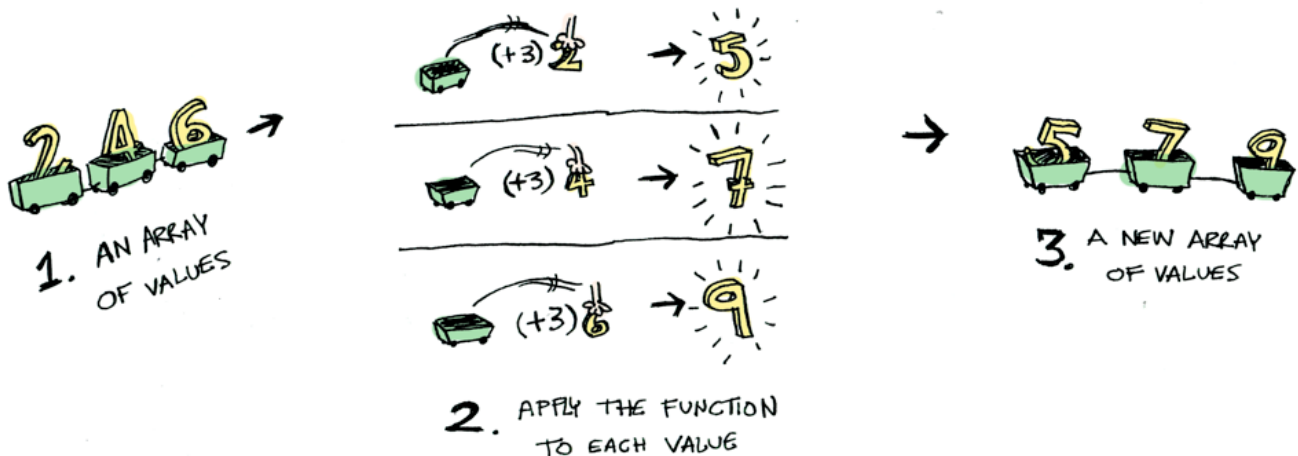
But in Haskell:

```
fmap (getPostTitle) (findPost 1)
```

If `findPost` returns a post, we will get the title with `getPostTitle`. If it returns `Nothing`, we will return `Nothing`! Pretty neat, huh? `<$>` is the infix version of `fmap`, so you will often see this instead:

```
getPostTitle <$> (findPost 1)
```

Here's another example: what happens when you apply a function to a list?



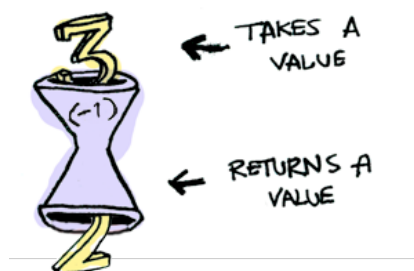
Lists are functors too! Here's the definition:

```
instance Functor [] where
    fmap = map
```

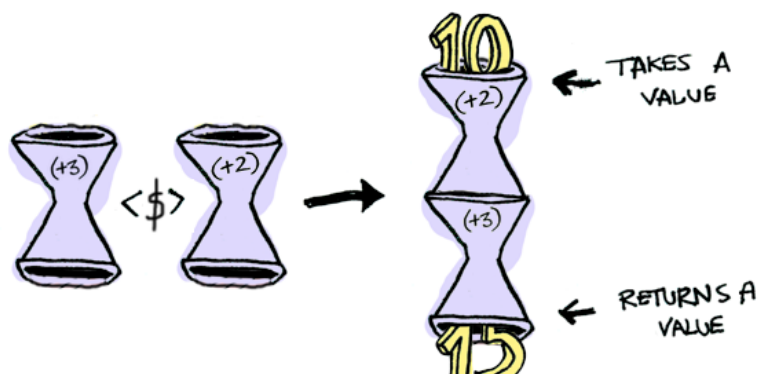
Okay, okay, one last example: what happens when you apply a function to another function?

```
fmap (+3) (+1)
```

Here's a function:



Here's a function applied to another function:





The result is just another function!

```
> import Control.Applicative
> let foo = fmap (+3) (+2)
> foo 10
15
```

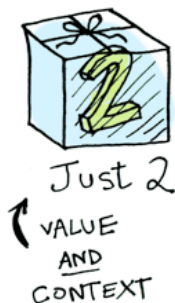
So functions are Functors too!

```
instance Functor ((->) r) where
  fmap f g = f . g
```

When you use `fmap` on a function, you're just doing function composition!

