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Functors, Applicatives, And Monads In Pictures

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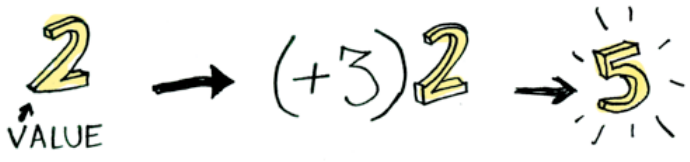
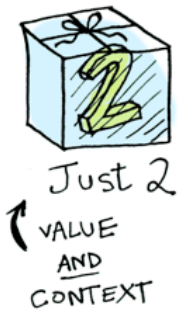
Here's a simple value:

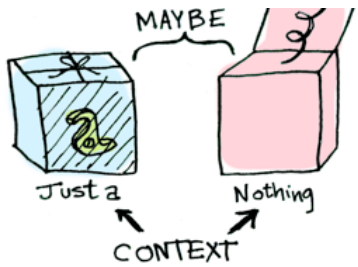
And we know how to apply a function to this value:



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:

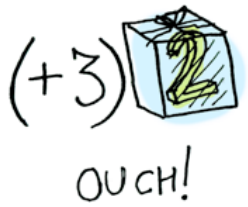



```
data Maybe a = Nothing | Just a
```

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:



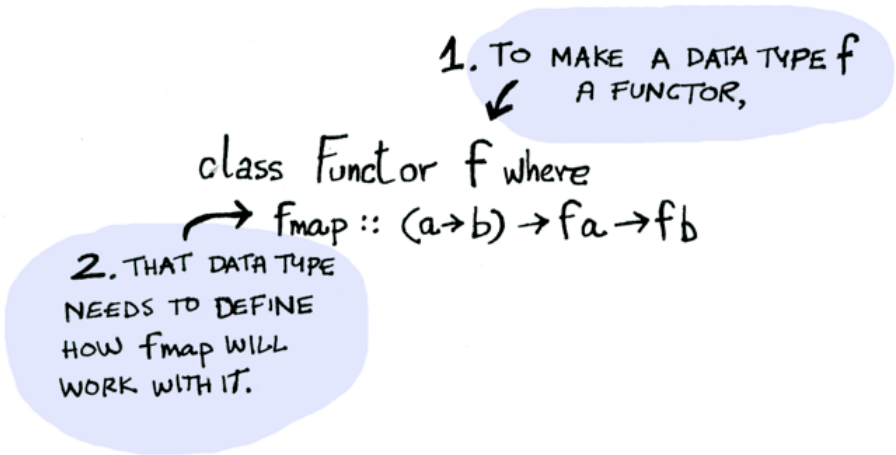
This is where `fmap` comes in. `fmap` is from the street, `fmap` is hip to contexts. `fmap` knows how to apply functions to values that are wrapped in a context. For example, suppose you want to apply `(+3)` to `Just 2`. Use `fmap`:

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

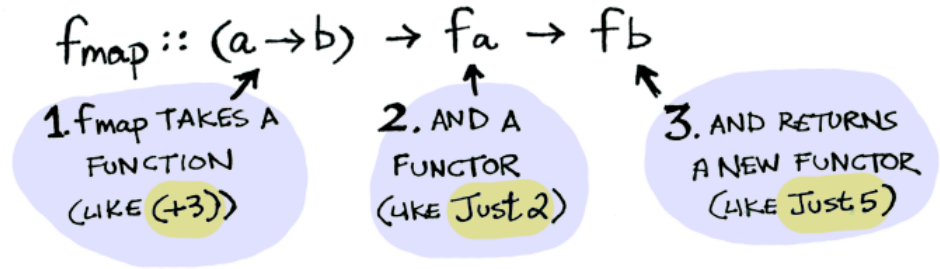
Bam! `fmap` shows us how it's done! But how does `fmap` know how to apply the function?

