CSCE 314: Programming Languages

Dr. Dylan Shell

Types and Classes in Haskell

Outline

- Data Types
- Class and Instance Declarations

Defining New Types

Three constructs for defining types:

1. **data** - Define a new data type from scratch, describing its constructors

2. **type** - Define a synonym for an existing type (like typedef in C)

3. **newtype** - A restricted form of data that is more efficient when it fits (if the type has *exactly one constructor* with *exactly one field* inside it). Used for defining "wrapper" types

Data Declarations

A completely new type can be defined by specifying its values using a data declaration.

```
data Bool = False | True
```

Bool is a new type, with two new values False and True.

- The two values False and True are called the constructors for the data type Bool.
- Type and constructor names must begin with an upper-case letter.
- Data declarations are similar to context free grammars. The former specifies the values of a type, the latter the sentences of a language.

More examples from standard Prelude:

```
data () = ()   -- unit datatype
data Char = … | ‘a’ | ‘b’ | …
```

Values of new types can be used in the same ways as those of built in types. For example, given

```
data Answer = Yes | No | Unknown
```

we can define:

```
answers      :: [Answer]
answers       = [Yes,No,Unknown]

flip         :: Answer -> Answer
flip Yes      = No
flip No       = Yes
flip Unknown = Unknown
```

Another example:

```
data Weekday = Mon | Tue | Wed | Thu | Fri | Sat | Sun
```

Constructors construct values, or serve as <u>patterns</u>

```
next :: Weekday -> Weekday
next Mon = Tue
next Tue = Wed
next Wed = Thu
next Thu = Fri
next Fri = Sat
next Sat = Sun
next Sun = Mon
```

```
workDay :: Weekday -> Bool
workDay Sat = False
workDay Sun = False
workDay _   = True
```

Constructors with Arguments

The constructors in a data declaration can also have parameters, e.g.:

```
data Shape = Circle Float | Rect Float Float
```

we can define:

```
square           :: Float → Shape
square n          = Rect n n

area             :: Shape → Float
area (Circle r) = pi * r^2
area (Rect x y) = x * y
```

- Shape has values of the form Circle r where r is a float, and Rect x y where x and y are floats.
- Circle and Rect can be viewed as <u>functions</u> that construct values of type Shape:

```
Circle :: Float → Shape
Rect   :: Float → Float → Shape
```

Another example:

```
data Person = Person Name EyeColor Age
type Name = String
data EyeColor = Brown | Blue | Green
type Age = Int
```

With just one constructor in a data type, often constructor is named the same as the type (*cf.* Person). Now we can do:

```
let x = Person “Jerry” Green 12
    y = Person “Tom” Blue 16
in …
```

Quiz: What are the types of the constructors Blue and Person?

```
Blue :: EyeColor
Person :: Name -> EyeColor -> Age -> Person
```

Pattern Matching

```
name (Person n _ _) = n

oldBlueEyes (Person _ Blue a) | a > 100 = True
oldBlueEyes (Person _ _ _) = False

> let yoda = Person “Yoda” Blue 999
   in oldBlueEyes yoda
True

findPrsn n (p@(Person m _ _):ps)
     | n == m = p
     | otherwise = findPrsn n ps

> findPrsn “Tom”
    [Person “Yoda” Blue 999, Person “Tom” Brown 7]
Person “Tom” Brown 7
```

Parameterized Data Declarations

Not surprisingly, data declarations themselves can also have parameters. For example, given

```
data Pair a b = Pair a b
```

we can define:

```
x = Pair 1 2
y = Pair "Howdy" 42

first :: Pair a b -> a
first (Pair x _) = x

apply :: (a -> a’)->(b -> b') -> Pair a b -> Pair a' b'
apply f g (Pair x y) = Pair (f x) (g y)
```

Another example:

Maybe type holds a value (of any type) or holds nothing

```
data Maybe a = Nothing | Just a
```

a is a type parameter, can be bound to any type

```
Just True :: Maybe Bool
Just “x”  :: Maybe [Char]
Nothing   :: Maybe a
```

we can define:

```
safediv     :: Int → Int → Maybe Int
safediv _ 0 = Nothing
safediv m n = Just (m `div` n)

safehead    :: [a] → Maybe a
safehead [] = Nothing
safehead xs = Just (head xs)
```

Type Declarations

A new name for an existing type can be defined using a type declaration.

```
type String = [Char]
```

String is a synonym for the type [Char].