Applicatives

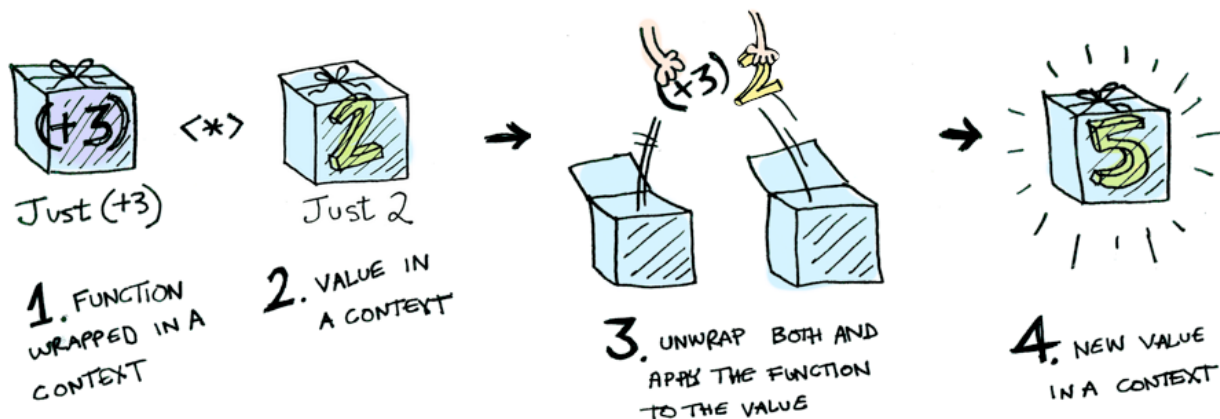
Applicatives take it to the next level. With an applicative, our values are wrapped in a context, just like Functors:



But our functions are wrapped in a context too!



Yeah. Let that sink in. Applicatives don't kid around. `Control.Applicative` defines `<*>`, which knows how to apply a function *wrapped in a context* to a value *wrapped in a context*:

