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BOB Conference, Berlin

The Essence of Programming

INNOQ

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My Agenda

- Structure in problem solving

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- Structure in problem solving
- Using function composition

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- Structure in problem solving
- Using function composition
- Learning about categories

My Agenda

- **Structure** in problem solving
- Using function **composition**
- Learning about **categories**



Stockholm, Sweden



- Haskell

- Haskell
- Clojure

- Haskell
- Clojure
- Erlang

- Haskell
- Clojure
- Erlang
- Scala

- Haskell
- Clojure
- Erlang
- Scala
- etc.

λ



Uppsala, Schweden



HAMSÍK

17





[O]



Avoid!

- Quick fixes

Avoid!

- Quick fixes
- Unnecessary layers of technology

Avoid!

- Quick fixes
- Unnecessary layers of technology
- Misunderstanding the problem itself

The Problem of Solving the Problem

"How to change and modify parts of a system without making the system as a whole more complicated"

Today

I'll tackle the problem of the problem by explaining why ...

Why Functional Programming Matters

John Hughes
The University, Glasgow

FAQ

- If functional programming matters ...

FAQ

- If functional programming matters ...
- ...Why is the functional fan-club so small? [2]

FAQ: Answers

- We are technical people

FAQ: Answers

- We are technical people
- We have technical discussions

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- We learn to say "it depends"

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- And that software engineering is about trade-offs

FAQ: Answers

- We are technical people
- We have technical discussions
- We learn to say "it depends"
- And that software engineering is about trade-offs
- But most of all to have faith in what is already working

"Faith triumphs over science [in programming]"

- Philip Waldler

Instead of ...

- Having tunnel vision

Instead of ...

- Having tunnel vision
- Justifying what we already know

Instead of ...

- Having tunnel vision
- Justifying what we already know
- Getting lost in technical discussions

We should ...

- Have an open mind

We should ...

- Have an open mind
- Justify science, logic

We should ...

- Have an open mind
- Justify science, logic
- Start with the fundamentals of problem solving

Only then can we lift ourselves over the everyday programming grind!

Why FP?

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- Functional programming does not only matter

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- It is universal! (direct correspondence with logic) [2]

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- \Rightarrow Lets us focus on the essence of programming

Why FP?

- Functional programming does not only matter
- It is universal! (direct correspondence with logic) [2]
- \Rightarrow Lets us talk about **the structure of problem solving**
- \Rightarrow Lets us focus on the **essence of programming**

The Fundamentals of Problem Solving



Nick
@Zorchenhimer

Found this in production today. I need a drink.

```
public static bool CompareBooleans(bool orig, bool val)
{
    return AreBooleansEqual(orig, val);
}

internal static bool AreBooleansEqual(bool orig, bool val)
{
    if(orig == val)
        return false;
    return true;
}
```

12:54 AM · 31 May 19 · Twitter Web Client

2,519 Retweets 7,054 Likes



We do our best to create modular, losely coupled, composable abstractions



- We program in order to solve problems (Orly? 🤔)

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- Then how do we solve problems?

CS: 101

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Divide and Conquer

- Elegant code = Code that is easy to understand

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- Elegant code = Code broken up into just big enough pieces

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- Elegant code = Code broken up into just big enough pieces (by divide and conquer)

CS: 101

Divide and Conquer

A computer program is ...

- A solution to a problem

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- A solution to many smaller problems

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- A solution to many smaller problems
- Complexity, split up into pieces

A computer program is ...

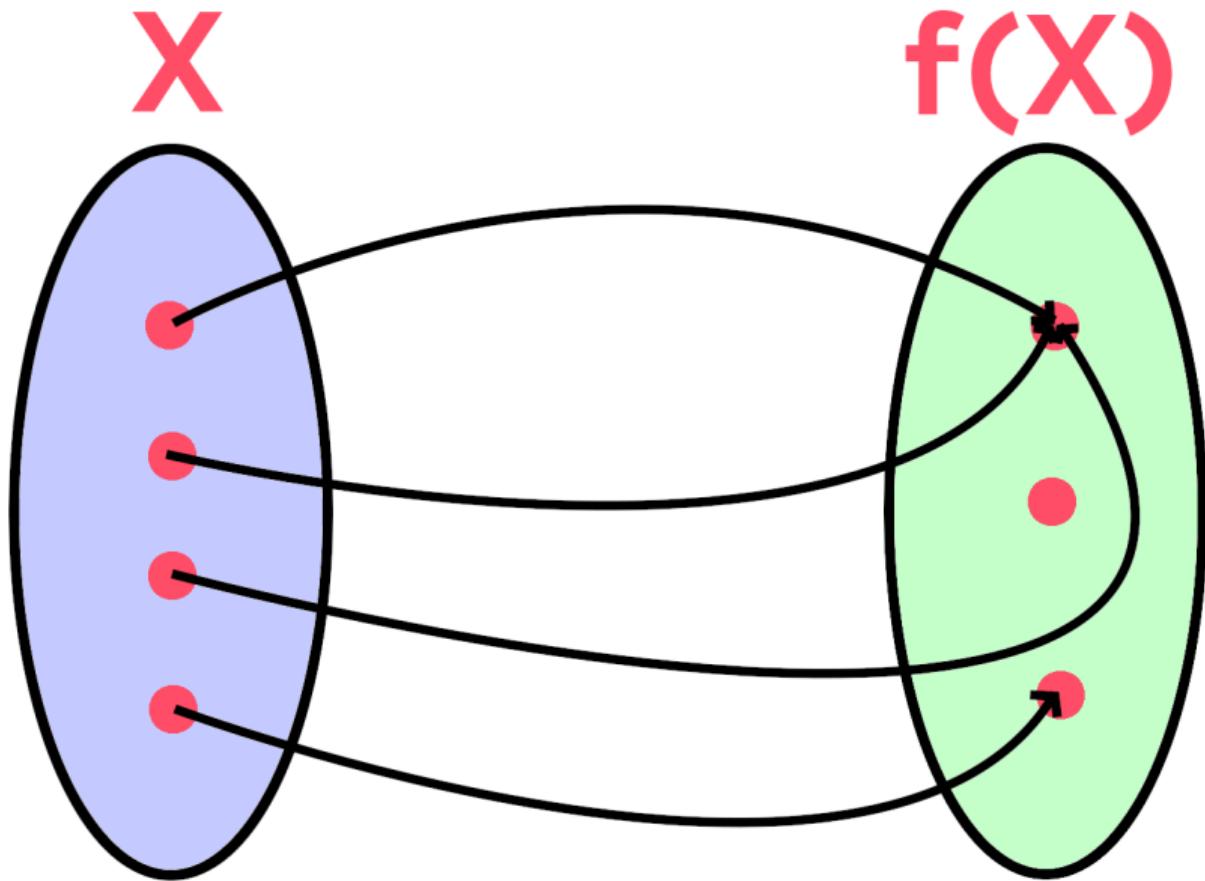
- A solution to a problem
- A solution to many smaller problems
- Complexity, split up into pieces
- Information flowing in a structure

A computer program is ...

- A solution to a problem
- A solution to many smaller problems
- Complexity, split up into pieces
- Information flowing in a structure (by divide and conquer)

How do we build information flow?

Enter the function



- We'd like to use the mathematical model of functions

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- But in programming, we cannot have mathematical functions

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- So let's think about our programs as a collection of pure functions ...
- ...composed together in a certain structure (by divide and conquer)

Divide and Conquer \implies Structure

Divide and Conquer \implies Structure = Function Composition

Divide and Conquer \implies Structure =
Function Composition = The Essence of Programming!

Now show me how to study the essence of programming!

Category Theory

(without most of the theory)



[3]

Category Theory

- Is the science of patterns

Category Theory

- Is the science of patterns
- Is the study of composition

Category Theory

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- Is the study of composition
- Is a language that abstracts structure across different fields

Category Theory

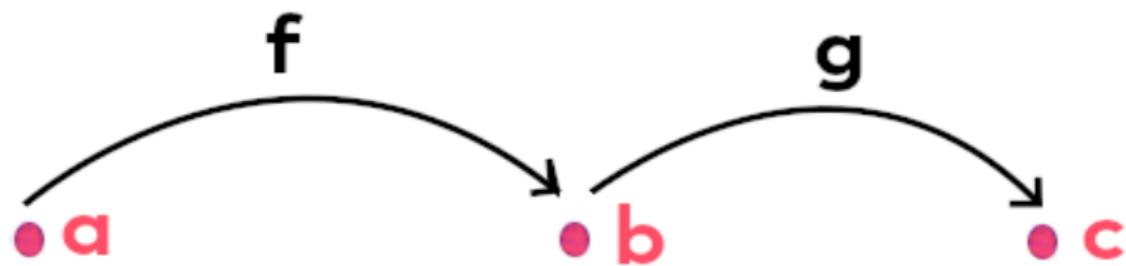
- Is the science of patterns
- Is the study of composition
- Is a language that abstracts structure across different fields
- Applies well to programming ...

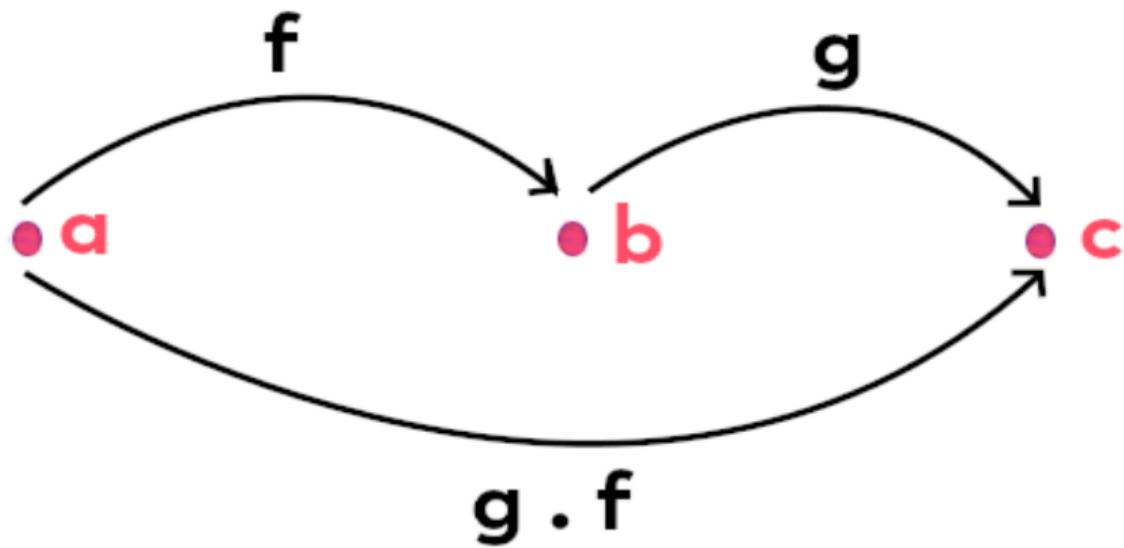
```
J
public static int isEven(int a) {
    if (a == 0) return 1;
    if (a == 2) return 1;
    if (a == 4) return 1;
    if (a == 6) return 1;
    if (a == 8) return 1;
    if (a == 10) return 1;
    if (a == 12) return 1;
    if (a == 14) return 1;
    // TODO: Add more checks.
    return 0;
}
```

Category Theory

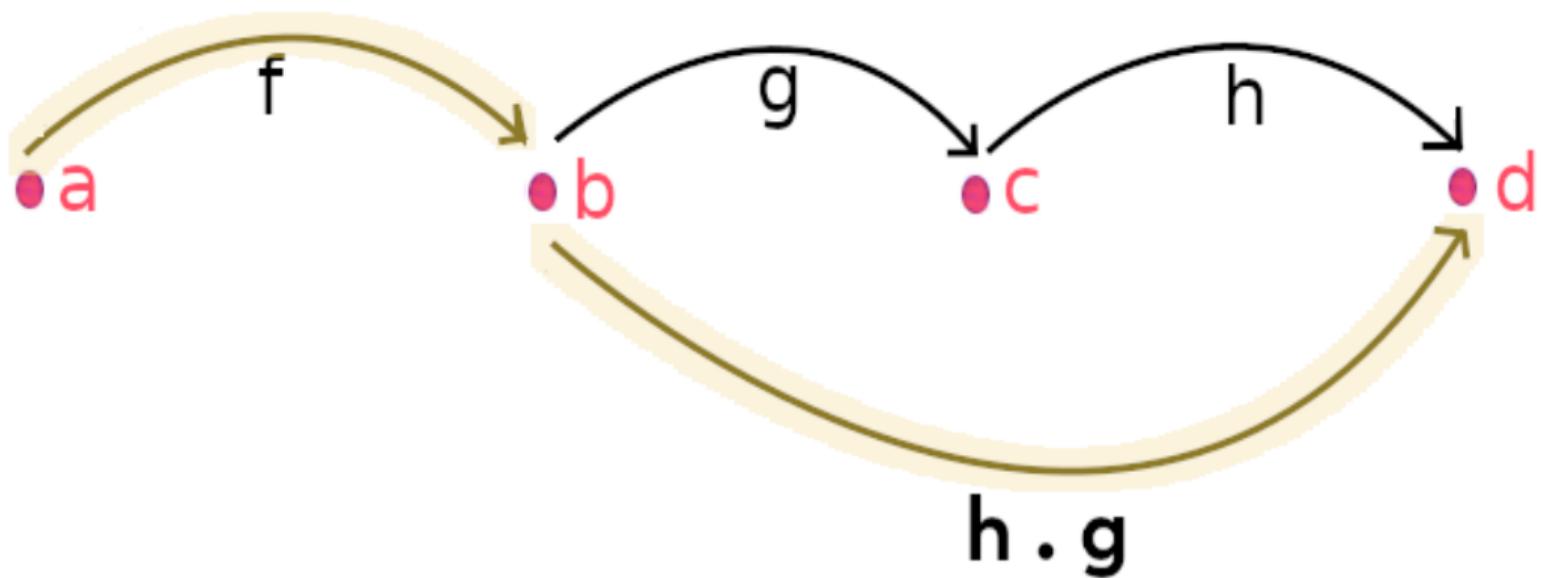
- Is the study of composition
- Is the science of patterns
- Is a language that abstracts structure across different fields
- Applies well to programming ...
- ...because programming is all about structure

