Kotlin Functors, Applicatives, And Monads In Picture

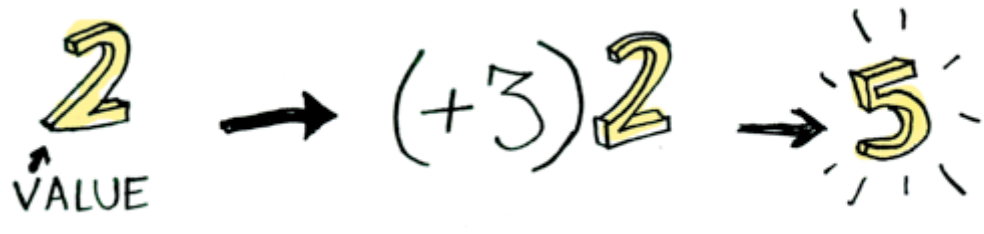
2017-08-25 •灰蓝天际

本文链接：https://hltj.me/kotlin/2017/08/25/kotlin-functor-applicative-monad.html 。

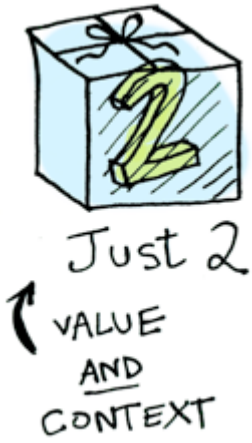
> *This is a translation of Functors, Applicatives, And Monads In Pictures from Haskell into Kotlin. I have also translated this into Chinese: Kotlin 版图解 Functor、Applicative 与 Monad.*
>
> *Different from the Kotlin translation from Swift, this is translated directly from the original article.*
>
> *If you enjoy this post be sure to say thanks to the author of the original version: Aditya Bhargava, @_egonschiele on Twitter.*

Here's a simple value:

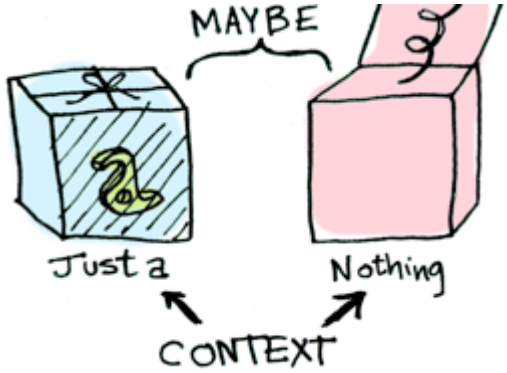
And we know how to apply a function to this value:



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:



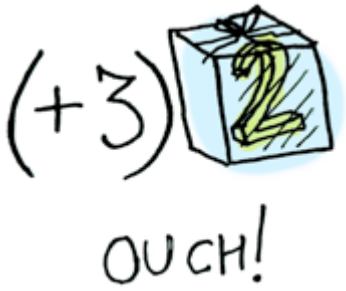

```
sealed class Maybe<out T> {
    object `Nothing#` : Maybe<Nothing>() {
        override fun toString(): String = "Nothing#"
    }
    data class Just<out T>(val value: T) : Maybe<T>()
}
```

In a second we'll see how function application is different when something is a `Just<T>` versus a `Nothing#`. First let's talk about Functors!

> ***Note:*** *Here use `Nothing#` instead of `Nothing`, since `Nothing` is a special type in Kotlin, see The Nothing type. And Kotlin has its own way for representing optinal value instead of using `Maybe`-like type, see Null Safety.*

Functors

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



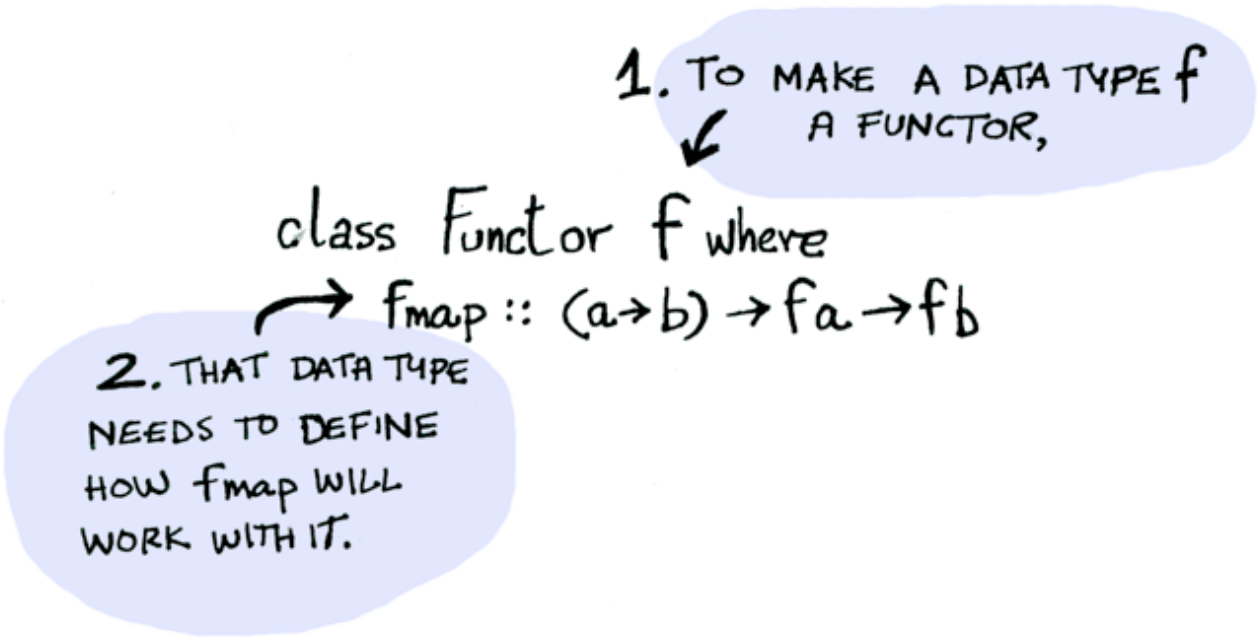
This is where `fmap` comes in. `fmap` is from the street, `fmap` is hip to contexts. `fmap` knows how to apply functions to values that are wrapped in a context. For example, suppose you want to apply `{ it + 3 }` to `Just(2)`. Use `fmap`:

```
> Maybe.Just(2).fmap { it + 3 }
Just(value=5)
```