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:



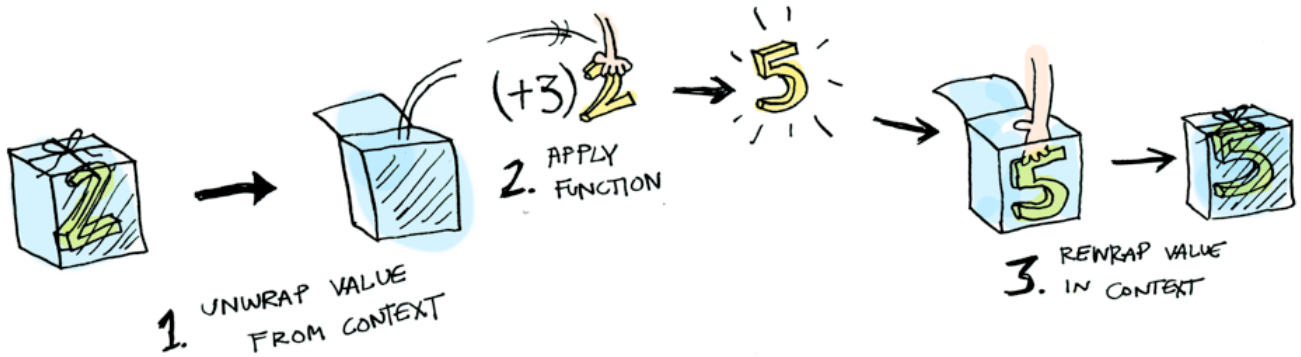
So we can do this:

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

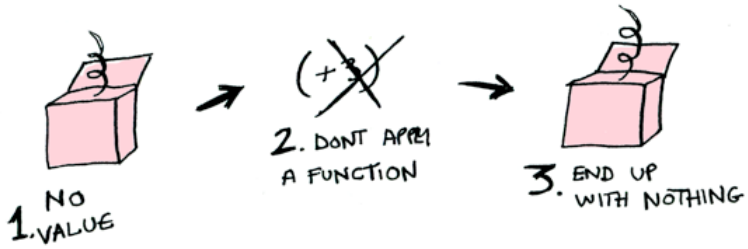
And `fmap` magically applies this function, because `Maybe` is a Functor. It specifies how `fmap` applies to `Just` s and `Nothing` s:

```
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
```

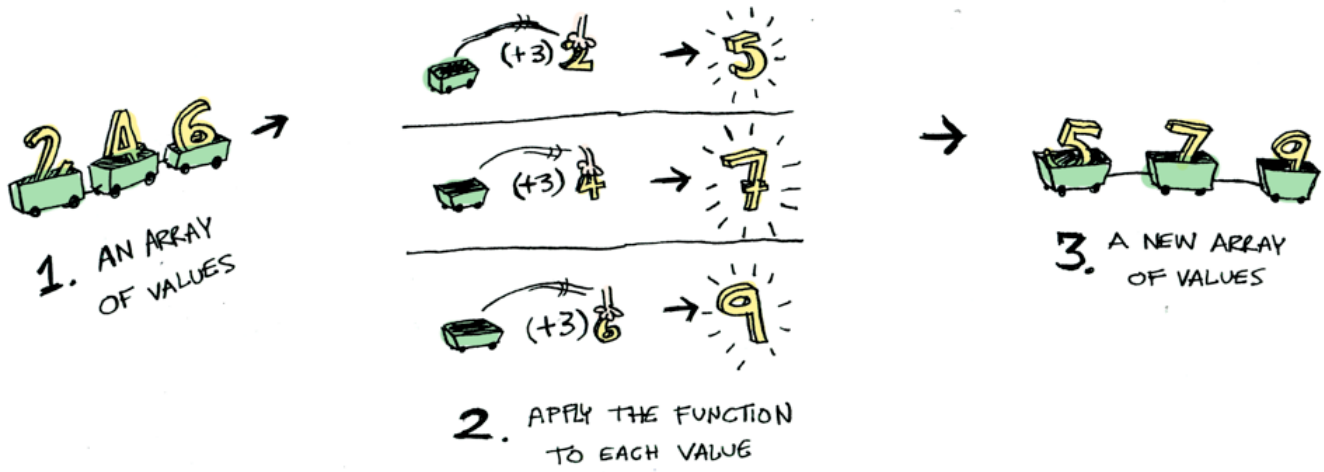
But in Haskell:

```
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?



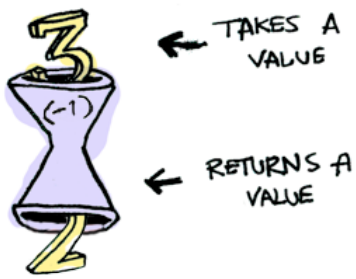
Lists are functors too! Here's the definition:

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

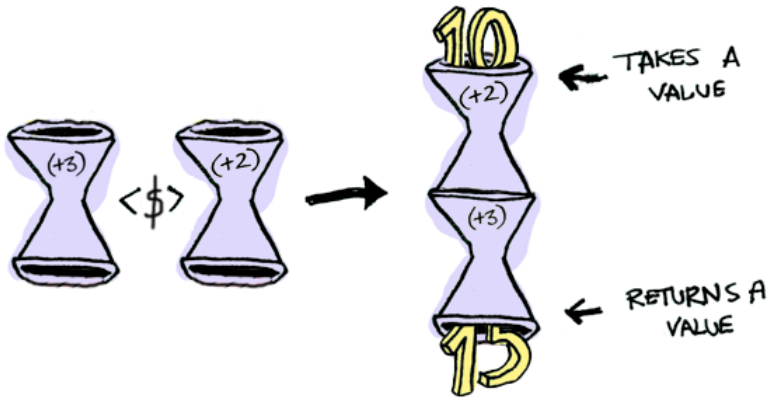
Okay, okay, one last example: what happens when you apply a function to another function?