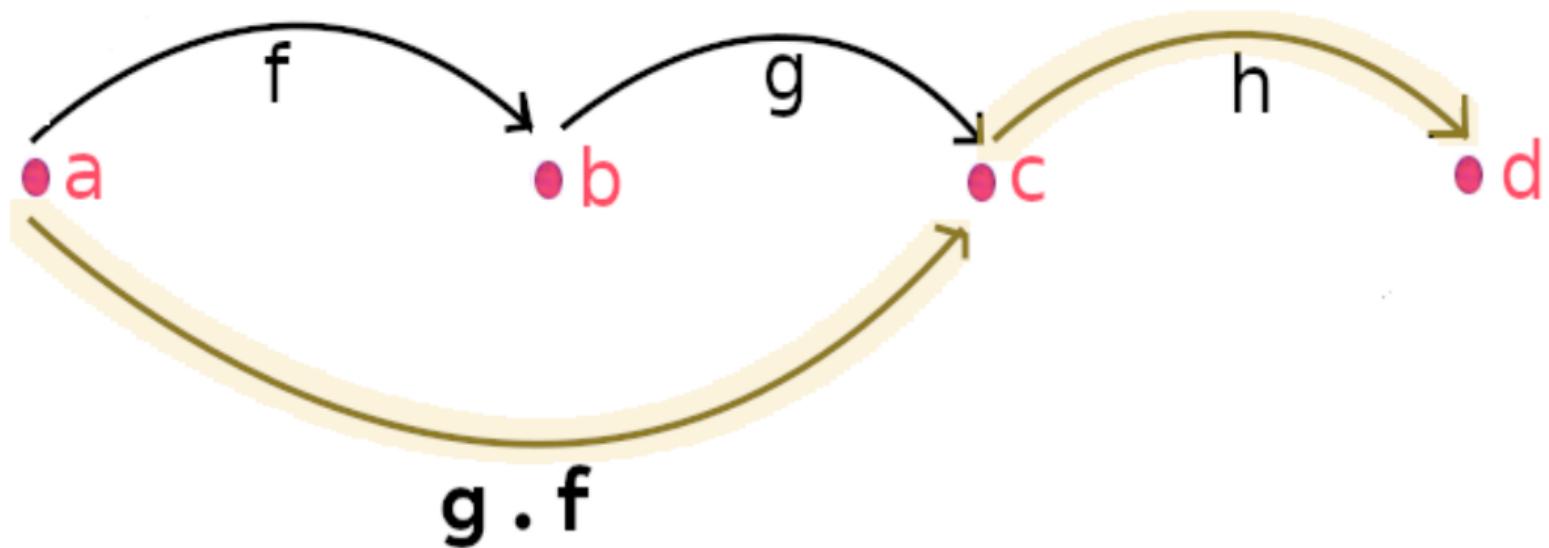
Ok, show me what a category is.

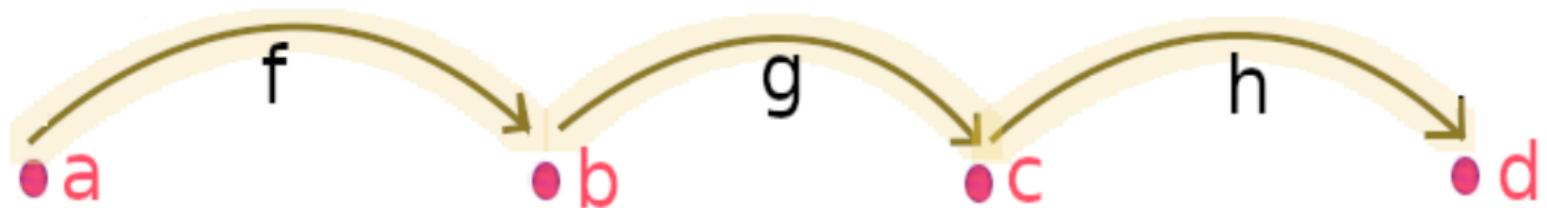


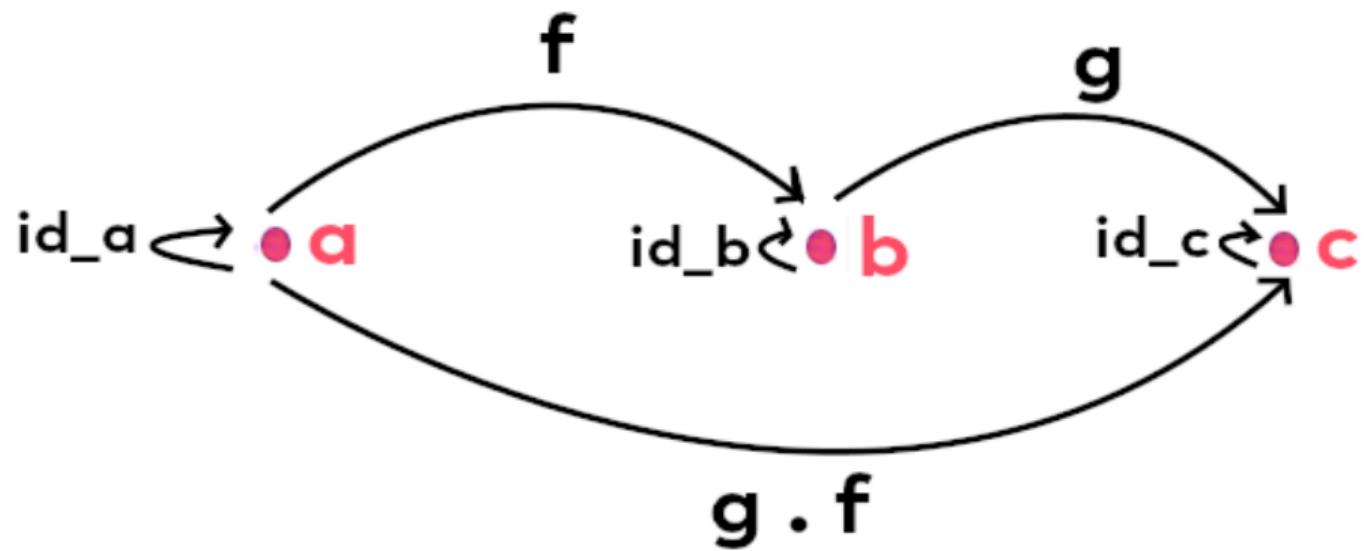


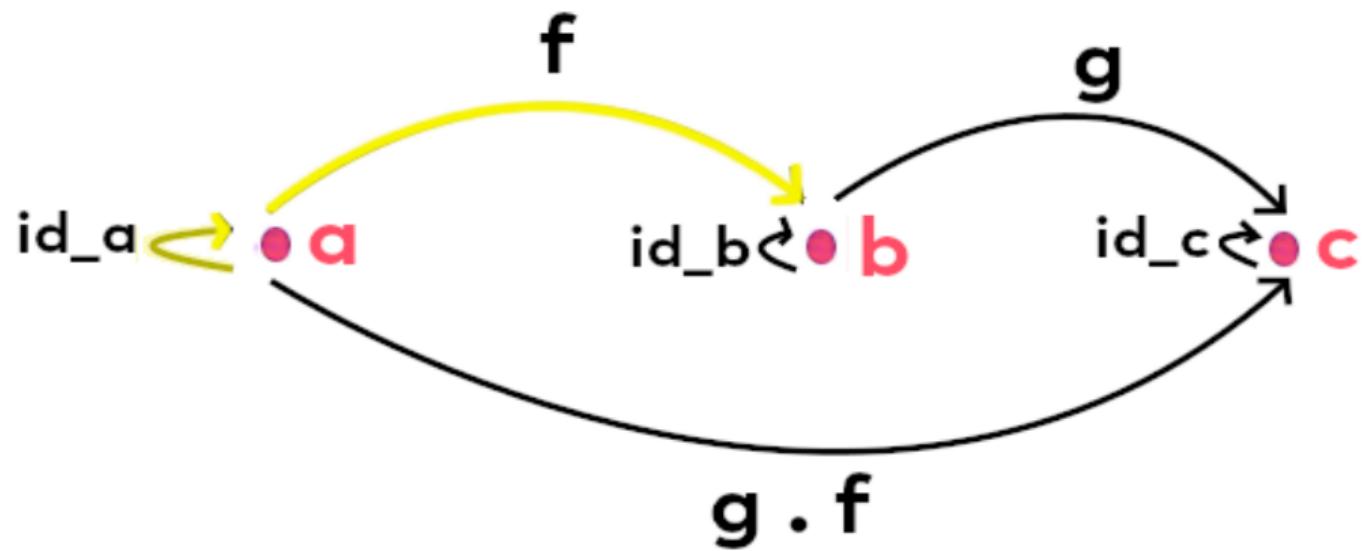


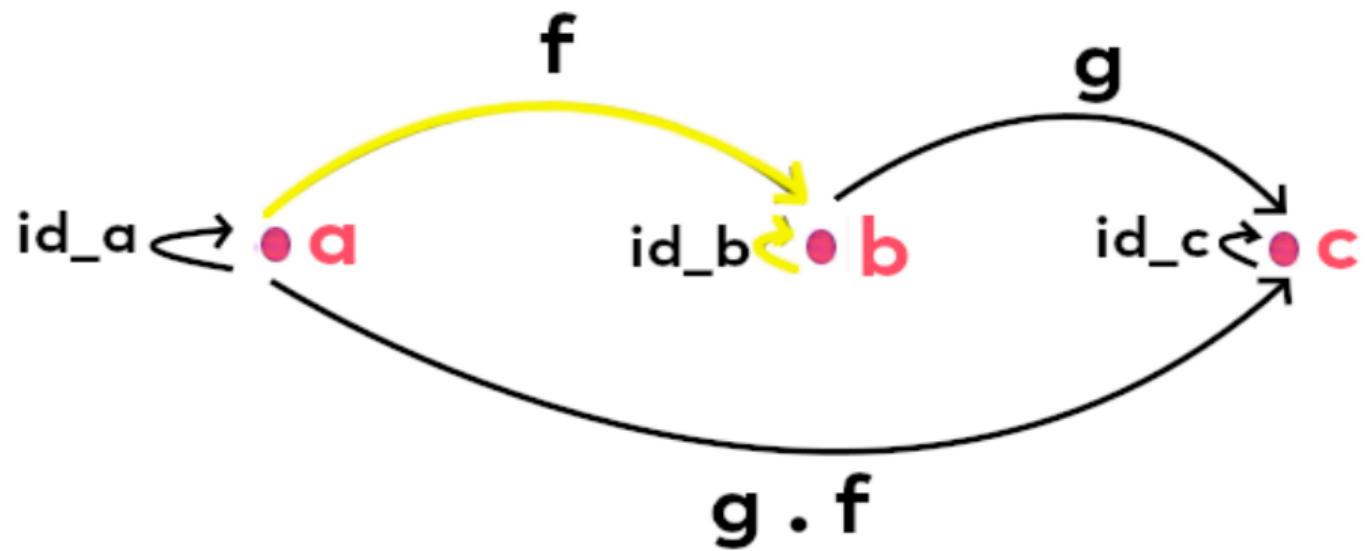












- That's it.

- That's it.
- CT leaves it to us to discover the meaning behind this simple structure

Then show me how to define a category with some meaning!

