

LENSES

Functional Programming II

Lukas Pietzschmann

lukas.pietzschmann@uni-ulm.de

Institute of Software Engineering and
Programming Languages
Ulm University

May 13th, 2024



AGENDA

1. What

2. Why

3. How

3.1 A little Overview

3.2 Lens Laws

3.3 The actual Package

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4.2 Prisms

4.3 Traversals

4.4 Isos

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LEARNING OBJECTIVES

Why do we need lenses?

Understand where the idea of lenses come from, and how one could have come up with them.

How can I use them?

Know the basic functions and operators and know how to discover new ones.

What else is there?

Know of other lens-like abstractions, why we presumably need them, and how they differ.

~~WTF are those types?~~

~~Understand the ins and outs of the lens package and every type.~~

1. WHAT

1

WHAT ARE LENSES

type Lens s t a b = forall f. **Functor** f \Rightarrow (a \rightarrow f b) \rightarrow s \rightarrow f t

What is the purpose of a lens, according to the types above?

A: A package for creating visualizations

B: A tool for handling nested ADTs

C: A framework for building UIs

D: A package for simulating optical lenses

1

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1

WHAT ARE LENSES

type Lens s t a b = forall f. **Functor** f \Rightarrow (a \rightarrow f b) \rightarrow s \rightarrow f t

In Haskell, types provide a pretty good explanation of what a function does. Good luck deciphering lens types.

Roman Cheplyaka

A: A package for creating visualizations

B: A tool for handling nested ADTs

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1

WHAT ARE LENSES

Well, “lens” is also a package ... Here are some random functions and operators from that package:

view	_1	allOf
set	^.	anyOf
over	^?!	concatOf

We'll shortly see what they do and how we can use them.

2. WHY

2.1

WHY DO WE NEED THEM

Imagine you want to parse configuration files in Haskell. To model them, you come up with the following ADTs:

```
data File = File {  
    name      :: String,  
    entries  :: [Entry]  
}  
data Entry = Entry {  
    key       :: String,  
    value    :: Value  
}  
data Value = Value {  
    curr  :: String,  
    def   :: String  
}
```

2.2

WHY DO WE NEED THEM

Let's say we parsed a file into the following configuration:

```
config = File "~/.config/nvim/init.lua" [  
  Entry "expandtab" (Value "" "true"),  
  Entry "cmdheight" (Value "0" "1"),  
  Entry "textwidth" (Value "88" "")  
]
```

Cool, isn't it. Now we want to work with this representation.

2.3

WHY DO WE NEED THEM

```
getEntry :: String → File → Entry  
getEntry k = head . filter ((=) k . key) . entries
```

```
getCurrentValue :: Entry → String  
getCurrentValue = curr . value
```

```
setCurrentValue :: String → Entry → Entry  
setCurrentValue newValue entry = entry {  
    value = (value entry) {  
        curr = newValue  
    }  
}
```

Oof, this sucks. And it gets even worse the deeper the ADT gets!

```
data File = File {  
    name    :: String,  
    entries :: [Entry]  
}  
data Entry = Entry {  
    key    :: String,  
    value  :: Value  
}  
data Value = Value {  
    curr :: String,  
    def  :: String  
}
```

2.4

LET'S REINVENT THE LENS

Let's see, if we can improve this by adding some modifier functions:

```
data File = File {  
  name    :: String,  
  entries :: [Entry]  
}  
data Entry = Entry {  
  key    :: String,  
  value  :: Value  
}  
data Value = Value {  
  curr :: String,  
  def  :: String  
}
```

```
modifyCurrentValue :: (String → String) → Value → Value  
modifyCurrentValue f value = value {  
  curr = f $ curr value  
}
```

```
modifyEntriesValue :: (Value → Value) → Entry → Entry  
modifyEntriesValue f entry = entry {  
  value = f $ value entry  
}
```

```
modifyEntriesCurrentValue :: (String → String) → Entry → Entry  
modifyEntriesCurrentValue = modifyEntriesValue . modifyCurrentValue
```

2.5

LET'S REINVENT THE LENS

We can use our modify-functions to implement a setter:

```
setCurrentValue' :: String → Entry → Entry  
setCurrentValue' = modifyEntriesCurrentValue . const
```

