Practical Haskell

October 20th 2025

System Programming Ghent
Ghent Functional Programming Group

Practicalities

- Public Wifi
  - AP: DV-Public
  - Password TODO
- Schedule
  - 19:00 Grab some food & drinks
  - 19:15 Presentation + breaks to experiment
  - 21: 00 Wrap-up + discuss
- Example Code
  - https://github.com/kdkeyser/practical-haskell
    - Branches step1, step2, step3, webservice

Who am I?

Koen De Keyser

- Programming (hobby + professional) in lots of different languages
  - Pascal, assembly, C++, C#, Python, Java, OCaml, Haskell, Go, Kotlin, Rust, Rescript
- 7 years full time functional programming in a production context
  - Haskell and OCaml @ Amplidata / Western Digital
  - Large scale storage systems
- Currently VP Engineering @ DoubleVerify, Publisher Division

DoubleVerify Ghent

- R&D site for DoubleVerify, ~ 25 people
- DV Publisher Suite (SaaS BI product) & Ad Measurement technology
- Large scale!
  - 100B events every day, 10B for just Publisher, O(PB) data sizes
  - 

Let’s do some Haskell

Haskell, what tools do I need?

- Haskell tooling has historically been challenging
- Much better now, still challenging when using bleeding edge version of the compiler and tools
- RustUp → GHCUp
  - https://www.haskell.org/ghcup/
- 3 major tools
  - Compiler: GHC
  - Package manager & build system: Cabal
  - Language Servier: HLS
- Package repository
  - https://hackage.haskell.org
- Search-by-type
  - https://hoogle.haskell.org/

Haskell, what tools do I need?

1. Install GHCUp
   - https://www.haskell.org/ghcup/
2. Install GHC, Cabal and HLS
   - `ghcup install ghc 9.12.2`
   - `ghcup install cabal 3.14.2.0`
   - `ghcup install hls 2.11.0.0`
   - `ghcup set ghc 9.12.2`
   - `ghcup set cabal 3.14.2`
   - `cabal update`
3. Install tooling for your IDE
   - VSCode: Haskell Extension, https://marketplace.visualstudio.com/items?itemName=haskell.haskell
   - IntelliJ: Haskell Plugin, https://plugins.jetbrains.com/plugin/24123-haskell-lsp

Hello World of Haskell

- Create a new project
  - cabal init
- We will create a project with
  - The project definition
    - hello-world.cabal
  - A number of modules
    - These live in /src/…
  - A main entry point
    - This lives in /app/Main.hs
  - A test suite
    - This lives in /test/Main.hs
- Building, testing, running
  - cabal build
  - cabal test
  - cabal run

```
$ mkdir hello-world
$ cd hello-world
$ cabal init
What does the package build:
   1) Library
 * 2) Executable
   3) Library and Executable
   4) Test suite
Your choice? [default: Executable] 3
…
$ cabal run
Resolving dependencies...
Build profile: -w ghc-9.12.2 -O1
In order, the following will be built (use -v for more details):
 - hello-world-0.1.0.0 (lib) (first run)
 - hello-world-0.1.0.0 (exe:hello-world) (first run)
Configuring library for hello-world-0.1.0.0...
Preprocessing library for hello-world-0.1.0.0...
Building library for hello-world-0.1.0.0...
[1 of 1] Compiling MyLib            ( src/MyLib.hs,
dist-newstyle/build/x86_64-linux/ghc-9.12.2/hello-world-0.1.0.0/build/MyLib.o,
dist-newstyle/build/x86_64-linux/ghc-9.12.2/hello-world-0.1.0.0/build/MyLib.dyn_o )
Configuring executable 'hello-world' for hello-world-0.1.0.0...
Preprocessing executable 'hello-world' for hello-world-0.1.0.0...
Building executable 'hello-world' for hello-world-0.1.0.0...
[1 of 1] Compiling Main             ( app/Main.hs,
dist-newstyle/build/x86_64-linux/ghc-9.12.2/hello-world-0.1.0.0/x/hello-world/build/hello-world/hello-world-tmp/Main
.o )
[2 of 2] Linking
dist-newstyle/build/x86_64-linux/ghc-9.12.2/hello-world-0.1.0.0/x/hello-world/build/hello-world/hello-world
Hello, Haskell!
someFunc
```

