

Melbourne Haskell Workshop 2013

DRAFT COPY

- 6 Hours (Plus Lunch)
- Expected attendance - 50 people

[\(HTML\)](#)

A 6-hour workshop intended to introduce and provide resources for working with Haskell.



This workshop is based around a central concept of domain modeling with Haskell.

Outcomes include...

- Creating, editing, running and interacting with Haskell programs
- Building the confidence to solve problems in the wild with Haskell
- Developing an understanding of the Haskell ecosystem
- Interacting with others in a collaborative environment

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Required Resources

Before you begin you will require the following...

A Text-Editor

We are assuming previous programming experience, however, if you would like a recommendation, have a look at [Notepad++](#), [Sublime Text](#), or the ever-popular [Emacs](#) and [Vim](#). Just make sure that you are fluent enough to embark on exercises as they appear in the workshop.

The Haskell Platform

In order to run the programs written during this workshop you will need a Haskell installation. The easiest way to get up and running is to install the latest Haskell Platform. This is a “batteries included” installation of GHC and Cabal that includes many of the most useful packages available in the Hackage ecosystem.

A Copy of the Workshop Scaffold Project

https://github.com/sordina/haskell_workshop

Either clone with git:

```
git clone https://github.com/sordina/haskell_workshop.git
```

... or [download the zip](#) from GitHub.

Useful Resources

These resources are available to help you with any issues you face when learning Haskell:

#haskell on [Freenode](#)

An IRC channel dedicated to discussion of Haskell. This is often the easiest place to fire off a one-off question that is simple enough not to warrant a permanent listing on the internet.

[Hackage](#)

Hackage is the primary repository for Haskell packages. It is public, searchable, versioned, and uses Cabal package metadata for classification. Furthermore, this can be used to easily browse package contents, documentation and source-code.

For example, browse the [Shake](#) package and look at some of the [Modules](#).

Hoogle

Hoogle is a Haskell module and function search-engine. Hoogle allows you to take advantage of the granular type-system used by Haskell to search not just for function-names, but for function type-signatures.

For example, have a look for the function with signature `Text -> ByteString`.

MFUG

MFUG is the Melbourne Functional Programmer's User Group. This group discusses many topics, including Haskell.

/r/haskell

For Reddit users, /r/haskell is a very useful resource with a great deal of information regarding recent developments in the Haskell ecosystem and community. This is a good place to ask some more advanced questions or start a flame-war.

Haskell News

Haskell News is a firehose-style haskell news aggregator taking information from sources as varied as academic-journals, and GitHub accounts.

HLint

HLint is a [linting tool](#) for Haskell source - It can often provide some useful hints about refactoring avenues for your code.

Learn You a Haskell (For Great Good)

Learn You a Haskell (For Great Good) is a wonderful introductory text on Haskell.

Real World Haskell

Real World Haskell aims to focus on solving real problems with Haskell. Several chapters of the book are somewhat dated in terms of the libraries used, but it still serves as a useful example of getting real work done with Haskell.

Welcome

Welcome to the Melbourne Haskell Workshop 2013.

This intent of this workshop is to provide a working introduction to Haskell for programmers in Melbourne who have not yet used the language in anger.

The workshop is split into chapters - each lasting an hour. Chapters will start with a few trivial introductory exercises to get your fingers warmed up, then the meat - an exercise that should be able to be solved using the material introduced up to that point (with help and hints available if needed).

Each chapter will conclude with an open-question. This question should provide inspiration for further consideration of how harder problems could be solved using Haskell, and for more advanced attendees, can be attacked instead of twiddling your thumbs after finishing the main exercise.

Why run a free haskell workshop?

There are a few kinds of benefits that we anticipate will result as an outcome of the workshop:

- Benefits to Individuals
- Benefits to the Community
- Benefits to the Volunteers
- Benefits to the Organisers
- Benefits to Industry
- Benefits to Relationships

Benefits to Individuals

- New Tools
- Experience writing Haskell
- An Introduction to the Wider Community

What do we hope that an individual attendee will gain by coming to the workshop?

Since this workshop is targeted towards beginners, we want an attendee to come away from the workshop with new tools at their disposal. Yes, a new language to reimplement existing knowledge with various platform benefits, but more importantly, a new tool for dissecting problems.

Learning a new problem-solving approach will almost certainly be the most challenging part of the workshop, but through the consistent delivery of exercises that benefit from domain modelling, we hope that the attendee will walk away with the confidence to attack new problems from the “Haskell Mindset”.