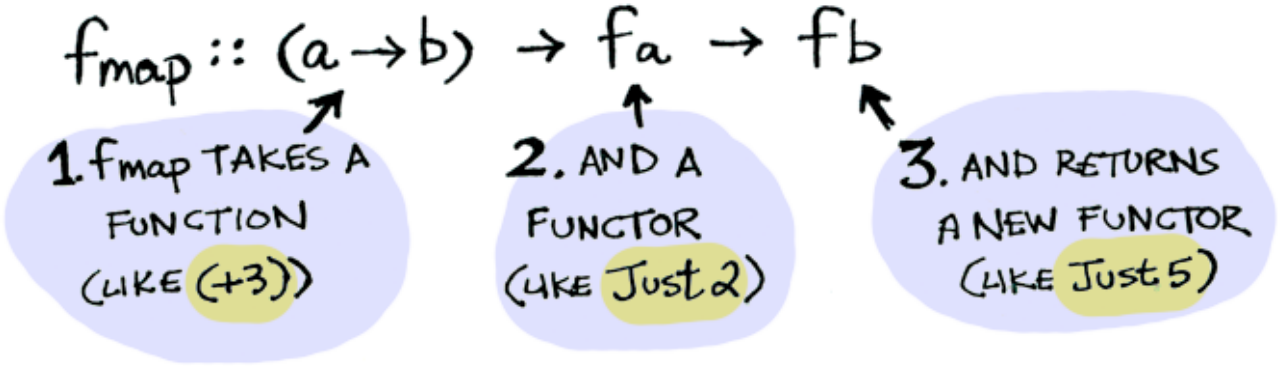
Bam! `fmap` shows us how it's done! But how does `fmap` know how to apply the function?

Just what is a Functor, really?

`Functor` is a typeclass in Haskell. Here's the definition:



In Kotlin, `Functor` can be considered as a type that defines `fmap` method/extension function. Here's how `fmap` works:



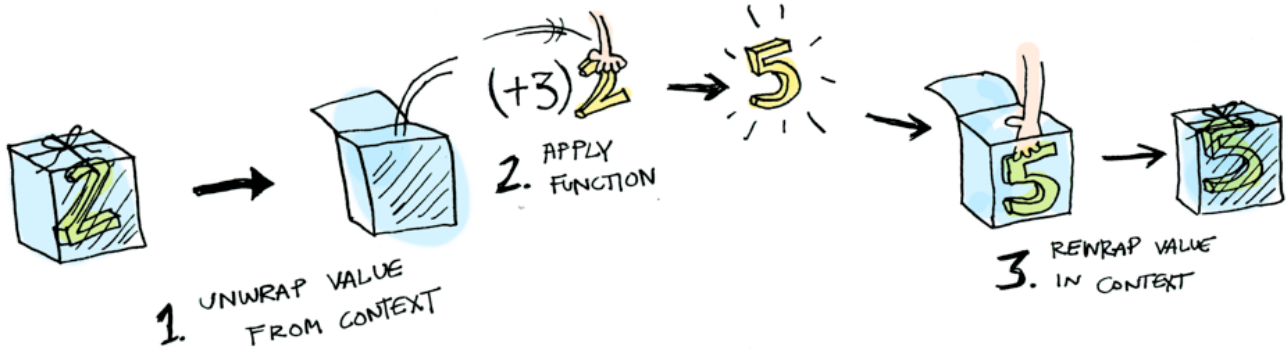
So we can do this:

```
> Maybe.Just(2).fmap { it + 3 }
Just(value=5)
```

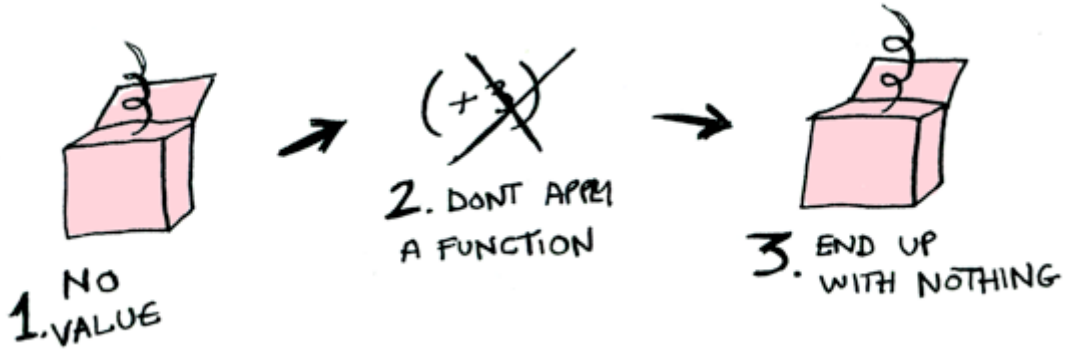
And `fmap` magically applies this function, because `Maybe` is a Functor. It specifies how `fmap` applies to `Just`s and `Nothing#`s:

```
fun <T, R> Maybe<T>.fmap(transform: (T) -> R): Maybe<R> = when(this) {
    Maybe.`Nothing#` -> Maybe.`Nothing#`
    is Maybe.Just -> Maybe.Just(transform(this.value))
}
```

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



So then you're like, alright `fmap`, please apply `{ it + 3 }` to a `Nothing#`?




```
> Maybe.`Nothing#`.fmap { x: Int -> x + 3 }
Nothing#
```

> ***Note:*** *Here the argument type of the lambda must be annotated explicitly, since there are many types can plus an* `Int` *in Kotlin.*

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 Kotlin:

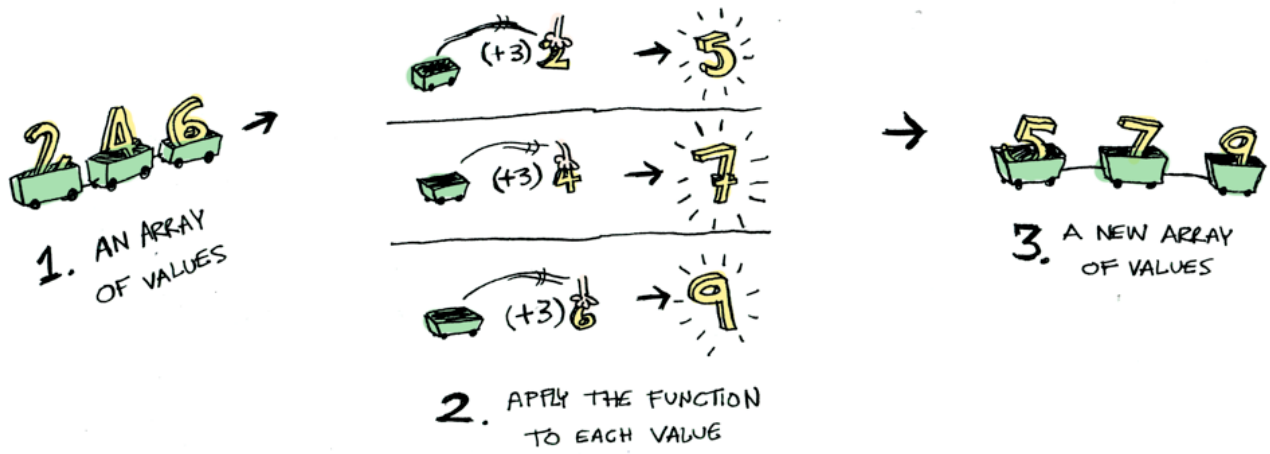
```
findPost(1).fmap(::getPostTitle)
```

If `findPost` returns a post, we will get the title with `getPostTitle`. If it returns `Nothing#`, we will return `Nothing#`! Pretty neat, huh?

We can even define an infix operator for `fmap`, `($)` (`<$>` in Haskell), and you will often see this instead:

```
infix fun <T, R> ((T) -> R).`($)`(maybe: Maybe<T>) = maybe.fmap(this)

::getPostTitle `($)` findPost(1)
```

Here's another example: what happens when you apply a function to an `Iterable` (`List` in Haskell)?



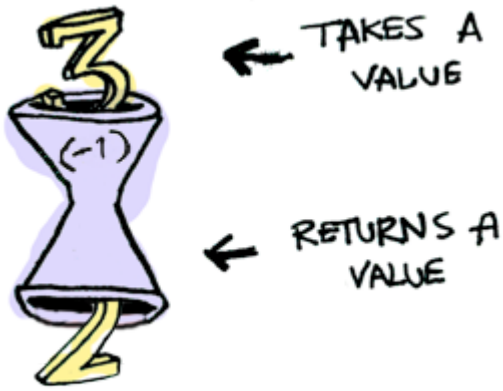
`Iterable`s are functors too! We can define the `fmap` for them:

```
fun <T, R> Iterable<T>.fmap(transform: (T) -> R): List<R> = this.map(transform
```

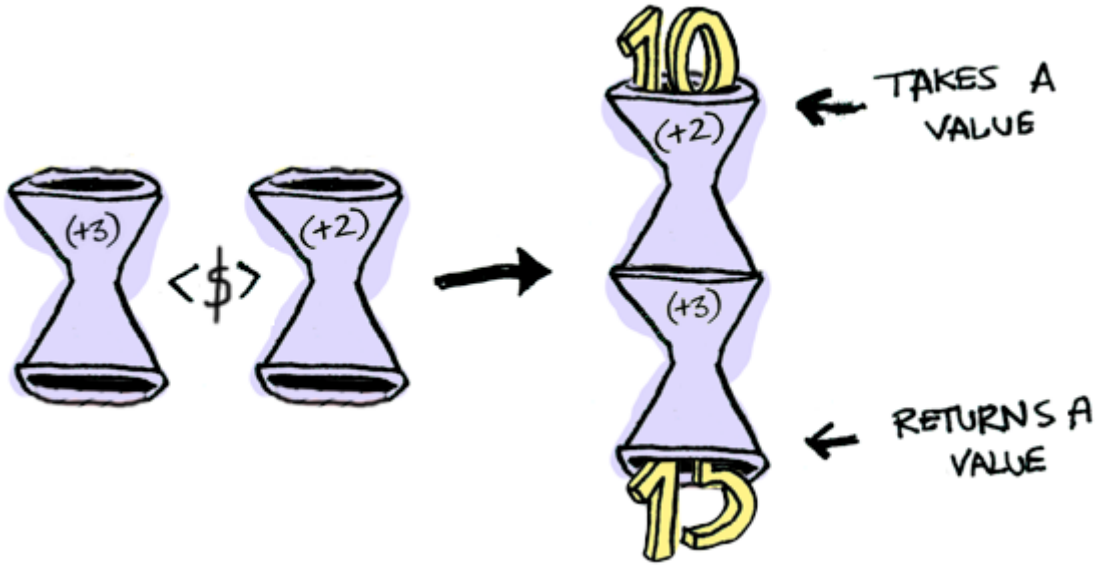
Okay, okay, one last example: what happens when you apply a function to another function?

```
{ x: Int - > x + 1 }.fmap { x: Int -> x + 3 }
```

Here's a function:



Here's a function applied to another function:



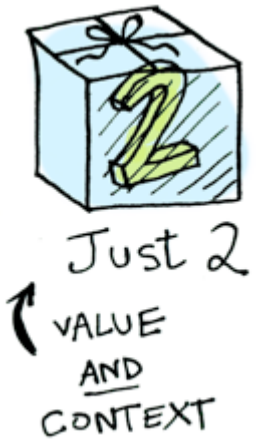
The result is just another function!

```
> fun <T, U, R> ((T) -> U).fmap(transform: (U) -> R) = { t: T -> transform(thi
> val foo = { x: Int -> x + 2 }.fmap { x: Int -> x + 3 }
> foo(10)
15
```

So functions are Functors too! When you use fmap on a function, you're just doing function composition!