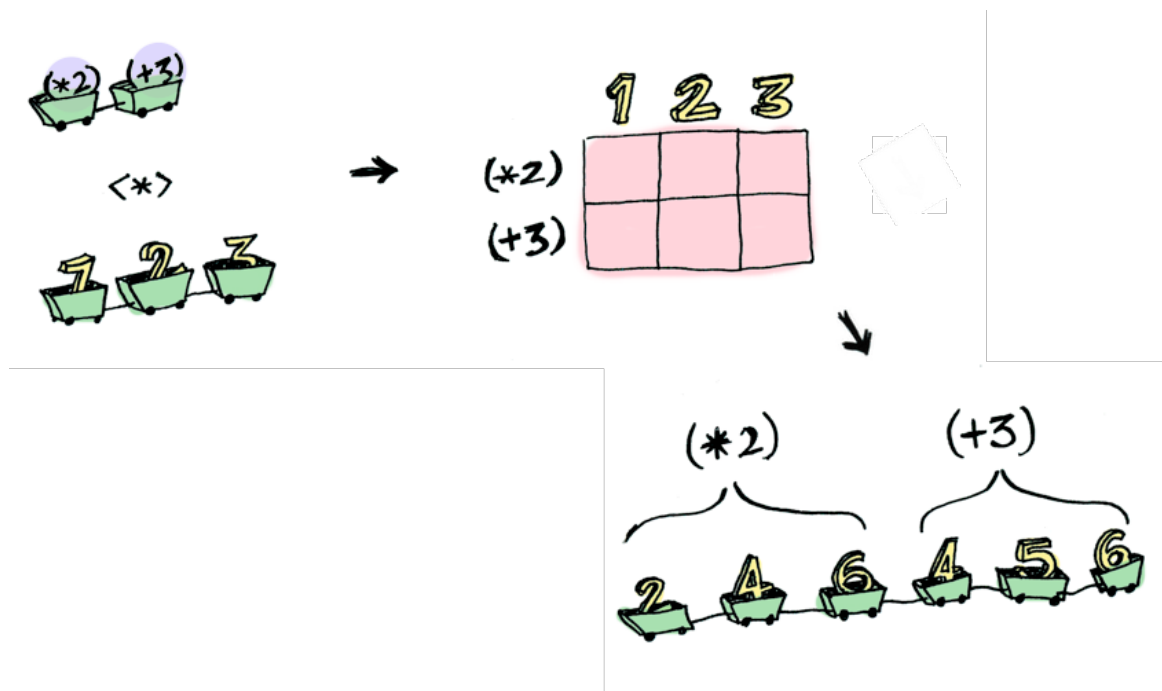


i.e:

```
Just (+3) <*> Just 2 == Just 5
```

Using `<*>` can lead to some interesting situations. For example:

```
> [(*2), (+3)] <*> [1, 2, 3]
[2, 4, 6, 4, 5, 6]
```



Here's something you can do with Applicatives that you can't do with Functors. How do you apply a function that takes two arguments to two wrapped values?

```
> (+) <$> (Just 5)
Just (+5)
> Just (+5) <$> (Just 4)
ERROR ??? WHAT DOES THIS EVEN MEAN WHY IS THE FUNCTION WRAPPED IN A JUST
```

Applicatives:

```
> (+) <$> (Just 5)
Just (+5)
> Just (+5) <*> (Just 3)
Just 8
```

Applicative pushes Functor aside. "Big boys can use functions with any number of arguments," it says. "Armed `<$>` and `<*>`, I can take any function that expects any number of unwrapped values. Then I pass it all wrapped values, and I get a wrapped value out! AHAHAHAHAH!"

```
> (*) <$> Just 5 <*> Just 3
Just 15
```

And hey! There's a function called `liftA2` that does the same thing:

```
> liftA2 (*) (Just 5) (Just 3)
Just 15
```

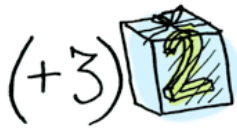
Monads

How to learn about Monads:

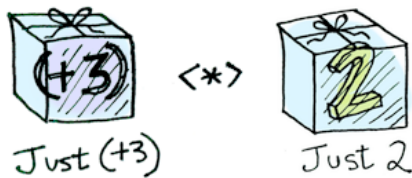
1. Get a PhD in computer science.
2. Throw it away because you don't need it for this section!

Monads add a new twist.

Functors apply a function to a wrapped value:

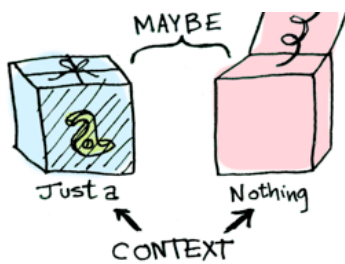


Applicatives apply a wrapped function to a wrapped value:



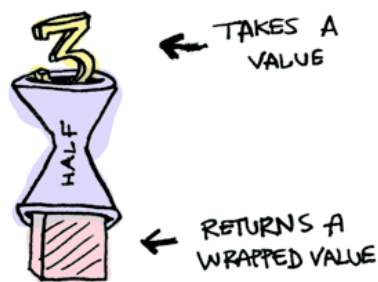
Monads apply a function **that returns a wrapped value** to a wrapped value. Monads have a function `>>=` (pronounced "bind") to do this.

