

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:

(t_1, t_2, \dots, t_n) is the type of n -tuples whose i th components have type t_i for any i in $1 \dots n$.

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
```

```
even :: Int → Bool
```

In general:

$t_1 \rightarrow t_2$ is the type of functions that map values of type t_1 to values to type t_2 .

Note:

- The arrow \rightarrow 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 curried functions, celebrating the work of Haskell Curry on such functions.

- Functions with more than two arguments can be carried 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 \rightarrow associates to the right.

$\text{Int} \rightarrow \text{Int} \rightarrow \text{Int} \rightarrow \text{Int}$



Means $\text{Int} \rightarrow (\text{Int} \rightarrow (\text{Int} \rightarrow \text{Int}))$.

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

`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
```

a = Bool

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

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 overloaded if its type contains one or more class constraints.

```
(+) :: Num a => a -> a -> a
```

For any numeric type a , $(+)$ takes two 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:

```
> 1 + 2  
3
```

a = Int

```
> 1.0 + 2.0  
3.0
```

a = Float

```
> 'a' + 'b'  
ERROR
```

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
```

Hints and Tips

- When defining a new function in Haskell, it is useful to begin by writing down its type;
- Within a script, it is good practice to state the type of every new function defined;
- When stating the types of polymorphic functions that use numbers, equality or orderings, take care to include the necessary class constraints.