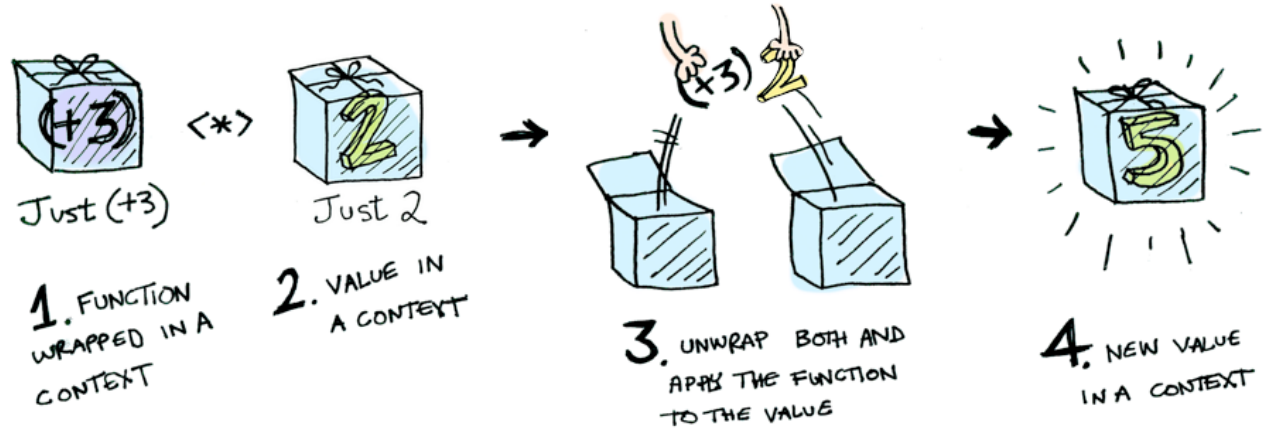
Applicatives

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. Applicative defines `(*)` (`<*>` in Haskell), which knows how to apply a function *wrapped in a context* to a value *wrapped in a context*:



i.e:

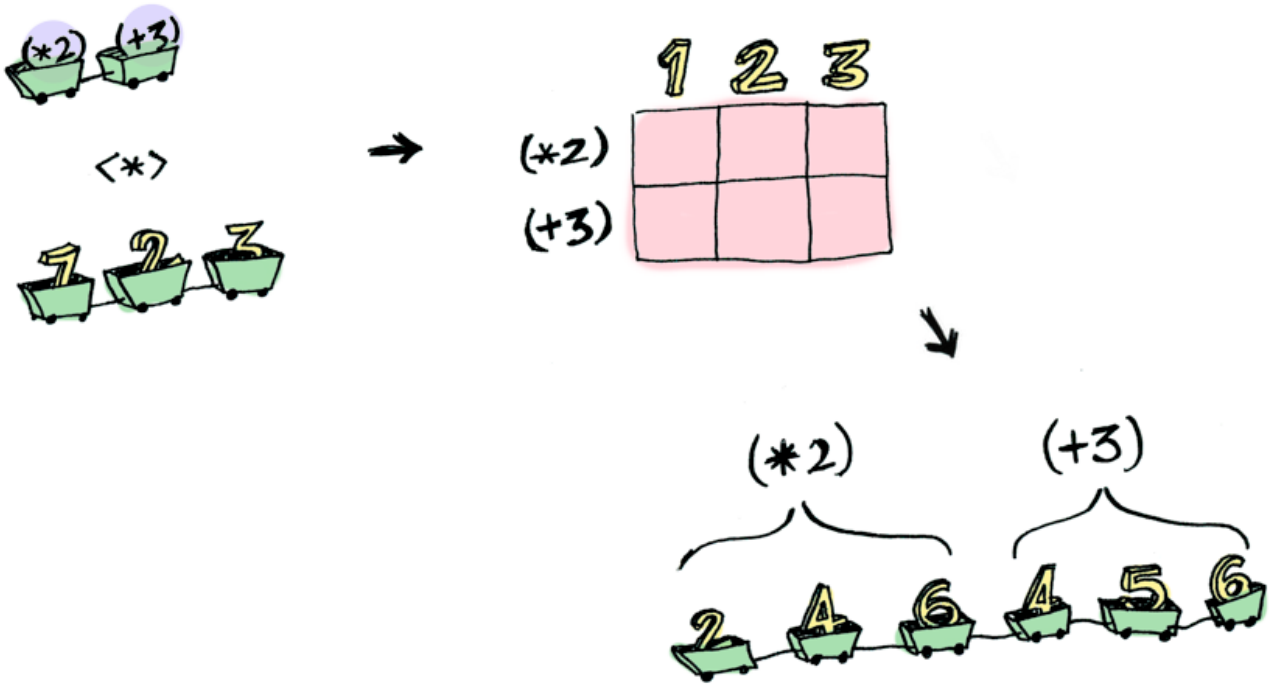
```
infix fun <T, R>  Maybe<(T) -> R>.`(*)`(maybe: Maybe<T>): Maybe<R> = when(this
    Maybe.`Nothing#` -> Maybe.`Nothing#`
    is Maybe.Just -> this.value `($)` maybe
}

Maybe.Just { x: Int -> x + 3 } `(*)` Maybe.Just(2) == Maybe.Just(5)
```

Using `(*)` can lead to some interesting situations. For example:

```
infix fun <T, R>  Iterable<(T) -> R>.`(*)`(iterable: Iterable<T>) = this.flatM
```

With this definition, we can apply a list of functions to a list of values:

```
> listOf<(Int) -> Int>({ it * 2 }, { it + 3 }) `(*)` listOf(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?