```
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
```

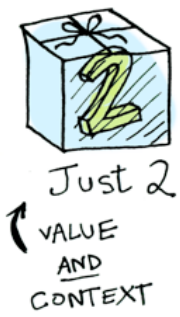
So functions are Functors too!

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

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

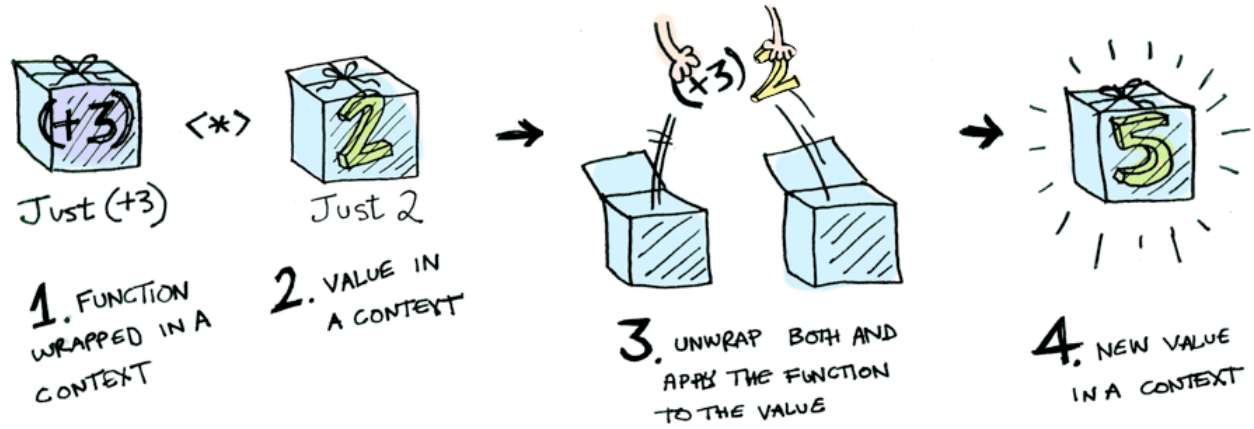
Applicatives

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*:

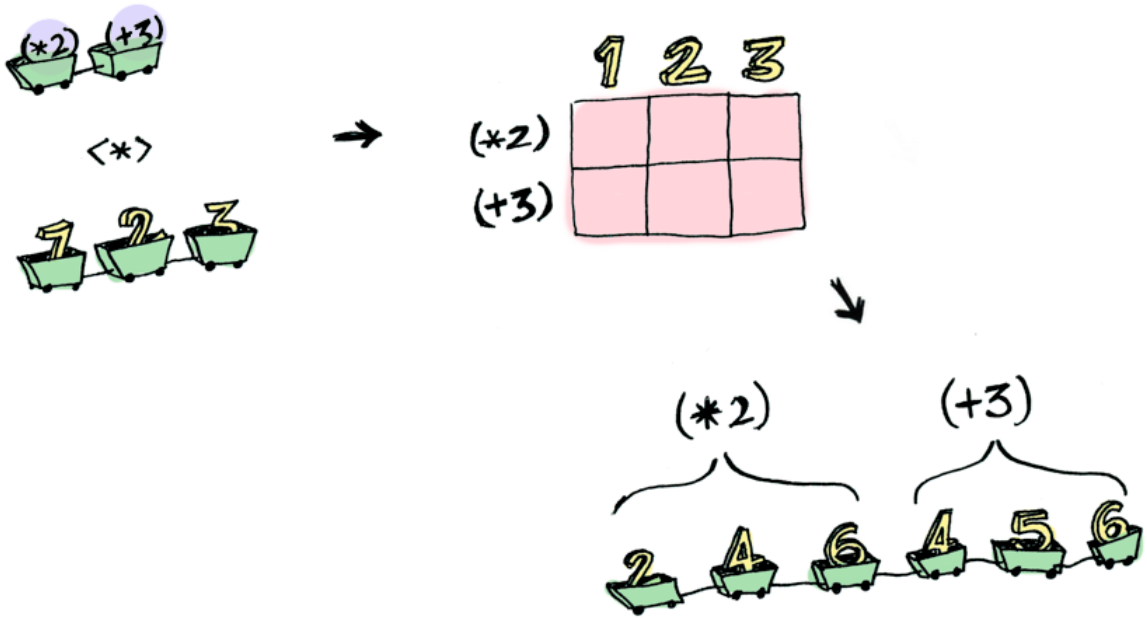


i.e:

```
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
```

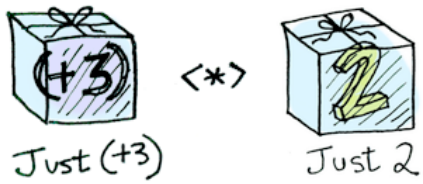
Monads

How to learn about Monads:

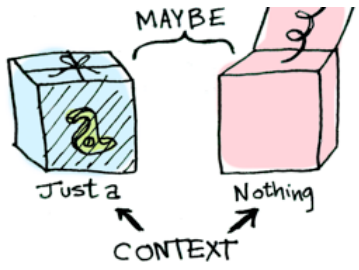
1. Get a PhD in computer science.
2. Throw it away because you don't need it for this section!

Monads add a new twist.
Functors apply a function to a wrapped value:

Applicatives apply a wrapped function to a wrapped value:

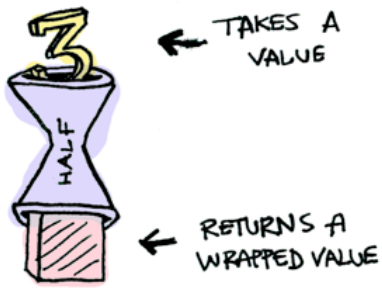


Monads apply a function **that returns a wrapped value** to a wrapped value. Monads have a function `>>=` (pronounced "bind") to do this.
Let's see an example. Good ol' `Maybe` is a monad:



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 `>>=` :

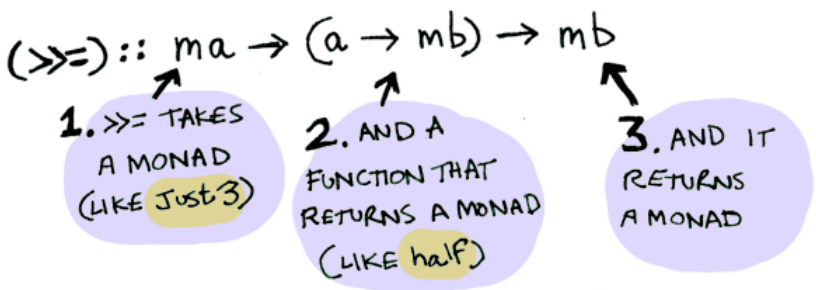
Here's how it works:

```
> 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
```

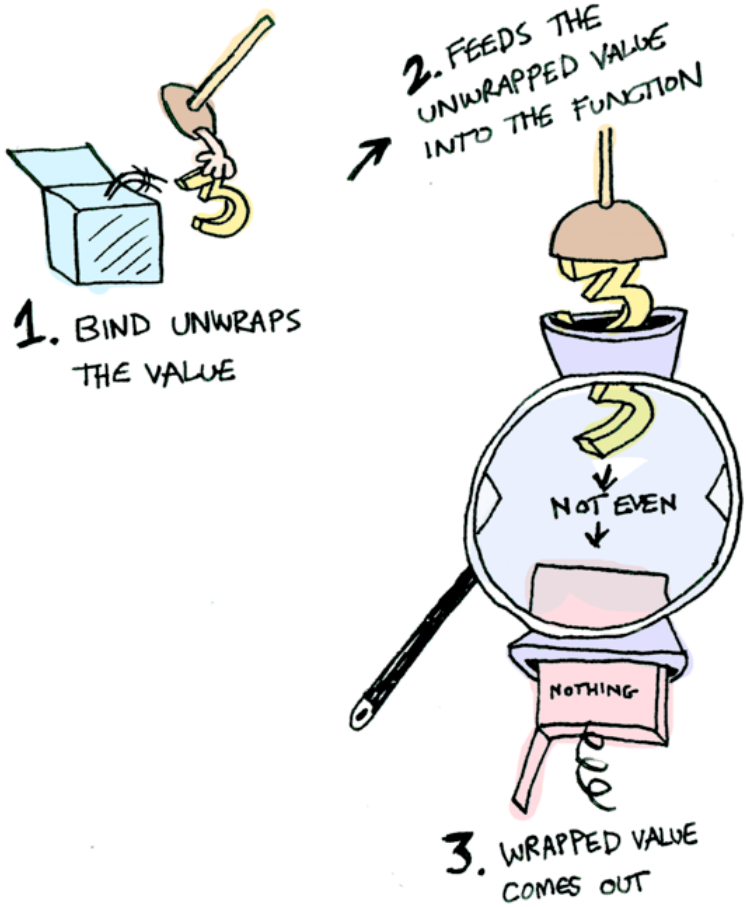
Where `>>=` is:



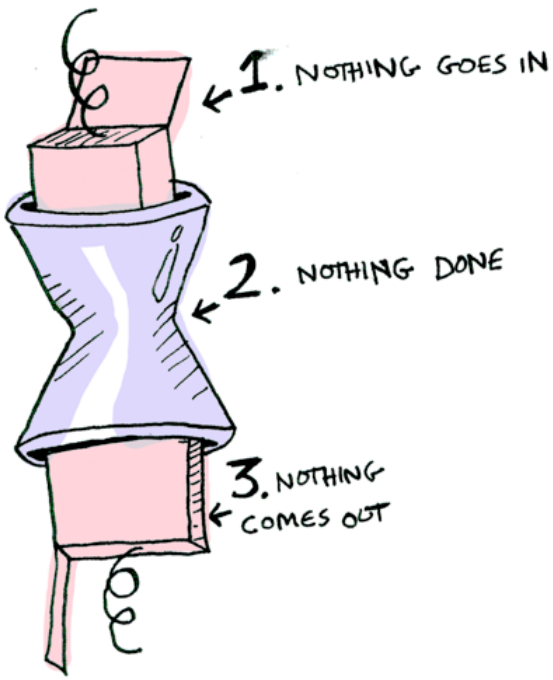
So `Maybe` is a Monad:

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

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

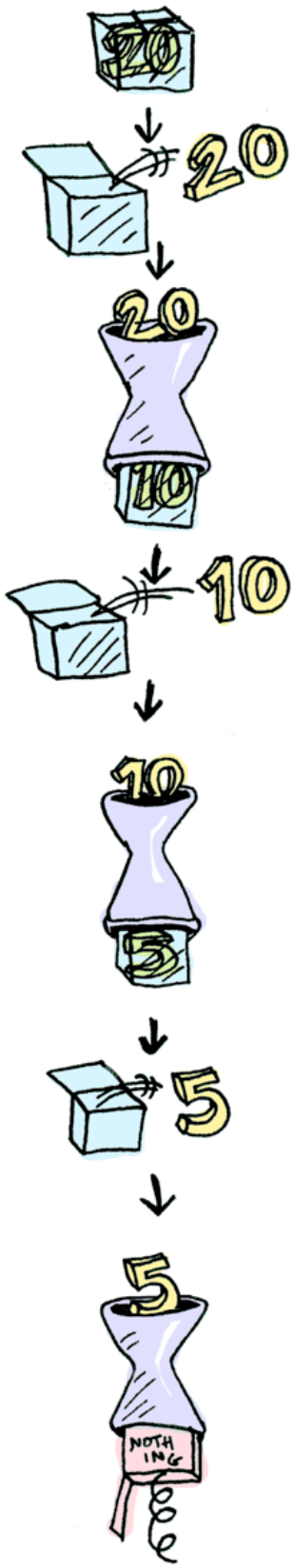


And if you pass in a `Nothing` it's even simpler:



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
```