Although there won’t be time to work on any large-scale problems, we hope that the approaches we demonstrate will be able to be applied with confidence to problems of any size.

Aside from the technical benefits, the workshop should provide a great opportunity for attendees to meet many other members of the Melbourne Haskell using community.

Benefits to the Community

- Haskell as a Tool for Communication
- Local Network Effects
- Consolidation

Often, Haskell (especially the type-system) can be an extremely effective means of communication of certain kinds of behaviors, requirements, and problems. If this workshop can help advance Haskell as a common language for inter-personal discussion of technical topics, then the barriers of communication will be lowered and the community as a whole should become more productive.

Often, it isn't until a particular community reaches a critical mass that it comes into its own. Currently the Melbourne Haskell community is reasonably disparate and unconnected (especially outside of MFUG). If the various groups of people using Haskell can be consolidated, then we would consider starting a regular Melbourne Haskell meetup. Just having the ability to ask questions in person can go a long way to advancing confidence in a particular topic, therefore, as the number of Haskell users increases locally, so to will the overall skill of individuals and the community as a whole.

Benefits to the Volunteers

- Experience
- Networking

We hope that for the volunteers, providing administrative and in-person assistance will be a rewarding experience. We are very open to people of any skill level helping out and this could be a great opportunity for newcomers to the community to get their fingers dirty by providing assistance at the workshop.

The workshop should also be a good networking opportunity for volunteers, as a stratified group of Haskellers of this size has not yet convened in Melbourne.

Benefits to Industry

It has been said that once you are comfortable programming Haskell, you become spoiled, and won't want to go back to your previous languages. Rather than quit your day-job, if Haskell's presence can be advanced in industry, then the Joy of programming Haskell will become a possibility in your day-to-day work-life. A longer-term goal to be sure.

This benefit may be the most tenuous outcome of the workshop, but as the mindshare of Haskell grows, the chances of it being used for projects within industry increases.

- An understanding of the language's strengths and weaknesses empowers decision makers to weigh up if the language is a suitable candidate to solve the technical problems at hand.

- Confidence is gained that there are enough people using the language that hiring a programmer will not be a problem if this is required.

The technical benefits to industry will have the most impact where a rigorous solution to a problem is necessary. In the financial sector, Haskell is beginning to become more popular as the cost of bugs can be very high. Technical benefits, however, are a moot point if Haskell does not see adoption.

If this workshop can give project-leaders in industry, making programming-language choices, the confidence to consider Haskell as a real candidate, then it will have gone a long way towards making Melbourne a more attractive place to be for people who wish to use Haskell in day-to-day work.

Benefits to the Organisers

Last-but-not-least -

For us, the organisers, running this workshop will be a great opportunity to see the Melbourne Haskell community in action. We're looking forward to working with you all, and expect that above all else we will have a lot of...

Fun!

Setup

Ensure that you have the following programs installed and functioning correctly:

GHCi

At a command prompt, enter the following command:

```
ghci
```

This should launch the GHC Haskell REPL.

Type the following to ensure that you have a functioning REPL:

```
1 + 1
```

This should yield the result:

```
2
```

You can use GHCi to perform calculations other than just "1 + 1".

Here is an example session:

```
> ghci
GHCi, version 7.6.2: http://www.haskell.org/ghc/  :? for help
Loading package ghc-prim ... linking ... done.
Loading package integer-gmp ... linking ... done.
Loading package base ... linking ... done.
[Prelude] > 1 + 2 + 3
6
[Prelude] > 100 / 2
50.0
[Prelude] > 6 ^ 7
279936
[Prelude] > ^D
Leaving GHCi.
```

Using GHCi...

Calculate the price of 42-bakers-dozens of eggs at \$3 per-egg.

```
[Prelude] 42 * 13 * 3
1638
```


Loading files in GHCi

There are many ways to load and execute Haskell code. For the purposes of this workshop, if you do not already have a workflow you are comfortable with, then we suggest the following steps:

- Write and edit your programs in files ending in the extension “.hs”
- When you are ready to test your program, load it into GHCi
- After making modifications to your program, reload the program in GHCi

Say you had written the following program `test.hs` in your home directory:

```
main = print "hello world"
```

