# Background – Type Classes (1B)

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This document was produced by using OpenOffice.

# Based on

http://learnyouahaskell.com/making-our-own-types-and-typeclasses#the-functor-typeclass

http://learnyouahaskell.com/functors-applicative-functors-and-monoids

Haskell in 5 steps
https://wiki.haskell.org/Haskell_in_5_steps

# Typeclasses and Instances

**Typeclasses** are like interfaces

defines some behavior
comparing for *equality*
comparing for *ordering*
*enumeration*

**Instances** of that **typeclass**
types possessing such behavior

such *behavior* is defined by

- **function definition**
- function **type declaration** only

**a function definition**

```
(==) :: a -> a -> Bool
x == y = not (x /= y)
```

**- a type declaration**

**a function type**

```
(==) :: a -> a -> Bool
```

**- a type declaration**

A function definition can be **overloaded**

http://learnyouahaskell.com/making-our-own-types-and-typeclasses#the-functor-typeclass

# Typeclasses and Type

**Typeclasses** are like interfaces

defines some behavior
- comparing for *equality*
- comparing for *ordering*
- *enumeration*

**Instances** of that **typeclass**

types possessing such behavior

a **type** is an **instance** of a **typeclass** implies

the function types declared by the **typeclass** are defined (implemented) in the **instance**

so that we can use the functions that the **typeclass** defines with that **type**

No relation with classes in Java or C++

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# **Car** Type Example

**the Eq typeclass**

defines the functions **==** and ***/=***

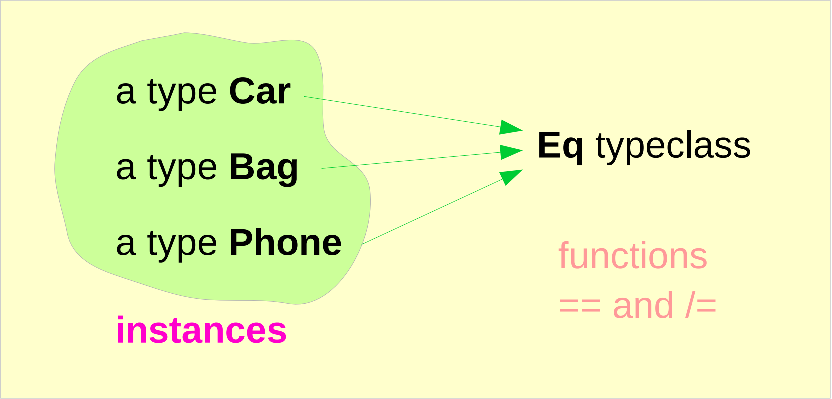
**a type Car**

comparing two cars c1 and c2 with the equality function ==

The Car type is an **instance** of Eq **typeclass**

**Instances** : various types

**Typeclass** : a group or a class of these similar types

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# TrafficLight Type Example (1)

```
class Eq a where
    (==) :: a -> a -> Bool        - a type declaration
    (/=) :: a -> a -> Bool        - a type declaration
    x == y = not (x /= y)         - a function definition
    x /= y = not (x == y)         - a function definition
```

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

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

```
ghci> Red == Red
True
ghci> Red == Yellow
False
ghci> Red `elem` [Red, Yellow, Green]
True
```

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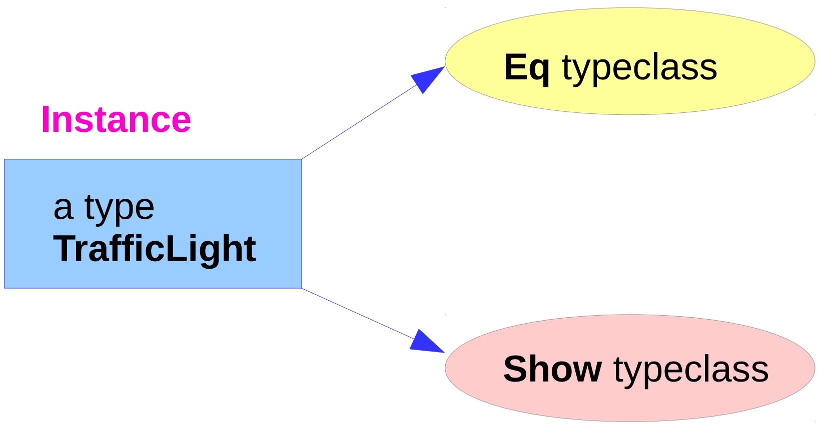
# **TrafficLight** Type Example (2)

```
class Show  a where
   show :: a  -> String
   * * *
```

