Week 5

Ch 7: Making Our Own Types and Type Classes
Ch 8: Input and Output

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COMP 481: Functional and Logic Programming

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Overview

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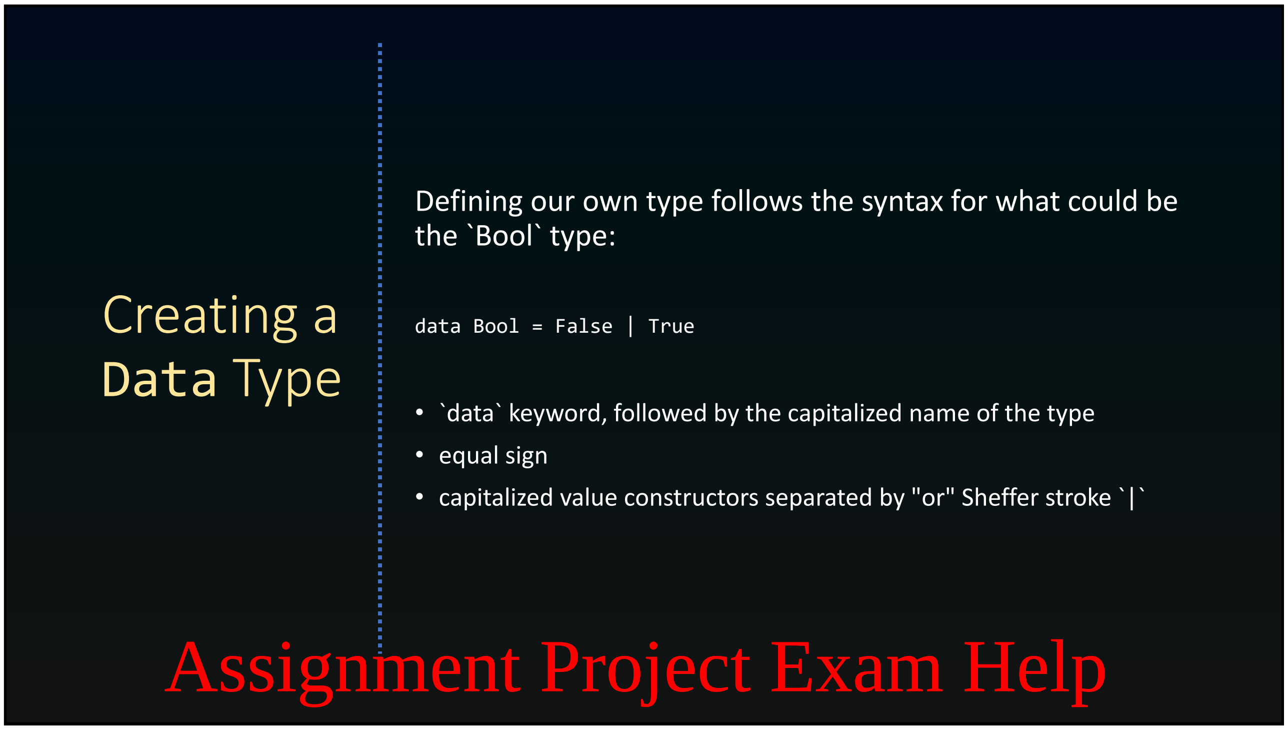

Creating a Data Type

Defining our own type follows the syntax for what could be the `Bool` type:

```
data Bool = False | True
```

- `data` keyword, followed by the capitalized name of the type
- equal sign
- capitalized value constructors separated by "or" Sheffer stroke `|`

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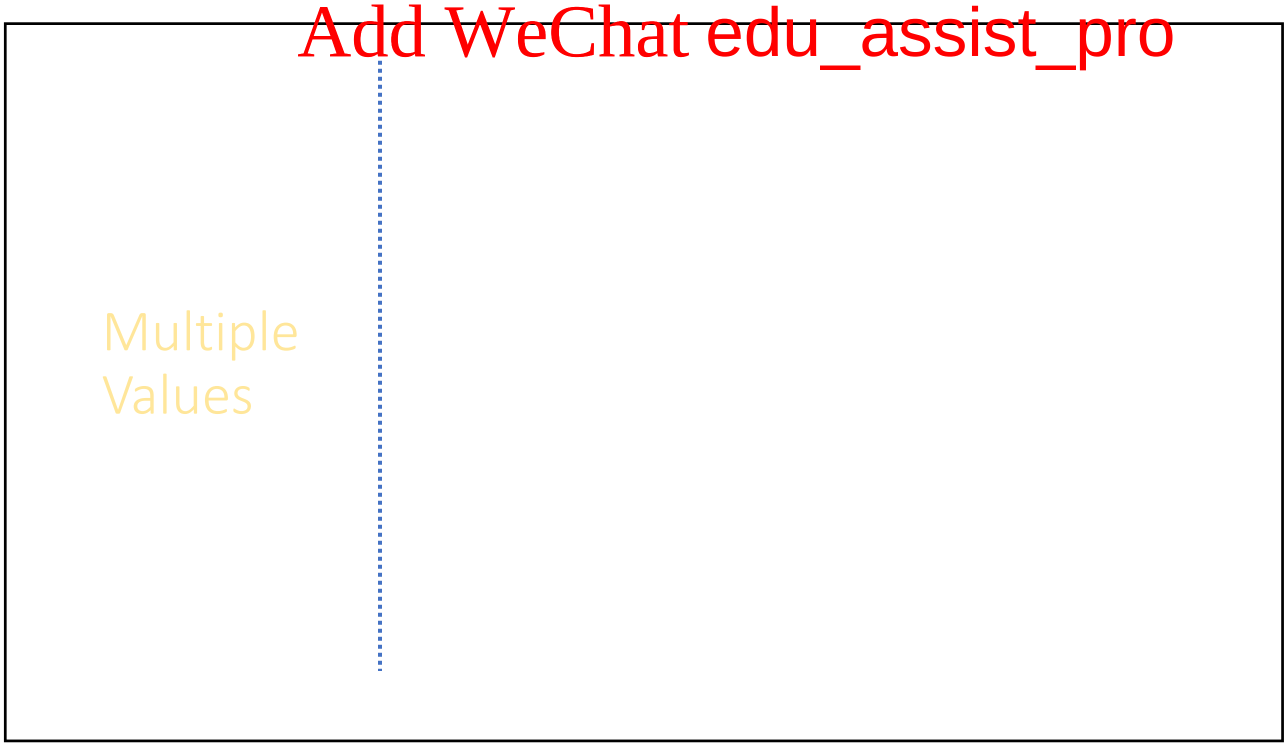

Multiple Values

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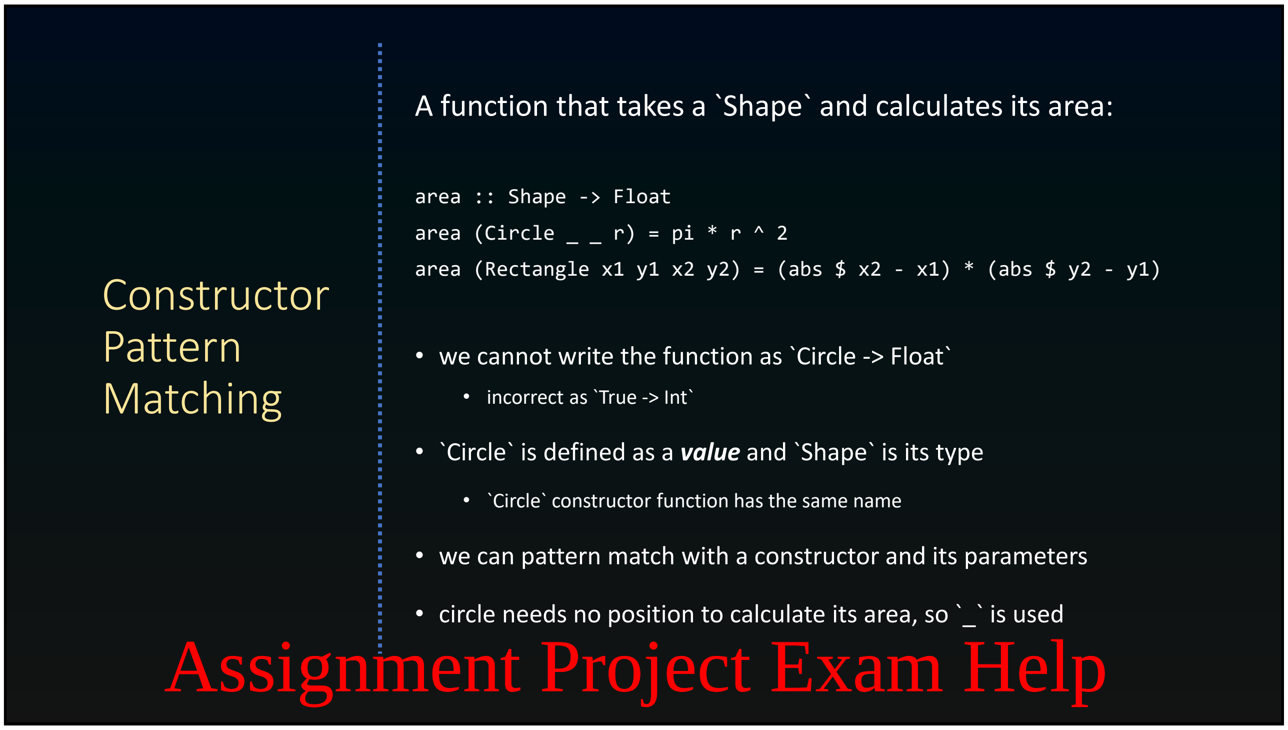

Constructor Pattern Matching

A function that takes a `Shape` and calculates its area:

```
area :: Shape -> Float
area (Circle _ _ r) = pi * r ^ 2
area (Rectangle x1 y1 x2 y2) = (abs $ x2 - x1) * (abs $ y2 - y1)
```

- we cannot write the function as `Circle -> Float`
  - incorrect as `True -> Int`
- `Circle` is defined as a ***value*** and `Shape` is its type
  - `Circle` constructor function has the same name
- we can pattern match with a constructor and its parameters
- circle needs no position to calculate its area, so `_` is used

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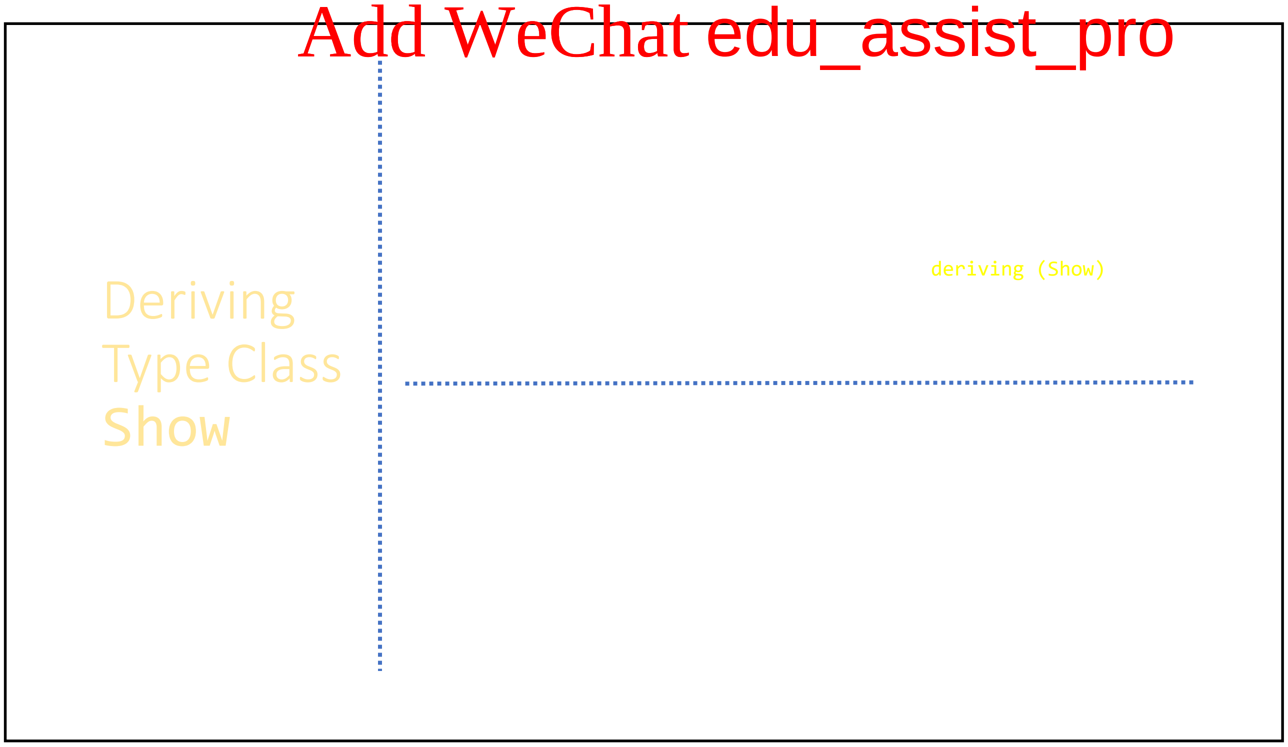

Deriving Type Class Show

```
deriving (Show)
```

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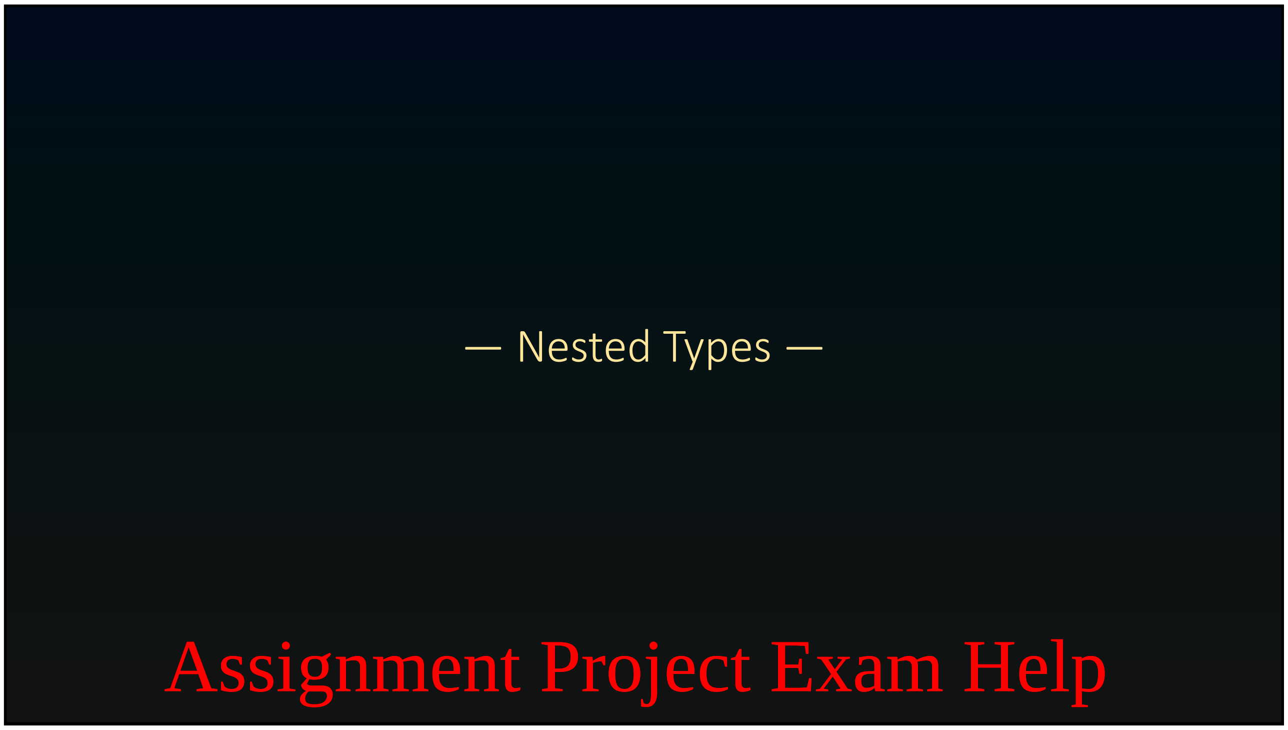

— Nested Types —

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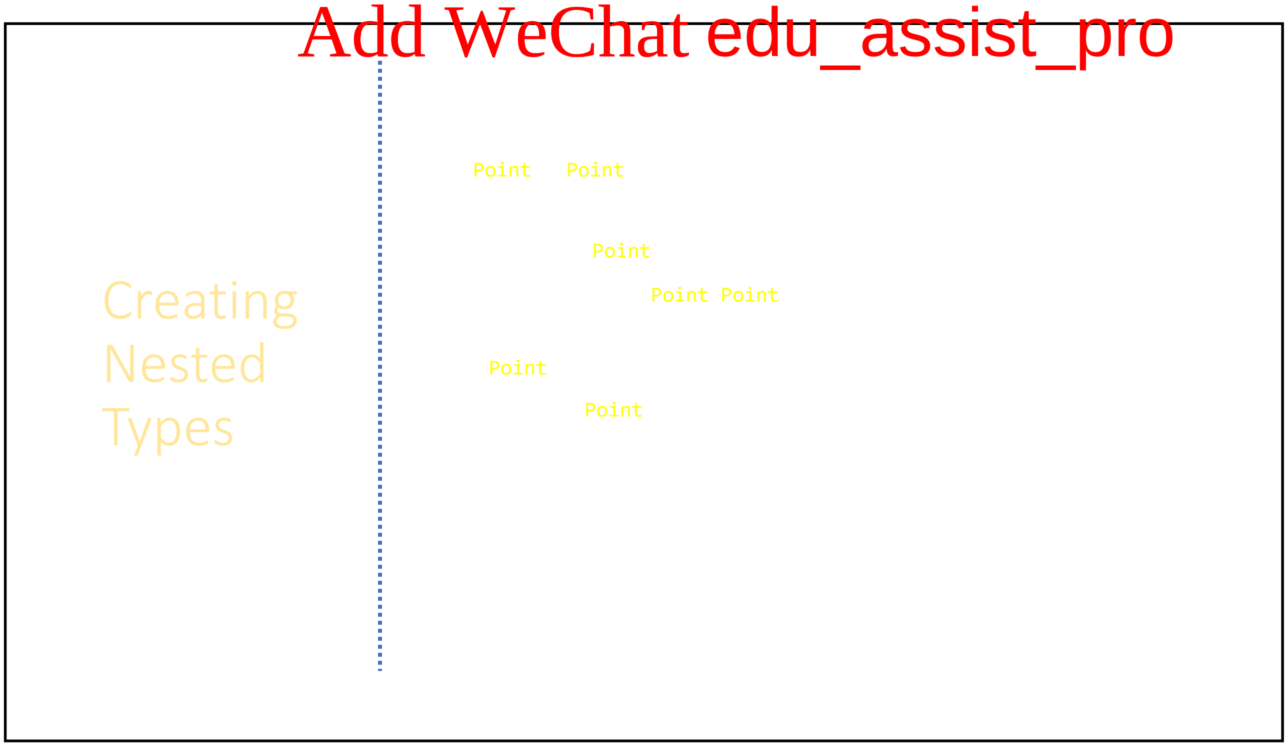

Creating Nested Types

Point
Point
Point
Point
Point
Point
Point

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Using Nested Constructors

```
area (Circle (Point 0 0) 24)

area . Rectangle (Point 0 0) $ Point 100 100
```

- a few reminders:
  - dot product composes functions (that take one parameter each)
  - `` `$` `` applies the function immediately after it (avoid writing parentheses)

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Export from Modules

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Private Code

Without `(..)`:

- a user could not create new shapes except with functions `baseCircle` and `baseRect`

- hiding constructors makes the `Shape` type more abstract
- might be good if we want to stop users from pattern matching with value constructors
- edits to the value constructors would not cascade (like we saw earlier with Shape and Point)
- we get back to this discussion later with `Data.Map`

Previously, we defined functions with the notation `->` between input parameters, but not so for constructors.