Load the file in GHCi to see it in action:

```
> ghci test.hs
GHCi, version 7.6.2: http://www.haskell.org/ghc/  :? for help
Loading package ghc-prim ... linking ... done.
Loading package integer-gmp ... linking ... done.
Loading package base ... linking ... done.
[1 of 1] Compiling Main                ( test.hs, interpreted )
Ok, modules loaded: Main.
[*Main] > main
"hello world"
```

... Unfortunately there is a bug in the program, so in your editor you make the change required to print “hello, world” with the mandated comma:

```
main = print "hello, world"
```

Now, back in GHCi, you can reload the program without exiting the REPL:

```
[*Main] > :reload
[1 of 1] Compiling Main                ( test.hs, interpreted )
Ok, modules loaded: Main.
[*Main] > main
"hello, world"
```

Much better!

- * Define a new numeric function in a source file
- * Load it in GHCi
- * Test your function in GHCi
- * Make a modification
- * Reload your changes without exiting GHCi
- * Test your changes

GHC

Create the following source file (program.hs):

```
main = print "hello world"
```

Compile the program as follows:

```
ghc --make program.hs
```

Run the program with the following command:

```
./program
```

The output should look as follows:

```
"hello world"
```

Compiled programs are almost always significantly faster than instructions run inside GHCi. Even greater speed-ups are possible by using the "-O" optimisation settings for GHC.

Using GHC...

Compile and run your own spin on Hello-World.

```
> echo 'main = print "hello homies"' > main.hs
> ghc --make main.hs
[1 of 1] Compiling Main                ( main.hs, main.o )
Linking main ...
> ./main
"hello homies"
```

Cabal

You should have access to a Cabal installation if you have installed the Haskell Platform.

Check that you have cabal by running:

```
cabal --version
```

This should output something similar to:

```
cabal-install version <VERSION>
using version <VERSION> of the Cabal library
```

Install the QuickCheck package using cabal.

```
> cabal update # not required if done recently
Downloading the latest package list from hackage.haskell.org
> cabal install quickcheck
...
```

An open-ended question:

Given that GHC is largely written in Haskell, how was GHC first compiled?

An open-ended question:

What are some of the current issues with the Haskell ecosystem?

Introduction

The following exercises are intended to be used to warm up your fingers, rather than your brain. These should be run through quickly to get you used to using your development environment.

Variables

In Haskell you can define a variable with the `=` sign.

Variables can be defined at the top-level (no-indentation):

```
myVariable = 2
```

Variable names should start with a lowercase letter and contain no spaces, or special characters, besides underscores, numbers, and `'`.

Define your own variable.

Type Signatures

You can annotate a definition with a valid type-signature:

```
myVariable2 :: Int  
myVariable2 = 1
```

Give your variable a type-signature.

String Literals

String literals look familiar:

```
myString :: String  
myString = "hello world"
```

Define a variable containing a string.

Tuples

Tuples look like this:

```
myTuplePair :: (Int, String)
myTuplePair = (1,"hello")
```

```
myTupleTrio :: (Int, String, Int)
myTupleTrio = (1,"hello",3)
```

They can be used to group multiple, differently-typed (heterogeneous) values.

Define a variable containing a tuple.

Functions

Functions are a core part of Haskell. Function definitions look like this:

```
myFunction :: ... -> ...
myFunction x y ... = ...
```

If a function `f` takes something of type `a` and returns something of type `b` we write the type signature as:

```
f :: a -> b
```

For example:

```
myAdd :: Int -> Int -> Int
myAdd x y = x + y
```

`myAdd` takes two numbers and returns the result of the addition of those two numbers.

Define a function `'myMultiply'` that multiplies 3 numbers.

Give your function a type-signature

```
myMultiply :: Int -> Int -> Int -> Int
myMultiply x y z = x * y * z
```

Lists

Lists are a commonly used data-structure in Haskell. Everything in a list has the same type (they are homogeneous).

Lists are built using the infix data-constructor `(:)` (pronounced “cons”). They also have a compact notation using `[...]`.

List literals look like:

```
list1 :: [Int]
list2 :: [Int]
list3 :: [String]

list1 = [1,2,3]
list2 = 1 : 2 : []
list3 = "hello" : "world" : []
```

Define a variable containing a list.

Give your variable a type-signature.

You can deconstruct a list by pattern matching the head and tail like so:

```
f (x:xs) = ...
```

Define a function to get the first element of a list.