How to define a category

1. Say what the objects are

How to define a category

1. Say what the objects are
2. Say what the arrows are

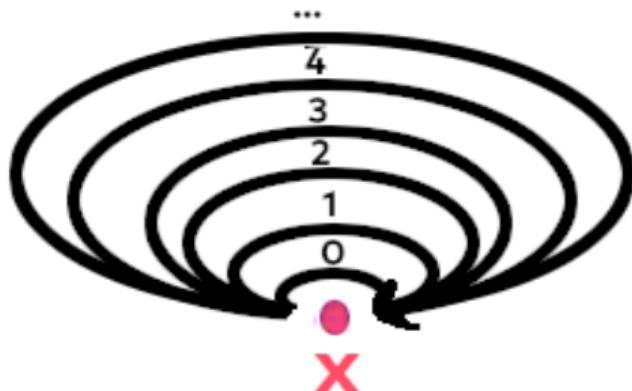
How to define a category

1. Say what the objects are
2. Say what the arrows are
3. Say what the identities are

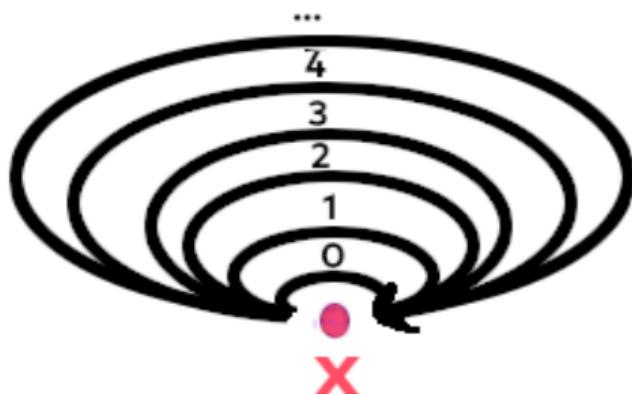
How to define a category

1. Say what the objects are
2. Say what the arrows are
3. Say what the identities are
4. Say how the arrows compose

Category M

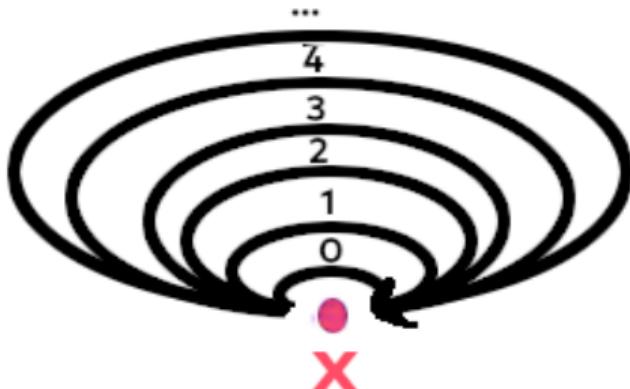


Category M



$\text{Obj}(M) = \{x\}$

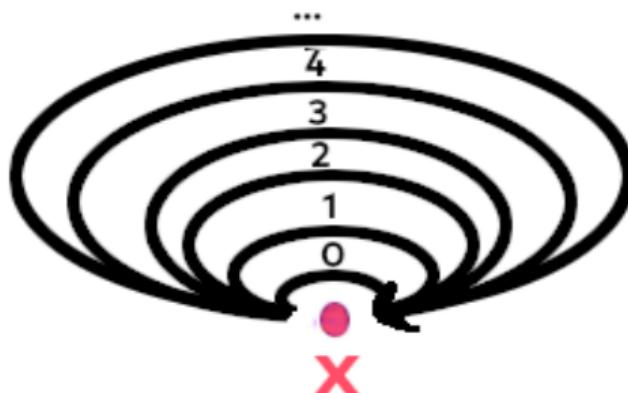
Category M



$$\text{Obj}(M) = \{x\}$$

$$\text{Hom}(M) = \mathbb{N}$$

Category M

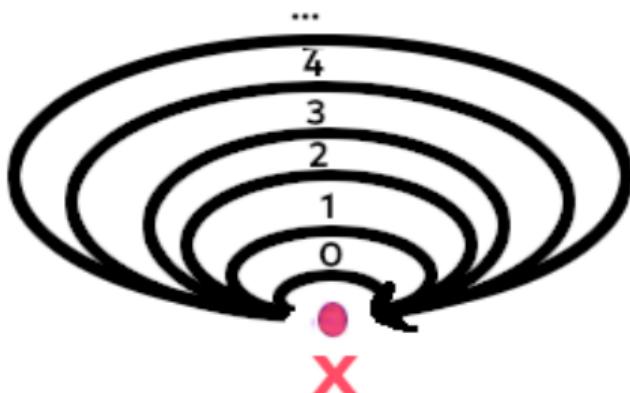


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Category M

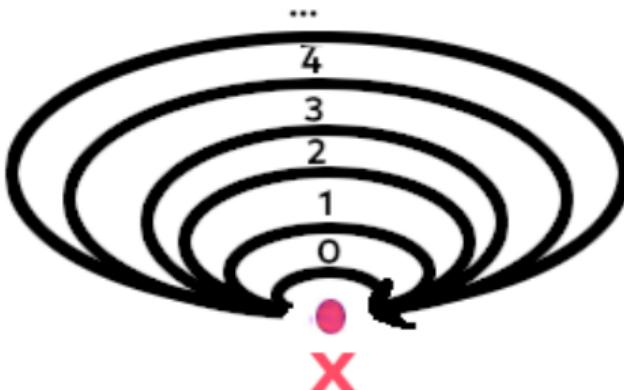


$$\text{Obj}(M) = \{x\}$$

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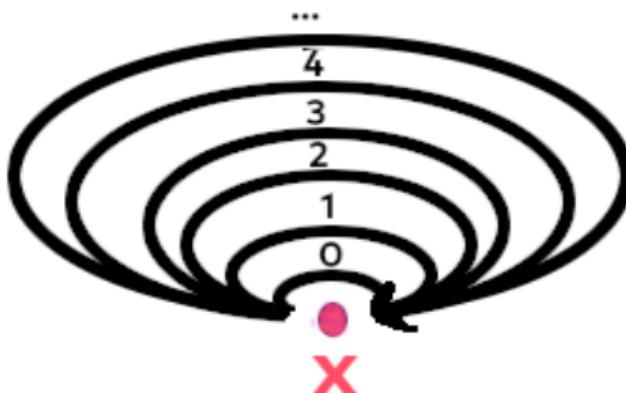
$$\text{Hom}(M) = \mathbb{N} \quad \text{composition} = (+)$$

Category M



Composition: For any two arrows n and m ,
there exists a composite arrow $(n + m)$

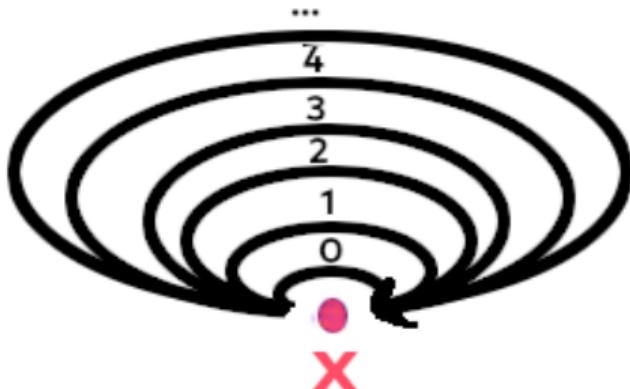
Category M



Composition: For any two arrows n and m ,
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Category M

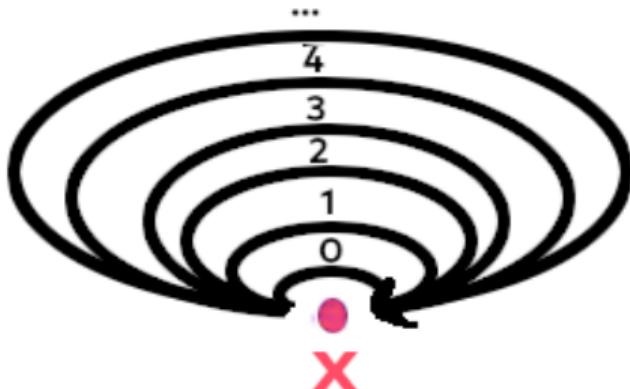


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Category M



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All logic is encoded in the composition

Programmers Category

- Programmers talk in data ...

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- ...and give the data **types**

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- ...and give the data **types**
- They spend their days transforming it with **functions** ...

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- ...and give the data **types**
- They spend their days transforming it with **functions** ...
- ...and **compose** those functions in order to D.R.Y

The Category of Types and Functions

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1. Objects → Types

The Category of Types and Functions

1. Objects → Types
2. Arrows → Functions

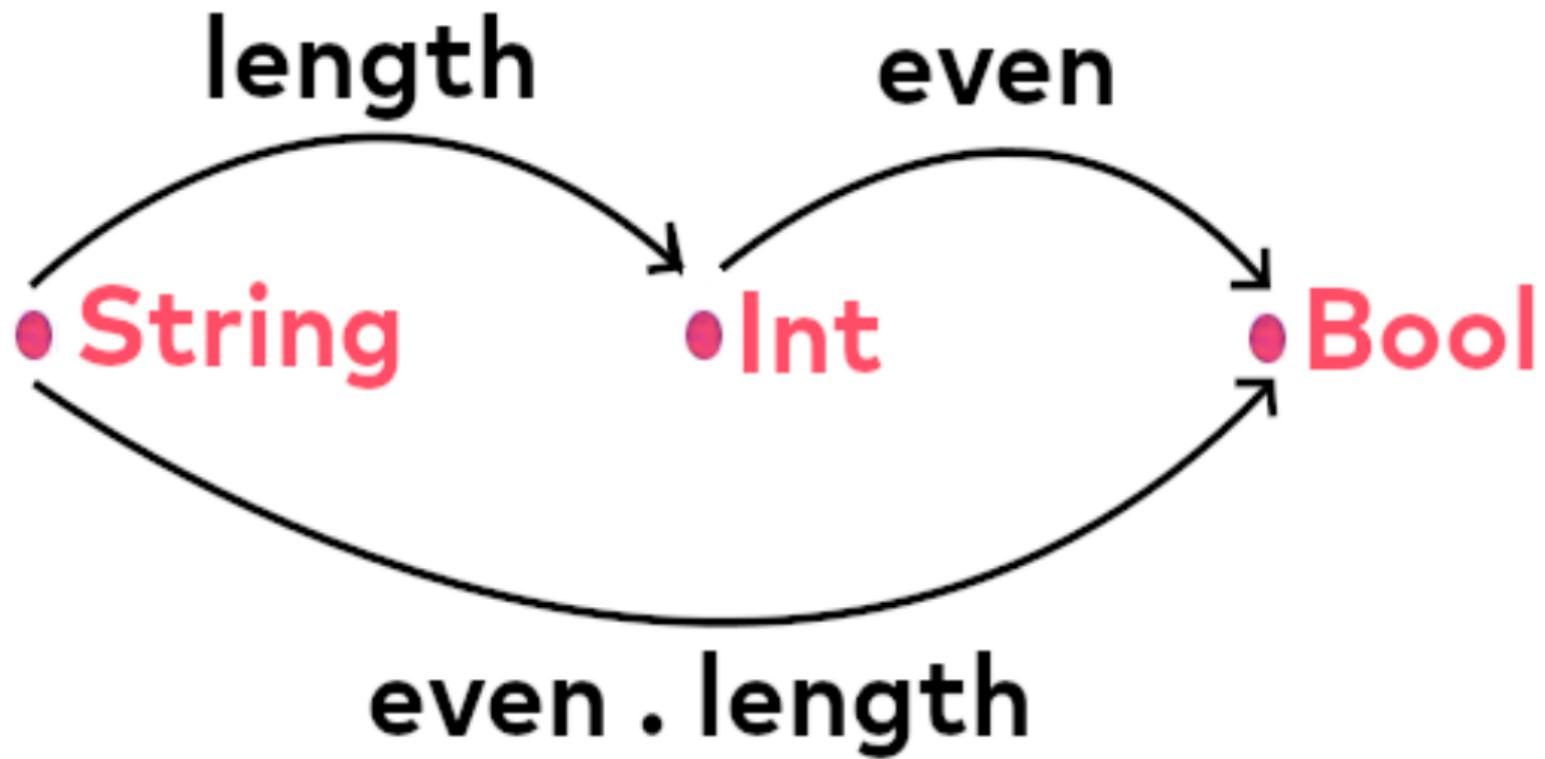
The Category of Types and Functions

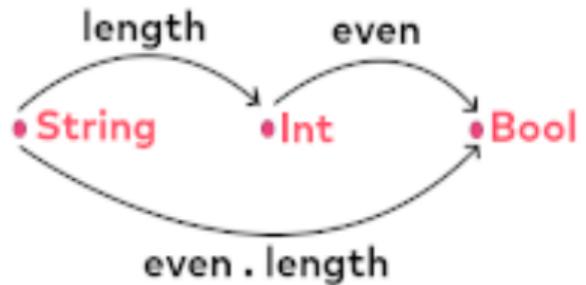
1. Objects → Types
2. Arrows → Functions
3. Composition → Function composition

The Category of Types and Functions

1. Objects → Types
2. Arrows → Functions
3. Composition → Function composition

A tool to study **essence of programming!**





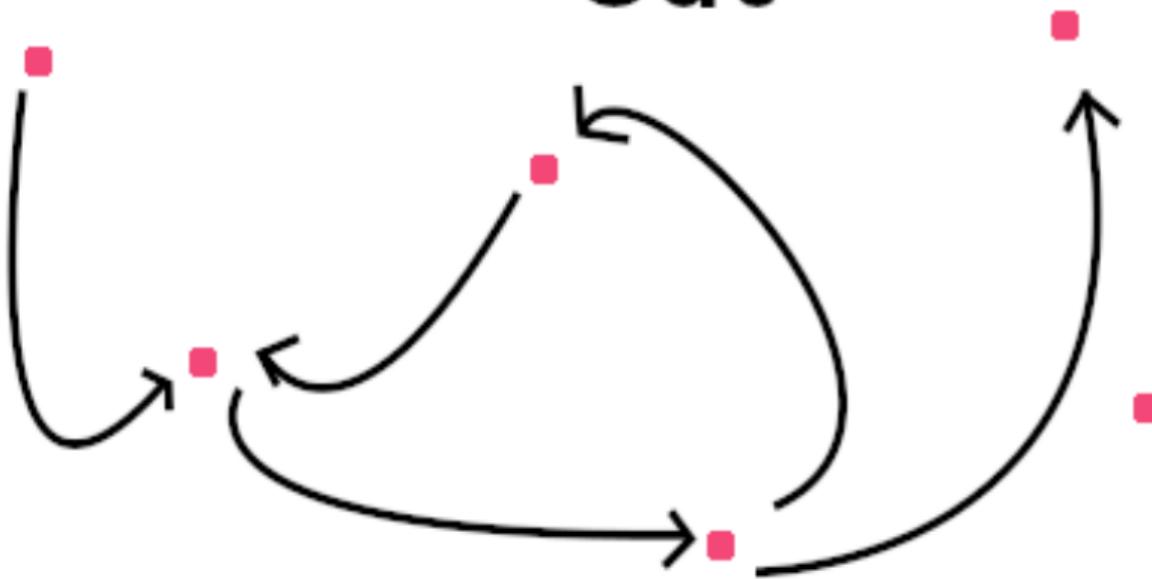




1



Cat



$\text{Ob}(\text{Cat}) = \text{categories}$

$\text{Hom}(\text{Cat}) = \text{functors}$



[4]