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Use Function Constructors

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— Record Syntax —

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Record Syntax

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Parameter Order

Choose to use record syntax when the order of the fields do not immediately make sense.

- a 3D vector would be obvious
  - the fields specify the coordinates `x` `y` `z` values
- but, for `Car` parameter order is arbitrary

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— Type Parameters —

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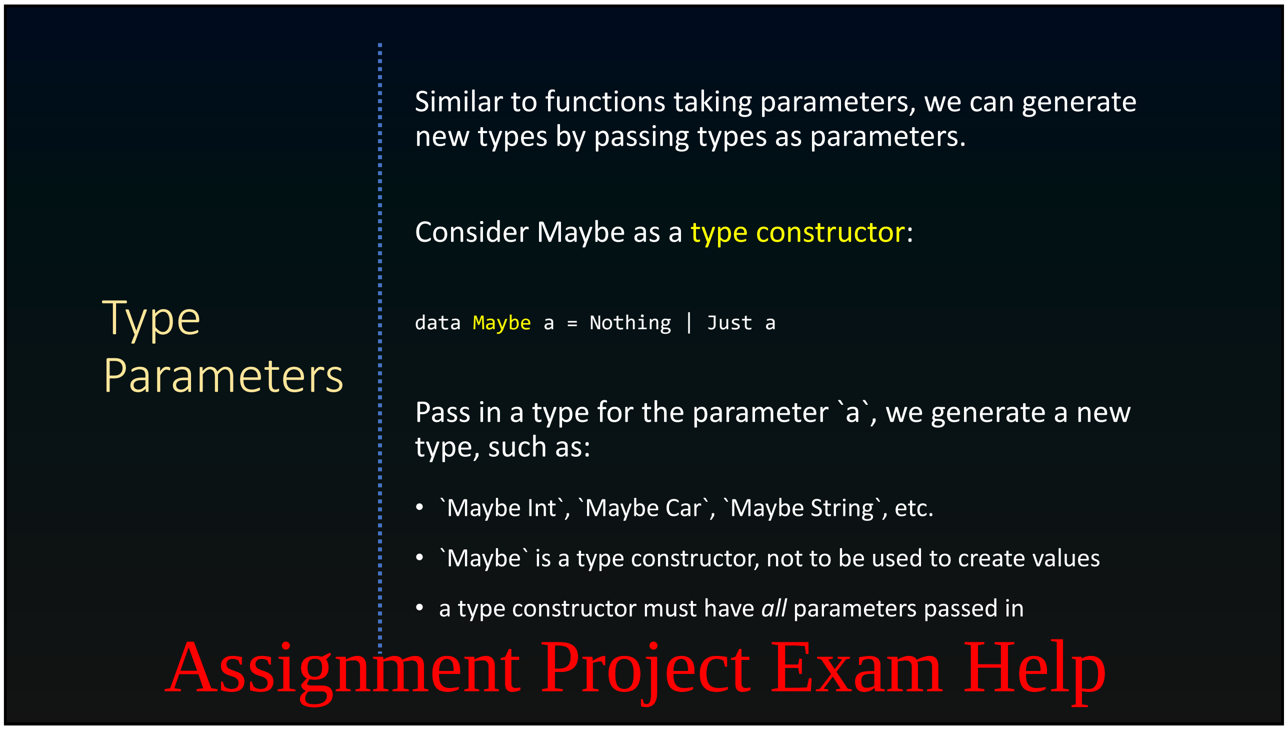

Type Parameters

Similar to functions taking parameters, we can generate new types by passing types as parameters.

Consider Maybe as a type constructor:

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

Pass in a type for the parameter \`a\`, we generate a new type, such as:

- \`Maybe Int\`, \`Maybe Car\`, \`Maybe String\`, etc.
- \`Maybe\` is a type constructor, not to be used to create values
- a type constructor must have *all* parameters passed in

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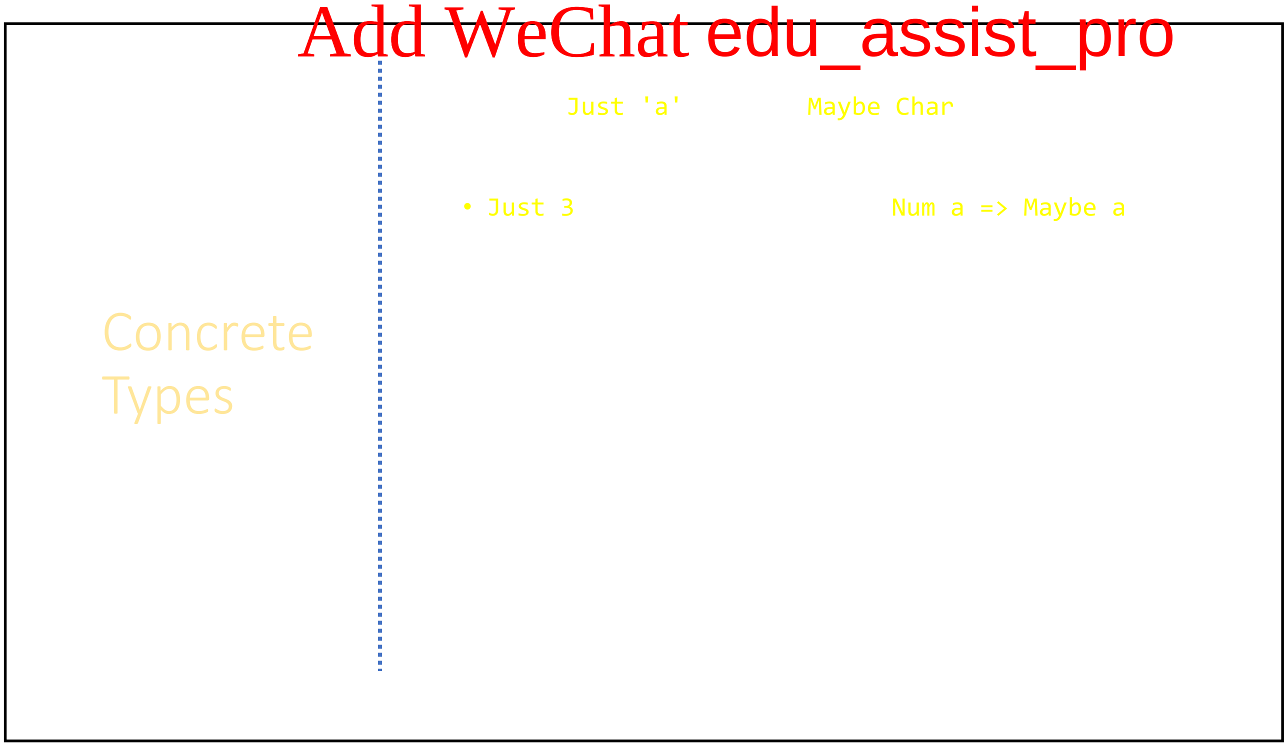

Concrete Types

Just 'a' Maybe Char

- Just 3 Num a => Maybe a

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Polymorphic Types

A more generic type such as `Maybe a` is polymorphic:

- `Maybe a` can manage different kinds of subtypes with type parameters `a`

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Practice with Maybe

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Practice Defining Concrete Types

Examples of defining concrete types similar to `Maybe a` where `a` is replaced by concrete type might be:

```
data IntMaybe = INothing | IJust Int

data StringMaybe = SNothing | SJust String

data ShapeMaybe = ShNothing | ShJust Shape
```

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Working with Polymorphic Types

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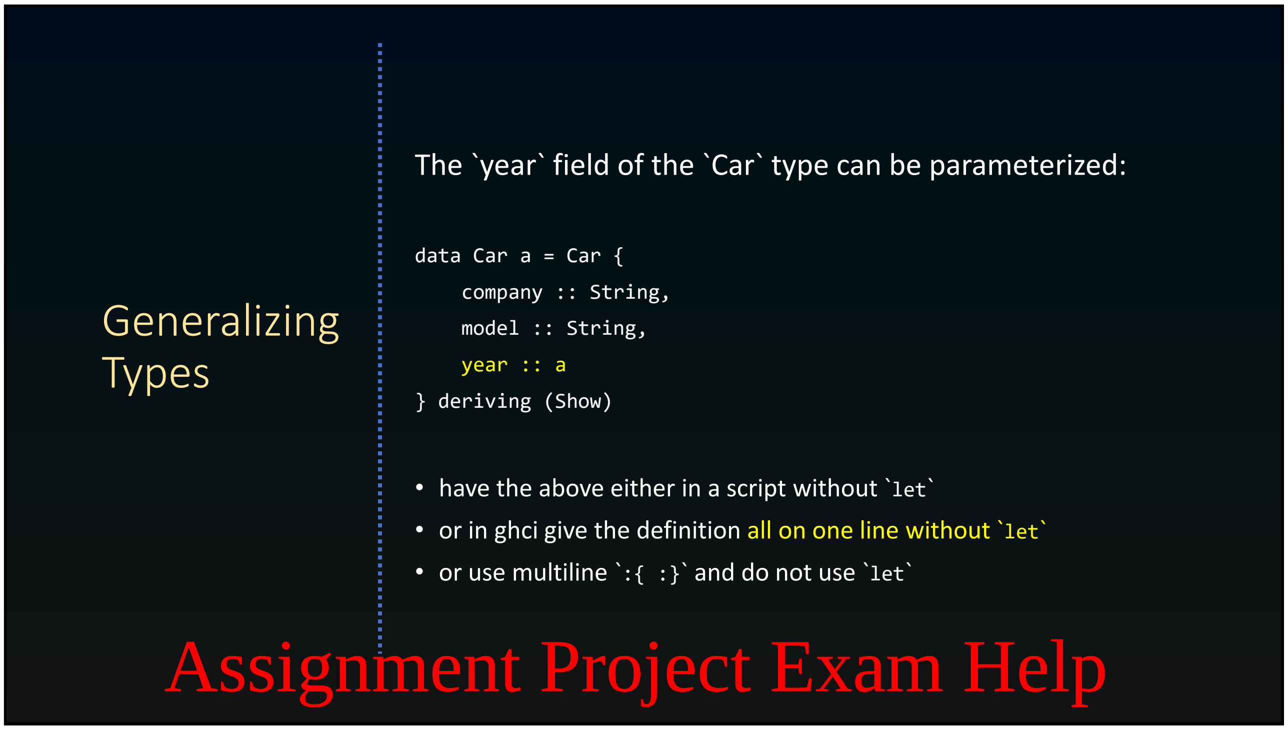

Generalizing Types

The `year` field of the `Car` type can be parameterized:

```
data Car a = Car {
    company :: String,
    model :: String,
    year :: a
} deriving (Show)
```

- have the above either in a script without `let`
- or in ghci give the definition all on one line without `let`
- or use multiline `:{ :}` and do not use `let`

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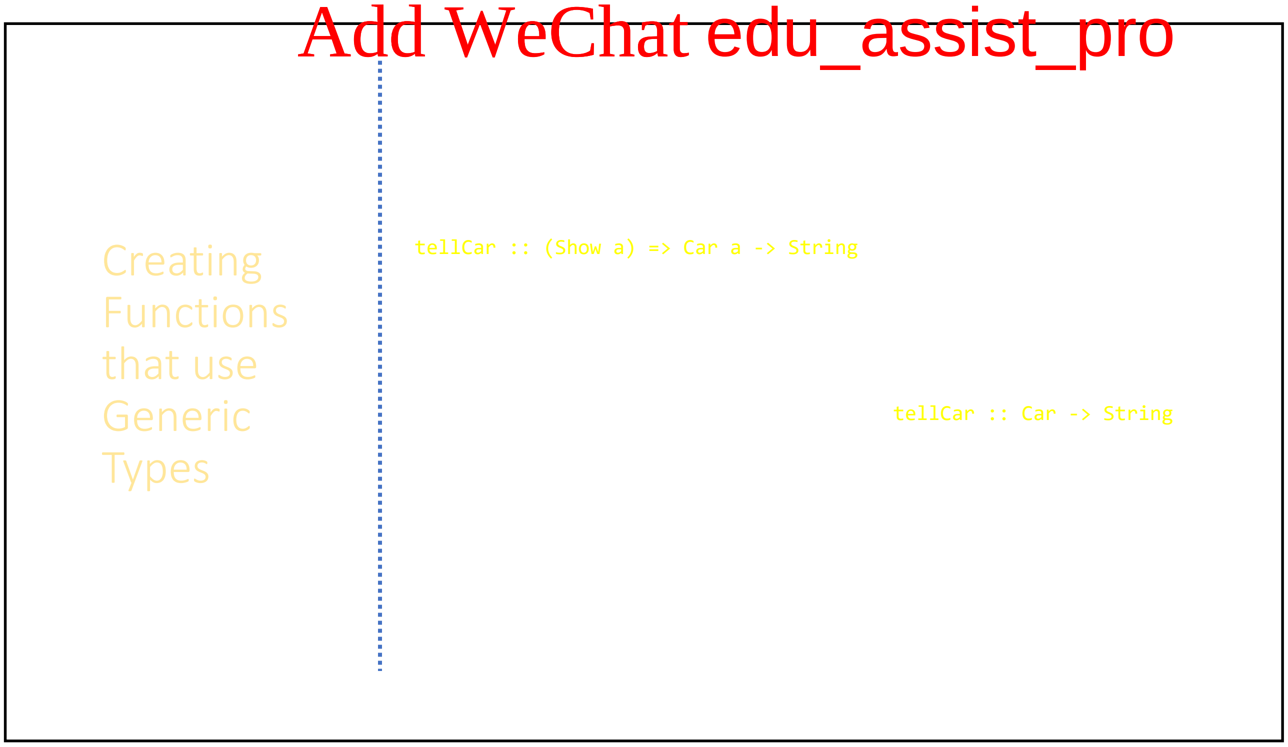

Creating Functions that use Generic Types

```
tellCar :: (Show a) => Car a -> String
```

```
tellCar :: Car -> String
```

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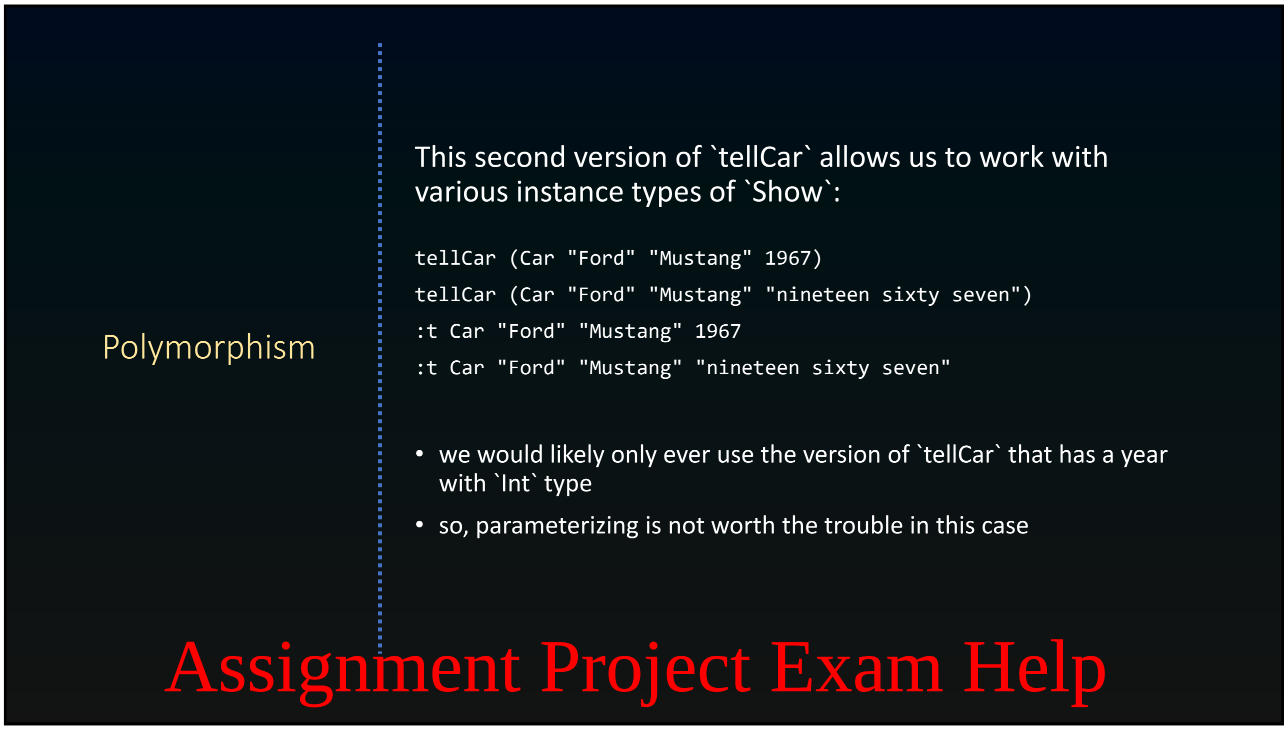

Polymorphism

This second version of `tellCar` allows us to work with various instance types of `Show`:

```
tellCar (Car "Ford" "Mustang" 1967)
tellCar (Car "Ford" "Mustang" "nineteen sixty seven")
:t Car "Ford" "Mustang" 1967
:t Car "Ford" "Mustang" "nineteen sixty seven"
```