Haskell, the language

Haskell, the language

Haskell is a

- pure
- lazy
- functional

programming language with

- strong type checking &
- type inference

Haskell, the language

- Functional
  - The core concepts are *the **function** and **function composition***
    - add x y = x + y
    - double x = 2*x
    - double . add = 2*(x+y)
  - Functions are “first class primitives”
    - Functions can take other functions as arguments (higher order functions)
      - apply f x y = f x y ⇒ apply sum 7 5 = 7+5 = 12
    - Functions can be partially applied
      - incrByFive = add 5

Haskell, the language

- Pure
    - Functions are **deterministic** calculations: the output is completely defined by the input
    - Functions do **not** have **side effects**
        - Cannot update of reference external variables (state)
    - **Referential transparency**
        - Any function (application) can be replaced by the value that function would evaluate to
        - Memoization
    - What about IO?
        - Pure function cannot have state, do IO, etc. (e.g. print)
        - Monadic IO: f (world) → updated world
            - later more about monads and IO

Haskell, the language

- Strong Type System
    - Every value has a well defined type at compile time
        - 5 :: Int
        - “Hello” :: String
        - add :: Int→Int→ Int
        - apply :: (a → b → c) → a → b → c
    - Powerful type level features
        - Sum and product types, GADT, higher kinded types, polymorphism, type classes, type families, …
    - “If it compiles, it works”
- Type Inference
    - The compiler can (in many cases) derive the types from the expressions
    - Best practice: explicitly define types at the function level

Haskell, the language

- Haskell programmer mindset: leverage the type system as much as possible
  - Type driven development (→ Hoogle)
  - Data driven architecture
  - OOP encapsulation → Type construction
- “Parse, don’t validate”
  - Transform your input into a well-defined data type with invariants
  - Type and invariants are now guaranteed across your code
  - https://lexi-lambda.github.io/blog/2019/11/05/parse-don-t-validate/
- Still doesn’t protect your from business logic misinterpretations / ill-defined specifications

Haskell, history and implications

- Haskell is originally a research language
  - Main contributors have been academia / research centers
    - Haskell can feel convoluted for non PLT researchers
  - Category Theory terminology can feel alien
    - “The study of mathematical structures and their relationships”
    - *“a monad is a monoid in the category of endofunctors”*
  - Inspiration for other (more commonly used) languages (e.g. Rust)
    - IO Monad introduced in 1995 (Haskell 1.3) → async IO
- Niche language in industry
  - https://wiki.haskell.org/Haskell_in_industry
  - Facebook (Simon Marlow)
    - Sigma, spam-fighting infrastructure, 1M+ req/s
    - Haxl, a DSL for optimizing access to distributed database backends

Haskell, why should you care?

- "Open your mind"
  - Think about what "computation" really means
  - In particular for parallel and concurrent programming
    - E.g. Software Transactional Memory, Execution "Strategies"
- Haskell typically enforces general best practices
  - Immutability, no global state, composability, …
- Peek into the future of programming languages
  - You get a ~ 10 year head start on ideas that might pop up in your favorite industry language
- Haskell in production? Your mileage may vary

Practical Haskell: a raytracer

Raytracer, step 1

- Create a bitmap where the color depends on the pixel coordinates
- Domain Concepts
  - Color & color spaces
  - Write a bitmap to a file
- Haskell Concepts
  - Product Type (tuples / triples / …)
  - Functions
  - Modules
  - Monadic IO and “do notation”

Raytracer, step 1 - (Product) Types

- Concrete Type
  - Represents a concrete piece of data, i.e. no further parameters can be provided to the type
  - Starts with capital letter
  - Built-in
    - `Integer, Bool, Float, Char,` …
  - User defined (e.g. product type)
    - `data Color = Color Float Float Float`
- Polymorphic Type
  - ~ Generics (Go, Java, …), ~ Templates (C++)
  - Contains one or more “placeholders” types (lowercase letter)
  - Built-in
    - `(a, b), [a],Maybe a`
  - User defined
    - `data Triple a b c = Triple a b c`

Raytracer, step 1 - Functions

- Functions contain a type definition and an implementation

```
srgb :: Float -> Float
srgb x =
 if x <= 0.0031308 then 12.92 * x else 1.055*(x ** (1.0 / 2.4)) - 0.05
```

- Functions can take other functions as arguments

```
generateImage :: (Int -> Int -> Color) -> Int -> Int -> Image Color
generateImage render width height =
…
```