Note: In Prelude this function is called `head`.

```
myHead (x:xs) = x -- This is a partial function, Beware!
```

Define a variable containing the first element of your list.

```
myFirstElement = myHead myList
```

Define Length

Define a function that takes a list and returns the length.

```
-- In Haskell type-signature syntax, this is written as:
myLength :: [a] -> Int
myLength = undefined
```

Your solution should have the form of:

```
myLength []      = ...
myLength (x:xs) = ...
```

Things to consider:

- What is the length of an empty list? (the base case)
- What is the length of xs?

```
mylength []      = 0
mylength (x:xs) = 1 + mylength xs
```

Define myMap

Define a function that takes a function from a to b "a -> b", and a list of as "[a]", and returns a list of bs "[b]".

Things to consider:

- What is the type-signature of myMap?
- What is the base-case of myMap?

```
myMap :: (a -> b) -> [a] -> [b]
myMap f [] = []
myMap f (x:xs) = f x : myMap f xs
```

Fun List Functions

For your reading pleasure, here are some definitions of common functions:

```
myFilter f []      = []
myFilter f (x:xs) = if f x then x : myFilter f xs
                  else      myFilter f xs
```

```
myFold f z []      = z
myFold f z (x:xs) = f x (myFold f z xs)
```

```
myReverse []      = []
myReverse (x:xs) = myReverse xs ++ [x]
```

```
myElem e []      = False
myElem e (x:xs) = if e == x then True
                  else myElem e xs
```

See if you can determine the type-signatures for these functions.

An open-ended question:

What is a good balance between safety and expressiveness in a programming-language?

ADTs (Algebraic Data Types)

[Haskell Wiki Link](#)

Algebraic Data Types are THE bread and butter of Haskell programs.

- Functions evaluate data by pattern-matching against ADTs
- Domains are modeled using ADTs
- Laziness is linked to ADTs
- Types can be derived from ADT definitions

But how does that help me?

An example of an ADT in Haskell:

```
data MyBool = MyTrue | MyFalse | MyNotSure

should_I_eat_something_bigger_than_my_own_head :: MyBool
should_I_eat_something_bigger_than_my_own_head = MyFalse
```

With this functionality, you are able to introduce your own "Enum" values.

The MyBool example is somewhat equivalent to the following C++ code:

```
enum MyBool { MyTrue, MyFalse, MyNotSure };
```

With the added bonus of not having out-of-bounds casting ruin your day.

If your problem space can be modeled using various discrete values, then this form of ADT will allow you to create a program that mirrors your problem!

You can add parameters to the data constructors:

```
data MyNullString = Nada | MyString String

stringy :: MyNullString
stringy = MyString "Whatever, It's just a string"

blanky :: MyNullString
blanky = Nada
```

Constructors can take multiple parameters:

```
data SomeJunk = Rubbish String | TrashPile String Int Bool
```

```
discards :: SomeJunk
discards = TrashPile "Junk Yard" 42 True
```

Furthermore, ADTs can be recursive:

```
data MyNumberList = Nada | SomeNumbers Int MyNumberList
```

```
numbers :: MyNumberList
numbers = SomeNumbers 1 (SomeNumbers 2 Nada)
```

Finally, ADTs can be parametrised by other types:

```
data MyContainer x = Jar x
```

```
contained :: MyContainer Int
contained = Jar 1
```

```
pun :: MyContainer (MyContainer String)
pun = Jar (Jar "Binks")
```

In general, the syntax of an ADT looks similar to the following:

```
ADT           := data <TypeName> <Variables> = <Constructors>
TypeName      := [A-Z] + [a-z' _]*
Parameters    := <ConcreteType> + (" " + <ConcreteType>)*
Constructors  := <Constructor> + (" | " + <Constructor>)*
Constructor   := <TypeName> + <Parameters>
Variables     := <Variable> + (" " + <Variable>)*
Variable      := [a-z] + [a-z' _]*
```

ConcreteType can't be defined syntactically, but it means that your type is "Fully Applied" (in Haskell terms, has a kind of *). An example of some concrete types are:

- String
- Int
- Maybe String
- [Int]

Examples of some non-concrete types are:

With all of this power at your disposal, it's time to define a list ADT yourself.

Define your own generic list ADT.

Things to consider:

- Should this ADT be parametrised?
- Should this ADT be recursive?
- Should this ADT have multiple constructors?
- Should the constructors be parametrised?

```
data MyList a = Empty | Items a (MyList a)
```

An open-ended question:

What would the ADT for a LISP-like language look like?