- we would likely only ever use the version of `tellCar` that has a year with `Int` type
- so, parameterizing is not worth the trouble in this case

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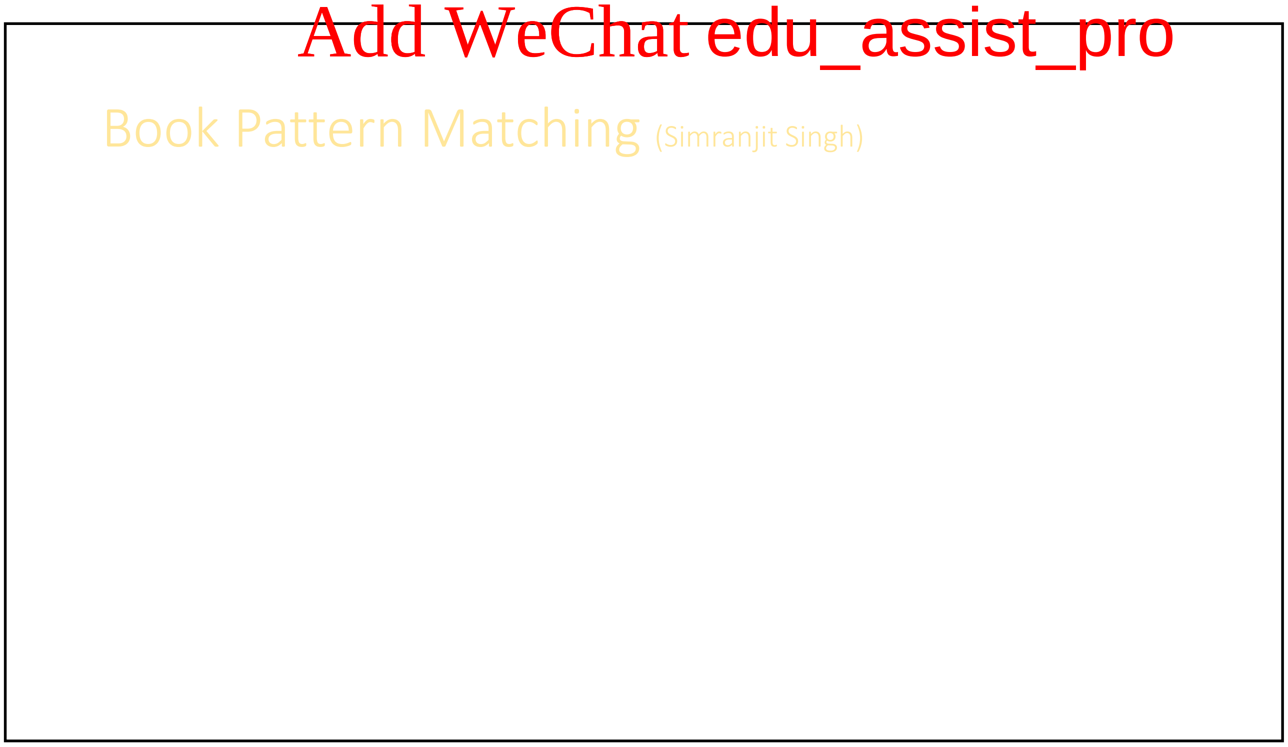

Book Pattern Matching (Simranjit Singh)

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Conventions of Type Parameters

Notice the generic types that use type parameters:

- have little need in their implementation for anything with respect to the type parameters

- e.g.: we would only do things with a list itself that has nothing to do directly with the type of its elements
- anything we would do with elements, such as a `sum`, we can specify its implementation when we specify the concrete type
- the same goes for the `Maybe`
  - it allows us to specify an implementation when we need to deal with potentially not having a value of a concrete type we want
  - (`Nothing`)
  - or having it (`Just x`)

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Class Constraints on Data Declarations

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— Example 3D Vector —

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3D Vector

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Matching Type Parameters

We restrict the vector functions for the parameter to be of type class `Num`, since we could not expect calculations where components are of type `Bool` nor `Char`.

- also notice that the definitions restrict only vectors of the same element concrete types to calculate together
  - cannot add vectors with one of type `Int` and the other `Double`
- notice no `Num` restriction in the type declaration of `Vector`
  - still need the same restrictions of type class in the functions anyway

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Type vs Value Constructors

type constructors

value constructors

`Vector a` `Vector a a a`

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Vector Functions

Give some vector functions a try:

```
Vector 3 5 8 `vplus` Vector 9 2 8
Vector 3 5 8 `vplus` Vector 9 2 8 `vplus` Vector 0 2 3
Vector 3 9 7 `vmult` 10
Vector 4 9 5 `dotProd` Vector 9.0 2.0 4.0
Vector 2 9 3 `vmult` (Vector 4 9 5 `dotProd` Vector 9 2 4)
```

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— Derived Instances —

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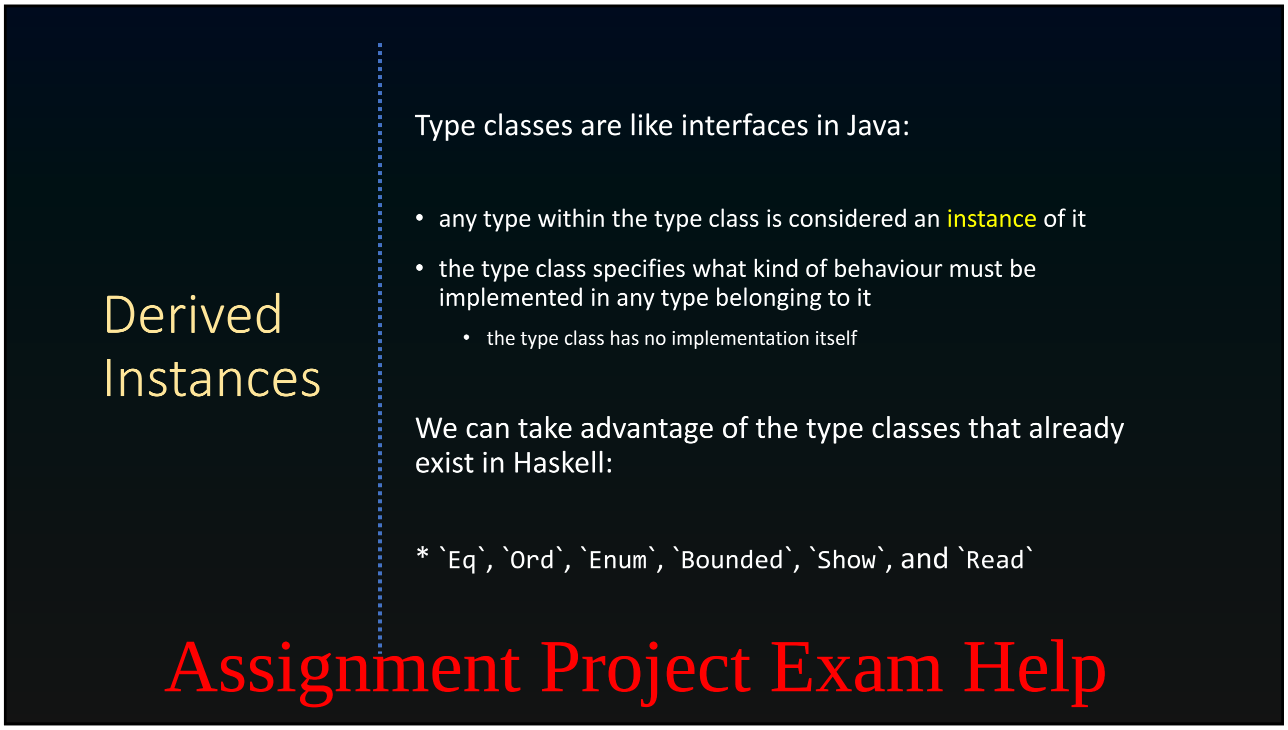

Derived Instances

Type classes are like interfaces in Java:

- any type within the type class is considered an instance of it
- the type class specifies what kind of behaviour must be implemented in any type belonging to it
  - the type class has no implementation itself

We can take advantage of the type classes that already exist in Haskell:

* `Eq`, `Ord`, `Enum`, `Bounded`, `Show`, and `Read`

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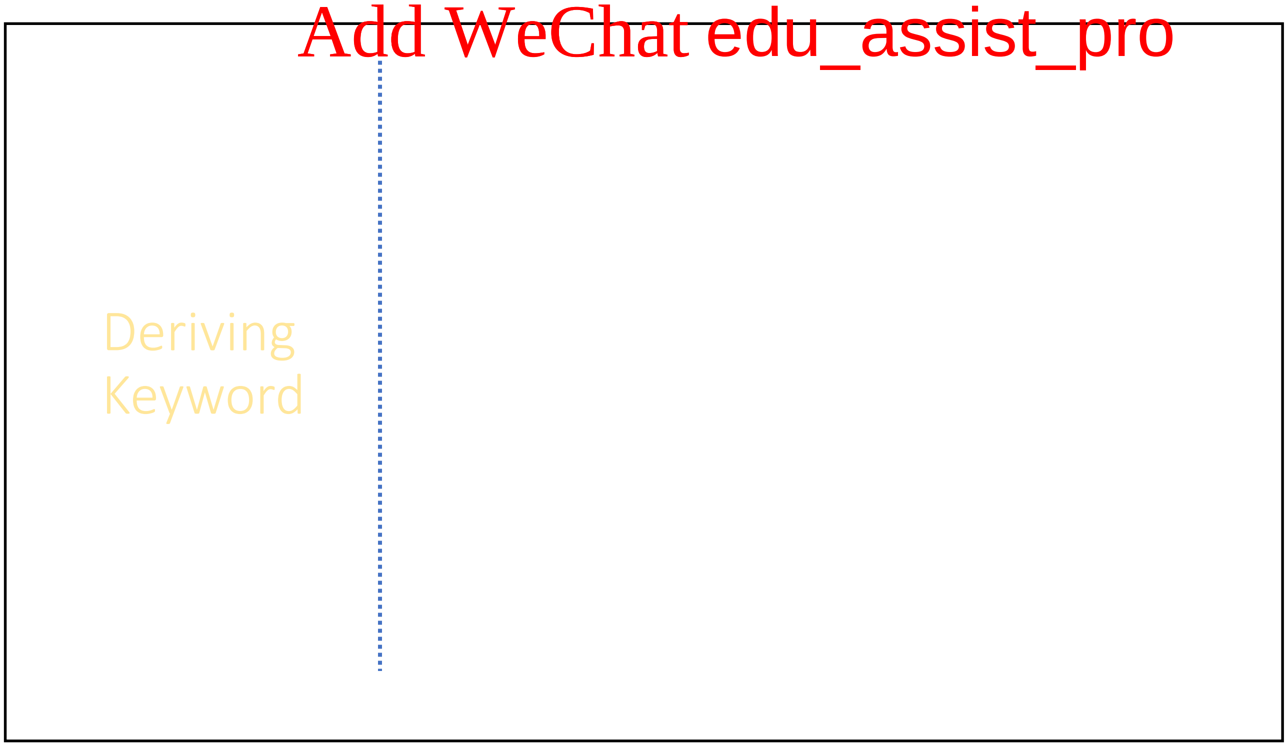

Deriving Keyword

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Using `==` on Eq Instances

We can test using `==` on values of our `Person` type:

```
mikeD = Person {firstName = "Michael", lastName = "Diamond", age = 43}
adRock = Person {firstName = "Adam", lastName = "Horovitz", age = 41}
mca = Person {firstName = "Adam", lastName = "Yauch", age = 44}
```

Give equality tests a try:

```
mca == adRock
mikeD == adRock
mikeD == mikeD
mikeD == Person {firstName = "Michael", lastName = "Diamond", age = 43}
```

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Using Behaviour of Class Type Instances

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— `Show` and `Read` —

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`Show` and `Read` Derived Instances

Show Read

Show Read

Show Read

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Convert Between String and Back

If we tried to print without the `Show` derivation, then Haskell would give us an error message.

We can convert back the other direction and get a `Person` value from a `String`.

- put the following in a script, then load in ghci:

```
mysteryDude =
    "Person { firstName =\"Michael\"" ++
    ", lastName =\"Diamond\"" ++
    ", age = 43}"
```

Give a type annotation to tell Haskell what concrete type it should evaluate:

```
read mysteryDude :: Person
```

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Type Annotations with Concrete Types

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— Ordering —

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Deriving Instances of `Ord`

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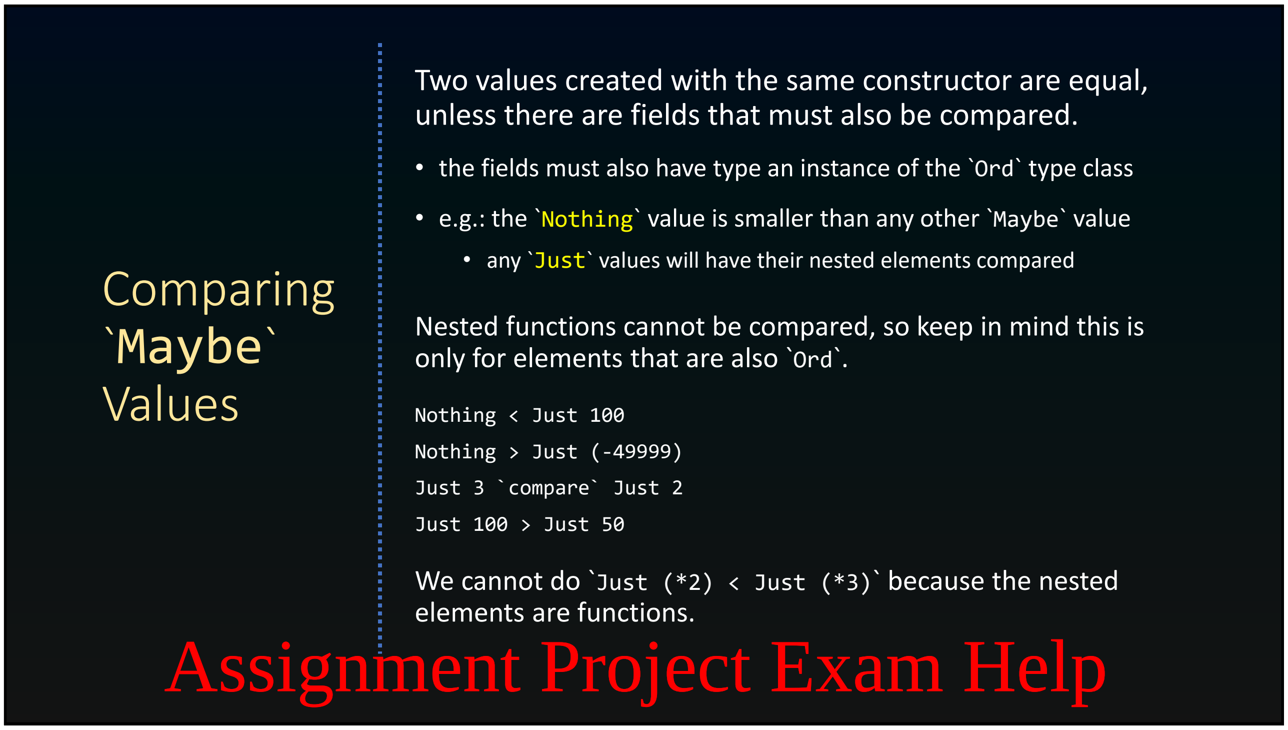

Comparing `Maybe` Values

Two values created with the same constructor are equal, unless there are fields that must also be compared.

- the fields must also have type an instance of the `Ord` type class
- e.g.: the `Nothing` value is smaller than any other `Maybe` value
  - any `Just` values will have their nested elements compared

Nested functions cannot be compared, so keep in mind this is only for elements that are also `Ord`.

```
Nothing < Just 100
Nothing > Just (-49999)
Just 3 `compare` Just 2
Just 100 > Just 50
```

We cannot do `Just (*2) < Just (*3)` because the nested elements are functions.

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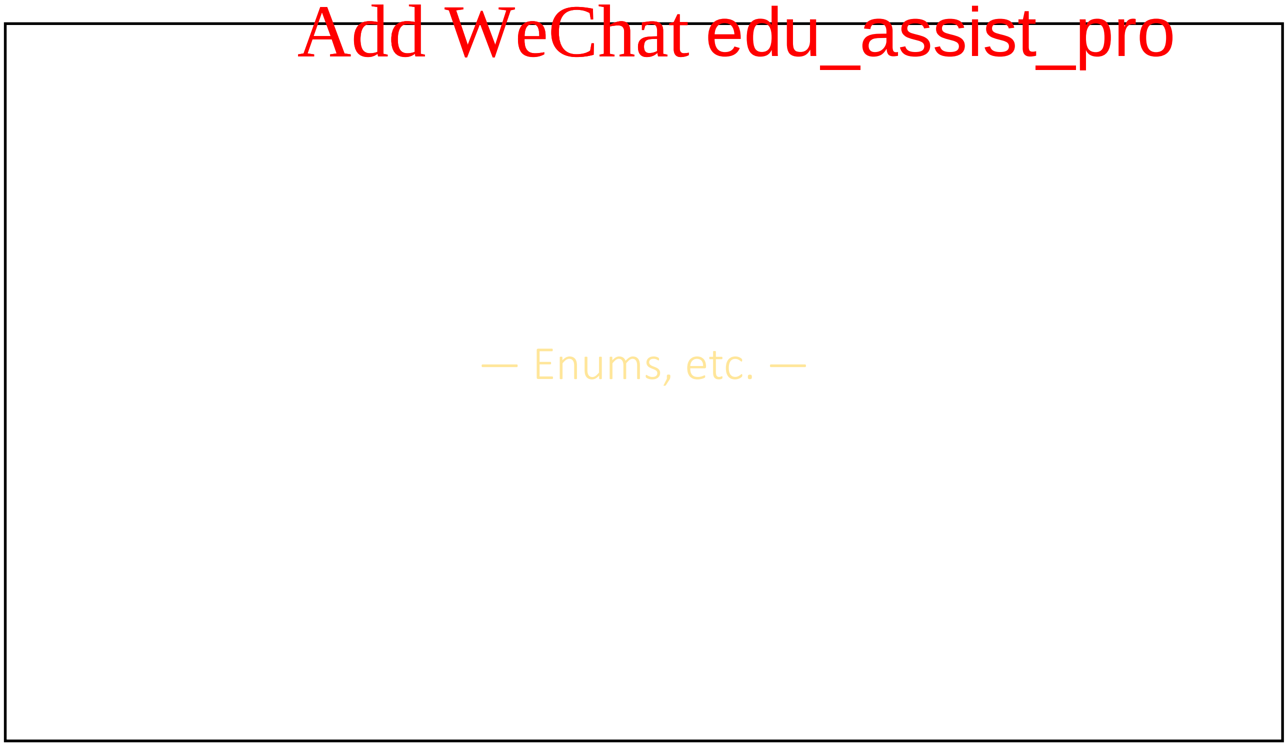

— Enums, etc. —

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Deriving `Enum` Instances

```
data Day = Monday | Tuesday | Wednesday | Thursday | Friday |
Saturday | Sunday
    deriving (Eq, Ord, Show, Read, Bounded, Enum)
```

Some reminders:

- \`Enum\` places values in a sequential order, with each value having a predecesor and a successor
- \`Bounded\` expects a type to have a lowest value and a largest value

With the above, try out a few simple statements:

```
Wednesday
show Wednesday
read "Wednesday" :: Day
```

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Instance Behaviour

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— Type Synonyms —

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Type Synonyms with `type`

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Using Type Synonyms

We first declared a `phoneBook` variable with type `[(String,String)]`.