Let's see an example. Good ol' `Maybe` is a monad:



Suppose `half` is a function that only works on even numbers:

```
half x = if even x
         then Just (x `div` 2)
         else Nothing
```



What if we feed it a wrapped value?



We need to use `>>=` to shove our wrapped value into the function. Here's a photo of `>>=` :



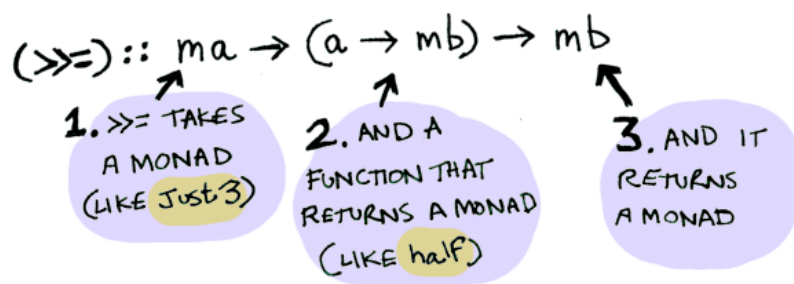
Here's how it works:

```
> Just 3 >= half
Nothing
> Just 4 >= half
Just 2
> Nothing >= half
Nothing
```

What's happening inside? `Monad` is another typeclass. Here's a partial definition:

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

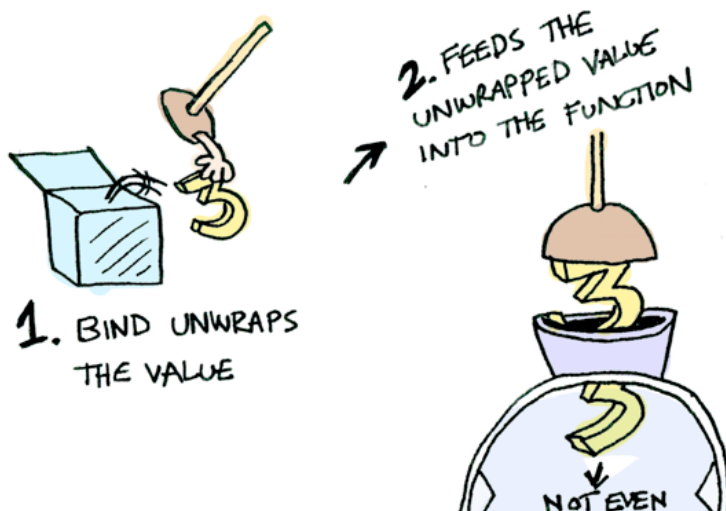
Where `>=` is:

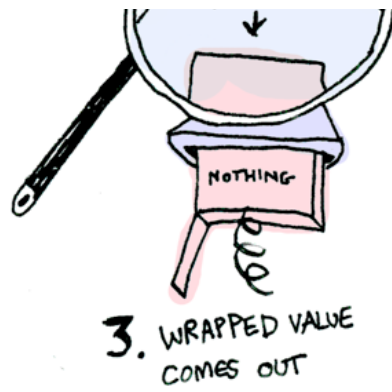


So `Maybe` is a `Monad`:

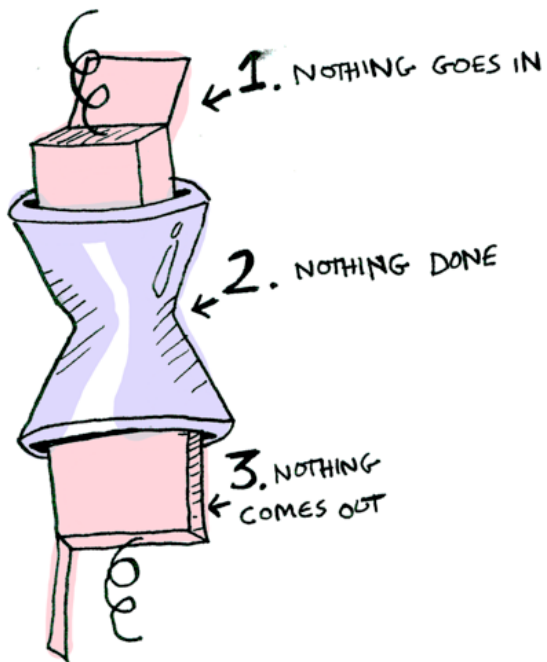
```
instance Monad Maybe where
  Nothing >= func = Nothing
  Just val >= func = func val
```

Here it is in action with a `Just 3` !