The Functor

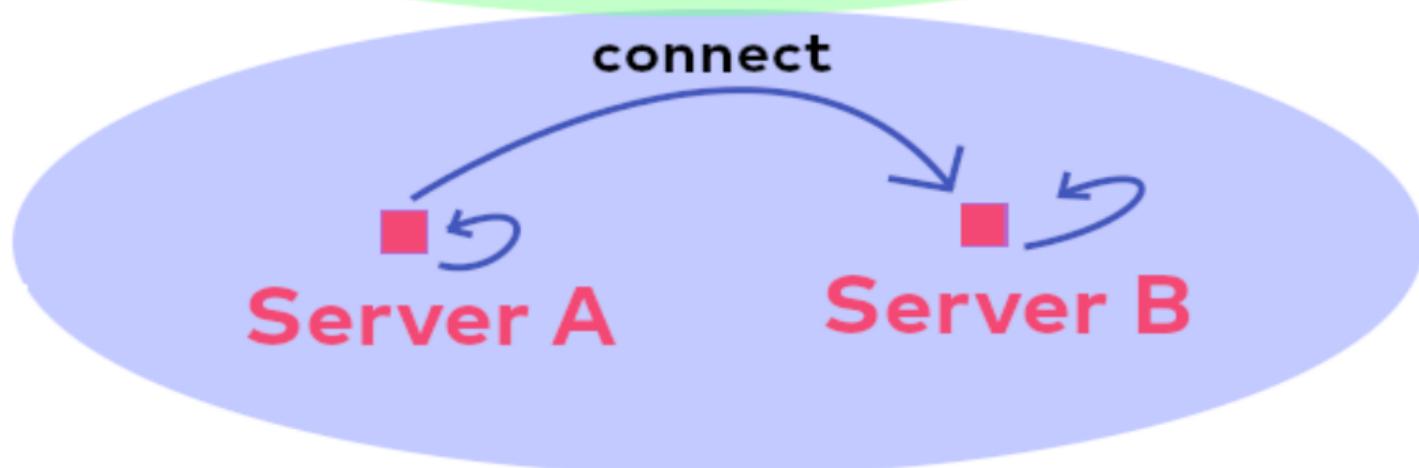
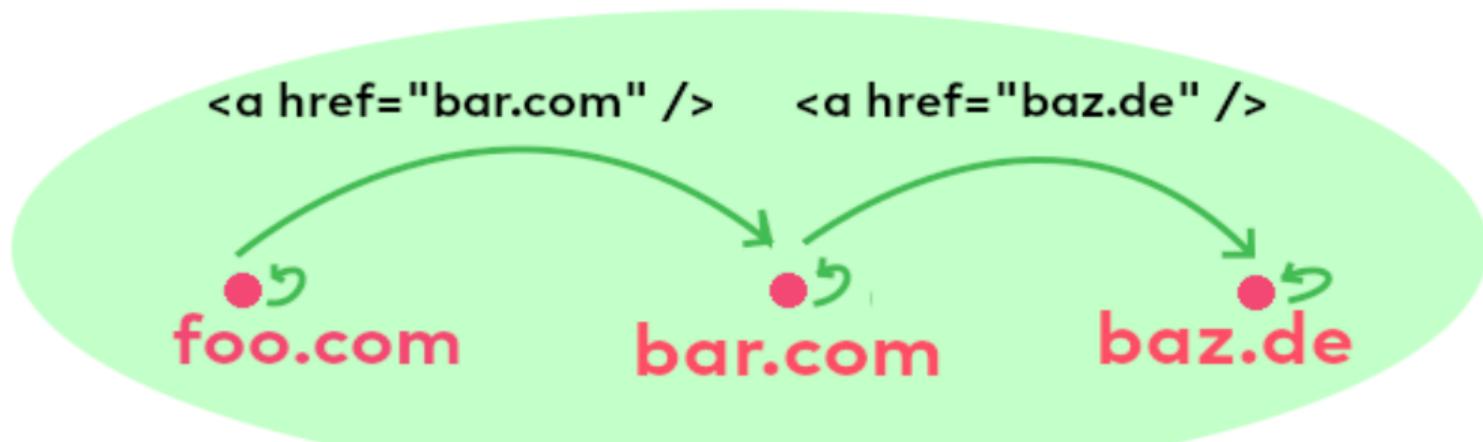
- Is a mapping between categories

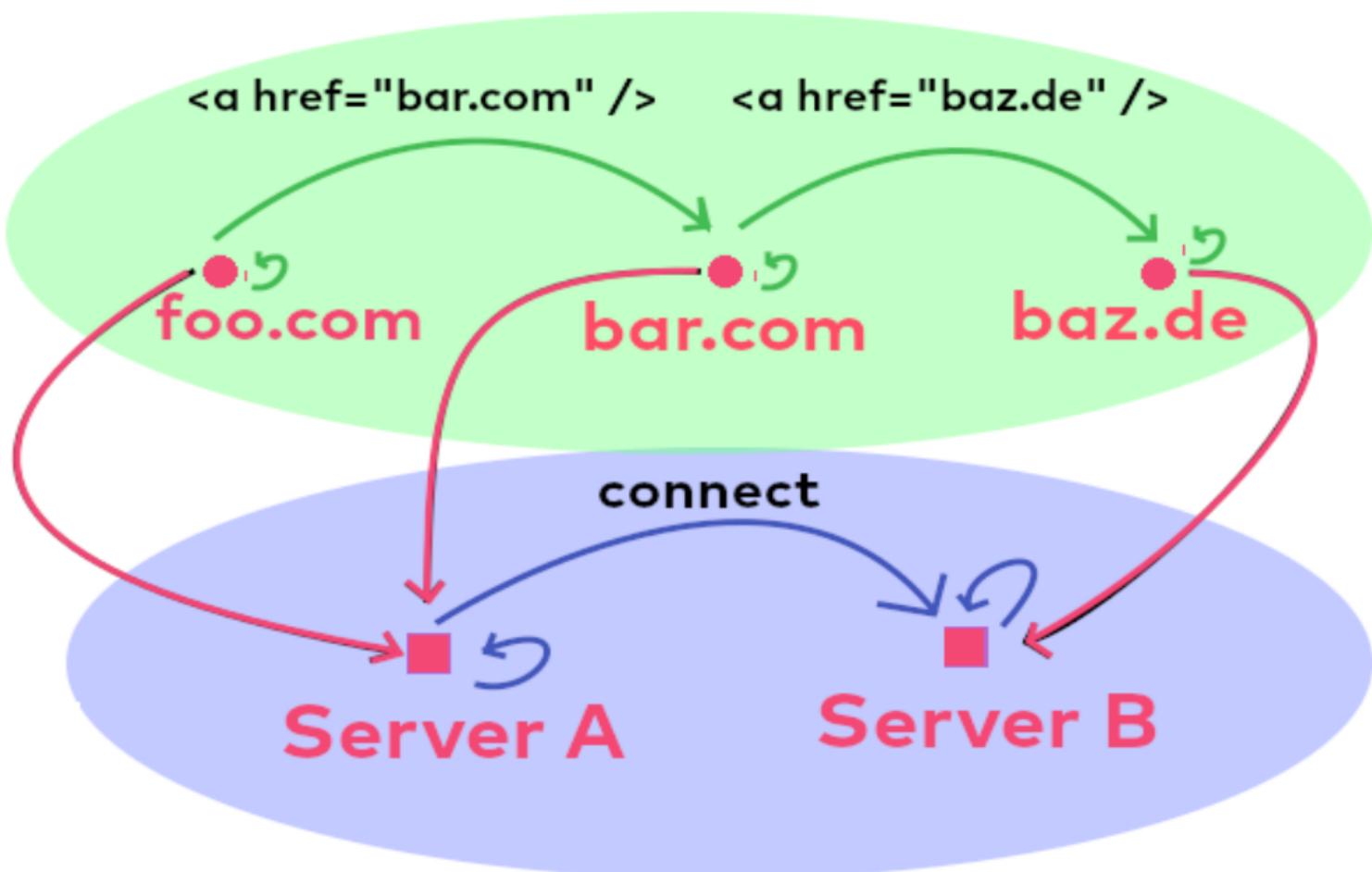
The Functor

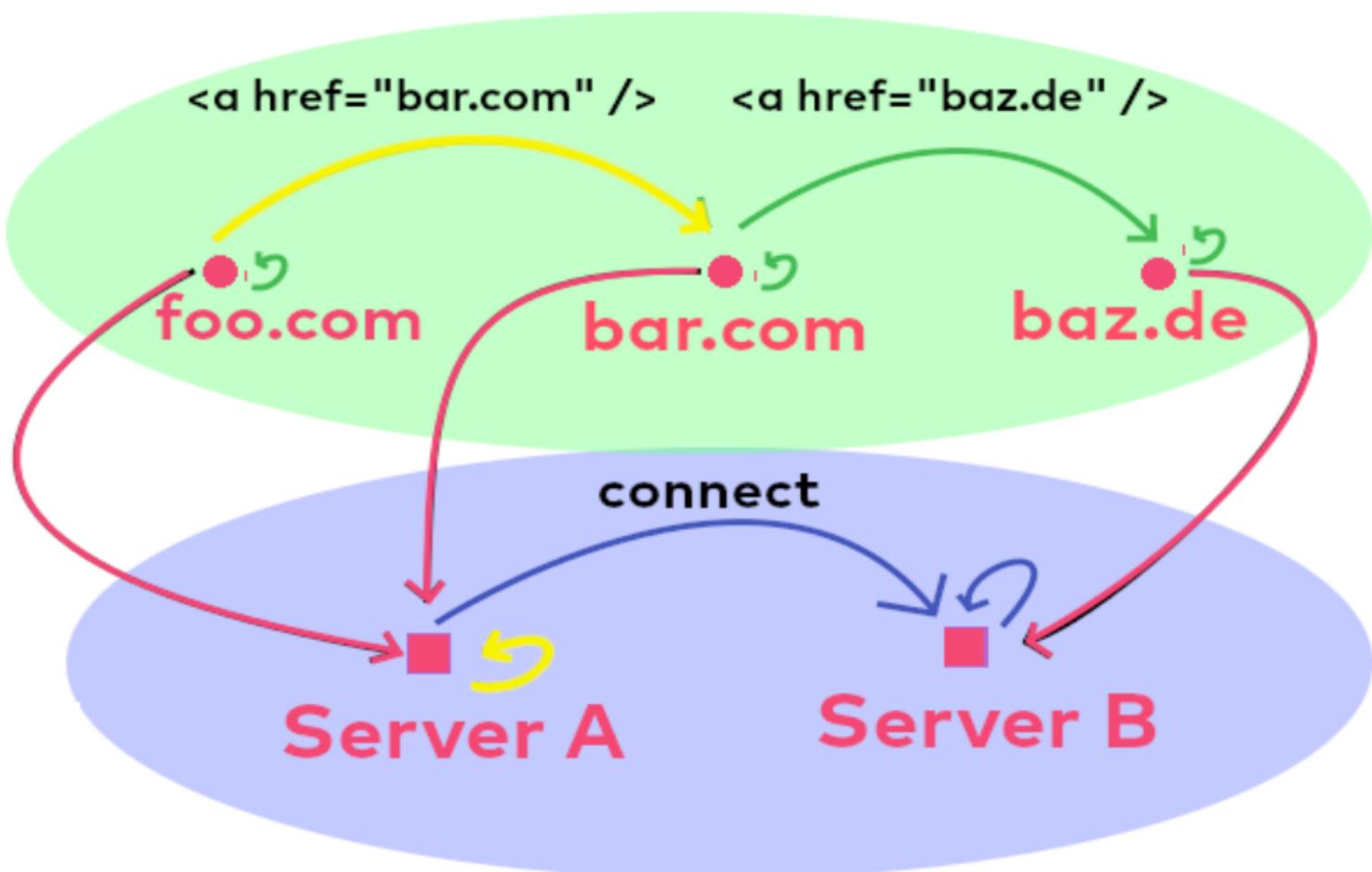
- Is a mapping between categories
- Maps objects into objects and arrows into arrows ...