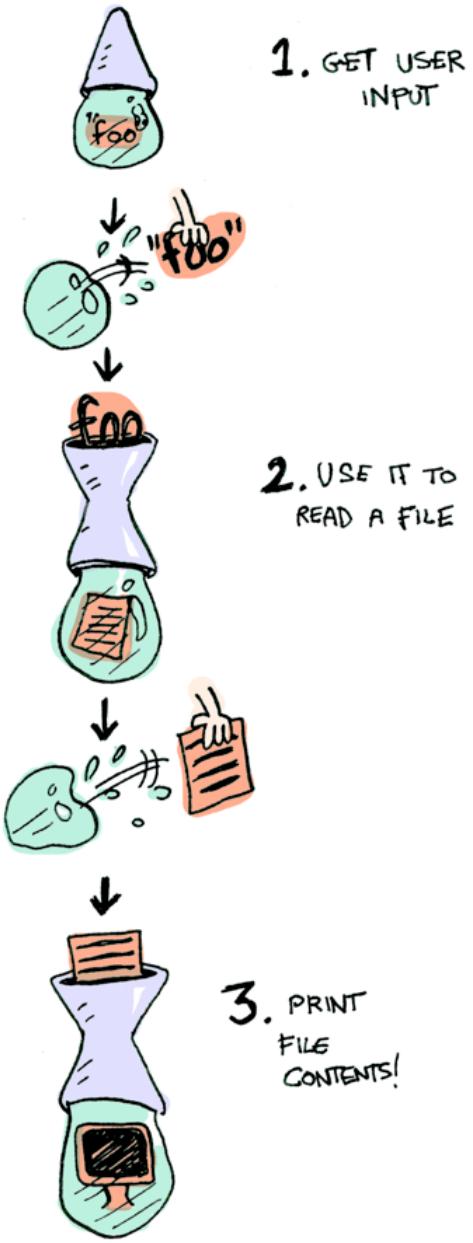
`readFile` takes a string (a filename) and returns that file's contents:


```
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 `>>=` !



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

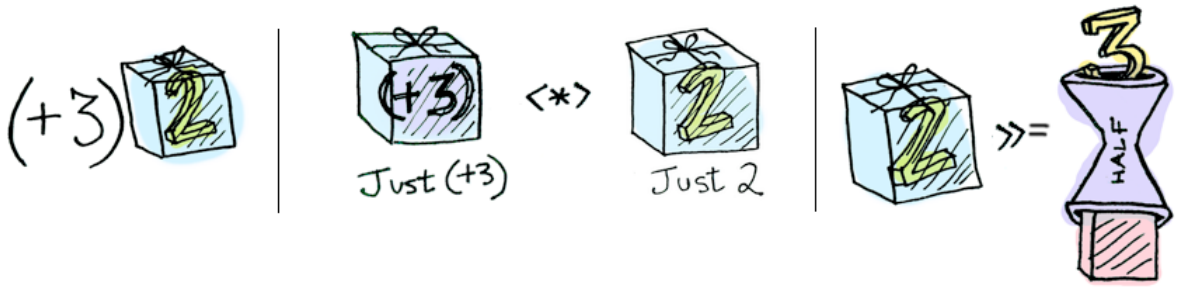
Aw yeah! Front row seats to the monad show!
Haskell also provides us with some syntactical sugar for monads, called `do` notation:

```
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
French
German
Japanese
Korean
Portuguese
Russian
Spanish
Turkish
Vietnamese

Programming languages:

Javascript
Python
Swift
Kotlin. This author also translated this Kotlin version into Chinese.
Kotlin (translated from the Swift translation)
Elm

If you translate this post, send me an email and I'll add it to this list!

For more monads and pictures, check out three useful monads.