Engaging, Large-Scale Functional Programming Education in Physical and Virtual Space

Kevin Kappelmann, Jonas Rädle, Lukas Stevens

July 28, 2022

Technical University of Munich

lambda DAλS

28–29 JULY 2022
KRAKÓW | POLAND

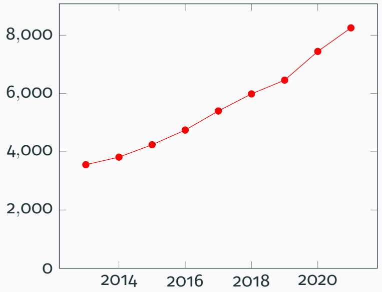
Challenges

Soaring Enrolments

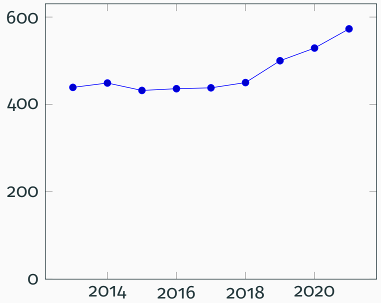
1. Number of Computer Science students exploded

Soaring Enrolments

Example: Computer Science at TU Munich



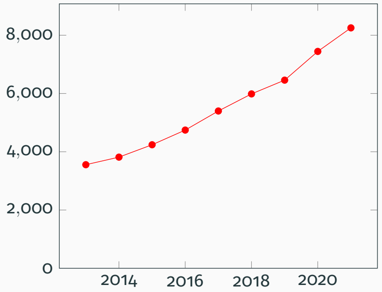
Number of CS students
(132% increase)



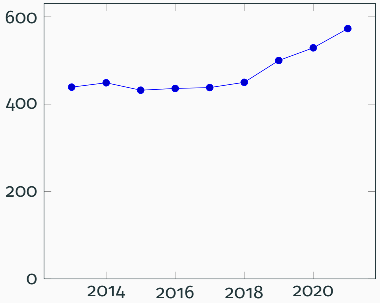
Number of CS academic staff
(31% increase)

Soaring Enrolments

Example: Computer Science at TU Munich



Number of CS students
(132% increase)



Number of CS academic staff
(31% increase)

1000+ students per course are the new normal

The Pandemic

2. Radical transition to online classes

The Pandemic

How can we go from here...

The Pandemic

to here...

The Pandemic

without ending up here?

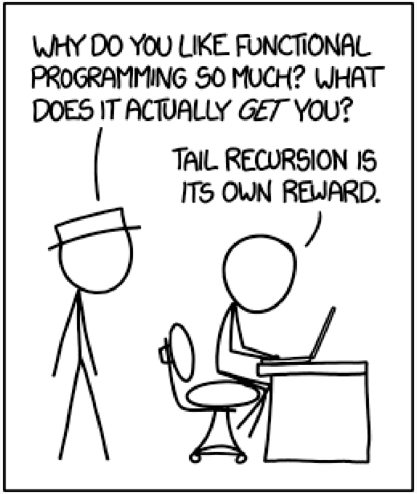
Usefulness of Functional Programming

3. Students question the usefulness of functional languages beyond academia

Usefulness of Functional Programming

CODE WRITTEN IN HASKELL IS GUARANTEED TO HAVE NO SIDE EFFECTS.
...BECAUSE NO ONE WILL EVER RUN IT?

xkcd.com/1312


WHY DO YOU LIKE FUNCTIONAL PROGRAMMING SO MUCH? WHAT DOES IT ACTUALLY *GET* YOU?
TAIL RECURSION IS ITS OWN REWARD.

xkcd.com/1270

There is hope!

- We managed to cope with all these challenges

There is hope!

- We managed to cope with all these challenges
- We share our insights, tools, and exercises for other educators

You can find our resources on:

`github.com/kappelmann/engaging-large-scale-functional-programming`

There is hope!

- We managed to cope with all these challenges
- We share our insights, tools, and exercises for other educators

You can find our resources on:
github.com/kappelmann/engaging-large-scale-functional-programming

Note: We used Haskell, but most ideas apply to any functional programming course

Practical Part

Practical Part

Engagement Mechanisms

Instant Feedback

Feedback must come fast!

Instant Feedback

Feedback must come fast!

- Automated testing and feedback

Instant Feedback

Feedback must come fast!

- Automated testing and feedback
    - *ArTEMiS* runs tests, manages scores, offers exam mode,...

Instant Feedback

Feedback must come fast!

- Automated testing and feedback
  - *ArTEMiS* runs tests, manages scores, offers exam mode,...
  - *Tasty* combines QuickCheck, SmallCheck, and HUnit tests

Instant Feedback

Feedback must come fast!