The getter is still fine:

```
getCurrentValue' :: Entry → String  
getCurrentValue' = def . value
```

```
data File = File {  
  name    :: String,  
  entries :: [Entry]  
}  
data Entry = Entry {  
  key    :: String,  
  value  :: Value  
}  
data Value = Value {  
  curr :: String,  
  def  :: String  
}
```

2.6

LET'S REINVENT THE LENS

Now, we can build our lens abstraction:

```
data Lens s a = Lens {  
    get :: s → a,  
    modify :: (a → a) → s → s  
}
```

We need to reimplement the function composition:

```
compose :: Lens a b → Lens b c → Lens a c  
compose (Lens g m) (Lens g' m') = Lens {  
    get = g' . g,  
    modify = m . m'  
}
```

For easier handling, we also define `set` as a little helper:

```
set :: Lens s a → a → s → s  
set (Lens _ modify) = modify . const
```

2.7

LET'S REINVENT THE LENS

Finally, we can build lenses for our ADTs:

```
data File = File {  
  name    :: String,  
  entries :: [Entry]  
}  
data Entry = Entry {  
  key    :: String,  
  value  :: Value  
}  
data Value = Value {  
  curr :: String,  
  def  :: String  
}  
data Lens s a = Lens {  
  get  :: s → a,  
  modify ::  
    (a → a) → s → s  
}
```

```
currentValueL :: Lens Value String
```

```
currentValueL = Lens {  
  get = curr,  
  modify = \f value → value { curr = f $ curr value }  
}
```

```
entryValueL :: Lens Entry Value
```

```
entryValueL = Lens {  
  get = value,  
  modify = \f entry → entry { value = f $ value entry }  
}
```

```
entryCurrentValueL :: Lens Entry String
```

```
entryCurrentValueL = entryValueL `compose` currentValueL
```


2.8

LET'S REINVENT THE LENS

Now we only have to plug our lens into `set`, `get`, or `modify`:

```
setCurrentValue'' :: String → Entry → Entry  
setCurrentValue'' = set entryCurrentValueL
```

```
getCurrentValue'' :: Entry → String  
getCurrentValue'' = get entryCurrentValueL
```

2.9

LET'S REINVENT THE LENS

Puh, that was kinda complicated. But again, think of how much less code you have to write:

```
let f = _foo v
    b = _bar f
    z = _baz b in
v { _foo = f {
      _bar = b {
        _baz = z + 1
      } } }
```

versus

```
v & foo . bar . baz +~ 1
```

We can now think “How can I traverse through this?” instead of “How do I un- and repack all of this?”.

LET'S REINVENT THE LENS

Our solution looks more flexible than what we had before. But there are still some problems:

- Still feels a bit clunky and boilerplate-heavy
- We always have to create **Lens** values
- No support for polymorphic updates

It's definitely not impossible to overcome these limitations, but we'll skip this for now.

Polymorphic Update

```
data Pair a b = Pair {e1 :: a, e2 :: b}
```

```
p :: Pair Int String
```

```
p = Pair 420 "is fun"
```

```
p { e1 = "FP" } ▶ Pair { e1 = "FP", e2 = "is fun" }
```

▶ Notice that the type has changed from `Pair Int String` to `Pair String String`. This is what we call *polymorphic update*.

Lenses are:


- A way to *focus* on a part of a data structure

Or more precisely:

- Just another abstraction
- Functional references
- Getters and Setters
- Highly composable and flexible
 - “The Power is in the Dot” Edward Kmett

- Luke Palmer creates a pattern he calls *Accessors* to ease stateful programming in Haskell [Pal07b]. He uses C's preprocessor to generate `readVal` and `writeVal` functions.^{⟨1⟩}
- Palmer generalizes his *Accessors* into something more like today's lenses. [Pal07a]
- Twan van Laarhoven comes up with a novel way to express lenses using the **Functor** class [Laa09]. We call them *van Laarhoven lenses*.

^{⟨1⟩}In another blog post he then swaps out the preprocessor in favour of Template Haskell.

- 
- Russell O'Connor realises van Laarhoven lenses have always supported polymorphic updates. [OCo12]
 - Edward Kmett realises that you can put laws on the notion of polymorphic updates. [Kme12]
 - Kmett pushed the first commit to the lens repository on GitHub

3. How

3.1

A LITTLE OVERVIEW

Lenses basically provide two kinds of operations:

- `view :: Lens' s a → s → a`
- `set :: Lens' s a → a → s → s`

To use them, we need the actual lens. It determines what part of the structure we want to focus on.