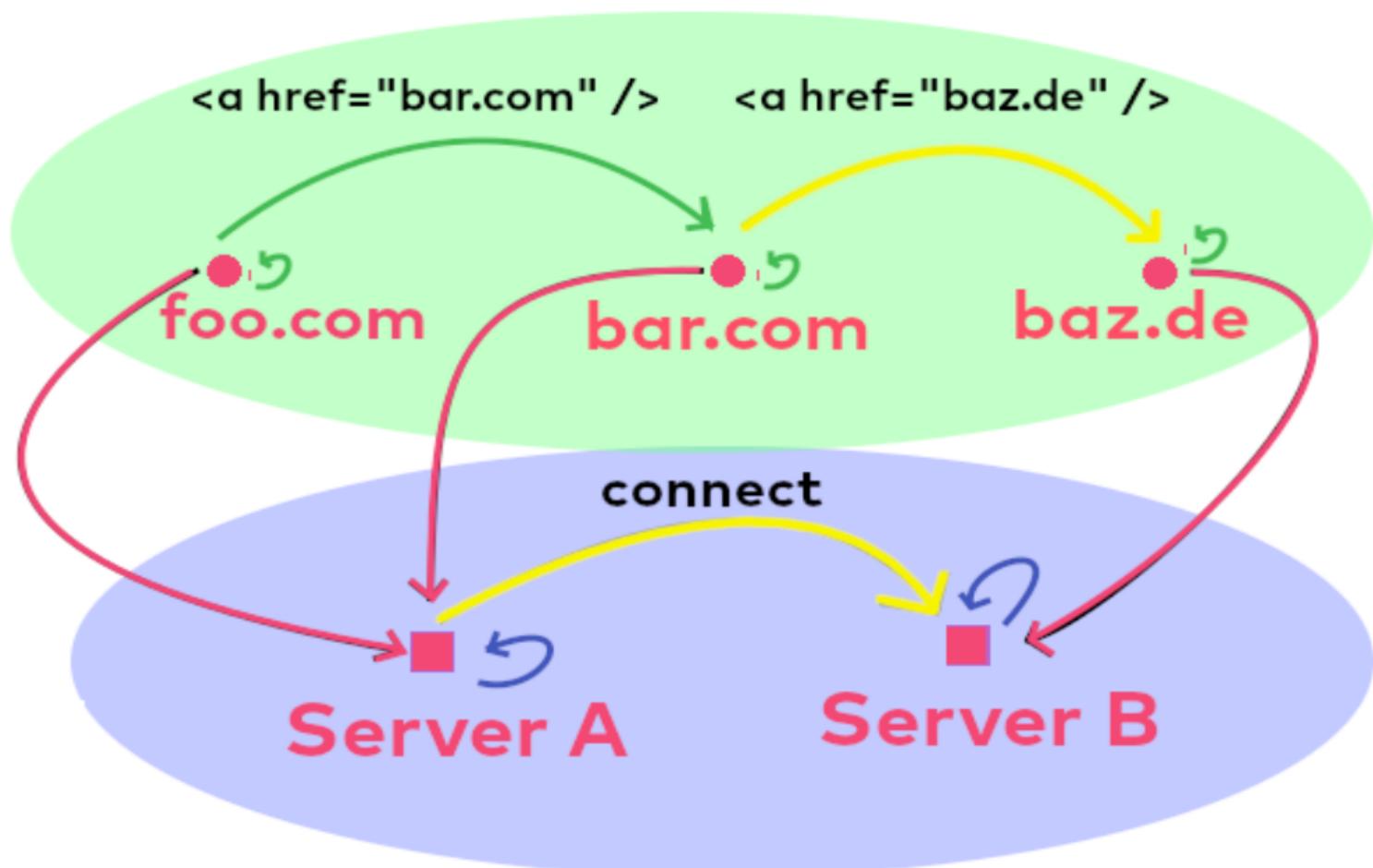
The Functor

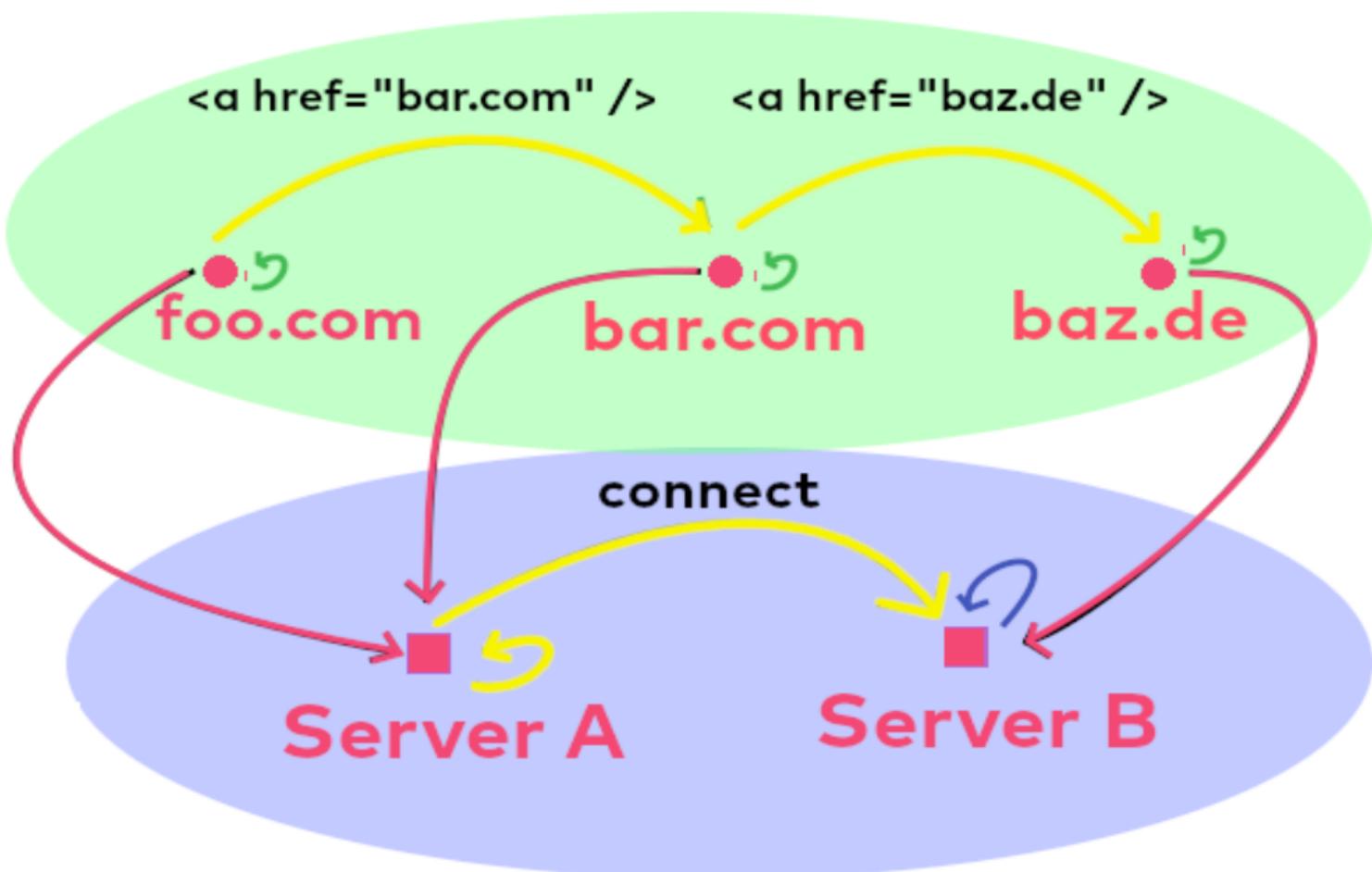
- Is a mapping between categories
- Maps objects into objects and arrows into arrows ...
- ...*Preserving structure!* (or meaning)

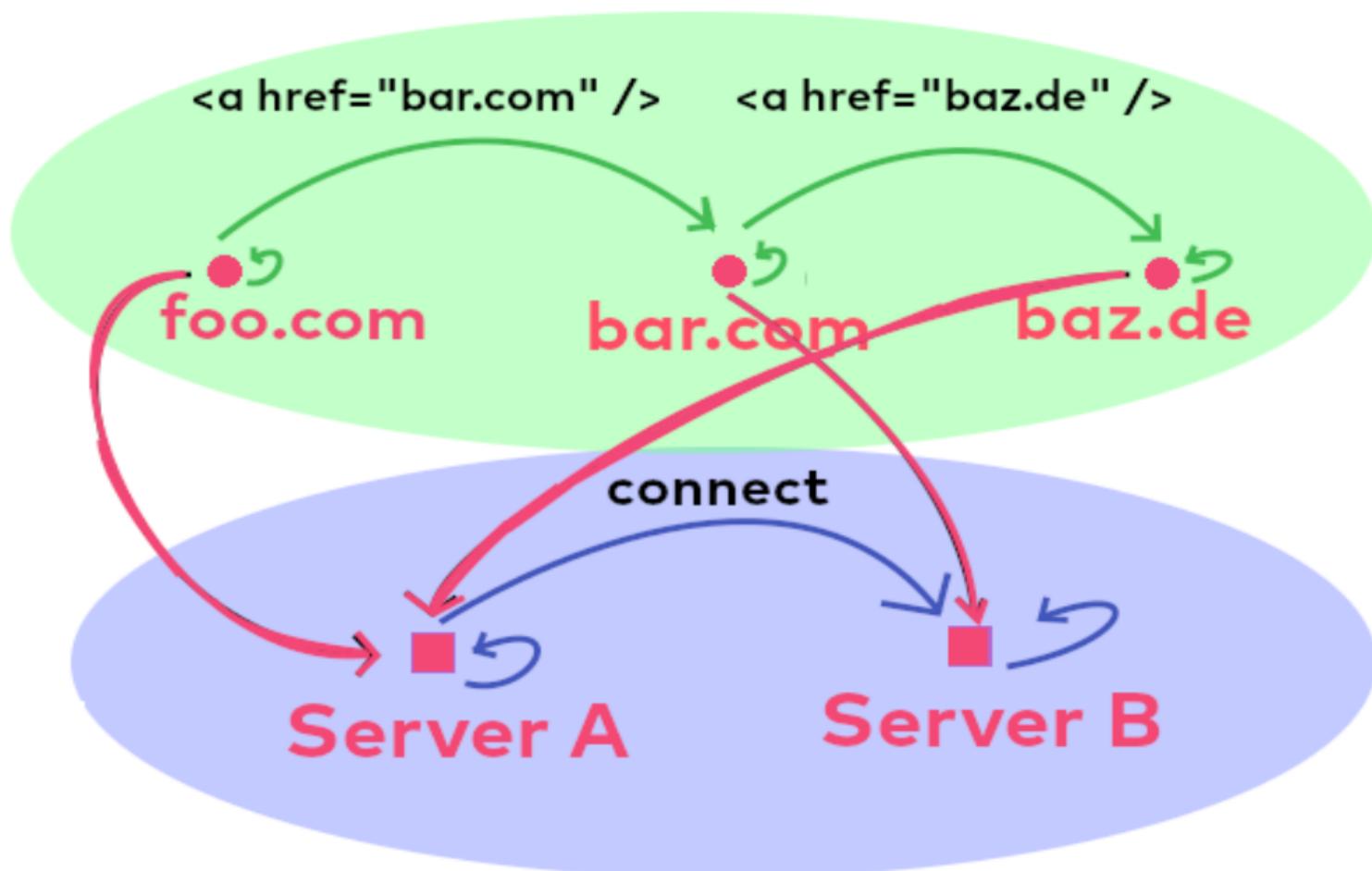




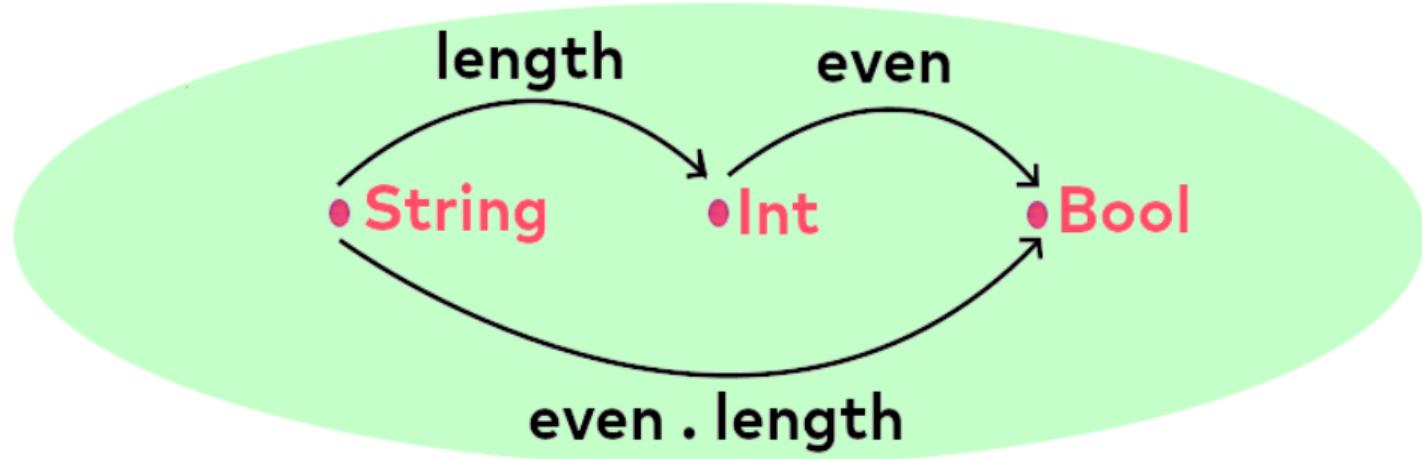
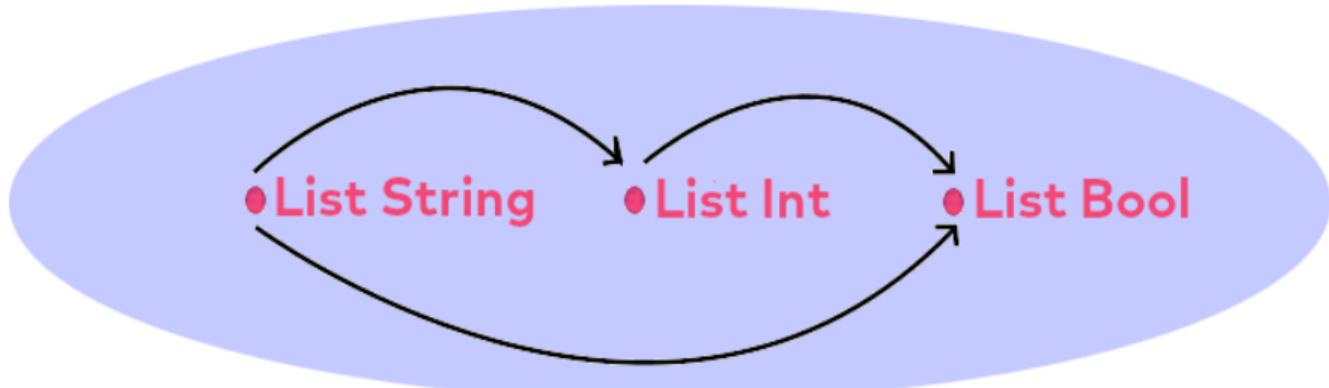