- Automated testing and feedback
    - *ArTEMiS* runs tests, manages scores, offers exam mode,...
    - *Tasty* combines QuickCheck, SmallCheck, and HUnit tests
    - *Check Your Proof* for automated proof checking

Instant Feedback

```
Lemma: xs ++ (ys ++ zs) .=. (xs ++ ys) ++ zs
Proof by induction on List xs
Case []
  To show: [] ++ (ys ++ zs) .=. ([] ++ ys) ++ zs
  Proof
                   [] ++ (ys ++ zs)
    (by def ++) .=. ys ++ zs
    (by def ++) .=. ([] ++ ys) ++ zs
  QED
Case x : xs
  To show: (x : xs) ++ (ys ++ zs) .=. ((x : xs) ++ ys) ++ zs
  IH: xs ++ (ys ++ zs) .=. (xs ++ ys) ++ zs
  Proof
  ...
```

Instant Feedback

Feedback must come fast!

- Automated testing and feedback
    - *ArTEMiS* runs tests, manages scores, offers exam mode,...
    - *Tasty* combines QuickCheck, SmallCheck, and HUnit tests
    - *Check Your Proof* for automated proof checking
- Manual reviews turned out to be inefficient...

Instant Feedback

Feedback must come fast!

- Automated testing and feedback
    - *ArTEMiS* runs tests, manages scores, offers exam mode,...
    - *Tasty* combines QuickCheck, SmallCheck, and HUnit tests
    - *Check Your Proof* for automated proof checking
- Manual reviews turned out to be inefficient...
    - *HLint* offers feedback more directly

Workshops With Industry Partners

Functional programming is practical!

Workshops With Industry Partners

Functional programming is practical!

- In 2020, we hosted 3 workshops with industry partners

Workshops With Industry Partners

Functional programming is practical!

- In 2020, we hosted 3 workshops with industry partners
    1. Design patterns for functional programs
    2. Networking and advanced IO
    3. User interfaces and functional reactive programming

Workshops With Industry Partners

Functional programming is practical!

- In 2020, we hosted 3 workshops with industry partners
    1. Design patterns for functional programs
    2. Networking and advanced IO
    3. User interfaces and functional reactive programming
- Great success: 120 registrations for 105 spots

Workshops With Industry Partners

Functional programming is practical!

- In 2020, we hosted 3 workshops with industry partners
    1. Design patterns for functional programs
    2. Networking and advanced IO
    3. User interfaces and functional reactive programming
- Great success: 120 registrations for 105 spots
- In some cases, workshop extended for multiple hours

Workshops With Industry Partners

Functional programming is practical!

- In 2020, we hosted 3 workshops with industry partners
  1. Design patterns for functional programs
  2. Networking and advanced IO
  3. User interfaces and functional reactive programming
- Great success: 120 registrations for 105 spots
- In some cases, workshop extended for multiple hours

Maybe you want to offer a workshop as well? :)

Competitions

Offer challenges to go beyond the syllabus!

Competitions

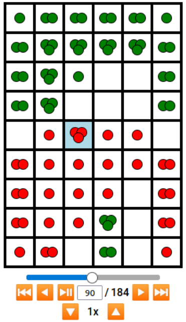
Offer challenges to go beyond the syllabus!

- Diverse, weekly competition exercises

Competitions

Tobias Markus vs. Severin Schmidmeier

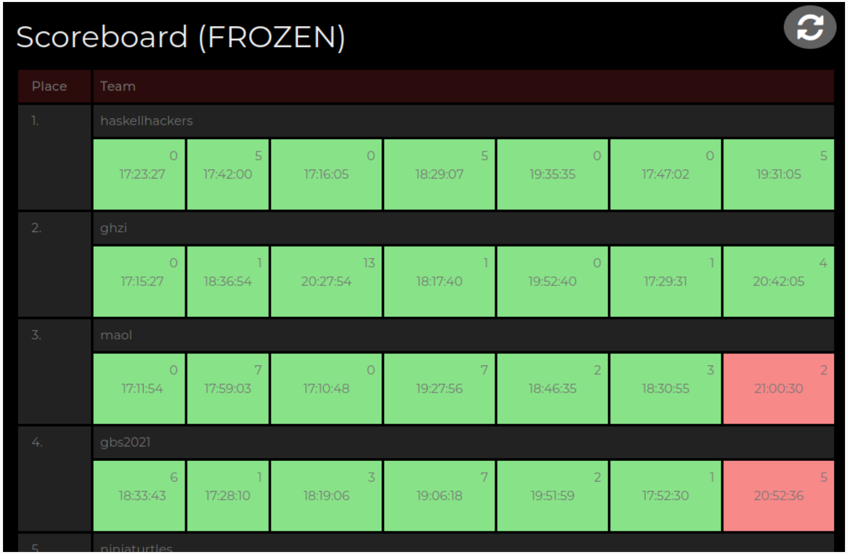
Winner: ● Severin Schmidmeier



Stats

Statistic	● Tobias Markus	● Severin Schmidmeier
Moves made	49	49
Orbs captured	40	89
Capture/loss ratio	0.4494	2.2250