Type declarations can be used to make other types easier to read. For example, given

```
type Pos = (Int,Int)
```

we can define:

```
origin    :: Pos
origin     = (0,0)

left      :: Pos → Pos
left (x,y) = (x-1,y)
```

Like function definitions, type declarations can also have parameters. For example, given

```
type Pair a = (a,a)
```

we can define:

```
mult        :: Pair Int -> Int
mult (m,n) = m*n

copy        :: a -> Pair a
copy x       = (x,x)
```

Type declarations can be nested:

```
type Pos   = (Int,Int)

type Trans = Pos -> Pos
```

However, they cannot be recursive:

```
type Tree = (Int,[Tree])
```

Recursive Data Types

New types can be declared in terms of themselves. That is, data types can be recursive.

```
data Nat = Zero | Succ Nat
```

Nat is a new type, with constructors Zero :: Nat and Succ :: Nat -> Nat.

A value of type Nat is either Zero, or of the form Succ n where n :: Nat. That is, Nat contains the following infinite sequence of values:

```
Zero

Succ Zero

Succ (Succ Zero)

. . .
```

Example function:

```
add :: Nat -> Nat -> Nat
add Zero n = n
add (Succ m) n = Succ (add m n)
```

Parameterized Recursive Data Types - Lists

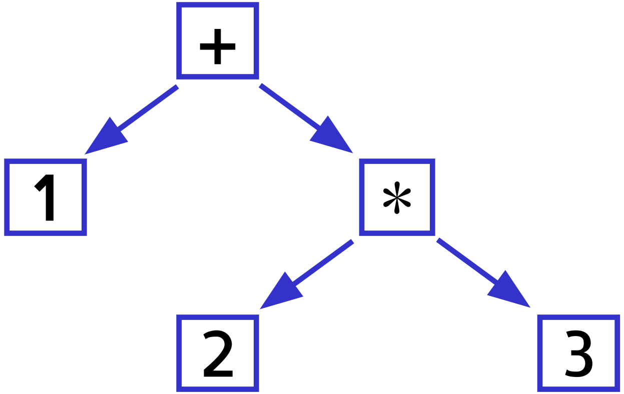
```
data List a = Nil | Cons a (List a)

sum :: List Int -> Int
sum Nil          = 0
sum (Cons x xs)  = x + sum xs

> sum Nil
0
> sum (Cons 1 (Cons 2 (Cons 2 Nil)))
5
```

Arithmetic Expressions

Consider a simple form of expressions built up from integers using addition and multiplication.



Using recursion, a suitable new type to represent such expressions can be declared by:

```
data Expr = Val Int
          | Add Expr Expr
          | Mul Expr Expr
```

For example, the expression on the previous slide would be represented as follows:

```
Add (Val 1) (Mul (Val 2) (Val 3))
```

Using recursion, it is now easy to define functions that process expressions. For example:

```
size            :: Expr → Int
size (Val n)     = 1
size (Add x y) = size x + size y
size (Mul x y) = size x + size y

eval            :: Expr → Int
eval (Val n)     = n
eval (Add x y) = eval x + eval y
eval (Mul x y) = eval x * eval y
```

Note:

- The three constructors have types:

```
Val :: Int → Expr
Add :: Expr → Expr → Expr
Mul :: Expr → Expr → Expr
```

- Many functions on expressions can be defined by replacing the constructors by other functions using a suitable <u>fold</u> function. For example:

```
eval = fold id (+) (*)
```

Trees

A binary Tree is either Tnil, or a Node with a value of type a and two subtrees (of type Tree a)

```
data Tree a = Tnil | Node a (Tree a) (Tree a)
```

Find an element:

```
treeElem :: (a -> Bool) -> Tree a -> Maybe a
treeElem p Tnil = Nothing
treeElem p t@(Node v left right)
  | p v = Just v
  | otherwise = treeElem p left `combine` treeElem p right
  where combine (Just v) r = Just v
        combine Nothing r  = r
```

Compute the depth:

```
depth Tnil                = 0
depth (Node _ left right) = 1 +
  (max (depth left) (depth right))
```

About Folds

A fold operation for Trees:

```
treeFold :: t -> (a -> t -> t -> t) -> Tree a -> t
treeFold f g Tnil = f
treeFold f g (Node x l r)
             = g x (treeFold f g l) (treeFold f g r)
```