- `_1 :: Lens' (a,b) a`
- `_2 :: Lens' (a,b) b`

With all that in place, we can now combine the operation with a lens (or a combination of lenses) and data:

- `set _2 "cool" ("FP is", "") ▶ ("FP is", "cool")`
- `view _1 ("hi", "there") ▶ "hi"`

Like with functors, applicatives, and monads, lenses *should* follow some rules:

1. Get-Put
2. Put-Get



Put-Put

We'll look at them in a bit more detail.

If you modify something by changing its subpart to exactly what it was before, nothing should happen.

```
set entryValueL (get entryValueL entry) entry = entry
```

- ▶ The lens should not modify the value or structure by itself.

If you modify something by inserting a particular subpart and then view the result, you'll get back exactly that subpart.

$$\text{get } \text{entryValueL } (\text{set } \text{entryValueL } v \text{ entry}) = v$$

- ▶ Setting values should be independent of any previous state.

If you modify something by inserting a particular subpart **a**, and then modify it again inserting a different subpart **b**, it's exactly as if you only did the second insertion.

$$\text{set } \text{entryValueL } v2 \text{ (set } \text{entryValueL } v1 \text{ entry)} = \text{set } \leftarrow \text{entryValueL } v2 \text{ entry} = 1$$

- ▶ Previous updates should not leave any traces.

DO I REALLY HAVE TO FOLLOW THEM?

- Yes, you should! Otherwise your lenses might behave weird.
- And weird unpredictable things are for OOP 😊
- But, we can get around them
- In fact, we can get around the whole process of creating a lens by hand
- You remember Template-Haskell, do you?

3.2.6

DO I REALLY HAVE TO FOLLOW THEM?

```
{-# LANGUAGE TemplateHaskell #-}
```

```
import Control.Lens
```

```
data File  = File  {_name  :: String, _entries :: [Entry]}
```

```
data Entry = Entry {_key   :: String, _value   :: Value  }
```

```
data Value = Value {_curr  :: String, _def     :: String }
```

```
makeLenses ''File
```

```
makeLenses ''Entry
```

```
makeLenses ''Value
```

3.3.1

THE LENS PACKAGE

- Until now, we have only used `view` and `set`
- But there are actually a lot more functions and operators
- I mean a looooooooooooooooooooooot; easily over 100
- Let's try to find a pattern in their names

3.3.2 THE LENS PACKAGE

Operators beginning with `^` behave like `view` functions:

```
Value "c" "d" ^. def ▶ "d"  
(1,2) ^.. both ▶ [1,2]  
Right 42 ^? _Left ▶ Nothing
```

Operators ending in `~` behave like `set` functions:

```
(_2 .~ 3) (0, 0) ▶ (0,3)  
(_2 +~ 3) (0, 39) ▶ (0,42)  
(_1 %~ (+1)) (3,2) ▶ (4,2)
```

Writing `lens .~ value $ adt` every time is not very nice. But as always, there's a special operator to our rescue: `& :: a → (a → b) → b`.

3.3.3

THE LENS PACKAGE

With this knowledge aquired, we can finally write concise Haskell-code:

`(6, 2) & both *~ 7 ▶ (42, 14)`

```
lens = entries . _last . value . curr
val = config ^?! lens ▶ "88"
config & lens .~ val ++ "0" ▶ curr = "880" inside config
over lens (++ "0") config ▶ curr = "880" inside config
```

`(0, "upd.") & _1 .~ "poly." ▶ ("poly.", "upd.")`

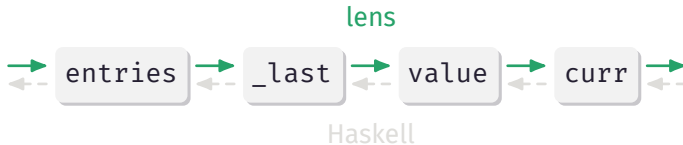
```
config = File "~/config/nvim/init.lua" [
  Entry "expandtab" (Value "" "true"),
  Entry "cmdheight" (Value "0" "1"),
  Entry "textwidth" (Value "88" "")
]
```

3.3.4

THE LENS PACKAGE

Gotchas

You might have noticed that lenses compose backwards:



This makes it weird for FP-enjoyers, but intuitive for OOP-weirdos. The same applies for all kinds of operators:

lens	Haskell
5 & (+1)	(+1) \$ 5
Just 5 <&> (+1)	(+1) <\$> (Just 5)

You might have noticed that lenses compose backwards:

lens

Backward composition of lenses. It's a minor issue, and I wouldn't mention it if it wasn't a great demonstration of how lens goes against the conventions of Haskell.

