Farewell

Functional Programming 2018/19

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[Faculty of Science
Information and Computing
Sciences]

Final menu

- Presentations about libraries and structures
- Q&A session
  - Ask me more in the break
- Closing remarks

Participation on research

We would like to gather your DomJudge assignments to perform research on programming education

- You do not need to do anything else than allowing us to look at the assignments
- Assignments are anonymized before anybody looks at it

Participation is **completely optional**

- During the exam I will give you a *formulier toestemming*, which you need to sign if you agree to help us

Presentations

- Parallelism with `monad-par`
- Semirings

Q&A session

Things with symbols: $, <$>, <*>, <|>, >>=

```
($) :: (a -> b) -> a -> b
```

Rule 1: writing $ is like writing a parentheses until the end of the expression

Rule 2: nested uses of $ create nested parentheses

```
f lst = map (+1) (filter even (map read lst))
-- Too many parentheses!
f lst = map (+1) $ filter even $ map read lst
-- In this case, better use composition
f     = map (+1) . filter even . map read
```

Things with symbols: <$>, <*>

```
-- From Functor and Applicative
fmap  ::    (a -> b) -> f a -> f b
(<$>) ::    (a -> b) -> f a -> f b
(<*>) :: f (a -> b) -> f a -> f b
```

If we have a bunch of arguments inside a context/functor/monad

```
x :: m a, y :: m b, z :: m c ...
```

and we want to apply a *pure* function

```
f :: a -> b -> ... -> r
```

we need to *lift* the function using a combination of them

```
f <$> x <*> y <*> z <*> ... :: m r
```

Things with symbols: <$>, <*>

```
mapM :: (a -> m b) -> [a] -> m [b]
mapM _ []     = return []
mapM f (x:xs) = (:) <$> f x <*> mapM f xs
                --        ---     ---------
                --        m b       m [b]
                --
                -- (:) :: b -> [b] -> [b]
```

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Things with symbols: `<|>`

`<|>` or `mplus` model the idea of *trying different possibilities*

- In the case of `[]`, concatenate all solutions

```
(<|>) = (++)
```

- In the case of `Maybe`, get the first one which doesn't fail
  - That is, obtain the first `Just`

```
Just x  <|> _ = Just x
Nothing <|> y = y
```

Things with symbols: >>=

(>>=) is the *bind* operation of a monad

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

- If you give me an a inside a monad
- And tell me how to continue if I "unwrap" the a for you
- Then I can apply the continuation to the value for you

```
do x <- thing    ===    thing >>= \x ->
   continue                  continue
```

Monoids

Monoid is the generalization of the properties exhibited by $+$, $\times$, list concatenation, $\vee$, $\wedge$, ...

- A binary operation `mappend` or `(<>)`
- Which is associative

```
(x <> y) <> z  ===  x <> (y <> z)
```

- And has a neutral element `mempty`

```
x <> mempty = x
mempty <> x = x
```

  - 0 for $+$, 1 for $\times$, `[]` for `(++)`, `False` for $\vee$, `True` for $\wedge$

Monoids and monads

Are monoids and monads related in any way?

Yes, they are deeply connected.

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But we don't have time to explain how now.

You need to look at *category theory*, a branch of mathematics (and computer science).

```
return :: a -> m a          -- is like `mempty`
join   :: m (m a) -> m a    -- is like `mappend`
```

Lecture 10, exercise 1

Finish the proof of `reverse . reverse = id`

We need the following lemmas:

```
-- Distributivity of (++) over reverse
reverse (xs ++ ys) = reverse ys ++ reverse xs
-- Reverse on singleton lists
reverse [x]        = [x]
```

The second one is simple equational reasoning.

Lecture 10, exercise 1

```
reverse (xs ++ ys) = reverse ys ++ reverse xs
```

By induction on `xs`:

Lecture 10, exercise 1

```
reverse (xs ++ ys) = reverse ys ++ reverse xs
```

By induction on `xs`:

- Case `xs = []`

```
reverse ([] ++ ys)
= {- defn of (++) -}
reverse ys

reverse ys ++ reverse []
= {- defn of reverse -}
reverse ys ++ []
= {- WE ARE STUCK AGAIN!!! -}
```