If you wish to learn about why ADTs are “Algebraic”, then have a look at:

- [The Algebra of Algebraic Data Types, Part 1](#)
- [The Algebra of Algebraic Data Types, Part 2](#)
- [The Algebra of Algebraic Data Types, Part 3](#)

The Garden

This chapter will focus on various kinds of trees.

```
data BinaryTree a = Empty | Node a (BinaryTree a) (BinaryTree a)
```

```
data RoseTree a = Node a [RoseTree a]
```

```
type Forrest a = [Tree a]
data Tree a = Branch a (Forrest a)
```

```
countF :: Forrest a -> Int
countF = sum . map countT
```

```
countT :: Tree a -> Int
countT (Branch _ f) = 1 + countF f
```

You have a Garden full of RoseBushes

Aphids

Seccatirs

Graft

Weed

Recreation

Ignore recursion with the power of parameters

Our adventurer intrepid, climbing high in hopes to find...
a single solitary flower, ends up being left behind.
Each fork of branches he encounters leave him in a deeper bind.
This thorny tree falls easiest with axes of another kind.

```
data RoseTree a = Node a [RoseTree a]
```

```
quest :: RoseTree (Maybe Rose)
quest = undefined
```

```
solution = climb quest
  where
    climb (Node (Just rose) branches) = rose
    climb (Node Nothing      branches) = map climb branches .... ?? !!!!
```

```

-- Another kind..... If a RoseTree is a Monad (of kind "* -> *")

instance Monad RoseTree where
  return x = Node x []
  Node x ts >>= f = Node x' (ts' ++ map (>>= f) ts)
    where Node x' ts' = f x

branches :: RoseTree a -> [RoseTree a]
branches f (Node a bs) = a : bs

solution2 = iterate (>>= branches) quest

```

Laziness

Haskell's evaluation strategies ~ Exploring the magic.

Often when looking at examples of Haskell functions you will come across examples of laziness in action. The canonical example used to demonstrate the lazy recursive approach of Haskell is the definition of the list of Fibonacci numbers -

```
fibs = 1 : 1 : zipWith (+) fibs (tail fibs)
```

This solution has a reputation for being somewhat mind-bending for beginners... What is going on here?

In order to show the start of an infinite list, use the 'take' function -

For example:

```
[Prelude] > let fibs = 1 : 1 : zipWith (+) fibs (tail fibs)
[Prelude] > take 10 fibs
[1,1,2,3,5,8,13,21,34,55]
```

Here is a Fibonacci solution in Javascript:

```
function fib(n) {
    if(n < 2) return 1
    return fib(n-1) + fib(n-2)
}
```

Most programmers won't have any problem with the usual recursive definition of `fibs`, so what makes the Haskell one special? Let's see if we can implement the Haskell version in Javascript:

```
// The Fibonacci Sequence in all its glory~
//
function fibs() { return [1, cons(1, zipWith(add, fibs, tail( fibs )))] }

exports.main = function() { runList(fibs, 13) }

// Helpers
//
function cons(h,t)      { return function() { return [h,t] }}
function head(list)     { return list()[0] }
function add(x,y)       { return x + y }
function tail(list)     { return function() { return list()[1]() }}

function zipWith(f, x, y) { return function() {
```

```

        return [ f(head(x), head(y)),
                  zipWith(f, tail(x), tail(y))] } }

function runList(list, n) { while(n --> 0) {
    console.log(head(list)); list = tail(list)}}

```

The main difference between a normal recursive definition and this one is that the recursion happens at the value level, as opposed to the function-call location.

Implement an infinite list of ascending numbers using lazy, value-based recursion.

```
ascending = 1 : zipWith (+) ascending ascending
```

An open-ended question:

Can all numeric-lists be defined by using value-based recursion?

Music

Once you have a model that reaches a sufficient level of complexity you will find that your data-types become recursive.

Here is a small musical target-language:

```
data Music
  = A_ -- Underscore Represents a Flat
  | A
  | A' -- Prime represents a Sharp
      -- ... B, C, D, E, F, G ...
  | Sequence [Music]
  | Sharp Music
  | Longer Integer Music
  | Higher Integer Music
```

Certainly not comprehensive enough to write Beethoven's 5th Symphony, but good enough for Baa Baa Black-Sheep.

```
intro  = Sequence [ C, C, G, G ]
run     = Sequence [ A, B, C, A ]
middle = Sequence [ F, F, E, E ]
run2    = Sequence [ D, C, D, E ]
baaBaa = Sequence [ Longer 2  intro
                    , Higher 12 run
                    , Longer 4   G
                    , Longer 2  middle
                    , run2
                    , Longer 4   C ]
```

In order to listen to this music, create a file with the following code:

```
import Midi
import qualified Data.ByteString as BS

main = BS.writeFile "baaBaa.mid" (make_music 4 4 (Longer 4 baaBaa))
```

Your task is to write a melody using this language. Try to write and compose functions, rather than declaring one big data-structure.