Use type synonym to make things a bit more readable:

```
type PhoneNumber = String
type Name = String
type PhoneBook = [(Name, PhoneNumber)]
```

See how much easier to read functions:

```
inPhoneBook :: Name -> PhoneNumber -> PhoneBook -> Bool
inPhoneBook name pnum pbook = (name, pnum) `elem` pbook
```

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Use of type

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Reducing Type Constructors

Remember, a type constructor takes type parameters and returns a concrete type, for example `AssocList Int String`.

Perhaps a partially applied type constructor, for example:

```
type IntMap v = Map Int v
```

…can be expressed more simply:

```
type IntMap = Map Int
```

To implement the above, you will likely need to do a qualified import and precede the `Map` with module name:

```
type IntMap = Map.Map Int
```

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Synonyms with Type Annotations

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— Two Kinds of Values —

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Either
Type

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More Reasoning for Errors

The `Either` type has similar result as for `Nothing` as `Maybe a` where one of the parameters is polymorphic.

- `Maybe` type helped deal with computations that could have an error
  - the error is for exactly one reason
  - e.g.: `find` did not get a match for it to return

With an `Either` type description, we have flexibility to pass forward more reasoning for an error.

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LockerMap Type

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Setup for Locker Lookup

Next, we will write a function that searches for the code in a locker map.

The return value of type `Either` helps deal with two ways the function could fail:

- the locker could be taken already, so no code should be given back
- the locker number might not exist

In both cases we use a different string to describe the error.

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Lookup Function

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Test Lookups

Add the lookup function to script file, then try some lookups:

```
lockerLookup 101 lockers
lockerLookup 100 lockers
lockerLookup 102 lockers
lockerLookup 110 lockers
lockerLookup 105 lockers
```

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— Recursive Data Structures —

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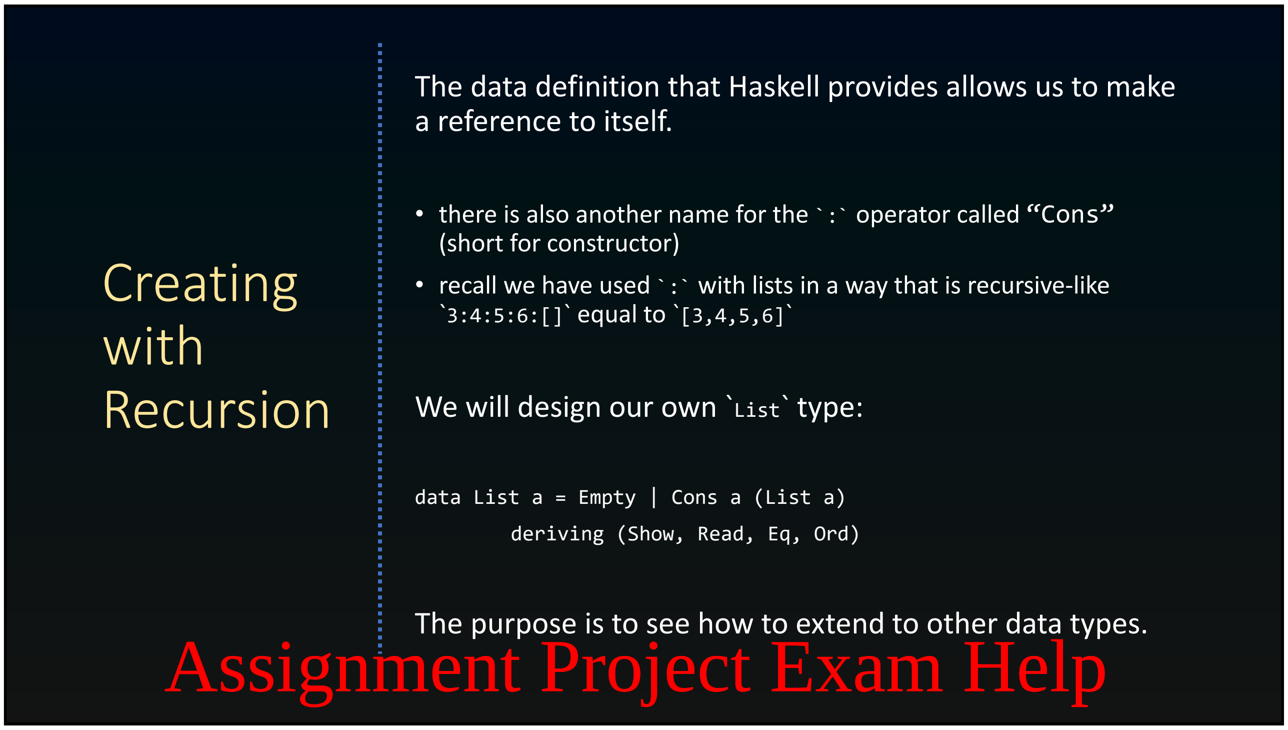

Creating with Recursion

The data definition that Haskell provides allows us to make a reference to itself.

- there is also another name for the `:` operator called "Cons" (short for constructor)
- recall we have used `:` with lists in a way that is recursive-like `3:4:5:6:[]` equal to `[3,4,5,6]`

We will design our own `List` type:

```
data List a = Empty | Cons a (List a)
        deriving (Show, Read, Eq, Ord)
```

The purpose is to see how to extend to other data types.

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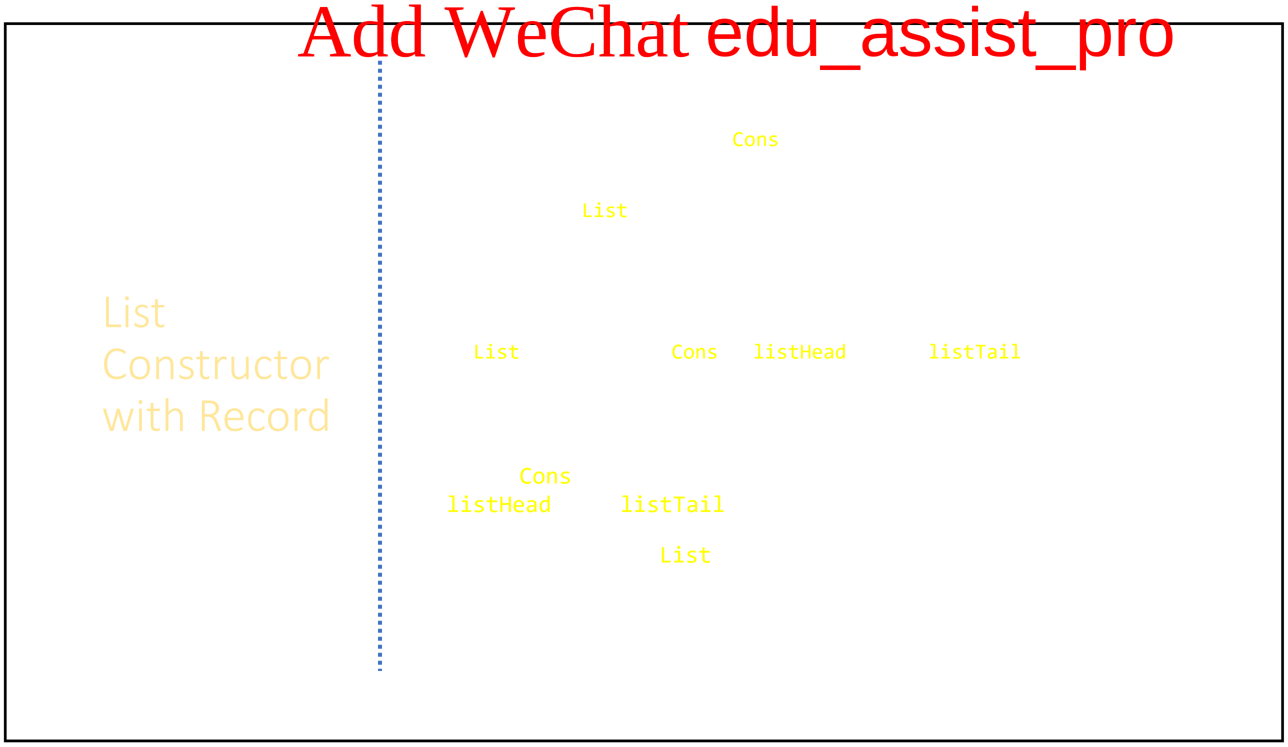

List Constructor with Record

Cons

List

List Cons listHead listTail

Cons
listHead listTail
List

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Using List Constructor

Observe creating List values, and its use of recursion:

```
5 `Cons` Empty
4 `Cons` (5 `Cons` Empty)
3 `Cons` (4 `Cons` (5 `Cons` Empty))
```

The above would be equivalent to:

```
5:[]
4:5:[]
3:4:5:[]
```

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Infix Declarations

data types

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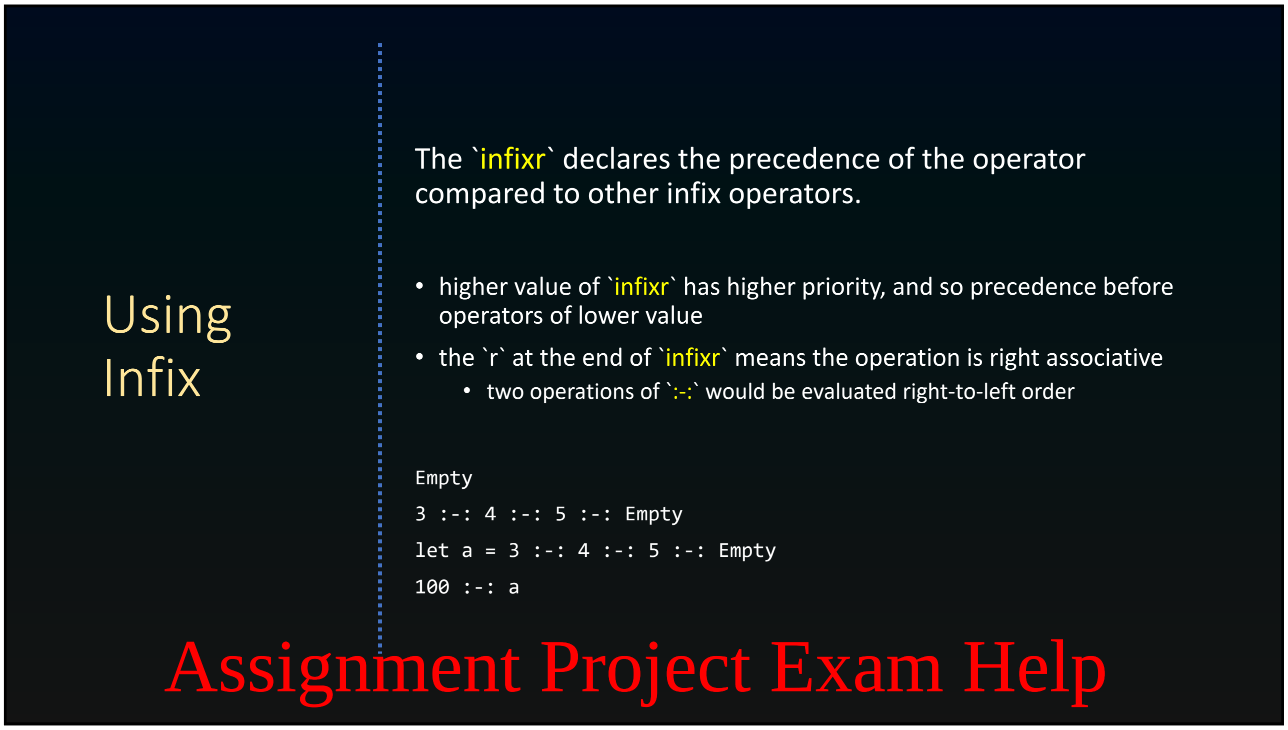

Using Infix

The `infixr` declares the precedence of the operator compared to other infix operators.

- higher value of `infixr` has higher priority, and so precedence before operators of lower value
- the `r` at the end of `infixr` means the operation is right associative
  - two operations of `:-:` would be evaluated right-to-left order

```
Empty
3 :-: 4 :-: 5 :-: Empty
let a = 3 :-: 4 :-: 5 :-: Empty
100 :-: a
```

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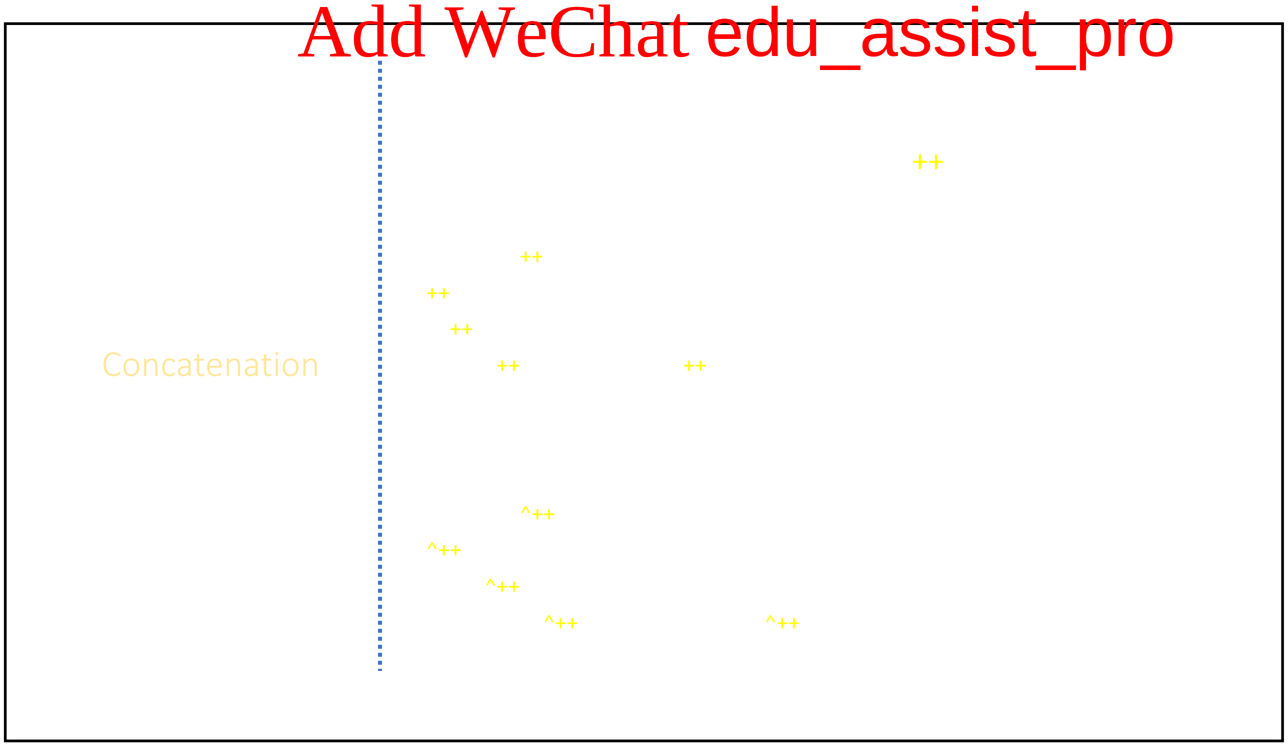

Concatenation

++

++
++
++
++ ++

^++
^++
^++
^++ ^++

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Constructors and Pattern Matching

Then give it a try:

```
let a = 3 :-: 4 :-: 5 :-: Empty
let b = 6 :-: 7 :-: Empty
a ^++ b
```

Notice how we pattern matched in the definition of `^++` with `x :-: xs` which is a constructor.

- pattern matching (only) works on constructors
- this follows our previous use of pattern matching `:` and `[]` and constant values like 8 and 'a'
  - which are actually constructors for the numeric and character types, respectively

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— Tree Type —

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Defining Trees

We now have enough to start implementing binary search trees. Recall…

- a tree node stores a value, and references to
    - a left subtree
    - a right subtree
- all values in left subtree are smaller than the current node
- all values in the right subtree are larger than the current node

We will not worry about keeping our trees balanced in this implementation.

```
data Tree a = EmptyTree | Node a (Tree a) (Tree a)
    deriving (Show)
```

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Node Values

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Insert with Trees (1)

We will start by making a function to create a one-node root-level tree:

```
singleton :: a -> Tree a
singleton x = Node x EmptyTree EmptyTree
```

Then we can use it to help us write an insertion function:

```
treeInsert :: (Ord a) => a -> Tree a -> Tree a
treeInsert x EmptyTree = singleton x
treeInsert x (Node y left right)
  | x == y   = Node x left right
  | x < y    = Node y (treeInsert x left) right
  | x > y    = Node y left (treeInsert x right)
```

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Insertion with Trees (2)

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Creating Trees Concisely

Now we can write code to create a tree very quickly:

```
let nums = [8,6,4,1,7,3,5]
let numsTree = foldr treeInsert EmptyTree nums
```

We insert numbers from a list into our tree

- one element at a time (from the right of the list)

The `numsTree` value is awkward to read all on one line.