We need to prove a separate lemma: `ts ++ [] = ts`

Lecture 10, exercise 1

- Case `xs = z:zs`
  - IH: `reverse (zs++ys) = reverse ys ++ reverse zs`

```
reverse ((z:zs) ++ ys)
= {- defn of (++) -}
reverse (z : (zs ++ ys))
= {- defn of reverse -}
reverse (zs ++ ys) ++ [z]
```

```
reverse ys ++ reverse (z:zs)
= {- defn of reverse -}
reverse ys ++ (reverse zs ++ [z])
= {- associativity of (++) -}
(reverse ys ++ reverse zs) ++ [z]
= {- IH -}
reverse (zs ++ ys) ++ [z]
```

Lecture 10, exercise 1

```
ts ++ [] = ts
```

By induction on `ts`:

Lecture 10, exercise 1

`ts ++ [] = ts`

By induction on `ts`:

- Case `ts = []`:

```
[] ++ []
= {- defn of (++) -}
[]
```

- Case `ts = p:ps`
  - IH: `ps ++ [] = ps`

```
(p:ps) ++ []
= {- defn of (++) -}
p : (ps ++ [])
= {- IH -}
p : ps
```

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Lectures 12/13, exercise 2

Define a function:

```
tuple :: Monad m => m a -> m b -> m (a, b)
```

using explicit (>>=), do-notation and applicative operators.

Lectures 12/13, exercise 2

```
tuple :: Monad m => m a -> m b -> m (a, b)
```

Using do-notation

```
tuple x y = do x' <- x
               y' <- y
               return (x', y')
```

Lectures 12/13, exercise 2

```
tuple :: Monad m => m a -> m b -> m (a, b)
```

Using do-notation

```
tuple x y = do x' <- x
               y' <- y
               return (x', y')
```

Using (>>=)

```
tuple x y = x >>= \x' ->
            y >>= \y' ->
            return (x', y')
```

Lectures 12/13, exercise 2

```
tuple :: Monad m => m a -> m b -> m (a, b)
```

Using applicative operators

We need to find a function `a -> b -> (a, b)` and lift it

```
pair x y = (x, y)          -- define it yourself
(,) :: a -> b -> (a, b)    -- constructor for pairs
```

To lift it, use a combination of <$> and <*>

```
tuple x y = (,) <$> x <*> y
```

Functor-applicative-monad hierarchy

Functor which is not applicatives?

Applicative which is not monad?

Functor-applicative-monad hierarchy

Functor which is not applicatives?

Applicative which is not monad?

Thanks, StackOverflow!

Functor which is not applicative

```haskell
data Pair a b = Pair a b  -- like a tuple

instance Functor (Pair a) where
  fmap f (Pair x y) = Pair x (f y)

instance Applicative (Pair a) where
  pure y = ({- what here?? -}, y)

-- You can fix it, but not for every "a"
instance Monoid a => Applicative (Pair a) where
  pure y = (mempty, y)
  (<*>)  = ...
```

Applicative which is not monad

```haskell
data ZipList a = ZL [a]

instance Applicative ZipList where
  pure x = ZL (repeat x)  -- infinite list of "x"s
  ZL fs <*> ZL xs = ZL (zipWith (\f x -> f x) fs xs)
  -- This obbeys all the laws!

-- You can use the "Monad" from lists
-- But then the following does not hold:
f <*> x  ===  do f' <- f
                 x' <- x
                 return (f' x')
```

Closing remarks

Goals for the course

- Learn the **functional** paradigm and **style**
  - You can apply FP techniques everywhere!
  - Every (serious) language has H-O functions
- Experience a **strong static type system**
- **Reason** about programs
  - Correct software is our ultimate goal

Courses about or using FP at UU

- *Functioneel Programmeren*
- Talen en Compilers: year 3, period 2
  - Haskell applied to compiler writing
- Software Testing en Verificatie: year 3, period 4
  - More reasoning about programs

If you want to know more

More Haskell?

- *Pearls of Functional Algorithm Design*, by Bird
  - Puzzles with a nice functional solution
- *the fun of programming*, by Gibbons and de Moor
  - Even more niceties in a functional style
- *Haskell from First Principles*, by Allen and Moronuki
  - Covers additional topics, like transformers
- *Beginning Haskell*, by, ehmmm… me
  - Which happens to be an intermediate book

If you want to know more

Learn other functional languages

- *F#* for the .NET platform
  - *Beginning F# 4.0* and *Expert F# 4.0*
- *Kotlin* and *Scala* for the Java platform
  - *Functional Kotlin*
  - *Functional Programming in Scala*
- *Swift* for iOS development
  - *Functional Swift*

If you want to know more

Or just drop by my office

Success with your exams!