- a type declaration

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

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




```
ghci> [Red, Yellow, Green]
[Red light,Yellow light,Green light]
```

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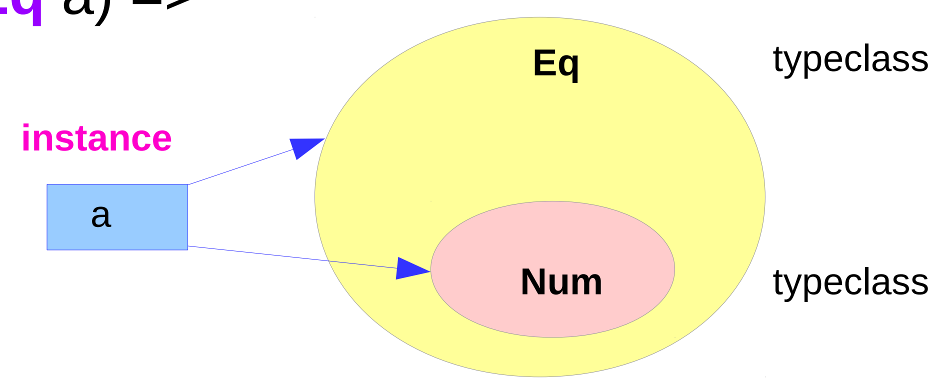
# Class Constraints

```
class (Eq a) => Num a where
  ...
```

```
class Num a where
  ...
```

(Eq a) =>




class constraint on a class declaration

an instance of Eq
before being an instance of Num

**Num** : a subclass of **Eq**

the required function bodies can be defined in

- the class declaration
- an instance declarations,

we can safely use == because a is a part of Eq

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# Class Constraints : class & instance declarations

class constraints in **class declarations**

to make a typeclass a **subclass** of another typeclass

**subclass**

```
class (Eq a) => Num a where
    …
```

class constraints in **instance declarations**

to express **requirements** about the contents of some type.

**requirements**

```
instance (Eq x, Eq y) => Eq (Pair x y) where
   Pair x0 y0 == Pair x1 y1 = x0 == x1 && y0 == y1
```

http://cmsc-16100.cs.uchicago.edu/2016/Lectures/07-type-classes.php

http://learnyouahaskell.com/making-our-own-types-and-typeclasses#the-functor-typeclass

# Class constraints in instance declaration examples

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

```
instance (Eq x, Eq y) => Eq (Pair x y) where
    Pair x0 y0 == Pair x1 y1 = x0 == x1 && y0 == y1
              ↑                    ↑            ↑
         Eq (Pair x y)           Eq x         Eq y
```

**Derived instance**

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# A Concrete Type and a Type Constructor

**a** : a concrete type

**Maybe** : not a concrete type
: a type constructor that takes one parameter
produces a concrete type.

**Maybe a** : a concrete type

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# Instance of **Eq**

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

to define our own type (defining a new data type)
allowed values are Red, Yellow, and Green
no class (type) instances

```
class Eq a where
   (==) :: a -> a -> Bool
   (/=) :: a -> a -> Bool
   x == y = not (x /= y)
   x /= y = not (x == y)

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

**class** :
  defining new **typeclasses**

**instance** :
  making types instances of a **typeclasses**

http://learnyouahaskell.com/making-our-own-types-and-typeclasses

# Instance of **Show**

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

```
ghci> Red == Red                                ◄  instance Eq TrafficLight
True
ghci> Red == Yellow                             ◄  instance Eq TrafficLight
False
ghci> Red `elem` [Red, Yellow, Green]           ◄  instance Eq TrafficLight
True
ghci> [Red, Yellow, Green]                      ◄  instance Show TrafficLight
[Red light,Yellow light,Green light]
```

http://learnyouahaskell.com/making-our-own-types-and-typeclasses

# Instance Maybe m