```
> { y: Int -> { x: Int -> x + y } } `($)` Maybe.Just(5)
Just(value=(kotlin.Int) -> kotlin.Int) // equal to `Maybe.Just { x: Int -> x +
> Maybe.Just { x: Int -> x + 5 } `($)` Maybe.Just(4)
ERROR ??? WHAT DOES THIS EVEN MEAN WHY IS THE FUNCTION WRAPPED IN A JUST
```

Applicatives:

```
> { y: Int -> { x: Int -> x + y } } `($)` Maybe.Just(5)
Just(value=(kotlin.Int) -> kotlin.Int) // equal to `Maybe.Just { x: Int -> x +
> Maybe.Just { x: Int -> x + 5 } `(*)` Maybe.Just(3)
Just(value=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!"

```
> { y: Int -> { x: Int -> x + y } } `($)` Maybe.Just(5) `(*)` Maybe.Just(3)
Just(value=15)
```

We can also define another Applicative's function `liftA2`:

```
fun <T> ((x: T, y: T) -> T).liftA2(m1: Maybe<T>, m2: Maybe<T>) =
    { y: T -> { x: T -> this(x, y) } } `($)` m1 `(*)` m2
```

And using `liftA2` do the same thing:

```
> { x: Int, y: Int -> x * y }.liftA2(Maybe.Just(5), Maybe.Just(3))
Just(value=15)
```

Monads

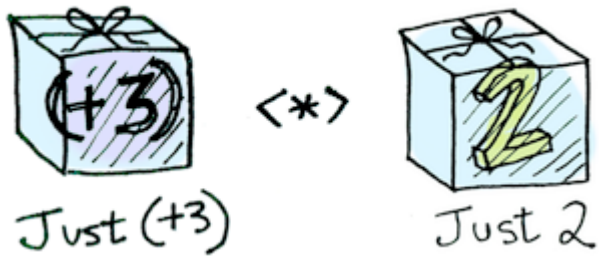
How to learn about Monads:

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.

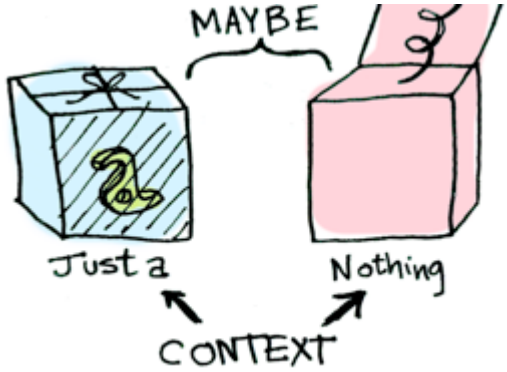
Functors apply a function to a wrapped value:

Applicatives apply a wrapped function to a wrapped value:



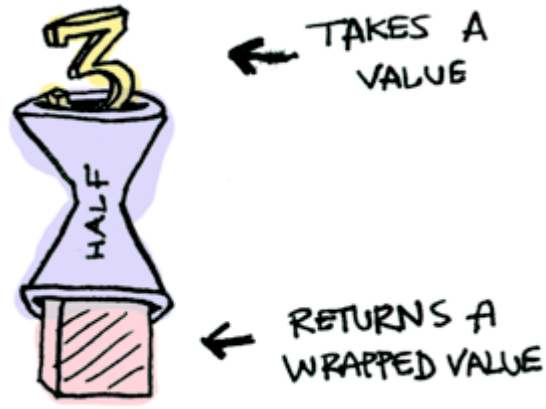
Monads apply a function **that returns a wrapped value** to a wrapped value. Monads have a function `))=` (`>>=` in Haskell, pronounced "bind") to do this.

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



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

```
fun half(x: Int) = if (x % 2 == 0)
                       Maybe.Just(x / 2)
                   else
                       Maybe.`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 `))=`:

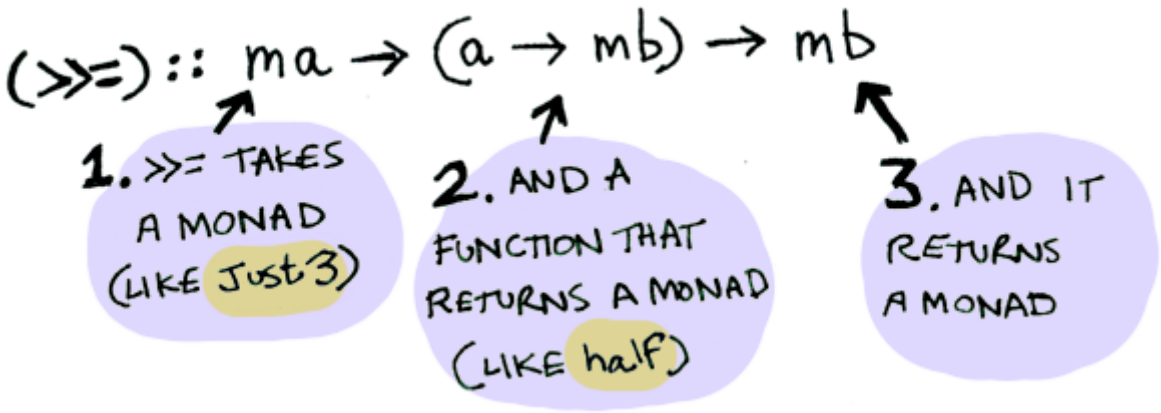
Here's how it works:

```
> Maybe.Just(3) `))=` ::half
Nothing#
> Maybe.Just(4) `))=` ::half
Just(value=2)
> Maybe.`Nothing#` `))=` ::half
Nothing#
```

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

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

Where `>>=` is:



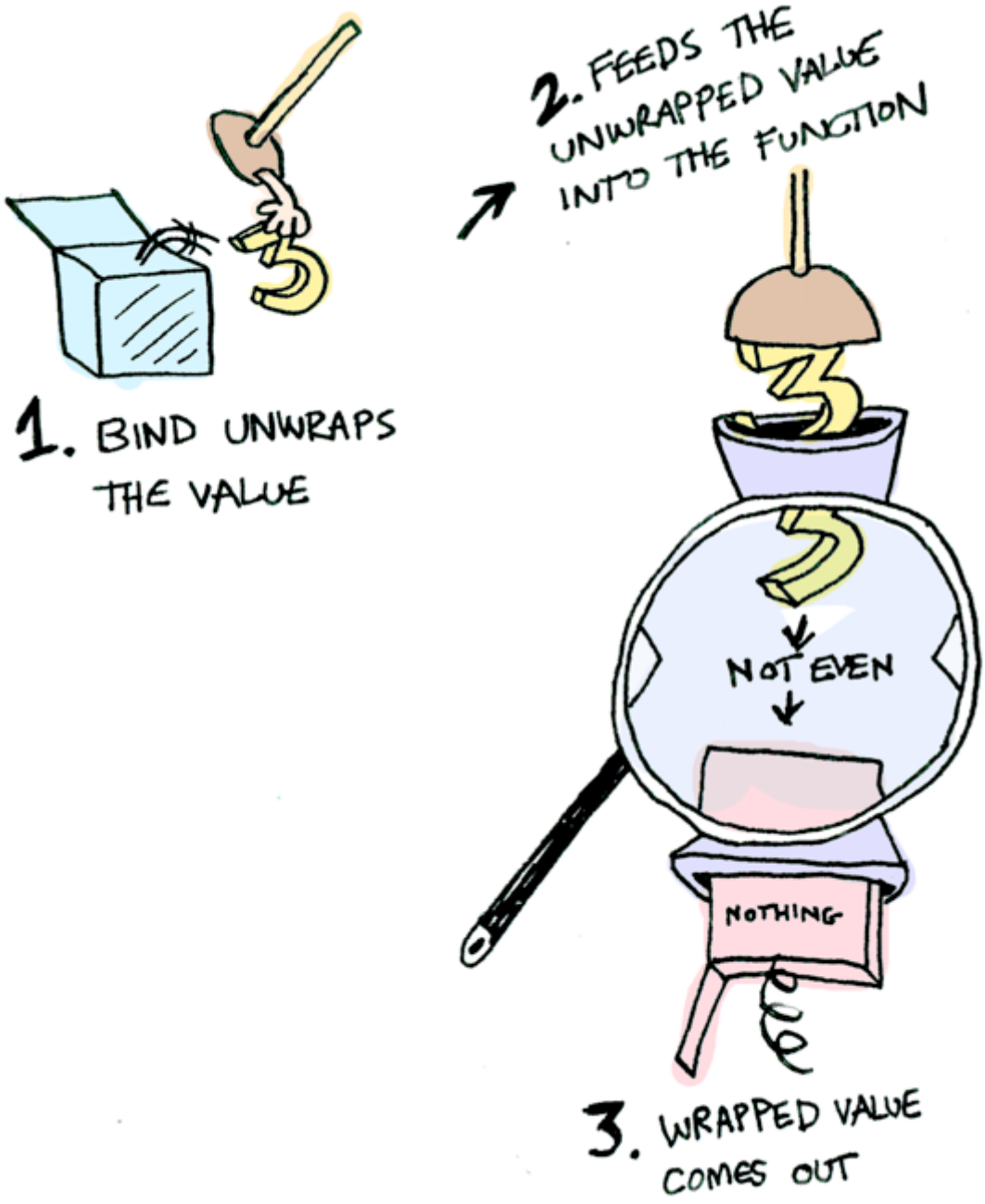
In Kotlin, `Monad` can be considered as a type that defines such an infix function:

```
infix fun <T, R> Monad<T>.`))=`(f: ((T) -> Monad<R>)): Monad<R>
```

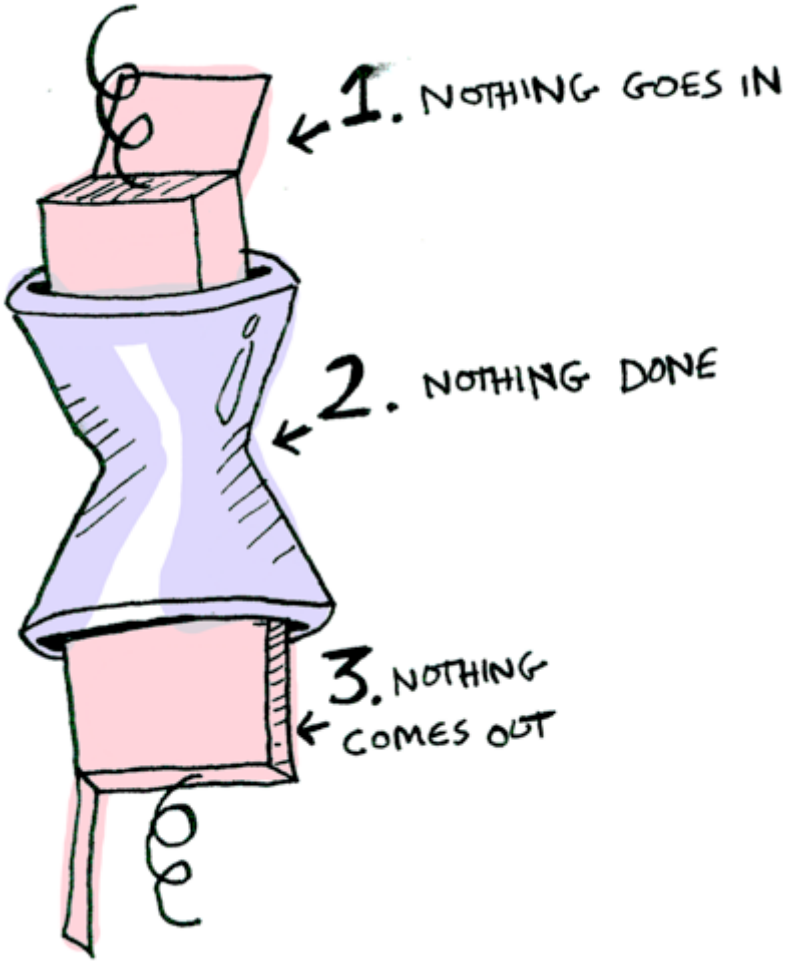
So `Maybe` is a Monad:

```
infix fun <T, R> Maybe<T>.`)=`(f: ((T) -> Maybe<R>)): Maybe<R> = when(this) {
    Maybe.`Nothing#` -> Maybe.`Nothing#`
    is Maybe.Just -> f(this.value)
}
```

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

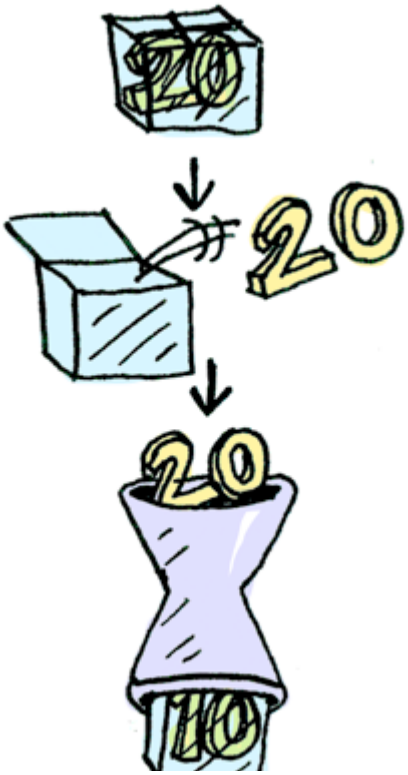


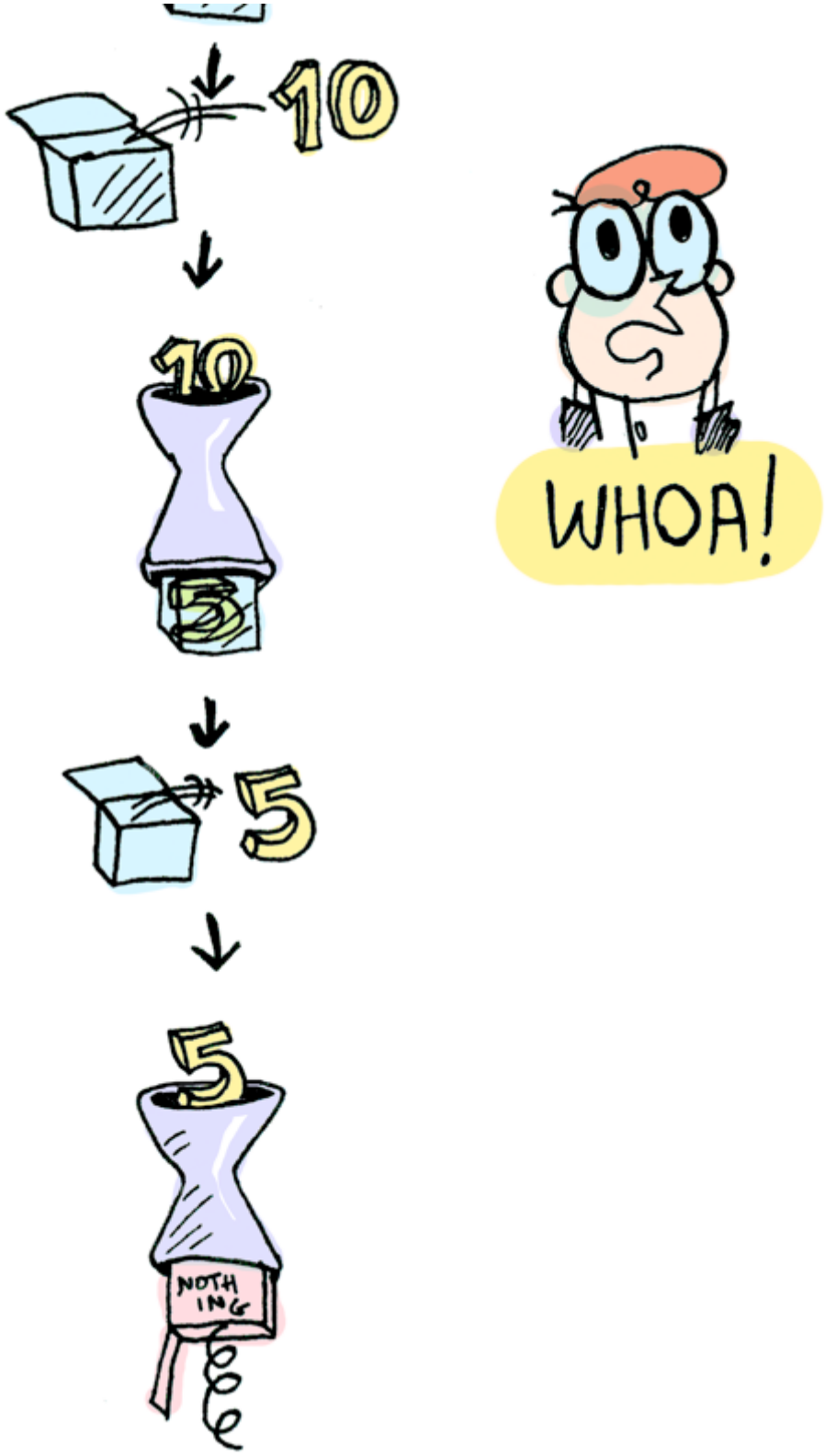
And if you pass in a `Nothing#` it's even simpler:



You can also chain these calls:

```
> Maybe.Just(20) `)=` ::half `)=` ::half `)=` ::half
Nothing#
```





> ***Note:*** *The built-in null safety syntax of Kotlin can provide monad-like operations including chaining the calls:*

```
fun Int.half() = if (this % 2 == 0) this / 2 else null

val n: Int? = 20
n?.half()?.half()?.half()
```

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:

> ***Note:*** *Since Kotlin doesn't distinguish between pure and impure function, it doesn't need IO monad at all. This is just an emulation:*
>
> ```
> data class IO<out T>(val `(-`: T)
>
> infix fun <T, R> IO<T>.`)=`(f: ((T) -> IO<R>)): IO<R> = f(this.`(-`)
> ```

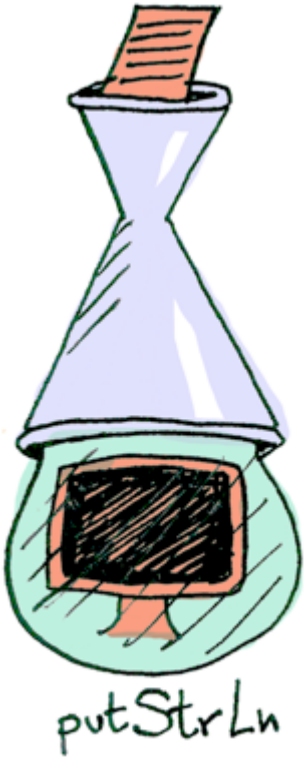
Specifically three functions. `getLine` takes no arguments and gets user input:


```
fun getLine(): IO<String> = IO(readLine() ?: "")
```

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

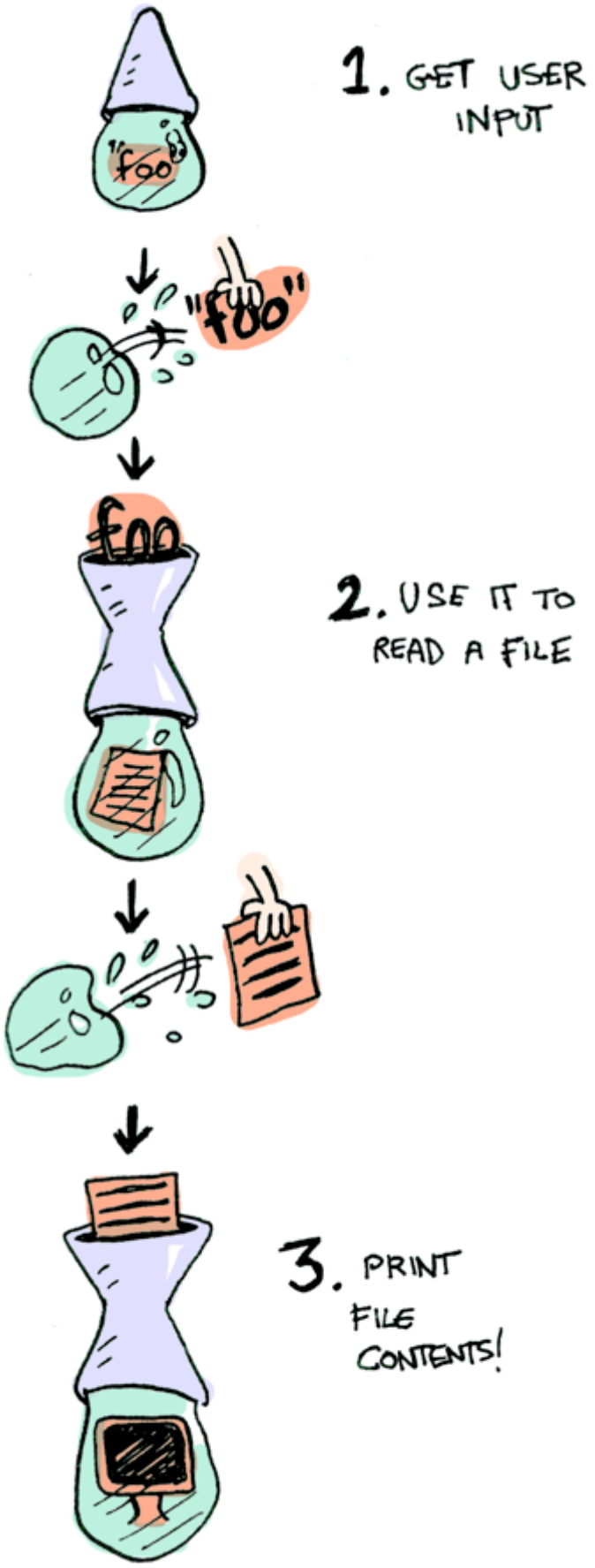

```
typealias FilePath = String

fun readFile(filename: FilePath): IO<String> = IO(File(filename).readText())
```

`putStrLn` takes a string and prints it:




```
fun putStrLn(str: String): IO<Unit> = IO(println(str))
```

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
```

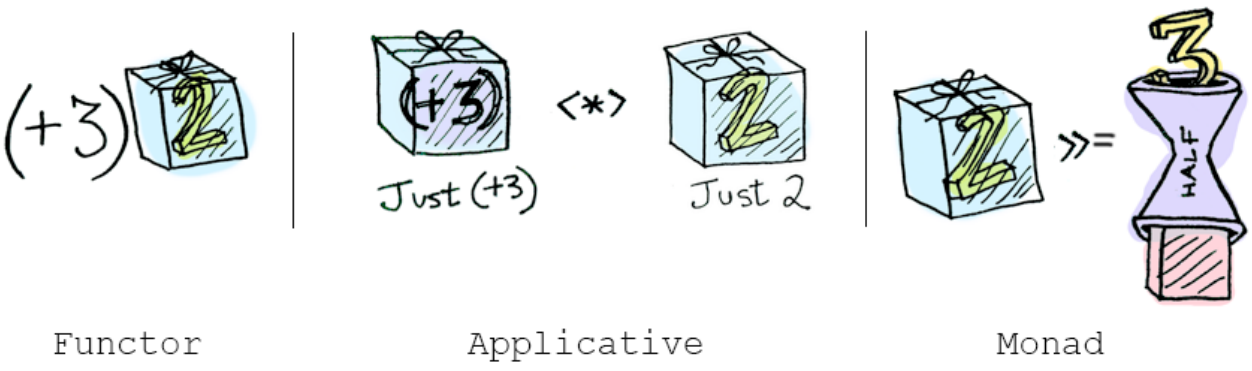
It can be emulated in Kotlin (where the `<-` operator in haskell is replaced with `(-` property and assignment):

```
fun <T> `do` (ioOperations: () -> IO<T>) = ioOperations()

val foo = `do` {
  val filename = getLine().`(-`
  val contents = readFile(filename).`(-`
  putStrLn(contents)
}
```

Conclusion

1. A functor (in haskell) is a data type that implements the `Functor` typeclass.
2. An applicative (in haskell) is a data type that implements the `Applicative` typeclass.
3. A monad (in haskell) 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.

Follow me on Twitter: JiaYanwei(hltj).

欢迎关注：

GitHub：hltj 微博：灰蓝天际（@hltj） Twitter：@jywhltj

公众号

微博

« Kotlin 版图解 Functor、Applicative 与 Monad

现代编程语言系列1：静态类型趋势 »