Raytracer, step 1 - Modules

- Haskell structures code in “Modules”
    - Single file per module, e.g. **`Color.hs`**

```haskell
{-# LANGUAGE ScopedTypeVariables #-}
module Color(
   Color (..),
   tosRGB
) where

data Color = Color Float Float Float

srgb :: Float -> Float
srgb x =
 if x <= 0.0031308 then 12.92 * x else 1.055*(x ** (1.0 / 2.4)) - 0.05
```

Language Extensions

Module name & exports

Type definitions

Functions

Raytracer, step 1 - Monadic IO

- Monad is a concept from category theory
  - But you can ignore that completely
- If we only have pure functions, how can we do IO?
  - Apply your “IO” to the world
    - `f :: World a → World b`
  - Need to be able to apply & sequence IO
    - `bind :: World a → (a → World b)`
- Monad definition
  - `bind :: m a → (a → m b)`
  - `>>= :: m a → (a → m b)`

Raytracer, step 1 - Monadic IO

- IO monad → m = IO
  - `main () :: IO ()`
  - `>>= :: IO a → (a → IO b)`
- “do” notation

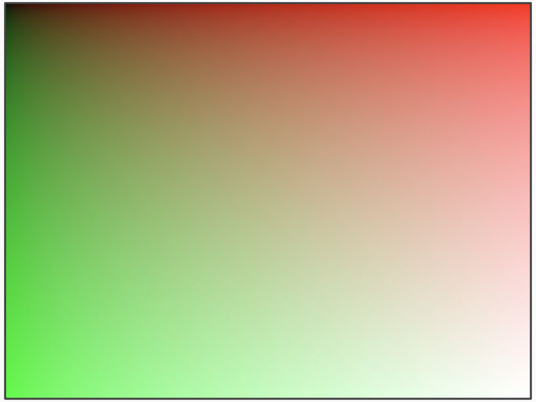
```
main :: IO ()
main = do
 r1 <- f1 ()
 r2 <- f2 r1
 f3 r2

main :: IO ()
main =
 f1 () >>= \r1 -> f2 r1 >>= \r2 -> f3 r2
```

Raytracer, step 1 - Monadic IO

- Monad is the most “powerful” way to chain side effects
  - Every side effect can inspect everything that happened before
    - including all previous side effects)
  - Need to execute sequentially (so sad!)
- Other options are possible!
  - Applicative functor
  - Arrows
  - Effect systems
- Inspecting side effects before execution
  - Haxl

Raytracer, step 1- “just do it”

- Create a bitmap where the color depends on the pixel coordinates
- Color & color spaces
  - Introduce a Color type that represents colors as 3 floats (0.0 … 1.0) for red/green/blue
  - Transform the r,g,b colors to the sRGB color space
    - Corrects for non-linearity of output devices (i.c. monitor)
    - See previous slide for formula
- Write a bitmap to a file
  - JuicyPixels library (search on https://hackage.haskell.org/)
  - Use **`saveBmpImage, generateImage and ImageRGBF`**
- Use https://hoogle.haskell.org/ to lookup helper / library functions
  - Search by type, e.g. Int → Float



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Raytracer, step 2

- Render a sphere in a uniform color in front of a camera
- Domain Concepts
  - Camera
  - Ray
  - Sphere
  - Vector
- Haskell Concepts
  - Product Type (named records)
  - Type Classes
  - Deriving

Raytracer, step 2: Product Type (2)

- A “Product Type” is the cartesian product of 2 or more other types
  - `data Color = Color Float Float Float`
- Easier to use as “records”
  - Names rather than positions
  - `data Vector = Vector { x :: Float, y :: Float, z :: Float }`
  - `v = Vector { x=1.0, y=0.5, z=0.7}`
  - Can still be constructed positionally e.g. `v = Vector 1.0 0.5 0.7`
  - Fields names become getters, i.e. `xValue = x v`
- Records are a bit clunky in Haskell
  - Lenses, optics, …

Raytracer, step 2: Type Classes

- If you know Rust → Type Classes ~ Traits
- Definition
  - **a type class defines a set of functions a type needs to implement**

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

- Built-in type classes
  - Show, Monad, Functor, …
- You can specify and/or implement type classes yourself (you don't need to "own" the type)

Raytracer, step 2: Deriving

- Generate (trivial) typeclass implementation at compile time
  - Show

```haskell
class Show a where
    show :: a -> String
    …
```

```haskell
data Vector = Vector {
    x :: Float,
    y :: Float,
    z :: Float
} deriving Show
```

