FP101x - Functional Programming

Programming in Haskell – Types and Classes

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Challenge the future

What is a Type?

A type is a name for a collection of related values. For example, in Haskell the basic type

```
Bool
```

contains the two logical values:

```
False          True
```

Type Errors

Applying a function to one or more arguments of the wrong type is called a type error.

```
> 1 + False
Error
```

1 is a number and False is a logical value, but + requires two numbers.

Types in Haskell

If evaluating an expression e would produce a value of type t, then e has type t, written

```
e :: t
```

Every well formed expression has a type, which can be automatically calculated at compile time using a process called type inference.

- All type errors are found at compile time, which makes programs safer and faster by removing the need for type checks at run time.

- In GHCi, the :type command calculates the type of an expression, without evaluating it:

```
> not False
True

> :type not False
not False :: Bool
```

Basic Types

Haskell has a number of basic types, including:

`Bool`	-	logical values
`Char`	-	single characters
`String`	-	strings of characters
`Int`	-	fixed-precision integers
`Integer`	-	arbitrary-precision integers
`Float`	-	floating-point numbers

List Types

A list is sequence of values of the same type:

```
[False,True,False] :: [Bool]

[’a’,’b’,’c’,’d’]  :: [Char]
```

In general:

[t] is the type of lists with elements of type t.

Note:

- The type of a list says nothing about its length:

```
[False,True]       :: [Bool]

[False,True,False] :: [Bool]
```

- The type of the elements is unrestricted. For example, we can have lists of lists:

```
[[’a’],[’b’,’c’]] :: [[Char]]
```

Tuple Types

A tuple is a sequence of values of different types:

```
(False,True)     :: (Bool,Bool)

(False,’a’,True) :: (Bool,Char,Bool)
```

In general:

(t1,t2,…,tn) is the type of n-tuples whose ith components have type ti for any i in 1…n.

Note:

- The type of a tuple encodes its size:

```
(False,True)       :: (Bool,Bool)

(False,True,False) :: (Bool,Bool,Bool)
```

- The type of the components is unrestricted:

```
(’a’,(False,’b’)) :: (Char,(Bool,Char))

(True,[’a’,’b’])  :: (Bool,[Char])
```

Function Types

A function is a mapping from values of one type to values of another type:

```
not     :: Bool → Bool

isDigit :: Char → Bool
```

In general:

t1 → t2 is the type of functions that map values of type t1 to values to type t2.

Note:

- The arrow → is typed at the keyboard as ->.
- The argument and result types are unrestricted. For example, functions with multiple arguments or results are possible using lists or tuples:

```
add       :: (Int,Int) → Int
add (x,y)  = x+y

zeroto    :: Int → [Int]
zeroto n   = [0..n]
```

Curried Functions

Functions with multiple arguments are also possible by returning functions as results:

```
add’     :: Int → (Int → Int)
add’ x y = x+y
```

add’ takes an integer x and returns a function add’ x. In turn, this function takes an integer y and returns the result x+y.

Note:

- add and add’ produce the same final result, but add takes its two arguments at the same time, whereas add’ takes them one at a time:

```
add  :: (Int,Int) → Int

add’ :: Int → (Int → Int)
```

- Functions that take their arguments one at a time are called <u>curried</u> functions, celebrating the work of Haskell Curry on such functions.

- Functions with more than two arguments can be curried by returning nested functions:

```
mult      :: Int → (Int → (Int → Int))
mult x y z = x*y*z
```

mult takes an integer x and returns a function mult x, which in turn takes an integer y and returns a function mult x y, which finally takes an integer z and returns the result x*y*z.

Why is Currying Useful?

Curried functions are more flexible than functions on tuples, because useful functions can often be made by partially applying a curried function.

For example:

```
add’ 1 :: Int → Int

take 5 :: [Int] → [Int]

drop 5 :: [Int] → [Int]
```

Currying Conventions

To avoid excess parentheses when using curried functions, two simple conventions are adopted:

The arrow → associates to the right.

```
Int → Int → Int → Int
```

Means Int → (Int → (Int → Int)).

- As a consequence, it is then natural for function application to associate to the <u>left</u>.

```
mult x y z
```

Means ((mult x) y) z.

Unless tupling is explicitly required, all functions in Haskell are normally defined in curried form.

Polymorphic Functions

A function is called polymorphic ("of many forms") if its type contains one or more type variables.

```
length :: [a] → Int
```

for any type a, length takes a list of values of type a and returns an integer.

Note:

- Type variables can be instantiated to different types in different circumstances:

```
> length [False,True]
2

> length [1,2,3,4]
4
```

a = Bool

a = Int

- Type variables must begin with a lower-case letter, and are usually named a, b, c, etc.

- Many of the functions defined in the standard prelude are polymorphic. For example:

```
fst  :: (a,b) → a

head :: [a] → a

take :: Int → [a] → [a]

zip  :: [a] → [b] → [(a,b)]

id   :: a → a
```

Overloaded Functions

A polymorphic function is called <u>overloaded</u> if its type contains one or more class constraints.

```
sum :: Num a ⇒ [a] → a
```

for any numeric type a, sum takes a list of values of type a and returns a value of type a.

Note:

- Constrained type variables can be instantiated to any types that satisfy the constraints:

```
> sum [1,2,3]
6


> sum [1.1,2.2,3.3]
6.6


> sum [’a’,’b’,’c’]
ERROR
```

a = Int

a = Float

Char is not a numeric type

- Haskell has a number of type classes, including:

`Num`	-	Numeric types
`Eq`	-	Equality types
`Ord`	-	Ordered types

- For example:

```
(+)  :: Num a ⇒ a → a → a

(==) :: Eq a  ⇒ a → a → Bool

(<)  :: Ord a ⇒ a → a → Bool
```

Exercises

(1) What are the types of the following values?

```
[’a’,’b’,’c’]

(’a’,’b’,’c’)

[(False,’0’),(True,’1’)]

([False,True],[’0’,’1’])

[tail,init,reverse]
```

(2) What are the types of the following functions?

```
second xs     = head (tail xs)

swap (x,y)    = (y,x)

pair x y      = (x,y)

double x      = x*2

palindrome xs = reverse xs == xs

twice f x     = f (f x)
```

(3) Check your answers using GHCi.

Happy Hacking!