Roman Cheplyaka

lens	Haskell
5 & (+1)	(+1) \$ 5
Just 5 <&> (+1)	(+1) <\$> (Just 5)

Writing a *Getter* is really easy. We can simply promote any *function* or *value* to a Getter.

- `to` builds a Getter from any function

```
("Hello", "FP2") ^. to snd ▶ "FP2"
```

- `like` always returns a constant value

```
("Hello", "FP2") ^. like 42 ▶ 42
```

Writing a *Setter* is only slightly more complicated, as we don't set the value directly, but apply a function on the focused part.

- `setting` receives a function, that applies another function to the correct value inside a structure

```
(4,1) & setting (\f (x,y) → (x,f y)) .~ 2 ▶ (4,2)
```

- `sets` is in theory a bit more flexible, but that's out of scope for today

```
(4,1) & sets (\f (x,y) → (x,f y)) .~ 2 ▶ (4,2)
```

Having a separate Getter and Setter is not always desirable. Now, we want to create our own lens that we can use as both Getter and Setter. This time, `makeLenses` doesn't count!

- We can use `lens` to combine a viewing and setting function


```
g = snd
s = \(a,_) b → (a,b)
_2 = lens g s
```

- You can also simply write a custom function with the type
`l :: forall f. Functor f ⇒ (a → f b) → s → f t`
 that satisfies all three lens laws. Good luck! We'll try it anyway.

3.3.8 THE LENS PACKAGE

How lens works [Rom19]

```
type Lens s t a b = forall f. Functor f => (a -> f b) -> s -> f t  
type Lens' s a = Lens s s a a
```

 The inner type we're interested in
The type of the whole structure

```
lens :: Functor f => (s -> a) -> (s -> a -> s) -> (a -> f a) -> s -> f s  
lens get set f s = ...
```

- We need to get from `s -> a` and `s -> a -> s` to `f s`
- We can get an `a` from our getter: `get s`
- With `a` and `f` we can make an `f a`: `f $ get s`


3.3.9 THE LENS PACKAGE

How lens works [Rom19]

```
lens :: Functor f => (s -> a) -> (s -> a -> s) -> (a -> f a) -> s -> f s
lens get set f s = set s <$> f (get s)
```

- We need to get from `s -> a` and `s -> a -> s` to `f s`
- We can get an `a` from our getter: `get s`
- With `a` and `f` we can make an `f a`: `f $ get s`
- Now, to get an `f s`, we can simply use

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


`set s` `f $ get s`

4. MORE GOODIES

4.1

VIRTUAL LENSES

A Getter does not always have to be backed by an actual structure. Theoretically, it can return *anything*:

```
get virtualProp(): number {  
    return 42  
}
```

We can easily achieve this behavior with lenses, too:

```
virtualProp = like 42  
(0,0) ^. virtualProp ▶ 42
```

4.2.1

PRISMS

So far, we only looked at product types. But what about sum types?
Prisms to the rescue!

```
data CanteenMeal = MainCourse String CanteenMeal  
                  | Dessert String
```

```
meal1 = MainCourse "Sattmacher" (Dessert "Pudding")  
meal2 = Dessert "Yogurt"
```

```
meal1 ^? _MainCourse . _2 . _Dessert ▶ Just "Pudding"  
meal2 ^? _MainCourse . _2 . _Dessert ▶ Nothing
```

```
meal1 & _MainCourse . _2 . _Dessert .~ "Yogurt"  
▶ Dessert "Yogurt" inside meal1
```

- We already used a prism: remember `_last` ?
- We can usually use them like a normal lens (there's just a little **Maybe** in the way)

```
case meal1 of
  MainCourse _ (Dessert d) → MainCourse {
    dessert = Dessert "Yogurt" }
  _ → meal1
```