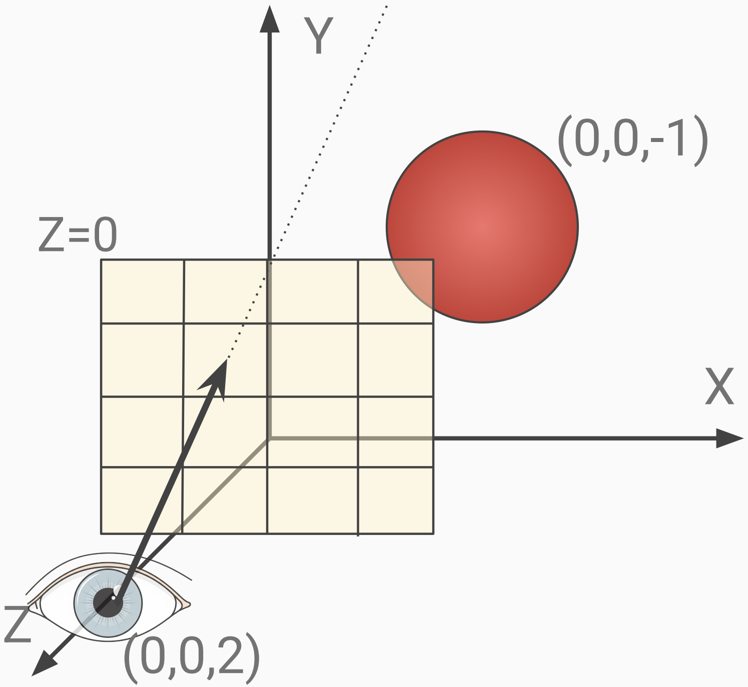
or

```haskell
data Vector = Vector {
    x :: Float,
    y :: Float,
    z :: Float
}
deriving instance Show (Vector)
```

  - Originally restricted to specific built-in typeclasses (`Eq, Ord, Enum, Ix, Bounded, Read, Show`)
  - Now a lot can be derived (e.g. ToJson, FromJson, …)
    - See GHC.Generics

Raytracer, step 2 - “just do it”

- Vector
    - 3D vector, with x,y,z components
- Ray
    - Starts at a specific point in 3D space, and follows a specific direction
- Sphere
    - Center (3D point) and radius.
- Camera Screen
    - Z=0
- Problem to solve
    - For each pixel on the screen, follow a ray from the eye through the pixel, and check if it hits the sphere. If it does, the pixel is red, otherwise black.



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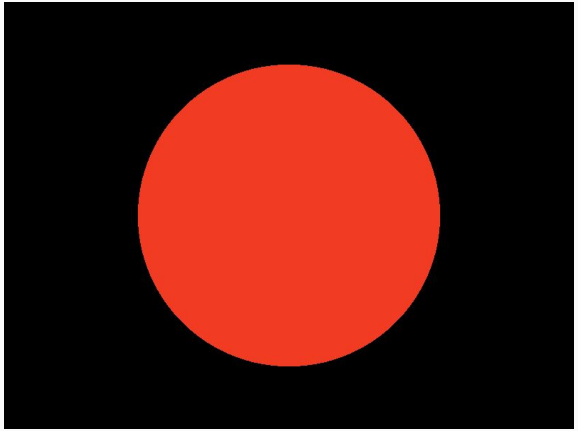

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Raytracer, step 3

- Render a sphere using specular lighting
- Domain Concepts
  - Lights
  - Unit Vector
  - Normal Vector
- Haskell Concepts
  - GADT (Generalized Algebraic Data Type)

Raytracer, step 3 - GADTs

- Definition: Sum type where the type parameters depend on the specific constructor used

```
data Expr a where
   EBool  :: Bool       -> Expr Bool
   EInt   :: Int        -> Expr Int
   EEqual :: Expr Int -> Expr Int   -> Expr Bool
```

Raytracer, step 3 - GADTs

- Common use case for GADTs: expressing invariants
- Vector
  - Can be **zero vs. non-zero**
  - Can be **unit vector vs. arbitrary length**
- Certain operations work only on vectors that have specific invariants
  - Cannot normalize a zero vector
  - A normal vector is expected to always be unit length
- Certain operations retain invariants, others don’t
  - Vector rotation: retains length / zeroness
  - Vector addition: does not retain length / zeroness