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Check for Elements in a Tree

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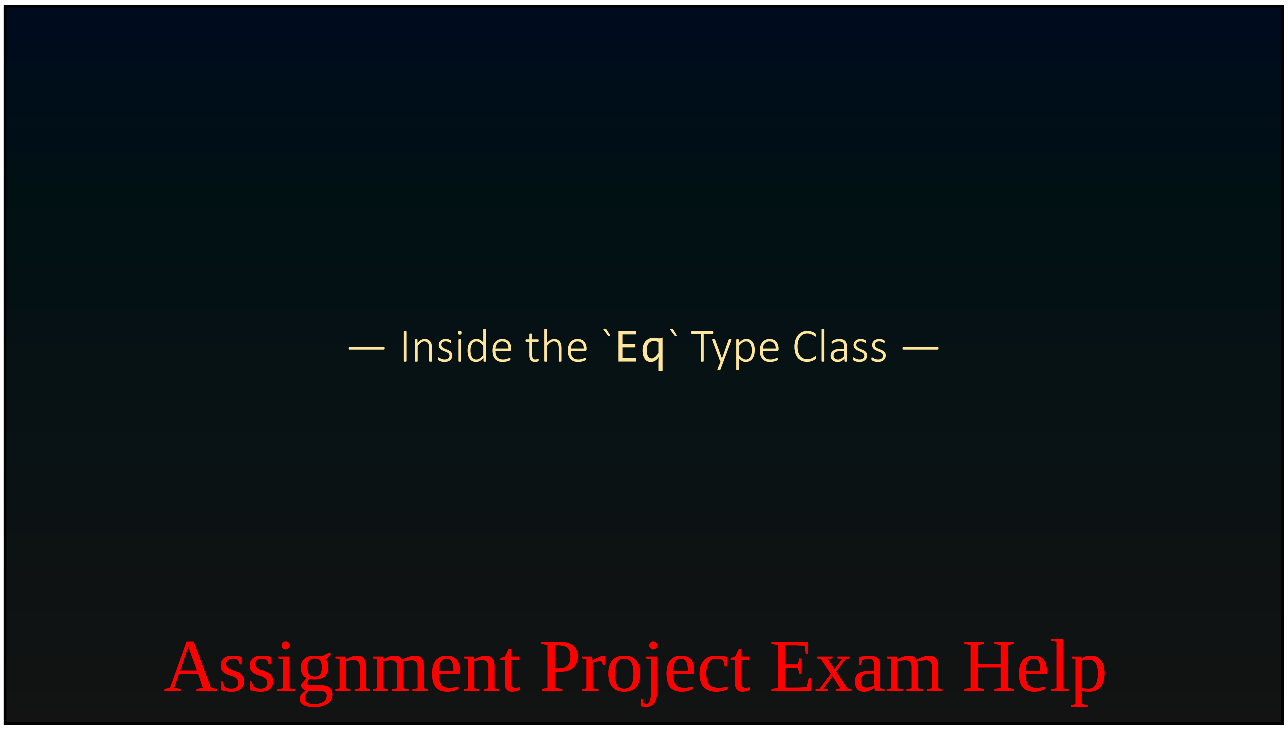

— Inside the `Eq` Type Class —

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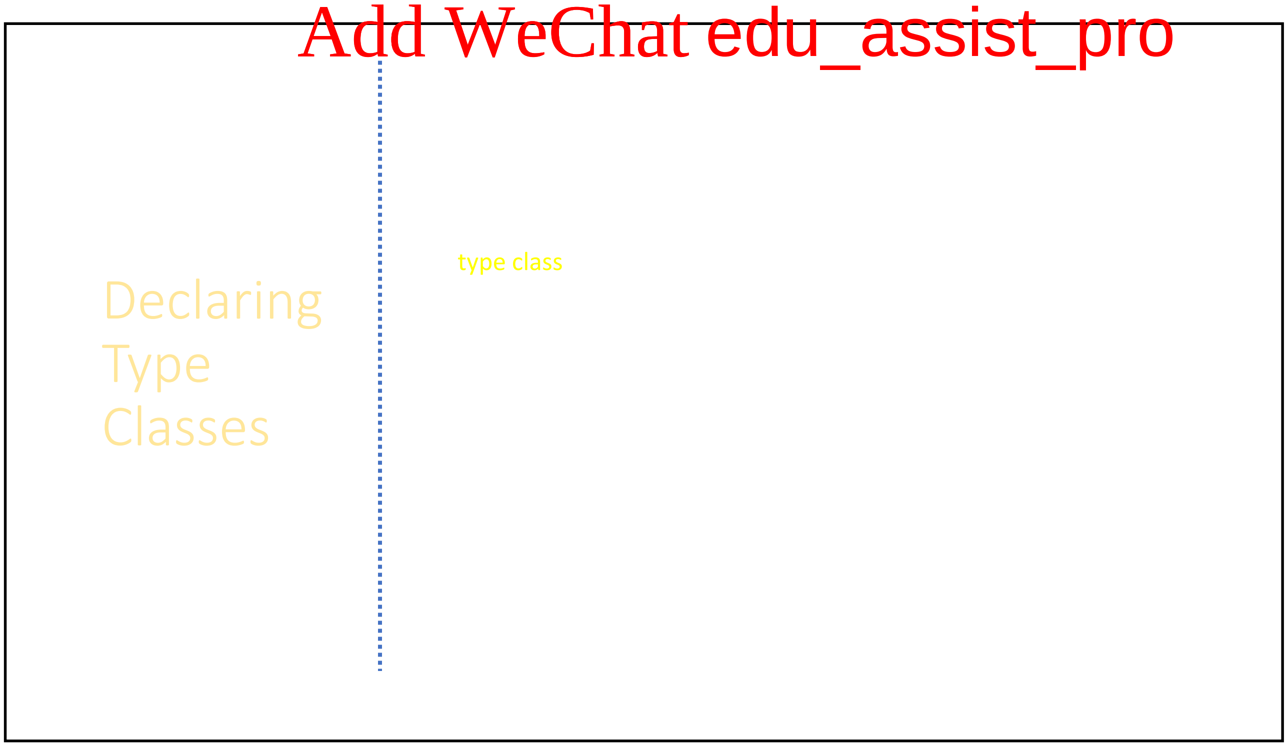

Declaring Type Classes

type class

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Eq Type Class Behaviour

- keyword `class` (not `type class`!)
- the `a` only need be lowercase, and represents whatever the type is that will become part of the `Eq` type class
- then the type descriptions for the functions (==) and (/=)
- these function type descriptions would elsewhere be observed to have restrictions of `(Eq a)`
- lastly, the two definitions of the functions (==) and (/=) are only implemented here involving the types
  - they are called mutually recursive (they depend on each other)

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— Traffic-Light Data Type —

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Creating Instances of Type Classes

We can also create our own instances of type classes.

But first, we will create a new type:

```
data TrafficLight = Red | Yellow | Green
```

Above lists the possible states of a `TrafficLight`.

Now let us make it an instance of `Eq`:

```
instance Eq TrafficLight where
    Red == Red       = True
    Green == Green   = True
    Yellow == Yellow = True
    _ == _  = False
```

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Implementing Mutually Recursive Functions

minimal complete definition

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Further Instancing with Show

Now we also make `TrafficLight` an instance of the `Show` type class:

```
instance Show TrafficLight where
    show Red = "Red Light"
    show Green = "Green Light"
    show Yellow = "Yellow Light"
```

Then make sure to not gloss over the following interactive testing:

```
Red == Red
Red == Yellow
Red `elem` [Red, Yellow, Green]
[Red, Yellow, Green]
```

- `Eq` could have just been derived, but not `Show` as you observe the last expression printed

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Date Instance of Show
(David Semke)

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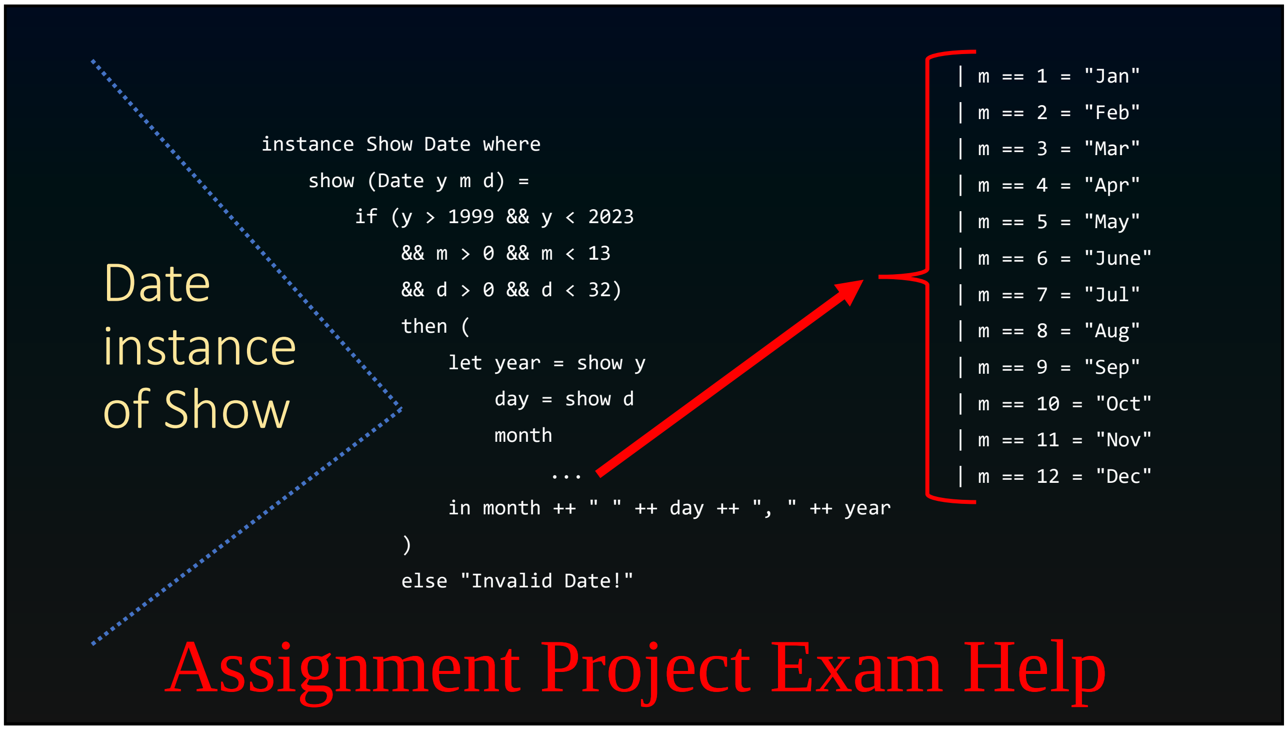

Date instance of Show

```
instance Show Date where
    show (Date y m d) =
        if (y > 1999 && y < 2023
            && m > 0 && m < 13
            && d > 0 && d < 32)
            then (
                let year = show y
                    day = show d
                    month
                        ...
                in month ++ " " ++ day ++ ", " ++ year
            )
            else "Invalid Date!"
```

```
| m == 1 = "Jan"
| m == 2 = "Feb"
| m == 3 = "Mar"
| m == 4 = "Apr"
| m == 5 = "May"
| m == 6 = "June"
| m == 7 = "Jul"
| m == 8 = "Aug"
| m == 9 = "Sep"
| m == 10 = "Oct"
| m == 11 = "Nov"
| m == 12 = "Dec"
```

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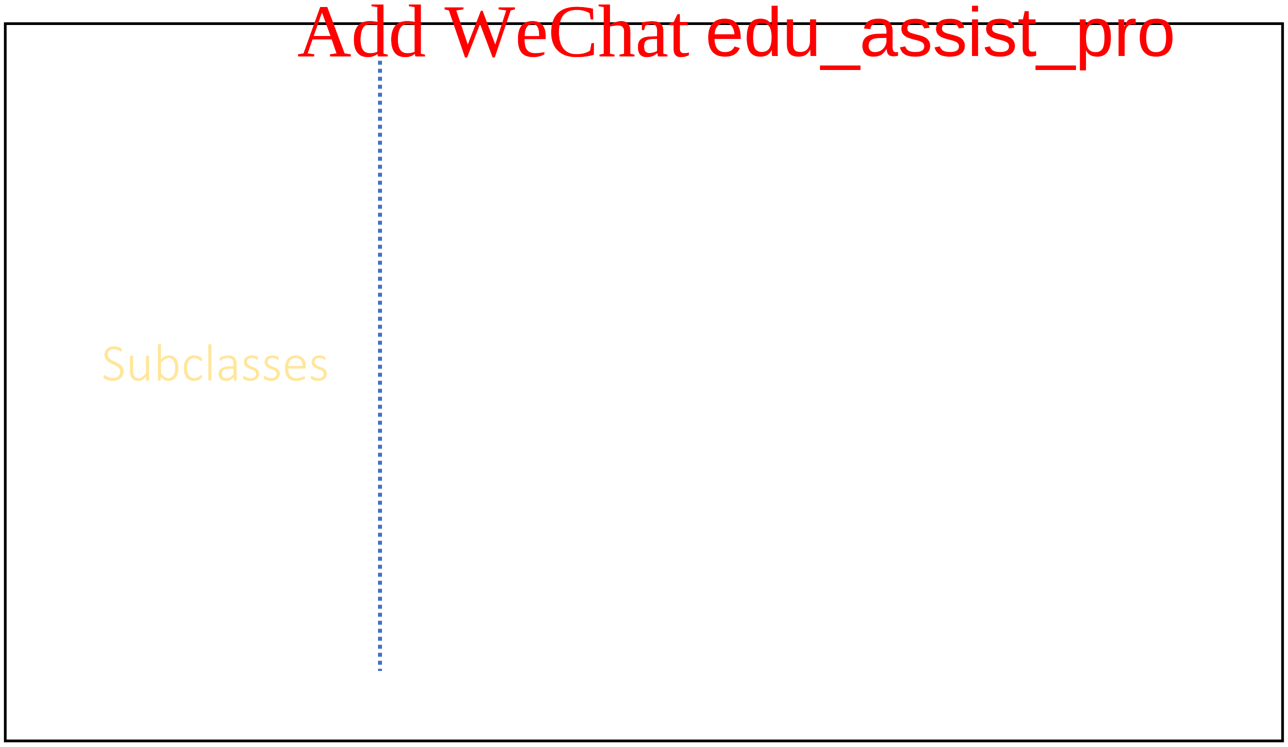

Subclasses

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— Parameterized Types as Instances of Type Classes —

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Toward Parameterization

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Parameterization

Remember, you must have a concrete type for all parameters listed for describing a function:

- e.g.: you cannot have a function of type `a -> Maybe`
- e.g.: you **can** have a function of type `a -> Maybe a`

This is also why we ***cannot*** have the following:

```
instance ~~Eq Maybe~~ where
```

- similar to why `Maybe` is not a concrete type
- we want to avoid repeating implementation for all the different concrete types
  - **not**: `instance Eq (Maybe Int)`, `instance Eq (Maybe Char)`, etc
  - so, use a type variable, i.e.:

```
instance Eq (Maybe m) where
    Just x == Just y    = x == y
    Nothing == Nothing  = True
    _ == _  = False
```

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Constraints on Parameters

Maybe a   a

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Class Constraints in Instance Declarations

So the class constraint makes sure that any `m` we pass in is of type `Eq`.

Note the two uses of class constraints:

- in class declarations, to make one type class a subclass of another
- in instance declarations,
  to require some possibly nested contents to be of some type
  - e.g.: we required contents of `Maybe` to be instance of type class `Eq`

We use similar syntax for describing functions,
e.g.: `(==) :: (Eq m) => Maybe m -> Maybe m -> Bool`:

- mentally replacing `a` type variable with your concrete types is what you need to do in your own implementations, since `==` has type `(==) :: (Eq a) => a -> a -> Bool`

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:info

`:info`

`:info Maybe`

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— `YesNo` Type Class —

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Boolean-like Type Class

```
if (0)  alert("YEAH!") else alert("NO!")
if ("") alert("YEAH!") else alert("NO!")
if (false) alert("YEAH!") else alert("NO!")
```

```
if ("WHAT") alert("YEAH!") else alert("NO!")
```

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YesNo Type Class (1)

We implement this for practice, and we typically would be better to rely on the default `Bool` type for test conditions.

```
class YesNo a where
    yesno :: a -> Bool
```

The above class type will mean any instance types will need to implement the `yesno` function.

- the intention of the `yesno` function:
  - should check value of type `a`
  - return some Boolean-like value of `True` or `False` of our custom design

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YesNo Type Class (2)

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YesNo Instance for Lists

Similarly, we can instance YesNo for lists:

```
instance YesNo [a] where
    yesno [] = False
    yesno _ = True
```

- we put a type variable `a` inside the list square brackets to
  - make the type concrete
  - without making any assumptions about the concrete type passed in

An interesting concise way to implement the `Bool` type:

```
instance YesNo Bool where
    yesno = id
```

The `id` (short for "identity") is a function from the standard library that just returns the parameter passed in.

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Many Instances of YesNo

`Maybe a`

`Tree a`

`TrafficLight`

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YesNo Testing

Test out the behaviour of `YesNo` instances:

```
yesno $ length []
yesno "haha"
yesno $ Just 0
yesno True
yesno EmptyTree
yesno []
yesno [0,0,0]
:t yesno
```

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JavaScript-like Behaviour

100

— The Functor Type Class —

101

Functors

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Functor Behaviour

This may look strange at first, but it will remind you of how we worked with the `map` function before on lists.

```
map :: (a -> b) -> [a] -> [b]
```

The `Functor` type class is quite a bit different from the previous ones we have seen so far.

- note that `f` is the major difference, being a parameterized type
  - so `f` is not a concrete type
  - `f` can be thought of as a context we want containing nested elements
- this allows us to program code to avoid having many nested calls
  - e.g.: `map` applies some function to elements of a list

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Implementation of `fmap`

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Empty Lists

Note that `fmap`:

- of an empty list of concrete type `[a]`
- just results in an empty list of concrete type `[b]`

  (whatever `a` and `b` happen to be implemented as)

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— Maybe as a Functor —

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Maybe as a Functor

Then any parameterized type is ripe for implementation with `Functor`, such as `Maybe`:

```
instance Functor Maybe where
    fmap f (Just x) = Just (f x)
    fmap f Nothing = Nothing
```

Again, notice we are filling in a type constructor `Maybe` and not a concrete type `(Maybe a)`.

- for `fmap` we have a description `(a -> b) -> Maybe a -> Maybe b`
- nested value of `Just` has the `a -> b` function applied to it
  - then we do not have to explicitly write that nesting ourselves later

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Check with Signatures

m a m b

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fmap Practice

Some expressions to try:

```
fmap (++ " BECOMES PART OF THE NESTED MAYBE VALUE!")
        (Just "Something serious.")
fmap (++ " BECOMES PART OF THE NESTED MAYBE VALUE!") (Nothing)
fmap (*2) (Just 200)
fmap (*2) Nothing
```

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— Trees as Functors —

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Tree Instance of Functor

Anything we make an instance of `Functor` type class is some kind of container, such as `Tree` we implemented:

- the `Tree` type constructor takes only one parameter
- to implement `fmap` it looks like `(a -> b) -> Tree a -> Tree b`

This time, we will have to implement things recursively:

- the base case of an empty tree is another empty tree
- anything else has the function applied to the root node, and `fmap` applied to left and right subtrees separately

```
instance Functor Tree where
    fmap f EmptyTree = EmptyTree
    fmap f (Node x left right) =
        (Node f x) (fmap f left) (fmap f right)
```

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Testing Tree Functor Behaviour

112

— Either as a Functor —

113

Two Type Parameters

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Map Instance of Functor

Similar types that have multiple type parameters can be made instance of Functor, say `Data.Map` with its type description `Map k v`.