—versus—

```
meal1 & _MainCourse . _2 . _Dessert .~ "Yogurt"
```

4.3.1

TRAVERSALS

Wouldn't it be nice to have a lens that focuses on a specific element of a traversable container? Let's start with every element:

```
["Hello", "there"] ^.. traverse ▶ "Hellothere"
```

Huh?! What's that? I would've expected ["Hello", "there"]. When viewing the result of `traverse`, it gets shoved through `mappend` first. That's why you typically `^..`.

```
[1..5] ^.. traverse ▶ [1,2,3,4,5]
```

```
[(1,2),(3,4)] ^.. traverse . _2 ▶ [2,4]
```

```
[1..5] & traverse +~ 1 ▶ [2,3,4,5,6]
```

4.3.2

TRAVERSALS

As promised, here's how we can focus on a specific element of a traversable:

```
[1..5] ^.. ix 1 ▶ [2]  
[1..5] ^.. ix 5 ▶ []
```

Returning an empty list on failure does not seem very nice. Let's use the prism-view-operator to get a **Maybe**:

```
[1..5] ^? ix 1 ▶ Just 2  
[1..5] ^? ix 5 ▶ Nothing
```

Here's a very short summary:

- An `Iso` is a connection between two types that are equivalent in every way
- Isos should follow the following laws:
 `forward . backward = id`
 `backward . forward = id`
- We can write our own `Iso` by providing a forward and backward mapping

4.4.2

Isos

```
maybeToEither = maybe (Left ()) Right  
eitherToMaybe = either (const Nothing) Just
```

```
someIso :: Iso' (Maybe a) (Either () a)  
someIso = iso maybeToEither eitherToMaybe
```

```
Just "hi" ^. someIso ▶ Right "hi"  
Left "ho" ^. from someIso ▶ Nothing
```

5. SUMMARY

Traversals

- Focus on multiple parts (also zero) of a data structure
- `^..` returns list of the focused parts



Lens

- Focus on a single part of a data structure
- `^.` returns the focused part directly

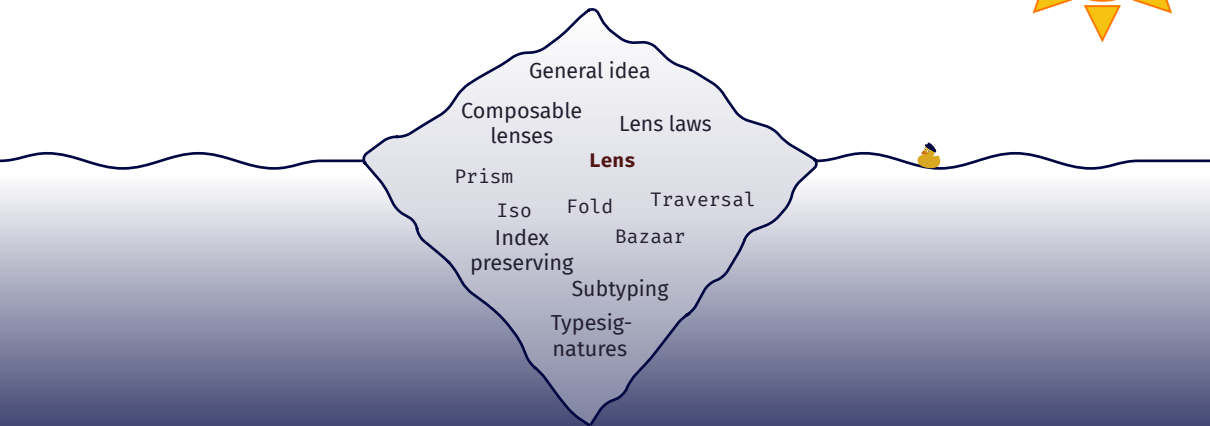
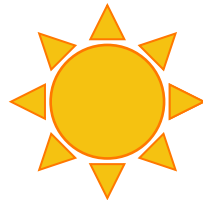


Prism

- Focus on a single part that may not exist
- `^?` returns the focused part inside a **Maybe**

5.2

AND SO MUCH MORE



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Lukas Pietzschmann

Ulm, May 13th, 2024

lukas.pietzschmann@uni-ulm.de