How? Replace all <u>Tnil</u> constructors with f, all <u>Node</u> constructors with g.

```
> let tt = Node 1 (Node 2 Tnil Tnil)
                  (Node 3 Tnil (Node 4 Tnil Tnil))
> treeFold 1 (\x y z -> 1 + max y z) tt
4
> treeFold 1 (\x y z -> x * y * z) tt
24
> treeFold 0 (\x y z -> x + y + z) tt
10
```

Deriving

- Experimenting with the above definitions will give you many errors
- Data types come with no functionality by default, you cannot, e.g., compare for equality, print (show) values etc.
- Real definition of Bool

```
data Bool = False | True
         deriving (Eq, Ord, Enum, Read, Show, Bounded)
```

- A few standard type classes can be listed in a deriving clause
- Implementations for the necessary functions to make a data type an instance of those classes are generated by the compiler
- deriving can be considered a shortcut, we will discuss the general mechanism later

Exercises

(1) Using recursion and the function add, define a function that multiplies two natural numbers.

(2) Define a suitable function fold for expressions, and give a few examples of its use.

(3) A binary tree is complete if the two sub-trees of every node are of equal size. Define a function that decides if a binary tree is complete.

Outline

- Data Types
- Class and Instance Declarations

Type Classes

1. A new class can be declared using the class construct
2. Type classes are classes of types, thus not types themselves

Example:

```
class Eq a where
    (==), (/=) :: a -> a -> Bool
    -- Minimal complete definition: (==) and (/=)
    x /= y   = not (x == y)
    x == y   = not (x /= y)
```

- For a type a to be an instance of the class Eq, it must support equality and inequality operators of the specified types
- Definitions are given in an instance declaration
- A class can specify default definitions

Instance Declarations

```
class Eq a where
   (==), (/=) :: a -> a -> Bool
   x /= y    = not (x == y)
   x == y    = not (x /= y)
```

Let us make Bool be a member of Eq

```
instance Eq Bool where
   (==) False False   = True
   (==) True True     = True
   (==) _ _           = False
```

- Due to the default definition, (/=) need not be defined
- deriving Eq would generate an equivalent definition

Showable Weekdays

```
class Show a where
  showsPrec :: Int -> a -> ShowS -- to control parenthesizing
  show :: a -> String

  showsPrec _ x s = show x ++ s
  show x          = showsPrec 0 x “”


data Weekday = Mon | Tue | Wed | Thu | Fri | Sat | Sun
instance Show Weekday where
  show Mon = “Monday”
  show Tue = “Tuesday”
  . . .
> map show [Mon, Tue, Wed]
[“Monday”, “Tuesday”, “Wednesday”]
```

Parameterized Instance Declarations

Every list is showable if its elements are

```
instance Show a => Show [a] where
  show []     = “[]”
  show (x:xs) = “[“ ++ show x ++ showRest xs
   where showRest []     = “]”
         showRest (x:xs) = “,” ++ show x ++ showRest xs
```

Now this works:

```
> show [Mon, Tue, Wed]
“[Monday,Tuesday,Wednesday]”
```

Showable, Readable, and Comparable Weekdays

```
data Weekday = Mon | Tue | Wed | Thu | Fri | Sat | Sun
      deriving (Show, Read, Eq, Ord, Bounded, Enum)
```

```
*Main> show Wed
"Wed"
*Main> read "Fri" :: Weekday
Fri
*Main> Sat Prelude.== Sun
False
*Main> Sat Prelude.== Sat
True
```

```
*Main> Mon < Tue
True
*Main> Tue < Tue
False
*Main> Wed `compare` Thu
LT
```

Bounded and Enumerable Weekdays

```
data Weekday = Mon | Tue | Wed | Thu | Fri | Sat | Sun
     deriving (Show, Read, Eq, Ord, Bounded, Enum)
```

```
*Main> minBound :: Weekday
Mon
*Main> maxBound :: Weekday
Sun
*Main> succ Mon
Tue
```

```
*Main> pred Fri
Thu
*Main> [Fri .. Sun]
[Fri,Sat,Sun]
*Main> [minBound .. maxBound] ::
[Weekday]
[Mon,Tue,Wed,Thu,Fri,Sat,Sun]
```