- then `fmap` would take
  - first parameter some function `v -> w`
  - second parameter a map of type `Map k v`
- `fmap` should then return a map of type `Map k w`
- see if you can implement how to make `Map k` an instance of `Functor`

Important: a `Functor` instance is the "context", e.g.: `Map`, and not the same thing as the function passed in to `fmap`.

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— Kinds —

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The `kind` Command

Every value in Haskell has a concrete type, but even each type has a type—known as a kind.

To check the kind of a type, use `:k` command:

```
:k Int
```

The result gives `Int :: *` where the `*` just means `Int` is a concrete type.

- read out loud as "star" or "type“

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One Type Parameter for Functors

Then let us take a look at the kind of `Either`:

```
:k Either
:k Either String
```

- the result for `:k Either` is `* -> * -> *`
- the next result is `* -> *`
- the `Functor` type class expects a type constructor of kind `* -> *`
- a `Functor` instance must be a type constructor function that takes one type parameter and returns a concrete type

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— Chapter 8: Input and Output —

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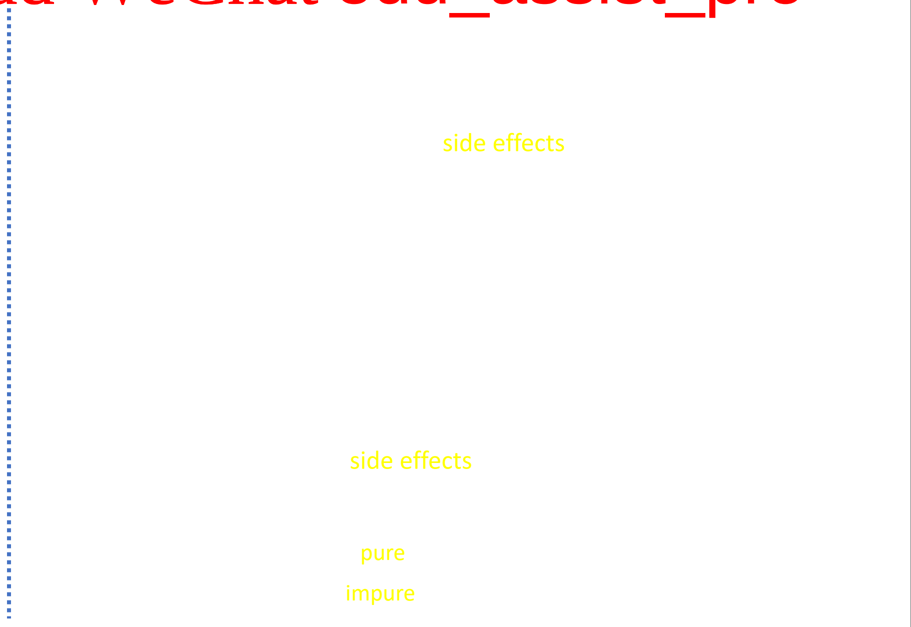
— Separating Pure from Impure —

121

I/O has Side Effects



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Scripts

We will move on to writing scripts that perform more than simply defining functions (and then testing them in ghci).

Let us start with the familiar "`Hello, World!`" program:

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

Save the above in a file called `` `hello.hs` ``.

- there could be different commands for compiling depending on your development environment

For Windows and the Haskell stack command line:

```
stack ghc hello
```

123

Compile and Run

`ghc --make hello`

`hello.exe`

`./hello`

`main`

`main`

`:script hello.hs`

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I/O Actions

Let us take a look at the type of the function `putStrLn`:

```
:t putStrLn
:t putStrLn "Hello, World!"
```

- First result: `putStrLn :: String -> IO ()`
- Second result: `putStrLn "Hello, World!" :: IO ()`

The first result has `putStrLn` function that takes a string and returns an I/O action that yields an empty tuple.

- printing to the terminal does not have any meaningful side effect, so the empty tuple represents a dummy value (`()` is also the description of its type)

An I/O action will be executed when we execute `main`.

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— Gluing I/O Actions Together —

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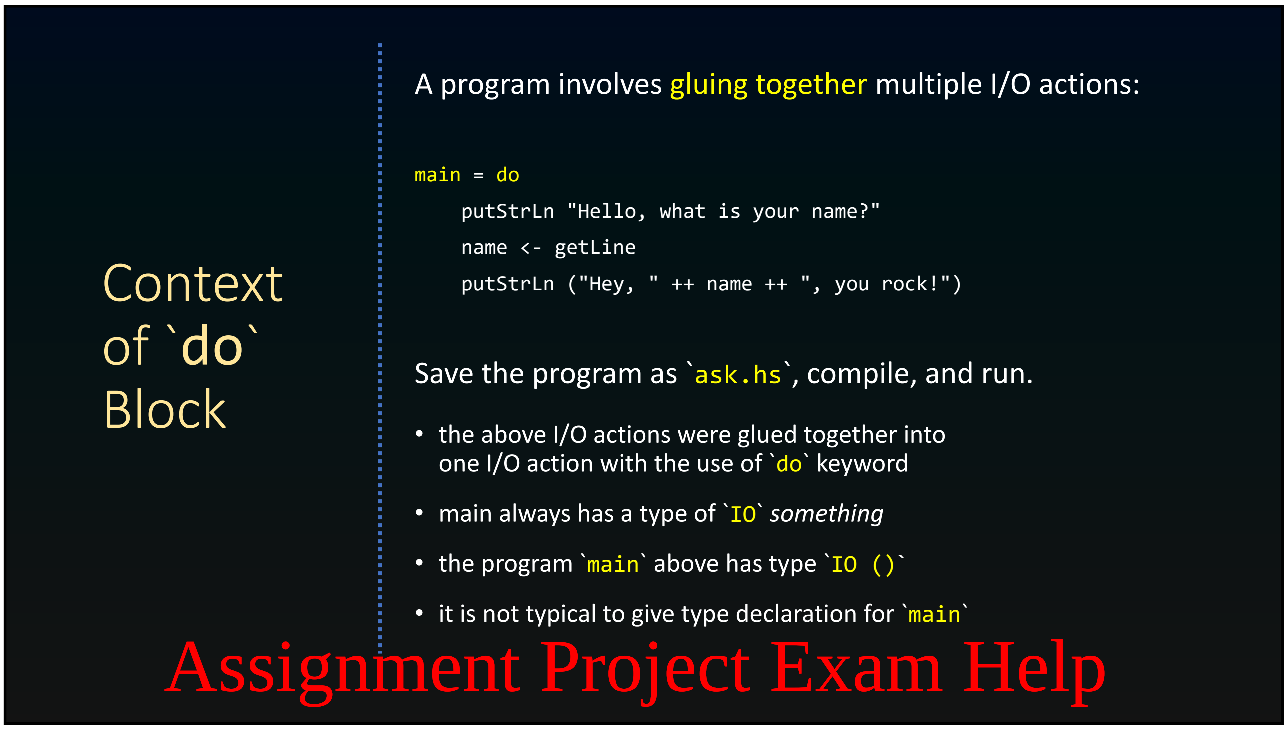

Context of `do` Block

A program involves gluing together multiple I/O actions:

```
main = do
    putStrLn "Hello, what is your name?"
    name <- getLine
    putStrLn ("Hey, " ++ name ++ ", you rock!")
```

Save the program as `ask.hs`, compile, and run.

- the above I/O actions were glued together into one I/O action with the use of `do` keyword
- main always has a type of `IO` *something*
- the program `main` above has type `IO ()`
- it is not typical to give type declaration for `main`

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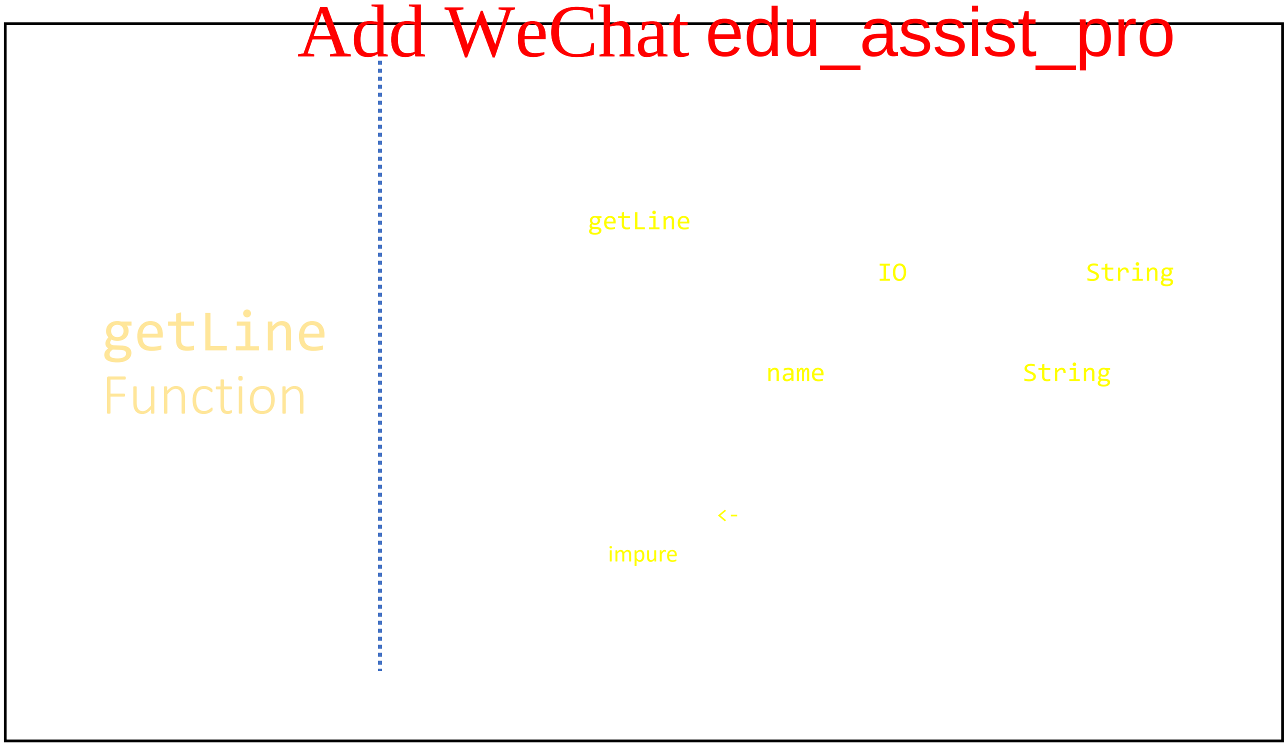


getLine Function

getLine

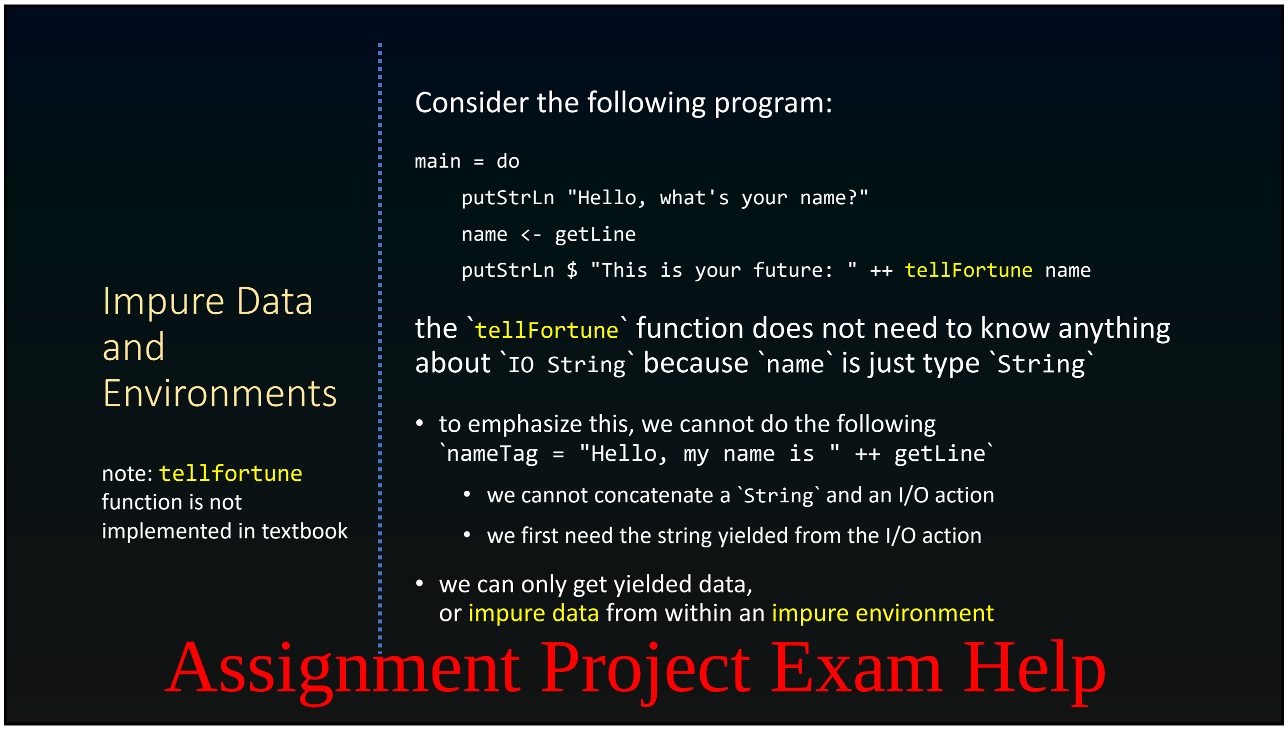
IO String

name String

<-

impure

128



Impure Data and Environments

note: tellfortune function is not implemented in textbook

Consider the following program:

```
main = do
    putStrLn "Hello, what's your name?"
    name <- getLine
    putStrLn $ "This is your future: " ++ tellFortune name
```

the `tellFortune` function does not need to know anything about `IO String` because `name` is just type `String`

- to emphasize this, we cannot do the following `nameTag = "Hello, my name is " ++ getLine`
  - we cannot concatenate a `String` and an I/O action
  - we first need the string yielded from the I/O action
- we can only get yielded data, or impure data from within an impure environment

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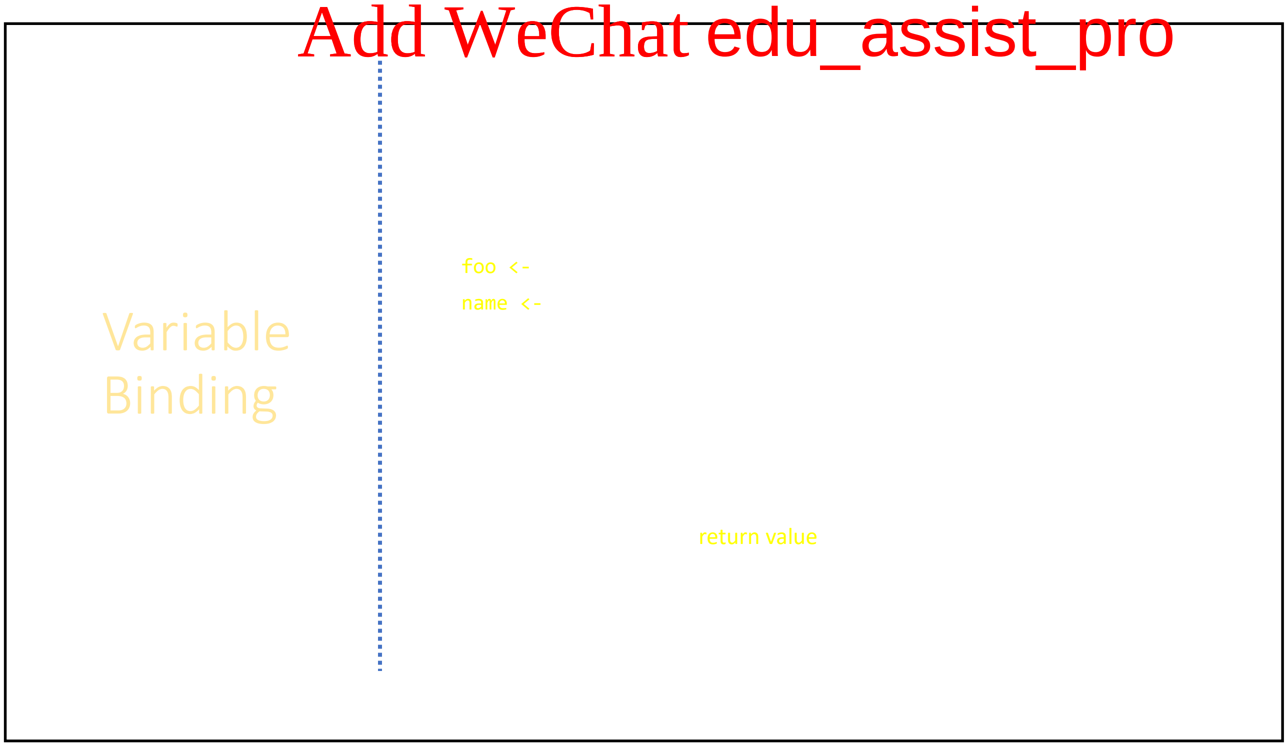

Variable Binding

```
    foo <-
    name <-
```

return value

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When I/O Actions Happen

The following is possible:

```
myLine = putStrLn
```

but it just gives another name to the `putStrLn` I/O action, so there is not much need.