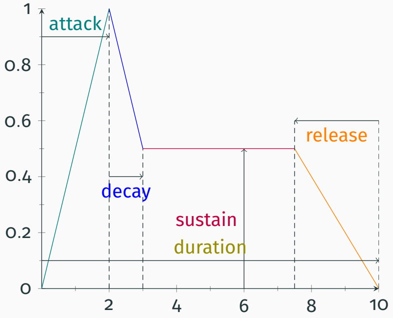
Competitions

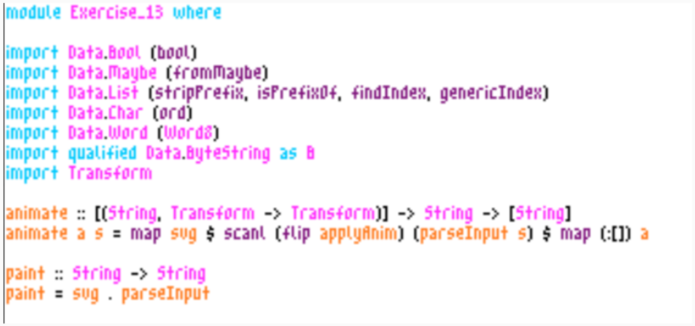


Scoreboard (FROZEN)

Place	Team						
1.	haskellhackers						
	🟩 0 17:23:27	🟩 5 17:42:00	🟩 0 17:16:05	🟩 5 18:29:07	🟩 0 19:35:35	🟩 0 17:47:02	🟩 5 19:31:05
2.	ghzi						
	🟩 0 17:15:27	🟩 1 18:36:54	🟩 13 20:27:54	🟩 1 18:17:40	🟩 0 19:52:40	🟩 1 17:29:31	🟩 4 20:42:05
3.	maol						
	🟩 0 17:11:54	🟩 7 17:59:03	🟩 0 17:10:48	🟩 7 19:27:56	🟩 2 18:46:35	🟩 3 18:30:55	🟥 2 21:00:30
4.	gbs2021						
	🟩 6 18:33:43	🟩 1 17:28:10	🟩 3 18:19:06	🟩 7 19:06:18	🟩 2 19:51:59	🟩 1 17:52:30	🟥 5 20:52:36
5.	ninjaturtles						

Competitions





```haskell
module Exercise_13 where

import Data.Bool (bool)
import Data.Maybe (fromMaybe)
import Data.List (stripPrefix, isPrefixOf, findIndex, genericIndex)
import Data.Char (ord)
import Data.Word (Word8)
import qualified Data.ByteString as B
import Transform

animate :: [(String, Transform -> Transform)] -> String -> [String]
animate a s = map svg $ scanl (flip applyAnim) (parseInput s) $ map (:[]) a

paint :: String -> String
paint = svg . parseInput
```

Competitions

Offer challenges to go beyond the syllabus!

- Diverse, weekly competition exercises
- Works extremely well to motivate talented students.

Competitions

Offer challenges to go beyond the syllabus!

- Diverse, weekly competition exercises
- Works extremely well to motivate talented students.
- Awards for top 30 students

Competitions

Offer challenges to go beyond the syllabus!

- Diverse, weekly competition exercises
- Works extremely well to motivate talented students.
- Awards for top 30 students

Maybe you want to offer awards or competitions as well? :)

I/O Mocking

Motivation

- Submissions (primarily) tested with QuickCheck

Motivation

- Submissions (primarily) tested with QuickCheck
- I/O is an important part of the syllabus

Motivation

- Submissions (primarily) tested with QuickCheck
- I/O is an important part of the syllabus

So how do we test I/O in Haskell?

The Standard Way

```haskell
copyFile :: FilePath -> FilePath -> IO ()
copyFile = _
```

The Standard Way

```haskell
copyFile :: MonadFileSystem m =>
            FilePath -> FilePath -> m ()
copyFile = _
```

The Standard Way

```haskell
import qualified Prelude
import Prelude hiding (readFile, writeFile)

class Monad m => MonadFileSystem m where
  readFile :: FilePath -> m String
  writeFile :: FilePath -> String -> m ()


copyFile :: MonadFileSystem m =>
            FilePath -> FilePath -> m ()
copyFile = _
```

The Standard Way

```haskell
import qualified Prelude
import Prelude hiding (readFile, writeFile)

class Monad m => MonadFileSystem m where
  readFile :: FilePath -> m String
  writeFile :: FilePath -> String -> m ()


copyFile :: MonadFileSystem m =>
            FilePath -> FilePath -> m ()
copyFile source target = do
  content <- readFile source
  writeFile target content
```