Testing

Haskell's type-system allows you to eliminate many kinds of errors that are usually combated using testing in more dynamic languages.

However, just because the type system can prevent some classes of error, doesn't mean that it can catch them all.



There are a couple of really useful approaches to testing used commonly by Haskell programmers:

- [QuickCheck](#)
- [HUnit](#)

QuickCheck focuses primarily on testing pure code, while HUnit provides means to test code that lives in the IO monad.

In the world of unit-testing, generating data can be a pain. Coming up with concise examples that test edge-cases and don't bother repeating useless properties is a real art-form that can take longer than writing the code to solve the problem at hand.

In many languages, frameworks and libraries have sprung up to aid with this problem by providing ways to generate various forms of valid and invalid test-data on demand.

An example of this form of library in Ruby is [Factory Girl](#). You specify the structure and properties of the data you want generated, and using the helpers provided by the framework you will be able to generate many unit tests to ensure that your application's code behaves as expected!

But hang-on... Why would we go about telling a Haskell library what the structure of our data looks like when in a great-deal of cases - Haskell already knows?

This is where the `Arbitrary` type-class from QuickCheck steps up to bat for us!

Let's say that we have a function `hyphenate` that takes a sentence and turns the spaces into hyphens - There should be no trailing or leading hyphens unless they were already there to begin with, and there should be no instance of multiple hyphens in a row in our output - For example:

```
"hello world"      => "hello-world"
"say      whaaaaa?" => "say-whaaaat?"
```

We get pretty excited and code up an enterprise solution ~

```
hyphenate :: String -> String
hyphenate s = map (replace ' ' '-') s

replace :: Char -> Char -> Char -> Char
replace x y c | c == x    = y
               | otherwise = c
```

Great!

Those examples we looked at earlier kind of look like some test-data. Let's write some unit-tests.

```
test1 :: Bool
test1 = hyphenate "hello world" == "hello-world"

test2 :: Bool
test2 = hyphenate "say      whaaaaa?" == "say-whaaaaat?"
```

Awwwwwww yis.

... Except test2 fails spectacularly... Hmm...

So we fix our test-data, we fix our function (hopefully?) and code up a few more tests, only to find we missed another edge-case when our client comes back with some trailing hyphens and mad as a raging bull... There has to be a better way!

Enter QuickCheck -

Rather than writing tests for individual applications, we write properties that cover the various specifications of the desired behavior:

```
import Data.List

prop_no_spaces :: String -> Bool
prop_no_spaces s = not (elem ' ' (hyphenate s))

prop_no_leading :: String -> Bool
prop_no_leading s = case hyphenate s of (x:xs) -> x /= '-'
                                         _       -> True

prop_no_trailing :: String -> Bool
prop_no_trailing s = prop_no_leading (reverse s)

prop_no_multiple :: String -> Bool
prop_no_multiple s = not (elem "--" (concatMap tails (inits s)))
```

That's all well and good, but how does that help us?

Check this out!

```

> quickCheck +names hyphen-solution-and-tests.hs
[Prelude] > [1 of 1] Compiling Main ( hy.hs, interpreted )
Ok, modules loaded: Main.
[*Main] > prop_no_spaces: +++ OK, passed 100 tests.
[*Main] > prop_no_leading: *** Failed! (after 44 tests and 7 shrinks):
" "
[*Main] > prop_no_trailing: +++ OK, passed 100 tests.
[*Main] > prop_no_multiple: +++ OK, passed 100 tests.
[*Main] > Leaving GHCi.

```

ZOMG - So much free test data!

This found an edge-case for us without too much trouble, and what's more, narrowed it down to the minimal failing example!

If you want to be able to take advantage of QuickCheck in the fashion performed in the example you will need to install QuickCheck and quickcheck-script:

```

> cabal install quickcheck quickcheck-script

```

In order to take advantage of QuickCheck's data-generation for custom data-types - take a look at the [Arbitrary](#) type-class.