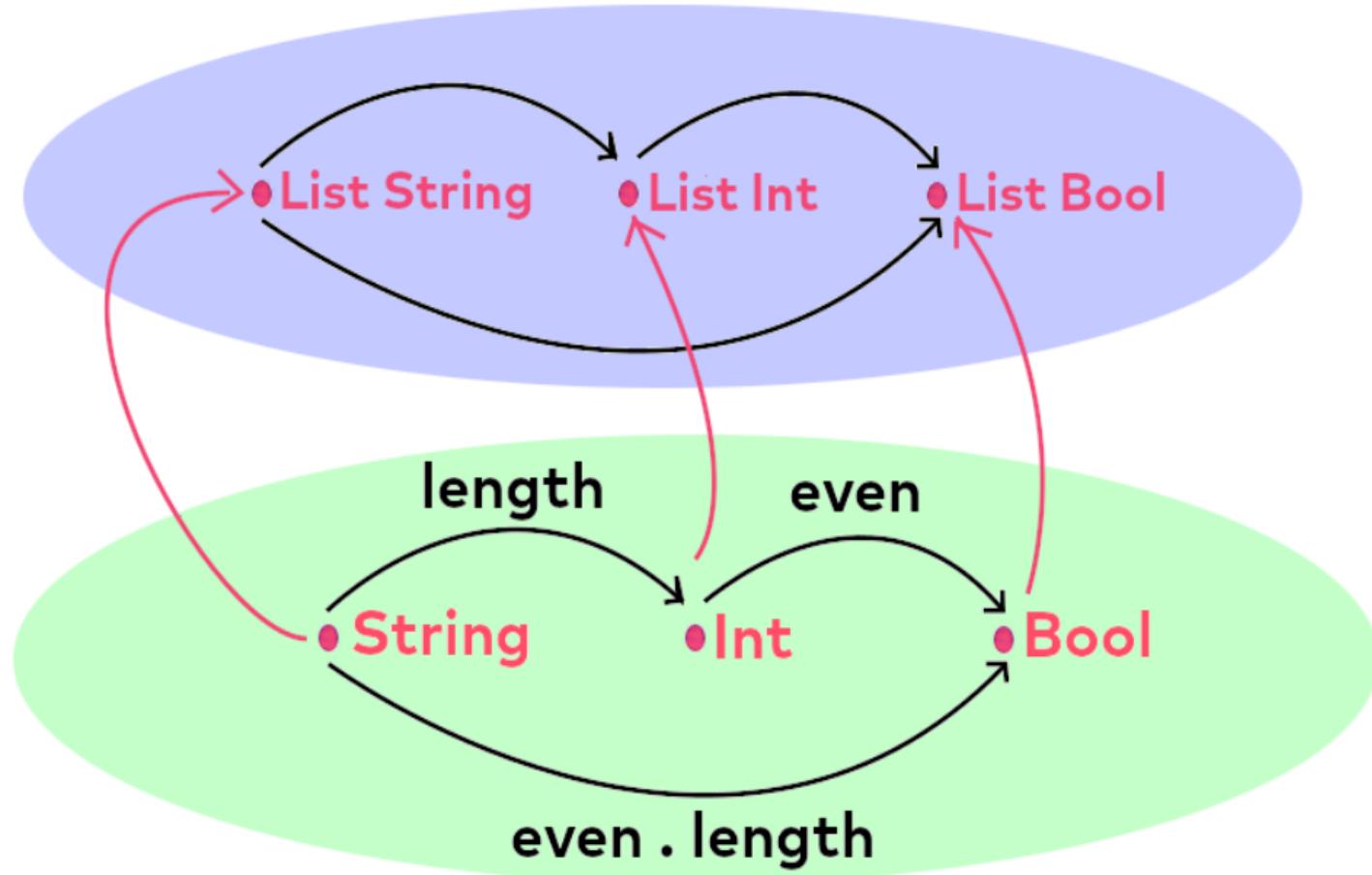


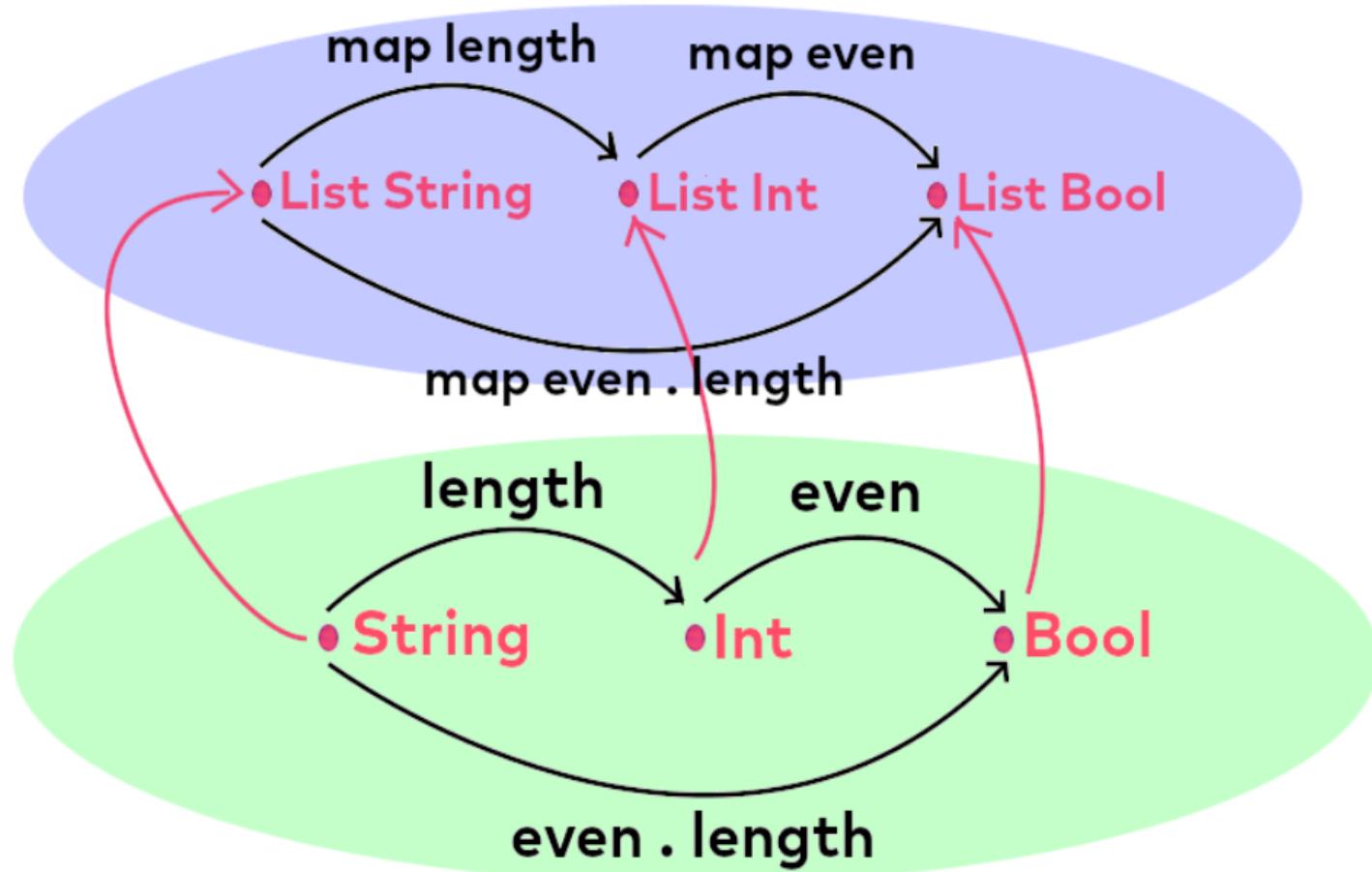




Functors in Programming







A Functor in ...

- Category theory: Mapping between categories

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- Programming: Way to construct a richer type from a simpler type (e.g. `Int -> List Int`)

A Functor in ...

- Category theory: Mapping between categories
- Programming: Way to construct a richer type from a simpler type (e.g. `Int -> List Int`)

How do we do this in practice?

Enter: *fmap*

- The programmatic way of of *mapping* between types and functions.

Enter: *fmap*

- The programmatic way of of **mapping** between types and functions.
- **Lifting** simpler types into richer types

Enter: *fmap*

- The programmatic way of of **mapping** between types and functions.
- **Lifting** simpler types into richer types
- Represented by the Functor class (by implementing `fmap`)

-- *Functor interface*

--

fmap :: **Functor** f => (a -> b) -> f a -> f b

--
--

Input 1: Function

^^^^^^^^^

fmap :: **Functor** f => (a -> b) -> f a -> f b

--
--

fmap :: **Functor** f => (a -> b) -> f a -> f b

Input 2: Enriched type
^^^

-- *Output: Enriched type*
--
fmap :: **Functor** f => (a -> b) -> f a -> f b
 ^ ^ ^

```
--
```

Input 1: Function

^^^^^^^^^

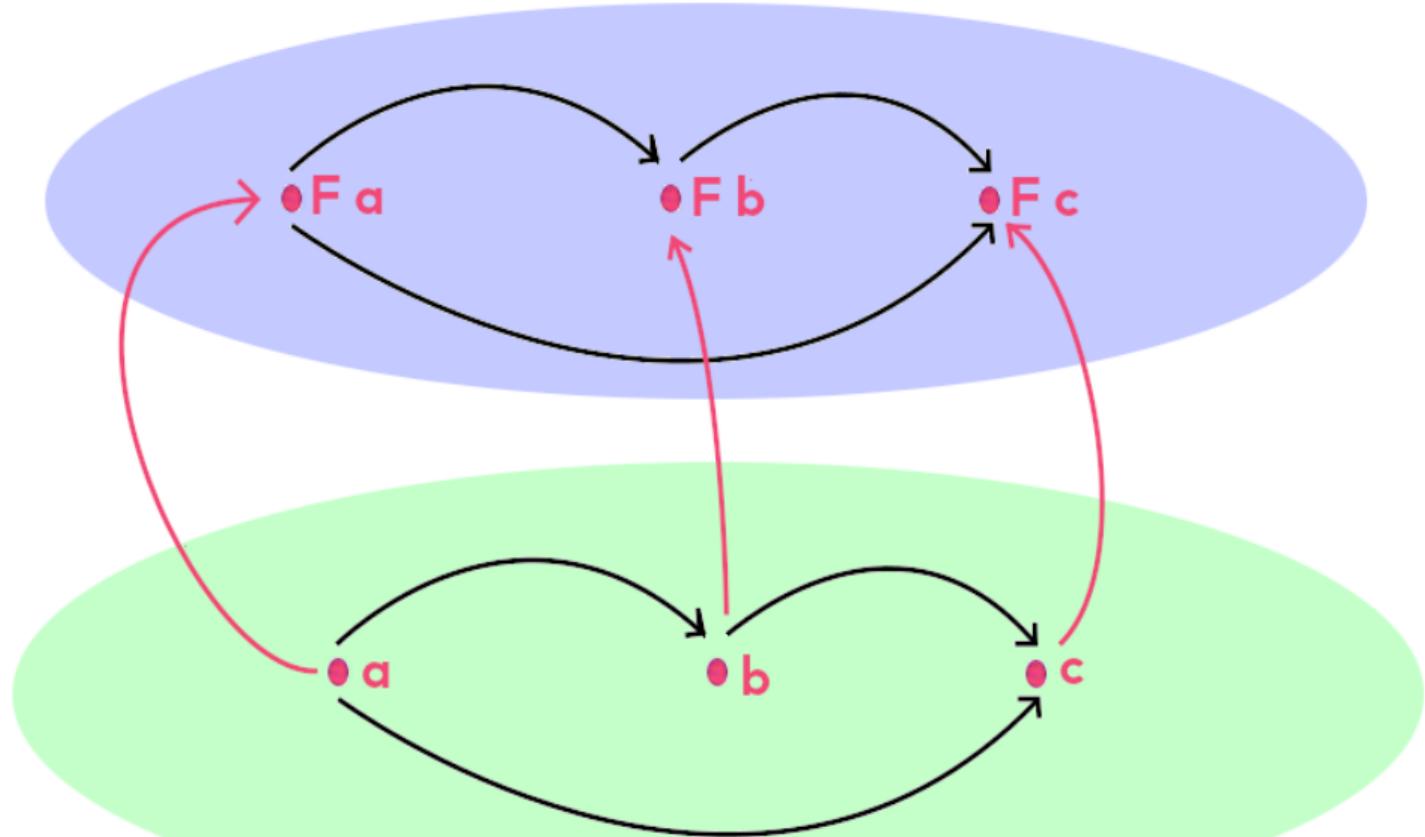
```
fmap :: Functor f => (a -> b) -> (f a -> f b)
```