```
instance Eq Maybe where
  ...
```

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

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

**Maybe** is not a concrete type

**Maybe m** is a concrete type

all types of the form **Maybe m**
to be part of the **Eq** typeclass,

but only those types where the **m**
(what's contained inside the **Maybe**)
is also a part of **Eq**.

http://learnyouahaskell.com/making-our-own-types-and-typeclasses

# Polymorphism in Haskell

Haskell's combination of

- purity
- higher order functions
- parameterized algebraic data types
- typeclasses

allows us to implement **polymorphism** on a much higher level

Types in Haskell

- don't have to think about types belonging to a big hierarchy of types
- think about what the types can act like
- and then connect them with the appropriate typeclasses

Example:

An Int can act like a lot of things

- like an equatable thing,
- like an ordered thing,
- like an enumerable thing, etc.

http://learnyouahaskell.com/functors-applicative-functors-and-monoids

# Open Typeclasses

**Typeclasses** are **open**:

- can define our own data type,
- can think about what it can act like
- can **connect** it with the **typeclasses** that define its behaviors.

Act
Behavior
Operation

the **type declaration** of a **function**
allows us to know a lot about a **function**

Define
Connect

can define **typeclasses** that define behavior
that is very general and abstract.

Example:
typeclasses that define operations for seeing if two things are equal
or comparing two things by some ordering.

- those are very **abstract** and elegant behaviors,
- those are not anything very **special**
  because these operations are most common

http://learnyouahaskell.com/functors-applicative-functors-and-monoids

# Functors, Applicatives, Monads

**functors**: you apply a function to a wrapped value
**applicatives**: you apply a wrapped function to a wrapped value
**monads**: you apply a function that returns a wrapped value, to a wrapped value

**functors**: using **fmap** or **<$>**
**applicatives**: using **<*>** or **liftA**
**monads**: using **>>=** or **liftM**

https://softwareengineering.stackexchange.com/questions/303472/what-is-the-purpose-of-wrapped-values-in-haskell

# Functors

Functors use the **fmap** or <$> functions

```
fmap or <$> Functor f => (a -> b) -> f a -> f b
```

This takes a function and applies to to the wrapped elements

```
fmap (\x -> x + 1) (Just 1)      -- Applies (+1) to the inner value, returning (Just 2)
fmap (\x -> x + 1) Nothing       -- Applies (+1) to an empty wrapper, returning Nothing

fmap (\x -> x + 1) [1, 2, 3]     -- Applies (+1) to all inner values, returning [2, 3, 4]
(\x -> x + 1) <$> [1, 2, 3]      -- Same as above
```

https://softwareengineering.stackexchange.com/questions/303472/what-is-the-purpose-of-wrapped-values-in-haskell

# Applicatives

Applicatives use the **<*>** function:

**<*> Applicative f => f (a -> b) -> f a -> f b**

This takes a wrapped function and applies it to the wrapped elements

```
(Just (\x -> x + 1)) <*> (Just 1)        -- Returns (Just 2)
(Just (\x -> x + 1)) <*> Nothing         -- Returns Nothing
Nothing <*> (Just 1)                     -- Returns Nothing
[(*2), (*4)] <*> [1, 2]                  -- Returns [2, 4, 4, 8]
```

https://softwareengineering.stackexchange.com/questions/303472/what-is-the-purpose-of-wrapped-values-in-haskell

# Monads – return

There are two relevant functions in the Monad typeclass:

```
return Monad m => a -> m a
(>>=) Monad m => m a -> (a -> m b) -> m b
```

The return function takes a raw, unwrapped value, and wraps it up in the desired monadic type.

```
makeJust :: a -> Maybe a
makeJust x = return x

let foo = makeJust 10          -- returns (Just 10)
```

https://softwareengineering.stackexchange.com/questions/303472/what-is-the-purpose-of-wrapped-values-in-haskell

# Monads – bind

The bind function lets you
temporarily unwrap the inner elements of a Monad
and pass them to a function that performs some action
that wraps them back UP in the same monad.

This can be used with the return function in trivial cases:

```
[1, 2, 3, 4] >>= (\x -> return (x + 1))      -- Returns [2, 3, 4, 5]
(Just 1) >>= (\x -> return (x + 1))          -- Returns (Just 2)
Nothing >>= (\x -> return (x + 1))           -- Returns Nothing
```

https://softwareengineering.stackexchange.com/questions/303472/what-is-the-purpose-of-wrapped-values-in-haskell

# Monads – a chain of functions

Where it gets interesting is when you have functions to chain together
that don't require you to use return.

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

You can call these functions like so:

```
getLine >>= (\x -> putStrLn x)        -- Gets a line from IO and prints it to the console
getLine >>= putStrLn                  -- With currying, this is the same as above
```

```
-- Reads a line from IO, converts to a number, adds 10 and prints it
getLine >>= (return . read) >>= (return . (+10)) >>= putStrLn . show
```

https://softwareengineering.stackexchange.com/questions/303472/what-is-the-purpose-of-wrapped-values-in-haskell

# Promises and Mediators

the concept of **promises** that's been gaining traction recently (particularly in Javascript).

A **promise** is an object that acts as a placeholder
for the result value of an asynchronous, background computation,
like fetching some data from a remote service.

a **mediator** between the asynchronous computation
and functions that need to operate on its anticipated result.

Act
Behavior
Operation

Define
**Connect**

https://softwareengineering.stackexchange.com/questions/303472/what-is-the-purpose-of-wrapped-values-in-haskell

# General Monad - MonadPlus

Haskell's **Control.Monad** module defines a typeclass, **MonadPlus**,
that enables abstract the common pattern eliminating **case** expressions.