I/O actions will be performed:

- when `main` is executed
- a `do` block is executed in main with an I/O action nested inside
  - `do` blocks glue together I/O actions
  - these blocks can be nested inside another `do` block
  - all will be performed if within any level nested inside `main`
- when we type an I/O action statement in ghci and press `ENTER`

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Example for Combining I/O Actions (Hunter Klassen)

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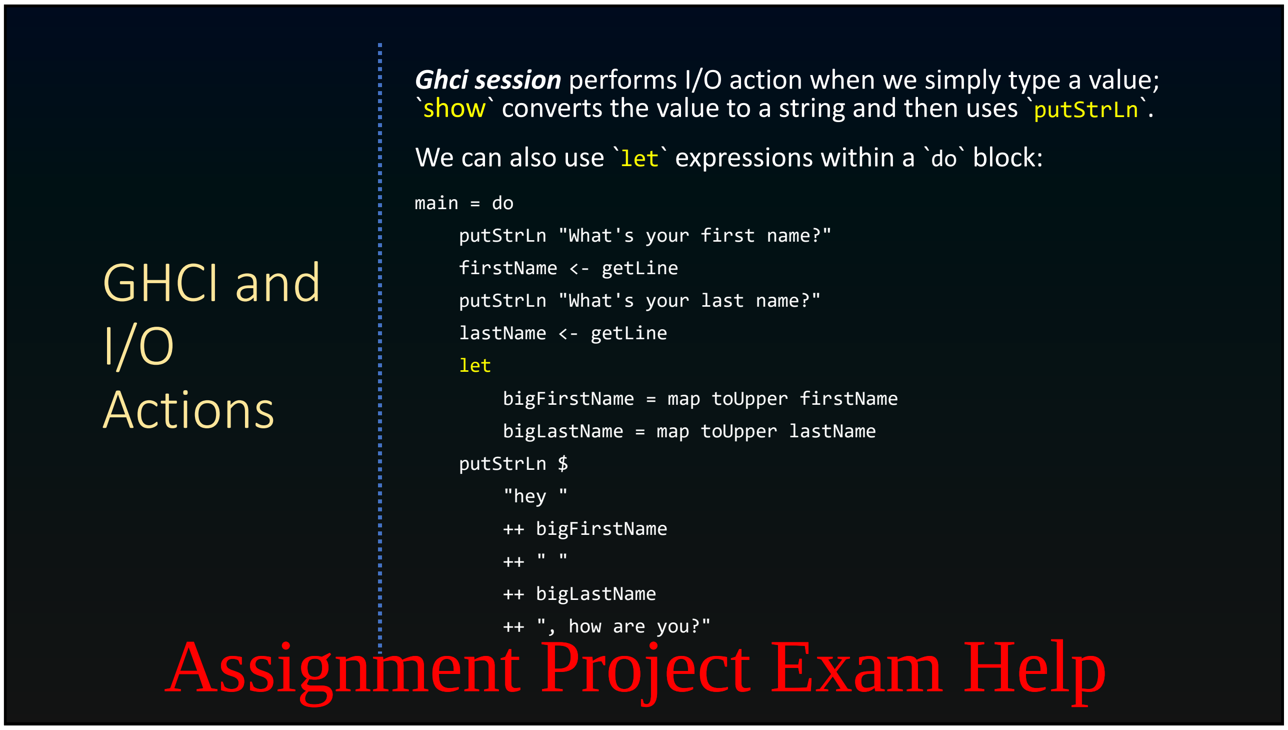

GHCI and I/O Actions

Ghci session performs I/O action when we simply type a value; \``show`\` converts the value to a string and then uses \``putStrLn`\`.

We can also use \``let`\` expressions within a \``do`\` block:

```
main = do
    putStrLn "What's your first name?"
    firstName <- getLine
    putStrLn "What's your last name?"
    lastName <- getLine
    let
        bigFirstName = map toUpper firstName
        bigLastName = map toUpper lastName
    putStrLn $
        "hey "
        ++ bigFirstName
        ++ " "
        ++ bigLastName
        ++ ", how are you?"
```

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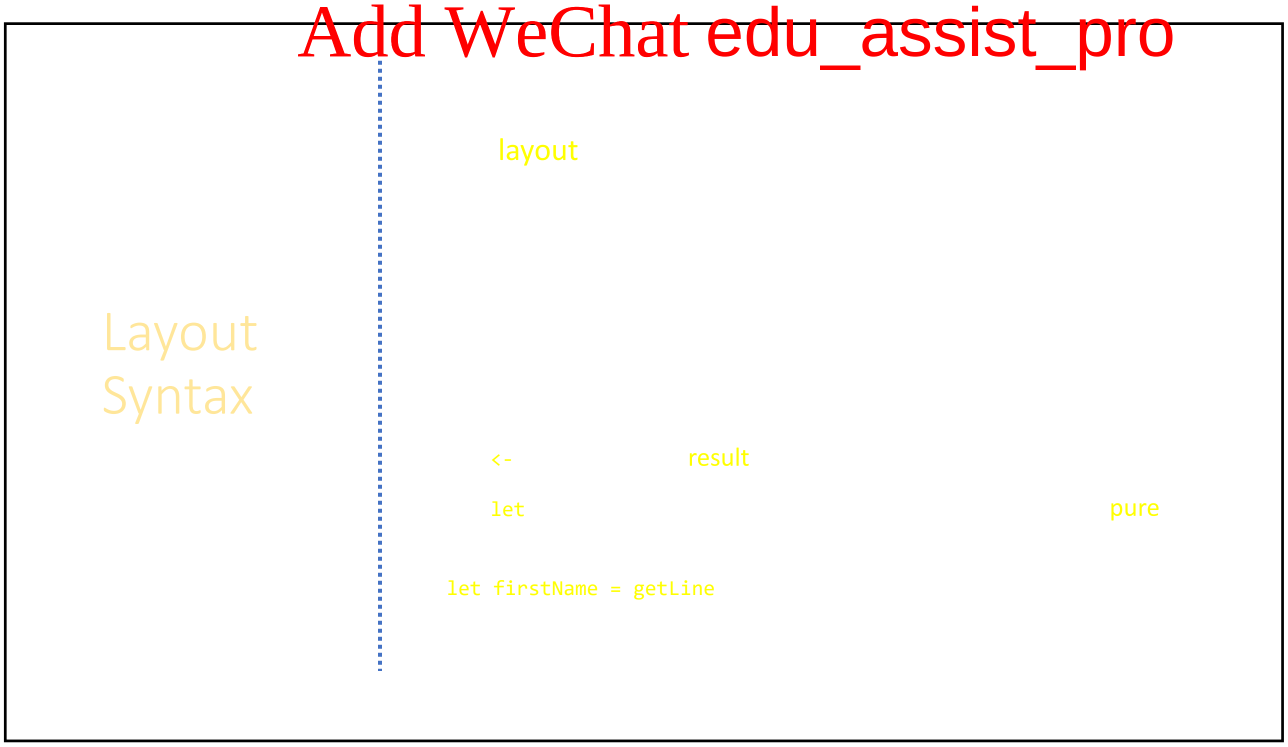

Layout Syntax

layout

<- result

let pure

`let firstName = getLine`

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— Reverse Strings in I/O —

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Recursive IO Actions

```
main





                   reverseWords
            main
    putStrLn $ "exiting main"

reverseWords
reverseWords
```

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Working with I/O Actions

- `putStrLn` statement when `main` exits helps you see recursion
- the recursive call to `main` is itself an I/O action
  - a nested `do` block glues `putStrLn` and `main` calls into ***one*** I/O action expected by `else`
- the `unwords` function concatenates all the words together from its input list
- the `return ()` statement is special when used inside an I/O action because it ***wraps*** a pure value into the type `IO a`
  - similarly, `return "ha"` will wrap a yield into the type `IO String`
- condition `if null line` at some point expects an empty string returned into it yielded from `getLine`

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return in Haskell

return

return

return

return

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I/O Action Wrapping and Unwrapping

Realize that `return` is the inverse of `<-`, wrapping and unwrapping, respectively, I/O action yield values.

- keep in mind the examples are just demonstration—use `let` to simply assign variables
- `return` is used to wrap as the result given back at the end of a `do` block when an expression itself is not an I/O action

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— Demonstrations of Some I/O Action Functions —

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End of Line

The following demonstrates the difference between `putStrLn` and `putStr`:

```
main = do
    putStr "Hey, "
    putStr "I'm "
    putStrLn "Andy!"
```

- observe that `putStr` does not move output to the next line

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One Output Character

putChar

```
    putChar
    putChar
    putChar
```

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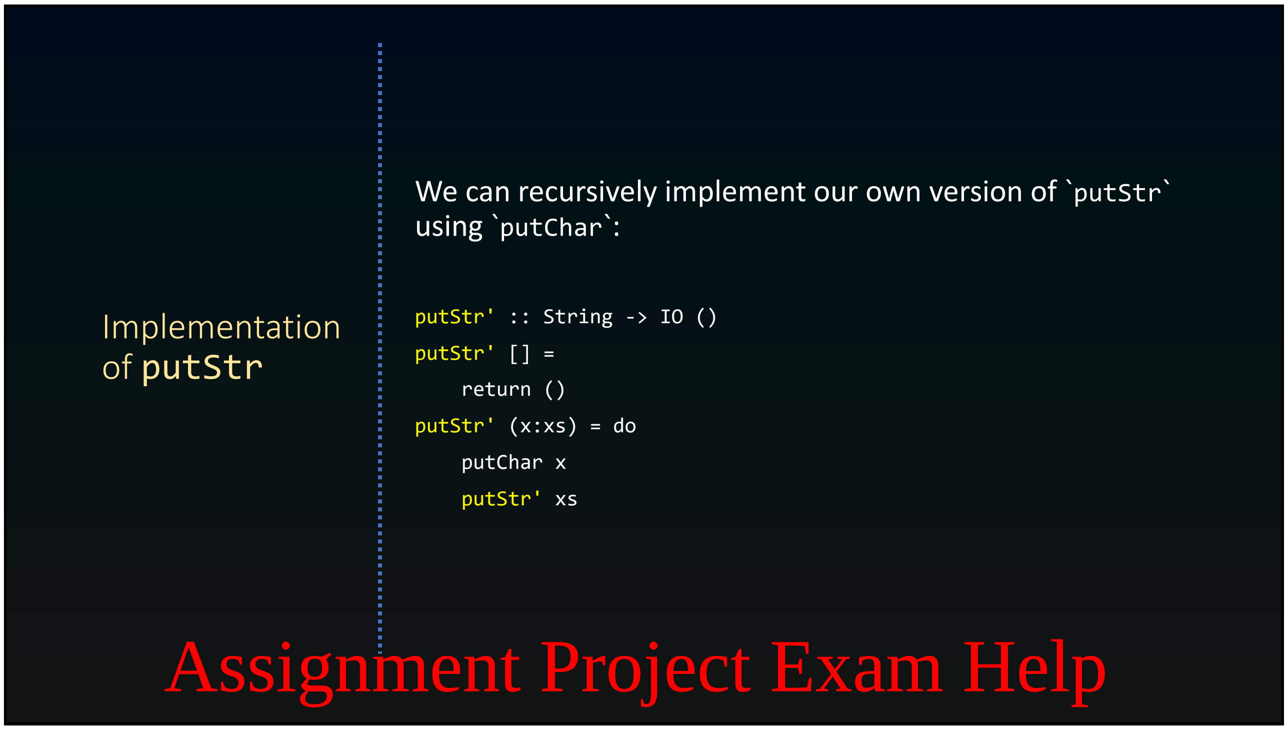

Implementation of `putStr`

We can recursively implement our own version of `putStr` using `putChar`:

```
putStr' :: String -> IO ()
putStr' [] =
    return ()
putStr' (x:xs) = do
    putChar x
    putStr' xs
```

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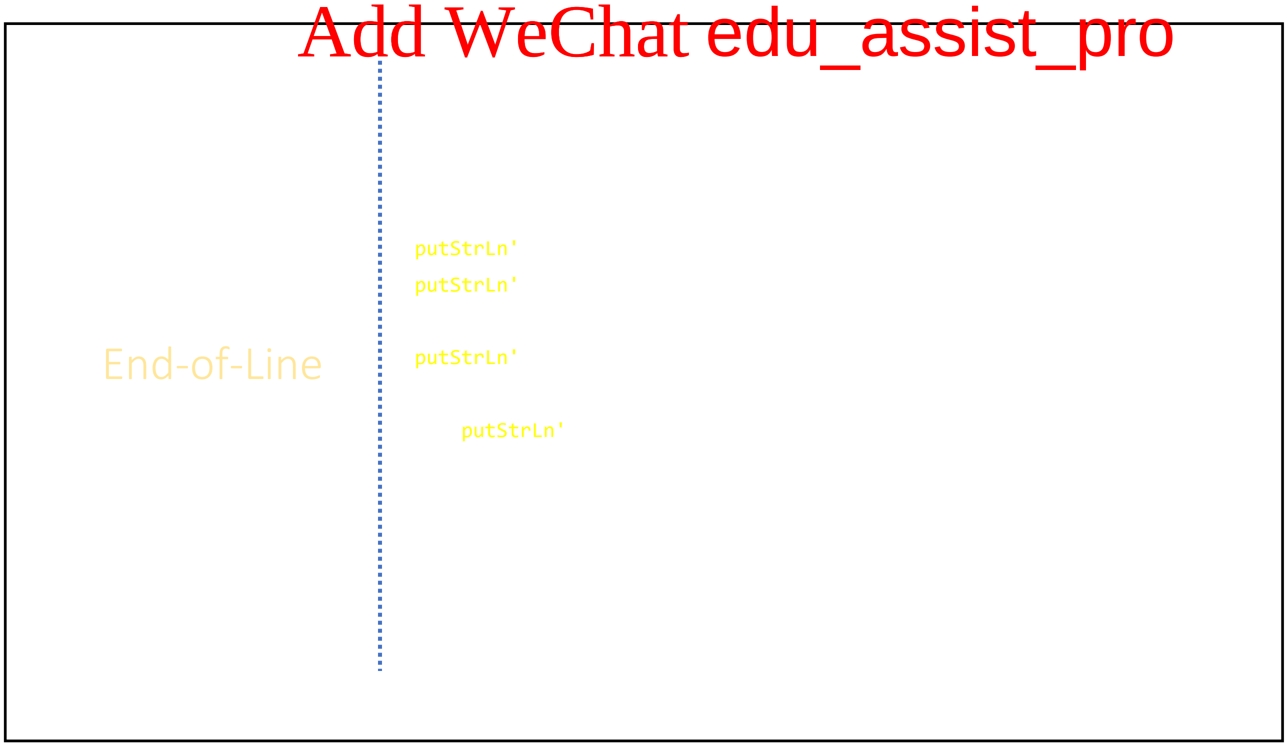

End-of-Line

```
putStrLn'
putStrLn'

putStrLn'

    putStrLn'
```

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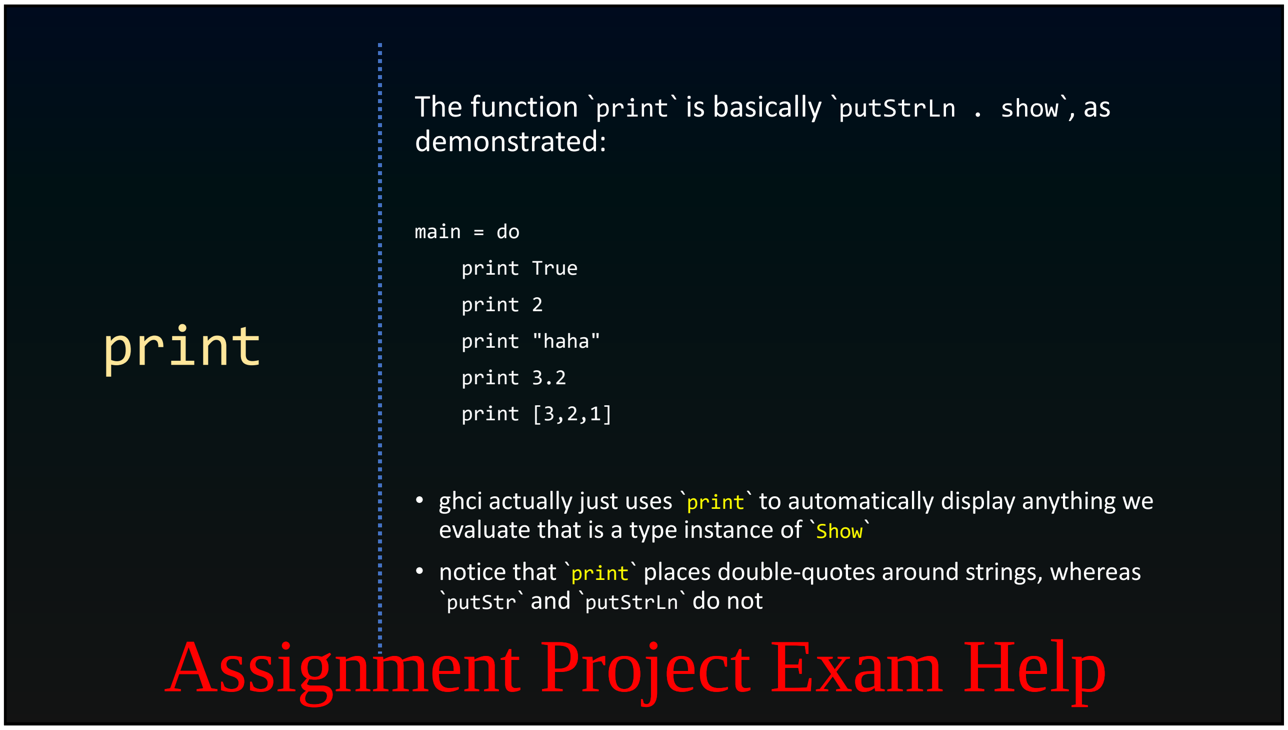

print

The function `print` is basically `putStrLn . show`, as demonstrated:

```
main = do
    print True
    print 2
    print "haha"
    print 3.2
    print [3,2,1]
```

- ghci actually just uses `print` to automatically display anything we evaluate that is a type instance of `Show`
- notice that `print` places double-quotes around strings, whereas `putStr` and `putStrLn` do not