--

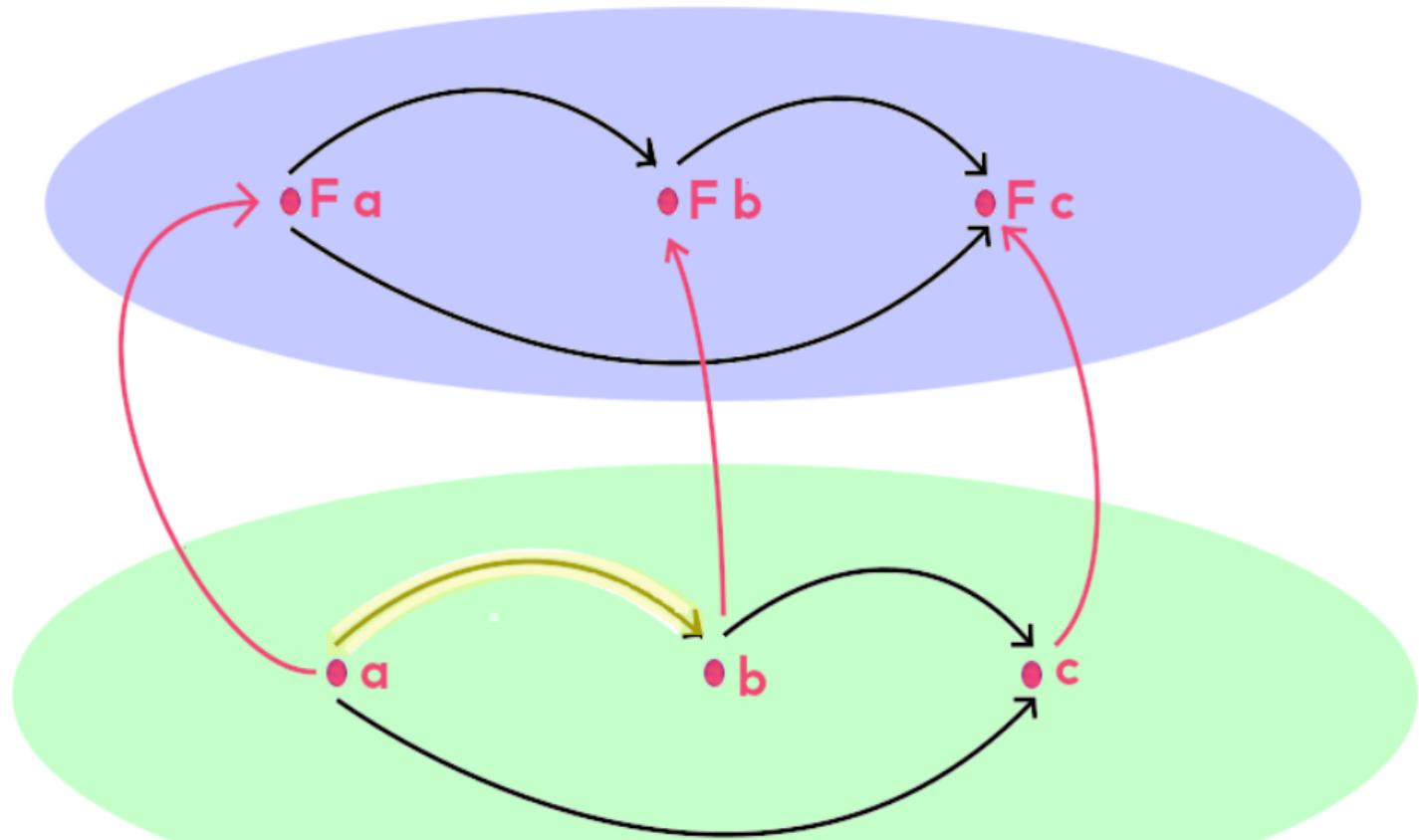
Output: Enriched function

^^^^^^^^^^^^^

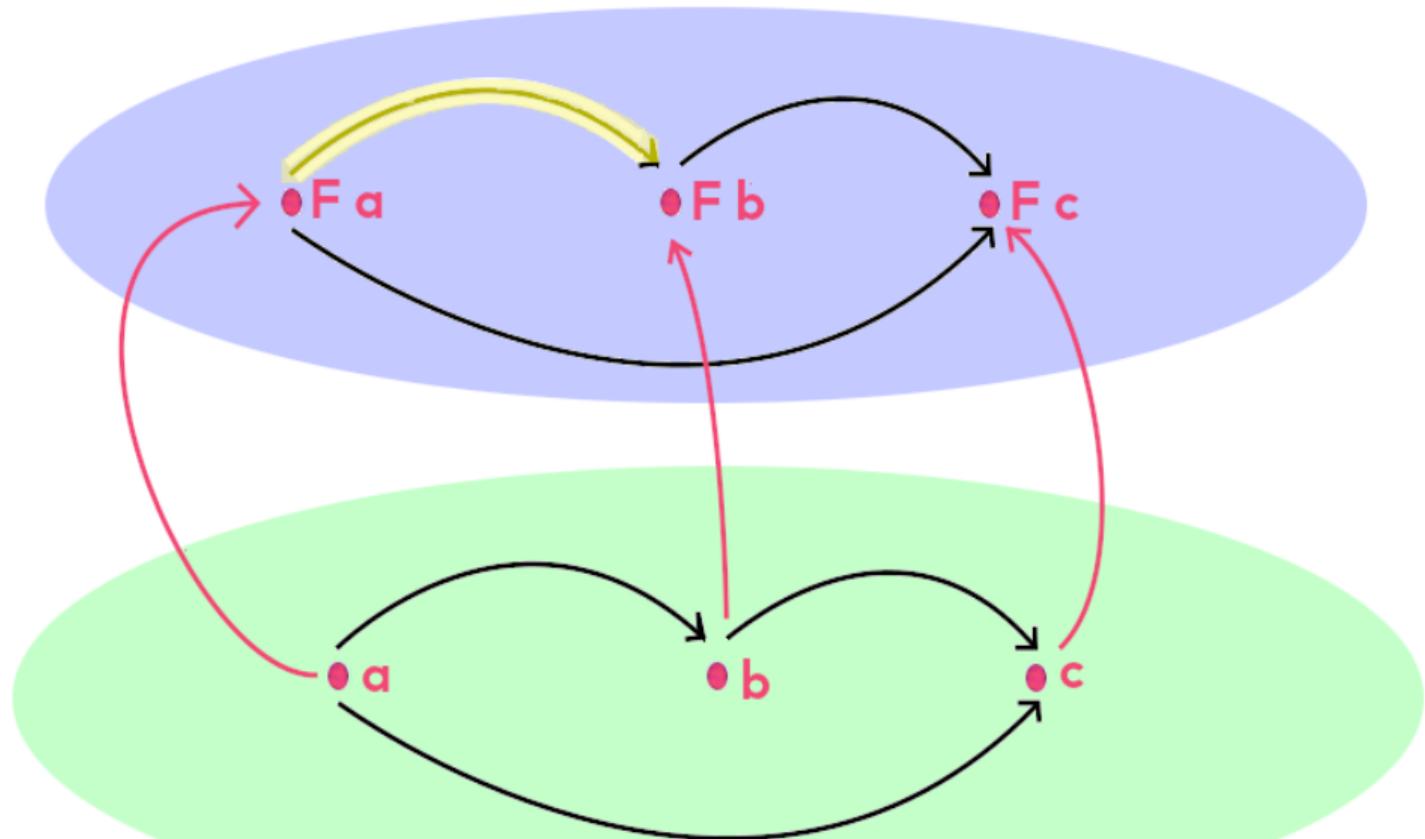
fmap :: **Functor** f => (a -> b) -> (f a -> f b)



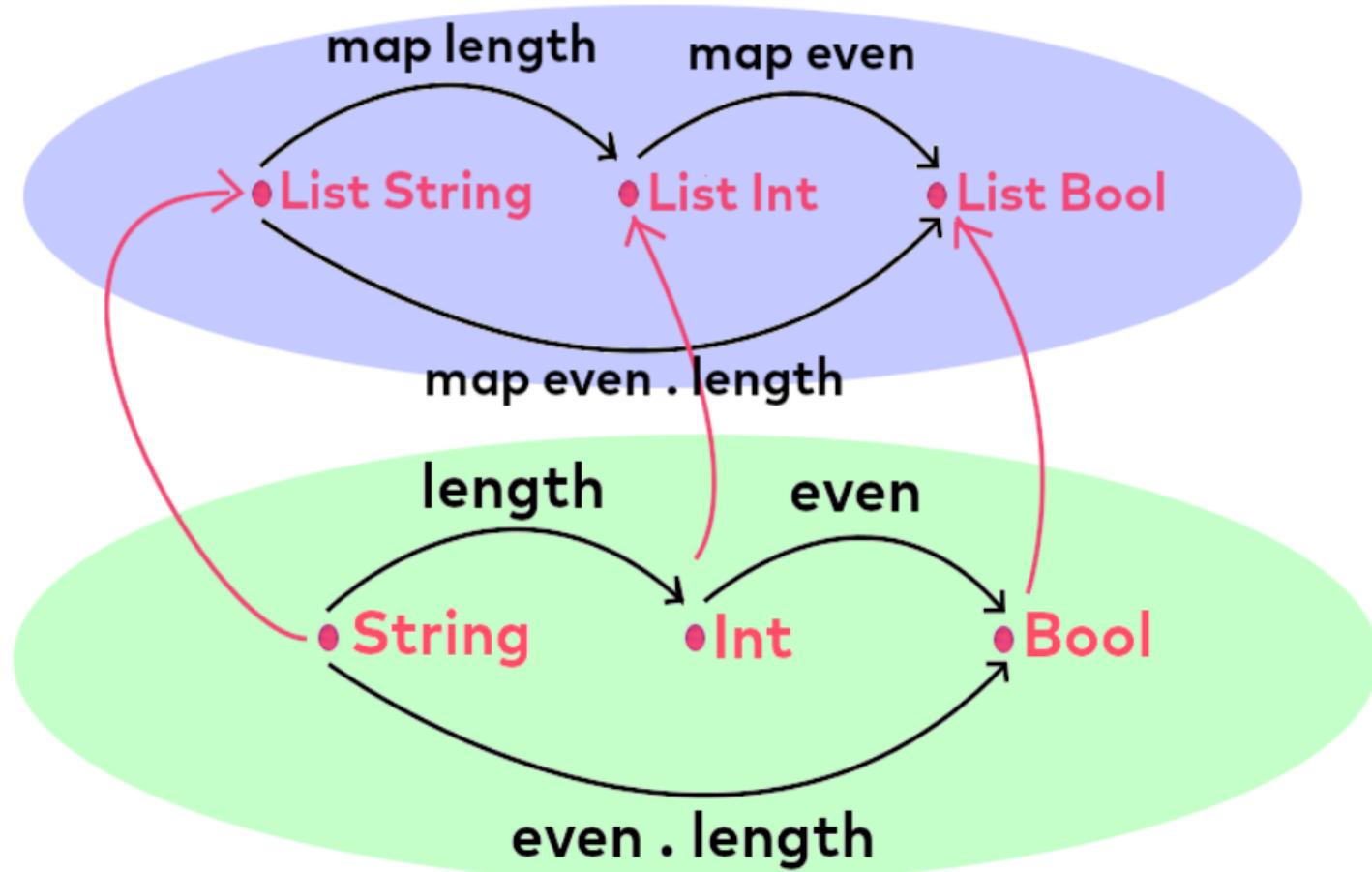
`fmap :: Functor F => (a -> b) -> (F a -> F b)`



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The Functor in ...

- Category Theory: Represents **new parts** of categories

The Functor in ...

- Category Theory: Represents new parts of categories
- Programming: Represents new computational contexts

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 - ▶ Retaining structure!
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The Functor in ...

- Category Theory: Represents new parts of categories
 - ▶ Retaining structure!
- Programming: Represents new computational contexts
 - ▶ Retaining structure!