```
class Monad m => MonadPlus m where
  mzero :: m a
  mplus :: m a -> m a -> m a
```

```
class (Monad m) => MonadPlus m where
```

```
instance MonadPlus [] where
  mzero = []
  Mplus = (++)
```

```
instance MonadPlus Maybe where
  mzero = Nothing

  Nothing `mplus` ys  = ys
  xs      `mplus` _ = xs
```

http://book.realworldhaskell.org/read/programming-with-monads.html

# General Monad - MonadPlus Laws

The class **MonadPlus** is used for monads that have a zero element and a plus operation:

```
class (Monad m) => MonadPlus m where
   mzero        :: m a
   mplus        :: m a -> m a -> m a
```

For lists, the zero value is [], the empty list.
The I/O monad has no zero element and is not a member of this class.

```
m >>= \x -> mzero    =    mzero
mzero >>= m          =    mzero
```

The zero element laws:

```
m `mplus` mplus      =    m
mplus `mplus` m      =    m
```

The laws governing the mplus operator

The mplus operator is ordinary list concatenation in the list monad.

http://book.realworldhaskell.org/read/programming-with-monads.html

# Functional Dependency (fundep)

```
class class Mult | a b -> c where
  (*) :: a -> b -> c
```

**c** is uniquely determined from **a** and **b**

.

Fundeps are not standard Haskell 98.
(Nor are multi-parameter type classes, for that matter.)
They are, however, supported at least in GHC and Hugs
and will almost certainly end up in Haskell'.

```
class class Mult where
  (*) :: a -> b -> c
```

https://wiki.haskell.org/Functional_dependencies

# Eq, Ord, Show classes

Since equality tests between values are frequently used

most of your own data types should be members of **Eq**.

Prelude classes

- **Eq**
- **Ord**
- **Show**

for the convenience, Haskell has a way to declare

such "obvious" **instance definitions**

using the keyword **deriving**.

https://en.wikibooks.org/wiki/Haskell/Classes_and_types

# Deriving instance example

```
data Foo = Foo {x :: Integer, str :: String}
    deriving (Eq, Ord, Show)
```

This makes **Foo** an **instance** of **Eq**

with an automatically generated definition of **==**

and also an **instance** of **Ord** and **Show**

```
data Foo = Foo {x :: Integer, str :: String}

instance Eq Foo where
  (Foo x1 str1) == (Foo x2 str2)
      = (x1 == x2) && (str1 == str2)
```

```
*Main> Foo 3 "orange" == Foo 6 "apple"
False
*Main> Foo 3 "orange" /= Foo 6 "apple"
True
```

https://en.wikibooks.org/wiki/Haskell/Classes_and_types

# Deriving instance pros and cons

The **types** of **elements** inside the **data** type

must also be **instances of the class** you are deriving.

Deriving instances

- synthesis of functions for a limited set of predefined classes
- against the general Haskell philosophy :

  "built in things are not special",
- induces compact codes
- often reduces errors in coding

  (an example: an instance of Eq such that x == y

  would not be equal to y == x would be flat out wrong).

https://en.wikibooks.org/wiki/Haskell/Classes_and_types

# Derivable Classes

**Eq**

Equality operators **==** and **/=**

**Ord**

Comparison operators **< <= > >=**; **min**, **max**, and **compare**.

**Enum**

For enumerations only. Allows the use of list syntax such as [Blue .. Green].

**Bounded**

Also for enumerations, but can also be used on types that have only one constructor.

Provides **minBound** and **maxBound** as the lowest and highest values that the type can take.

**Show**

Defines the function **show**, which converts a value into a string, and other related functions.

**Read**

Defines the function **read**, which parses a string into a value of the type,

and other related functions.

https://en.wikibooks.org/wiki/Haskell/Classes_and_types

## References

[1] ftp://ftp.geoinfo.tuwien.ac.at/navratil/HaskellTutorial.pdf
[2] https://www.umiacs.umd.edu/~hal/docs/daume02yaht.pdf