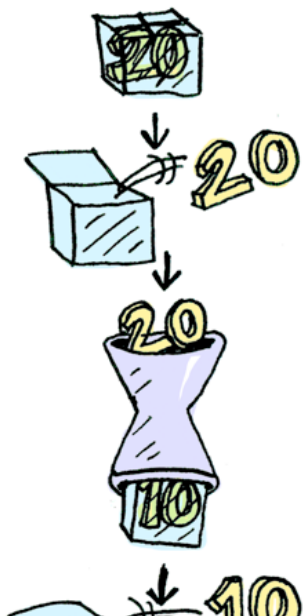


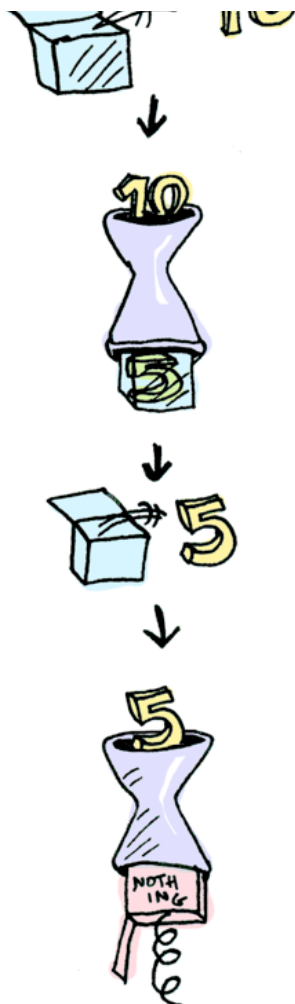
And if you pass in a `Nothing` it's even simpler:



You can also chain these calls:

```
> Just 20 >= half >= half >= half
Nothing
```





Cool stuff! So now we know that `Maybe` is a `Functor`, an `Applicative`, and a `Monad`.

Now let's mosey on over to another example: the `IO` monad:



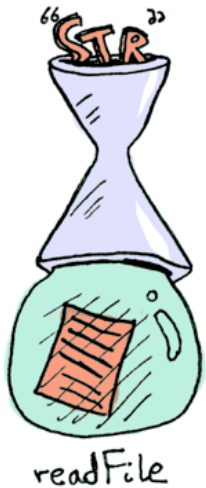
Specifically three functions. `getLine` takes no arguments and gets user input:





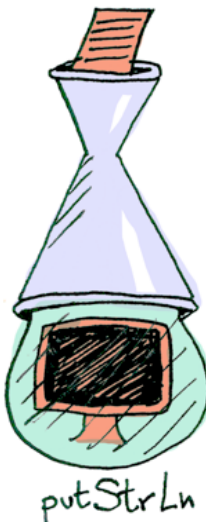
```
getLine :: IO String
```

`readFile` takes a string (a filename) and returns that file's contents:



```
readFile :: FilePath -> IO String
```

`putStrLn` takes a string and prints it:



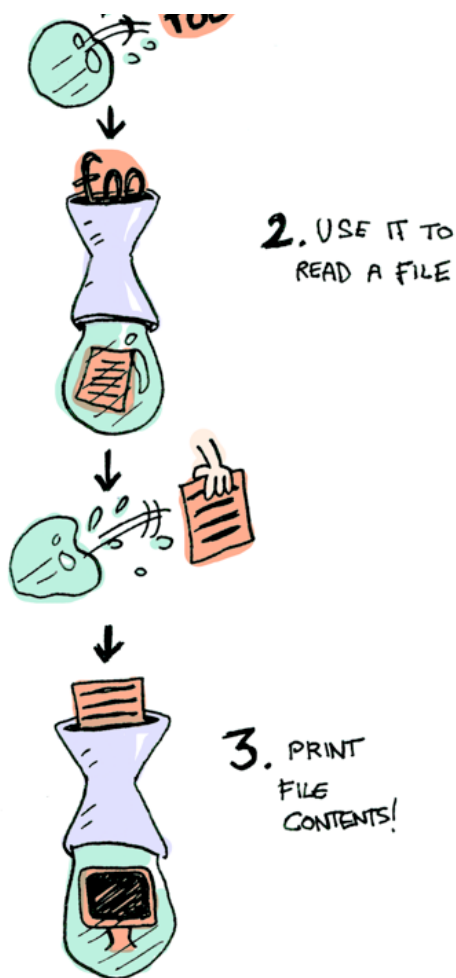
```
putStrLn :: String -> IO ()
```

All three functions take a regular value (or no value) and return a wrapped value. We can chain all of these using `>>=` !



1. GET USER
INPUT





```
getLine >>= readFile >>= putStrLn
```

Aw yeah! Front row seats to the monad show!

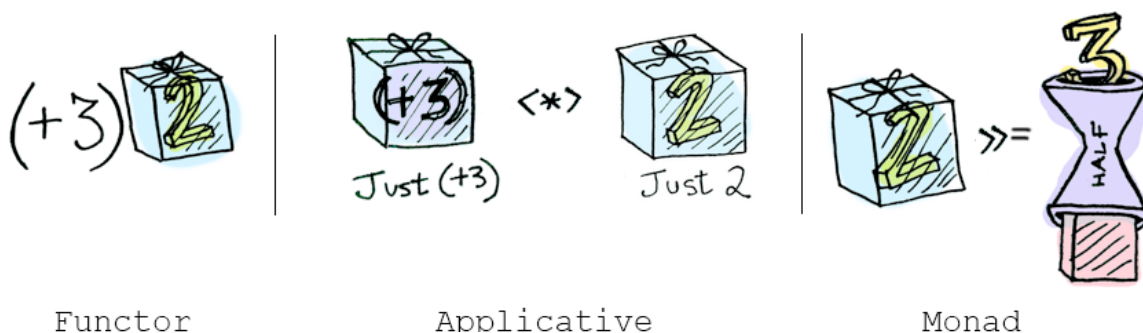
Haskell also provides us with some syntactical sugar for monads, called `do` notation:

```
foo = do
  filename <- getLine
  contents <- readFile filename
  putStrLn contents
```

Conclusion

1. A functor is a data type that implements the `Functor` typeclass.
2. An applicative is a data type that implements the `Applicative` typeclass.
3. A monad is a data type that implements the `Monad` typeclass.
4. A `Maybe` implements all three, so it is a functor, an applicative, *and* a monad.

What is the difference between the three?



+ +

functors: you apply a function to a wrapped value using `fmap` or `<$>`

applicatives: you apply a wrapped function to a wrapped value using `<*>` or `liftA`

monads: you apply a function that returns a wrapped value, to a wrapped value using `>>=` or `liftM`

So, dear friend (I think we are friends by this point), I think we both agree that monads are easy and a SMART IDEA(tm). Now that you've wet your whistle on this guide, why not pull a Mel Gibson and grab the whole bottle. Check out LYAH's [section on Monads](#). There's a lot of things I've glossed over because Miran does a great job going in-depth with this stuff.

Translations

This post has been translated into:

Human languages:

[Chinese](#)

[Another Chinese translation](#)

[Chinese, Kotlin](#)

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Programming languages:

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[Kotlin](#). This author also translated this Kotlin version into [Chinese](#).

[Kotlin \(translated from the Swift translation\)](#)

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For more monads and pictures, check out [three useful monads](#).

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