Multiple Instantiations

```
instance MonadFileSystem IO where
  readFile = Prelude.readFile
  writeFile = Prelude.readFile
```

Multiple Instantiations

```haskell
instance MonadFileSystem IO where
  readFile = Prelude.readFile
  writeFile = Prelude.readFile

data MockFileSystem =
  MockFileSystem (Map FilePath String)
instance MonadFileSystem (State MockFileSystem) where
  readFile = _
  writeFile = _
```

The Problem

What is the problem with

```haskell
copyFile :: MonadFileSystem m =>
            FilePath -> FilePath -> m ()
copyFile = _
```

The Problem

What is the problem with

```haskell
copyFile :: MonadFileSystem m =>
            FilePath -> FilePath -> m ()
copyFile = _
```

Lack of transparency!

The Solution

Delay mocking to the compliation stage

The Solution

Delay mocking to the compliation stage

by replacing the *IO* module with a mixin.

The Mixin

```haskell
data RealWord = RealWord {
  workDir :: FilePath,
  files :: Map File Text,
  handles :: Map Handle HandleData,
  user :: IO (),
  ...
}
```

The Mixin

```haskell
data RealWord = RealWord {
  workDir :: FilePath,
  files :: Map File Text,
  handles :: Map Handle HandleData,
  user :: IO (),
  ...
}

newtype IO a = IO { unwrapIO ::
  ExceptT IOException (PauseT (State RealWorld)) a }
```

The Pause Monad

```haskell
class Monad m => MonadPause m where
  pause :: m ()
  stepPauseT :: m a -> m (Either (m a) a)
```

An Example Interaction

Student submission

```haskell
main = do
  x <- getLine
  putStrLn $ "Hi " ++ x
```

Mock user

```haskell
user s = do
  hPutStrLn stdin s
  out <- hGetLine stdout
  when (out /= _)
       (fail $ _)
```

An Example Interaction

Student submission

```
main = do
  x <- getLine
  putStrLn $ "Hi " ++ x
```

Mock user

```
user s = do
  hPutStrLn stdin s
  out <- hGetLine stdout
  when (out /= _)
       (fail $ _)
```

An Example Interaction

```
Student submission
main = do
  x <- getLine
  putStrLn $ "Hi " ++ x
```

```
Mock user
user s = do
  hPutStrLn stdin s
  out <- hGetLine stdout
  when (out /= _)
       (fail $ _)
```

An Example Interaction

Student submission

```
main = do
  x <- getLine
  putStrLn $ "Hi " ++ x
```

Mock user

```
user s = do
  hPutStrLn stdin s
  out <- hGetLine stdout
  when (out /= _)
       (fail $ _)
```

An Example Interaction

```
Student submission
main = do
  x <- getLine
  putStrLn $ "Hi " ++ x
```

```
Mock user
user s = do
  hPutStrLn stdin s
  out <- hGetLine stdout
  when (out /= _)
       (fail $ _)
```

An Example Interaction

Student submission

```
main = do
  x <- getLine
  putStrLn $ "Hi " ++ x
```

Mock user

```
user s = do
  hPutStrLn stdin s
  out <- hGetLine stdout
  when (out /= _)
       (fail $ _)
```

An Example Interaction

Student submission

```
main = do
  x <- getLine
  putStrLn $ "Hi " ++ x
```

Mock user

```
user s = do
  hPutStrLn stdin s
  out <- hGetLine stdout
  when (out /= _)
       (fail $ _)
```

An Example Interaction

Student submission

```haskell
main = do
  x <- getLine
  putStrLn $ "Hi " ++ x
```

Mock user

```haskell
user s = do
  hPutStrLn stdin s
  out <- hGetLine stdout
  when (out /= _)
       (fail $ _)
```

An Example Interaction

Student submission

```haskell
main = do
  x <- getLine
  putStrLn $ "Hi " ++ x
```

Mock user

```haskell
user s = do
  hPutStrLn stdin s
  out <- hGetLine stdout
  when (out /= _)
       (fail $ _)
```

An Example Interaction

```
Student submission
main = do
  x <- getLine
  putStrLn $ "Hi " ++ x
```

```
Mock user
user s = do
  hPutStrLn stdin s
  out <- hGetLine stdout
  when (out /= _)
       (fail $ _)
```

Find more in our repository!

- Games, music synthesiser, turtle graphics,...
- Proof checker for inductive and equational reasoning
- More engagement mechanisms and insights, our technical setup,...

`github.com/kappelmann/engaging-large-scale-functional-programming`

Any questions?

Thanks to Tobias Nipkow, Manuel Eberl, our student assistants, our industry partners (Active Group, QAware, TNG Technology Consulting, and Well-Typed), and our 2000 Haskell students