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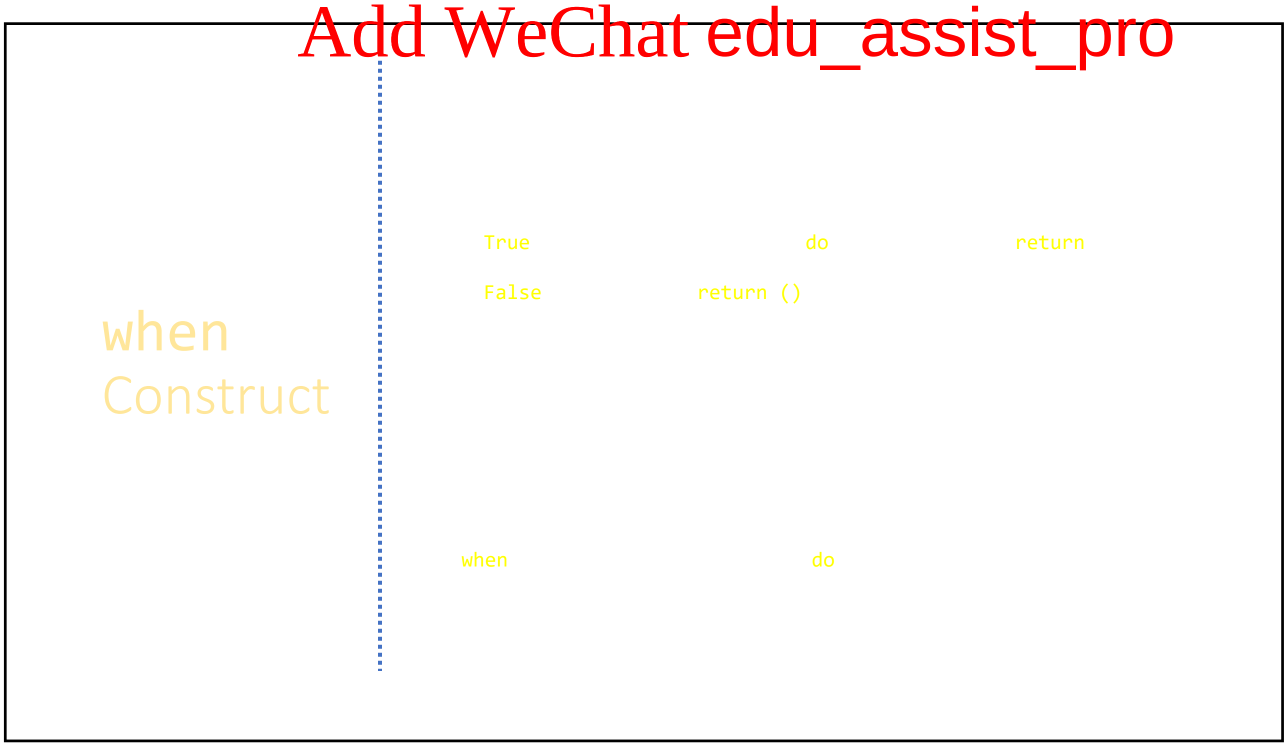

when Construct

True do return

False return ()

when do

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return ()

Without the `when` function, then we are forced to write the `else` statement corresponding to `if`:

```
main = do
    input <- getLine
    if (input == "SWORDFISH")
        then putStrLn input
        else return ()
```

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sequence

sequence

getLine

sequence

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Lists of I/O Actions

``map print [1,2,3,4]`` results in a list of I/O actions,

- but not itself an I/O action!
- therefore, it will not be executed when we press `ENTER` or run it in a program

This is the next use of `sequence`, to execute such a list:

```
sequence $ map print [1,2,3,4]
```

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Ignoring Output

sequence

_ <-

_ <-

_ =

_ = 3

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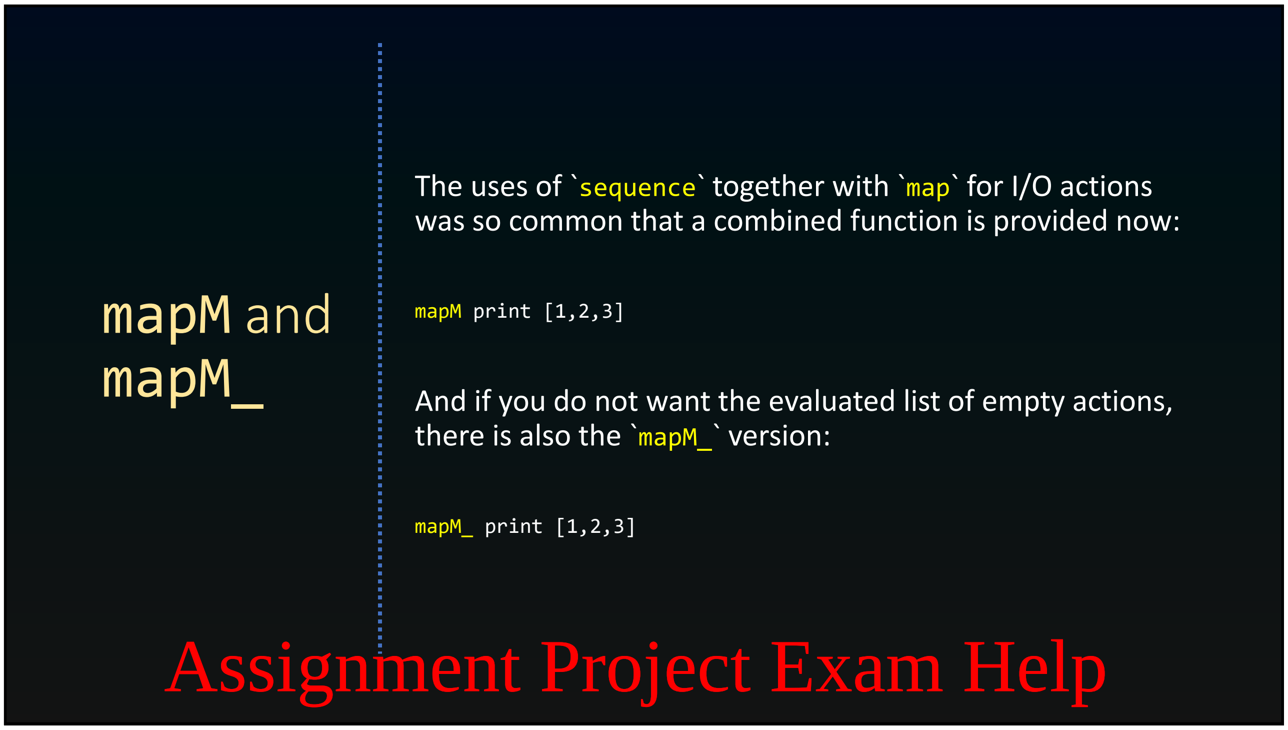

mapM and mapM_

The uses of `sequence` together with `map` for I/O actions was so common that a combined function is provided now:

```
mapM print [1,2,3]
```

And if you do not want the evaluated list of empty actions, there is also the `mapM_` version:

```
mapM_ print [1,2,3]
```

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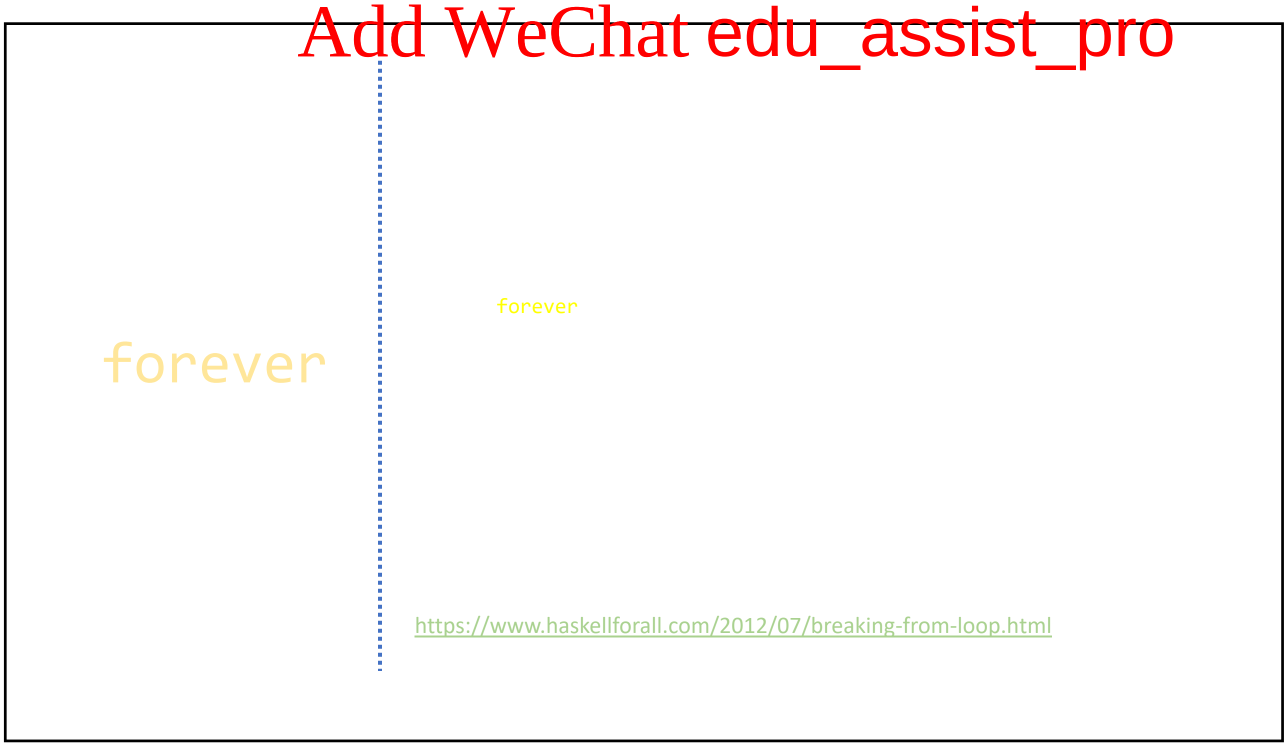

forever

```
forever
```

https://www.haskellforall.com/2012/07/breaking-from-loop.html

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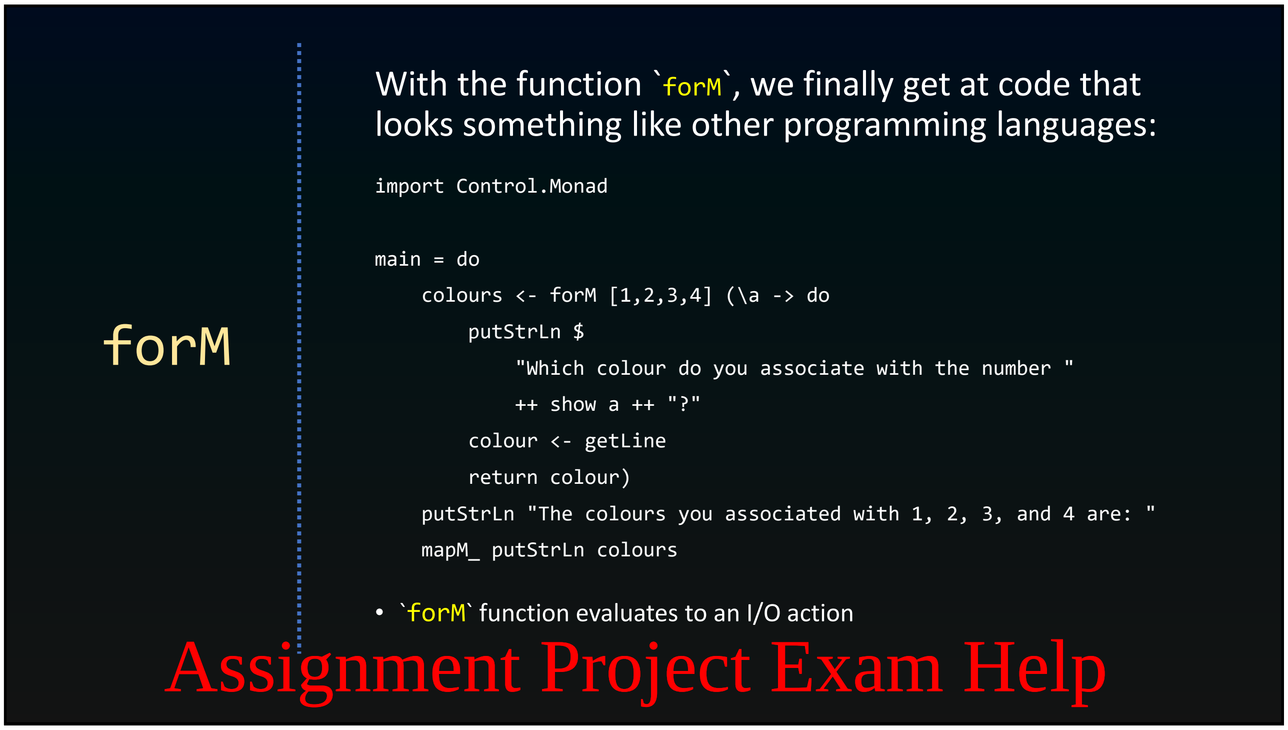

forM

With the function `forM`, we finally get at code that looks something like other programming languages:

```
import Control.Monad

main = do
    colours <- forM [1,2,3,4] (\a -> do
        putStrLn $
            "Which colour do you associate with the number "
            ++ show a ++ "?"
        colour <- getLine
        return colour)
    putStrLn "The colours you associated with 1, 2, 3, and 4 are: "
    mapM_ putStrLn colours
```

- `forM` function evaluates to an I/O action

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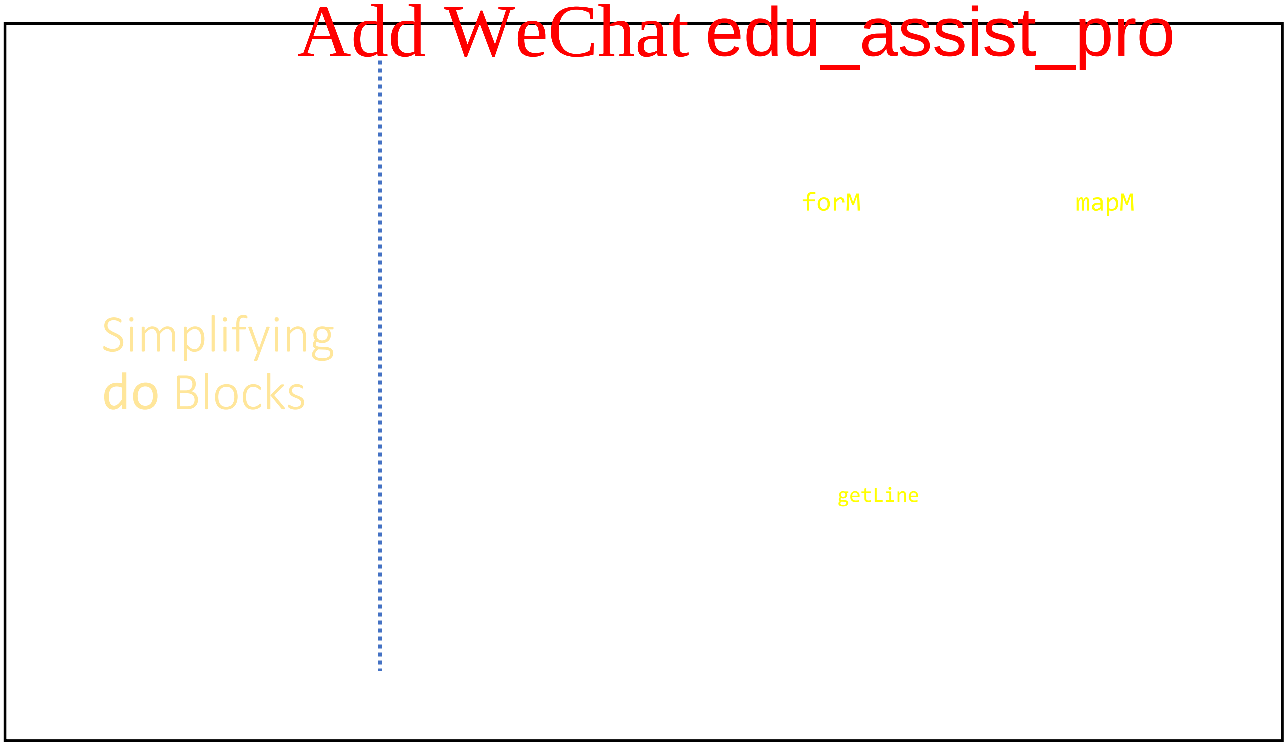

Simplifying do Blocks

forM mapM

getLine

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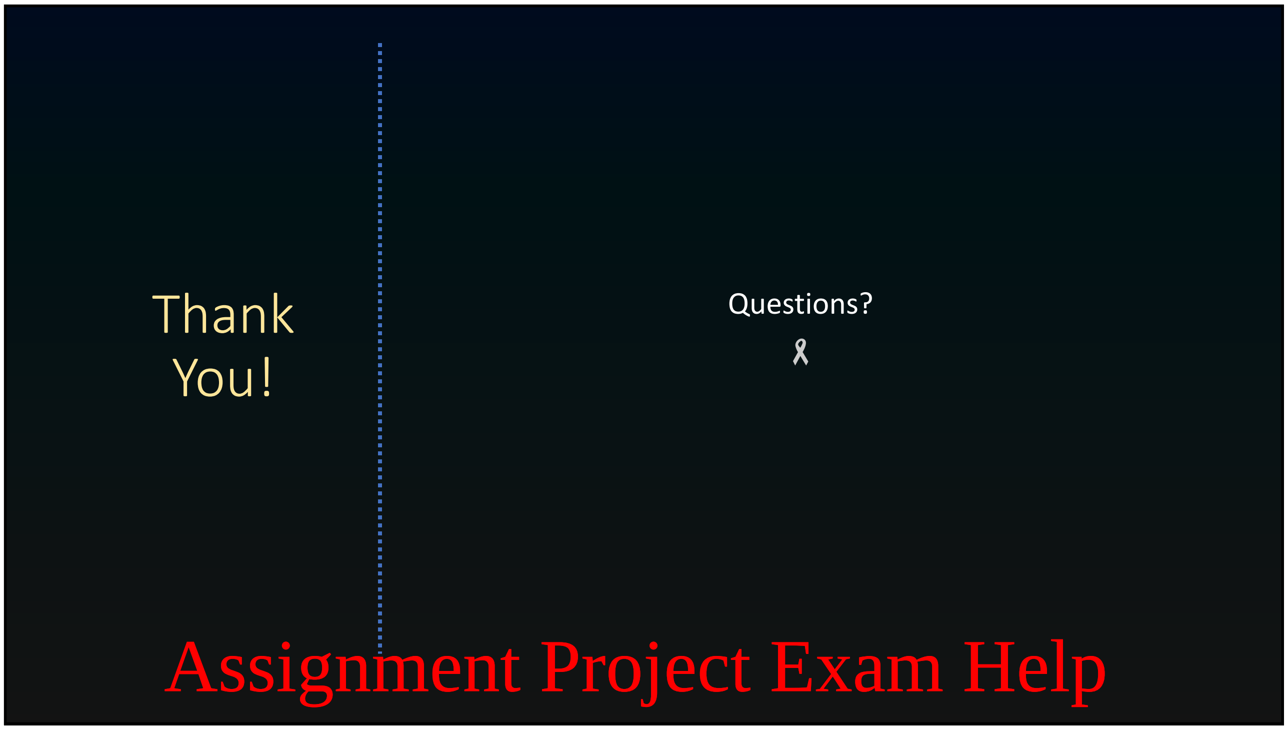

Thank You!

Questions?