⇒ Lets us focus on original program structure in a new context

Example Contexts

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- List: Where computations may have multiple return values

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- Maybe (Optional): Where **failures** might occur

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- IO: Where **side effects** can happen

Example Contexts

- List: Where computations may have **multiple return values**
 - Maybe (Optional): Where **failures** might occur
 - IO: Where **side effects** can happen
- Use the functor to abstract over the context!

Now show me how to make a type a functor!

```
--  
-- How to make List a functor  
--  
instance Functor [] where  
    fmap f xs = map f xs
```

```
--  
-- How to make Maybe a functor  
--  
instance Functor Maybe where  
    fmap f (Just x) = Just (f x)  
    fmap f Nothing = Nothing
```

```
--  
-- How to make IO a functor  
--  
instance Functor IO where  
    fmap f action = do  
        x <- action  
        return (f x)
```

List Implements fmap!

```
prompt> fmap length ["Y0", "Y00", "Y000"]  
[2,3,4]
```

```
prompt> fmap even [1..10]  
[False,True,False,True,False,True,False,True]
```

```
prompt> fmap (even . length) ["ah", "aha", "ehhhhh"]  
[True,False,True]
```

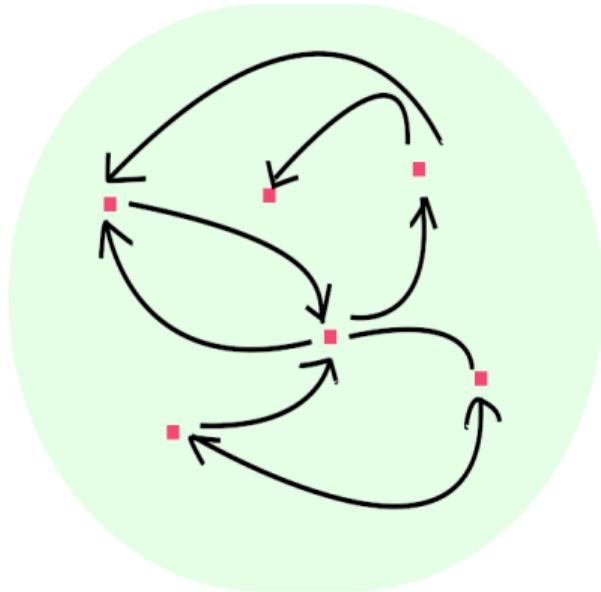
Maybe Implements fmap!

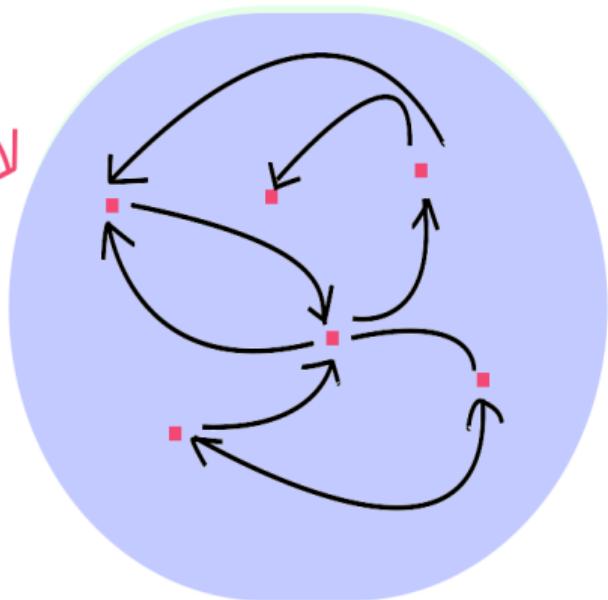
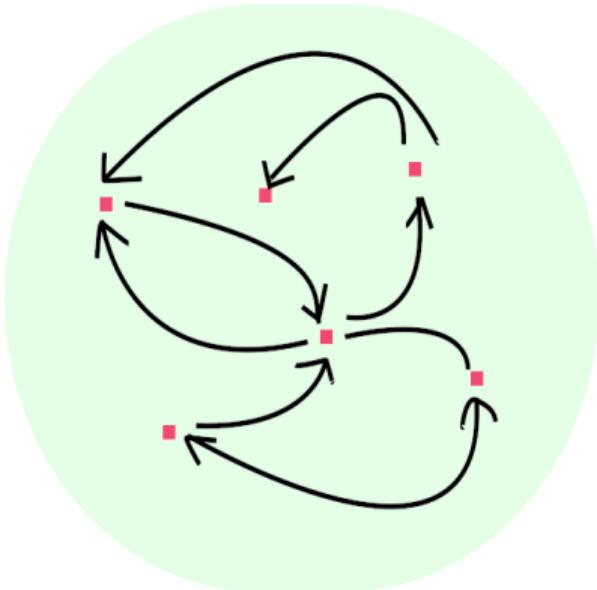
```
ghci> fmap even Nothing  
Nothing  
ghci> fmap length (Just "Y000")  
Just 4  
ghci> fmap (even . Length) (Just "Y000")  
(Just True)
```

IO implements fmap!

Get a string from the command line...

```
prompt> fmap length getLine ←  
HELLOWORLD  
10 ... and an integer  
prompt> fmap even getInt ←  
33  
False  
prompt> fmap (even . length) getLine  
HELLO  
False
```





Instances

Functor []	# Source	Since: 2.1	Functor Max	# Source	Since: 4.9.0.0
Functor Maybe	# Source	Since: 2.1	Functor Min	# Source	Since: 4.9.0.0
Functor IO	# Source	Since: 2.1	Functor Complex	# Source	Since: 4.9.0.0
Functor Par1	# Source	Since: 4.9.0.0	Functor (Either a)	# Source	Since: 3.0
Functor NonEmpty	# Source	Since: 4.9.0.0	Functor (V1 :: Type -> Type)	# Source	Since: 4.9.0.0
Functor ReadP	# Source	Since: 2.1	Functor (U1 :: Type -> Type)	# Source	Since: 4.9.0.0
Functor ReadPrec	# Source	Since: 2.1	Functor ((,) a)	# Source	Since: 2.1
Functor Down	# Source	Since: 4.11.0.0	Functor (ST s)	# Source	Since: 2.1
Functor Product	# Source	Since: 4.8.0.0	Functor (Proxy :: Type -> Type)	# Source	Since: 4.7.0.0
Functor Sum	# Source	Since: 4.8.0.0	Arrow a => Functor (ArrowMonad a)	# Source	Since: 4.6.0.0
Functor Dual	# Source	Since: 4.8.0.0	Monad m => Functor (WrappedMonad m)	# Source	Since: 2.1
Functor Last	# Source	Since: 4.8.0.0	Functor (ST s)	# Source	Since: 2.1
Functor First	# Source	Since: 4.8.0.0	Functor (Arg a)	# Source	Since: 4.9.0.0
Functor STM	# Source	Since: 4.3.0.0	Functor (Rec1 f)	# Source	Since: 4.9.0.0
Functor Handler	# Source	Since: 4.6.0.0	Functor (URec Char :: Type -> Type)	# Source	Since: 4.9.0.0
Functor Identity	# Source	Since: 4.8.0.0	Functor (URec Double :: Type -> Type)	# Source	Since: 4.9.0.0
Functor ZipList	# Source	Since: 2.1	Functor (URec Float :: Type -> Type)	# Source	Since: 4.9.0.0
Functor ArgDescr	# Source	Since: 4.6.0.0	Functor (URec Int :: Type -> Type)	# Source	Since: 4.9.0.0
Functor OptDescr	# Source	Since: 4.6.0.0	Functor (URec Word :: Type -> Type)	# Source	Since: 4.9.0.0
Functor ArgOrder	# Source	Since: 4.6.0.0	Functor (URec (Ptr ()) :: Type -> Type)	# Source	Since: 4.9.0.0
Functor Option	# Source	Since: 4.9.0.0	Functor f => Functor (Alt f)	# Source	Since: 4.8.0.0
Functor Last	# Source	Since: 4.9.0.0	Functor f => Functor (Ap f)	# Source	Since: 4.12.0.0
Functor First	# Source	Since: 4.9.0.0	Functor (Const m :: Type -> Type)	# Source	Since: 2.1
			Arrow a => Functor (WrappedArrow a b)	# Source	Since: 2.1

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[O]

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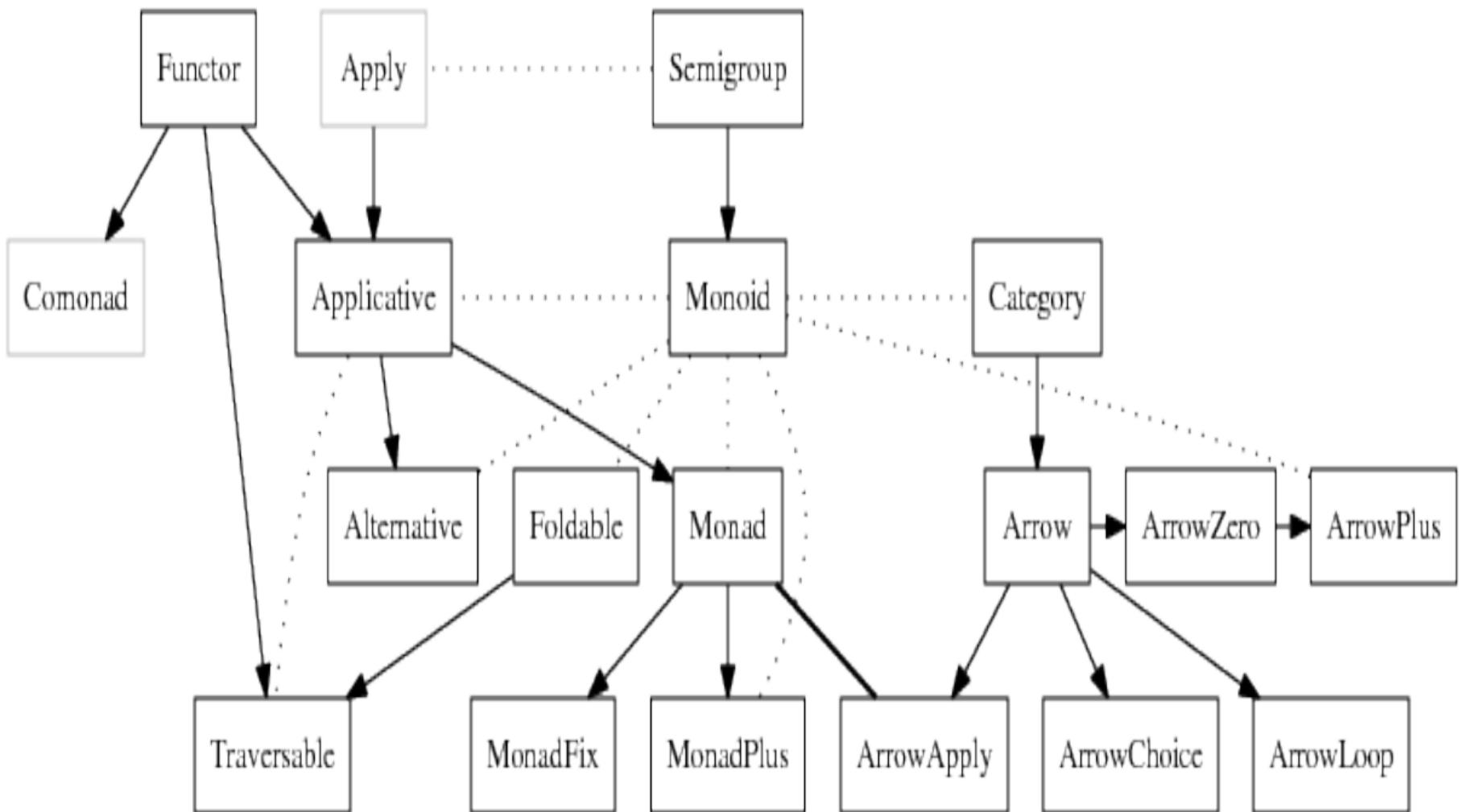
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The functor is just the beginning ...



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- Structure emerges through composition
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- Category theory lets us study composition ...
- ...and provides tools such as the functor that encourages us to focus on interactions between things, not things themselves

Structurize, don't optimize 😊

Thank you! Questions?

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- 0 : <http://cdn.makeuseof.com/wp-content/uploads/2014/09/stress-free-programming-frustration.jpg?x92042>
- 1 : <https://insights.stackoverflow.com/survey/2019#technology>
- 2 : https://en.wikipedia.org/wiki/Curry%E2%80%93Howard_correspondence
- 3 : https://en.wikipedia.org/wiki/Design_Patterns
- 4 : https://golem.ph.utexas.edu/category/2012/01/vorsicht_funktor.html

Laws

- Associativity in a category: $h . g . f = (h . g) . f = h . (g . f)$
- Identity in a category (for $f :: a \rightarrow b$): $f . id_a = f, id_b . f = f$
- Functor retains structure under composition:
if $h = g . f$, then $F h = F g . F f$
- Functor retains structure under identity: $F id_a = id_{\{F a\}}$

Curry-Howard Isomorphism

- Void \iff False
- () \iff True
- Product Types \iff OR
- Sum Types \iff AND
- A \rightarrow B \iff If A then B

Notes on functor as a typeclass

Interfaces methods are always associated with an object instance. In other words, there is always an implied 'this' parameter that is the object on which the method is called. All inputs to a type class function are explicit.