Write QuickCheck properties for the constraints required in the Rose-Tree exercise from The Garden.

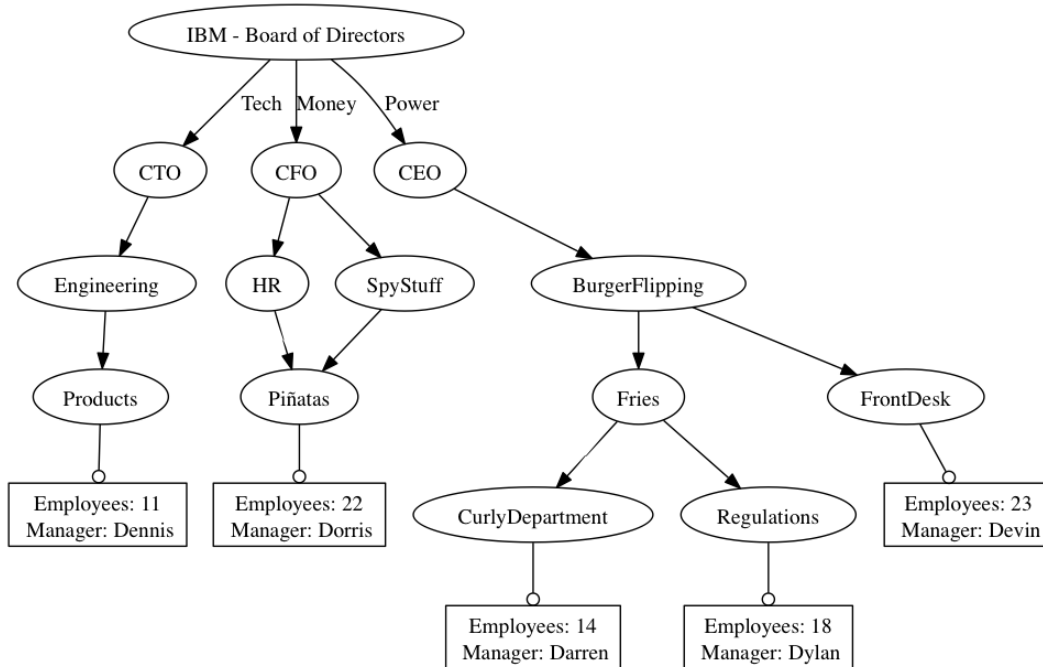
[Link to The Garden Chapter](#)

Org Chart

You are an employee of International Banking Machines.

The CEO has asked you to model the org-chart with a computer program in order to perform some analysis on the effectiveness of middle-managers.

Before you are able to perform your calculations, you will have to decide how you will model your data. Construct a Haskell data-type to represent the various types of employees and departments shown in the following diagram:



Construct a function that builds up your datastructure from the following plain-text input format:

Employees

| Name | Title | Salary | Department | Managing Department | Subordinates |
|--------|---------|--------|------------------|---------------------|--------------|
| Dennis | Manager | \$33K | Products | Products | 11 |
| Dorris | Manager | \$42K | Piñatas | HR | 22 |
| Darren | Manager | \$34K | Curly Department | Fries | 13 |
| Dylan | Manager | \$54K | Regulations | Fries | 18 |
| Devin | Manager | \$64K | Front Desk | BurgerFlipping | 23 |

Your function should have the following signature:

```
process :: String -> OrgChart
```

Symbolic Differentiation

Your Highschool math teacher has decided to introduce differentiation of single-variable polynomials. . .

This is in super easy once you grasped the concept:

Polynomial term differentiation:

$$a.x^n.\frac{d}{dx} = n.a.x^{n-1}$$

Linearity of differentiation:

$$(a + b)\frac{d}{dx} = a\frac{d}{dx} + b\frac{d}{dx}$$

But you don't wish to perform the undoubtedly large number of rote-examples required after your moment of epiphany.

In this exercise you should develop a data-type to represent a single-variable polynomial expression.

After you feel confident that you can represent any such expression, write a function using the two rules listed to provide the following function:

```
differentiate :: Polynomial -> Polynomial
differentiate = ...
```

Appendix

- [Hutton's Razor](#)
- [Implementing Functional Languages: A Tutorial](#)
- [QuickCheck Wikipedia Page](#)
- [QuickCheck on Hackage](#)
- [99 Haskell Problems](#)