Raytracer, step 3 - GADTs

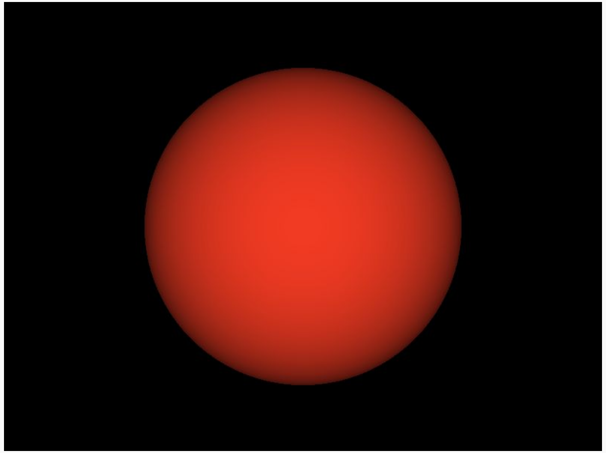
```
data Zero
data NonZero a
data UnitLength
data Unknown

data VectorGADT a where
 Zero :: VectorGADT Zero
 Unit :: Vector -> VectorGADT (NonZero UnitLength)
 NonZeroUnknownLength :: Vector -> VectorGADT (NonZero Unknown)
 Unknown :: Vector -> VectorGADT Unknown

normalize :: VectorGADT (NonZero a) -> VectorGADT (NonZero UnitLength)
rotate :: VectorGADT a -> Float -> VectorGADT a
add :: VectorGADT a -> VectorGADT b -> VectorGADT Unknown
nonZero :: VectorGADT a -> Maybe (VectorGADT (NonZero Unknown))
```

Raytracer, step 3 - "just do it"

- Specular lighting with a uniform light source
  - The color (intensity) is determined by the angle at which the light hits an object
  - Angle α between
    - the light source direction
    - the normal of the object at the point where the light hits
- Introduce
  - Normal vector for sphere (it's a unit vector!), i.e. perpendicular to the surface
  - Uniform light source (direction + intensity)
- Calculate specular lighting for a sphere
  - Intensity ~ $\cos^3 \alpha$
- Use vector dot product to calculate $\cos \alpha = v_1 \cdot v_2$
  - v_1 and v_2 must be unit vectors



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Practical Haskell: a web service

Haskell for web services

Haskell is surprisingly well suited for network IO intensive applications

Why?

- Monadic IO >> Async IO
- Purity enables concurrency
- High performance runtime (MIO)
- Lots of high-quality libraries

Web Service Frameworks

Haskell has a variety of web frameworks, with various levels of complexity / completeness *(and levels of maintenance)*

- Core Web Server → Warp
    - HTTP(1/2)
    - Fast
    - Low-level
- Routing + high-level request / response logic
    - Scotty
    - Servant
- Batteries included frameworks
    - Yesod

Scotty example

Let’s look at an example using Scotty which does:

- Routing
- Path parameter parsing
- JSON parsing + generation
- Cross-request state
    - Unique user id generation

Doesn’t look to be async, but it is fully non-blocking behind the scenes

Scotty example

Performance is really good for a (very) high level language

- MIO, Haskell IO subsystem
  - Scales to 40+ cores
  - Typically scales better than Go, similar to Node.js with sufficient pre-forked processes
    - But no single-thread limitation for your logic
    - https://share.google/uNaOe0mTpdaX2o8CW
- Tell cabal to run your program across all cores
  - `ghc-options: -threaded -rtsopts -with-rtsopts=-N`

Scotty example

- Saturates all cores on 10 core Intel i7-13800H
- 500 connections, minimal work per request

```
$ wrk -c 500 -d 30 -t 8 http://localhost:3000/fast
Running 30s test @ http://localhost:3000/fast
  8 threads and 500 connections
  Thread Stats   Avg      Stdev     Max   +/- Stdev
    Latency     1.21ms    1.34ms  59.76ms   88.82%
    Req/Sec    51.09k     4.92k   63.64k    70.58%
  12207630 requests in 30.04s, 2.08GB read
Requests/sec: 406430.48
Transfer/sec:     70.93MB
```

Scotty example

- 20 ms work per request
- 2000 connections, theoretical maximum of 100 000 req/s

```
$wrk -c 2000 -d 30 -t 8 http://localhost:3000/slow/20
Running 30s test @ http://localhost:3000/slow/20
  8 threads and 2000 connections
  Thread Stats   Avg      Stdev     Max   +/- Stdev
    Latency    24.18ms    4.06ms  84.46ms   87.17%
    Req/Sec    10.32k     1.11k   12.34k    72.00%
  2465488 requests in 30.07s, 470.25MB read
Requests/sec:  81985.91
Transfer/sec:     15.64MB
```

Let’s discuss