Types and strings

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Types in Haskell are a way of *categorizing values*; they provide a syntactic restriction on how complex expressions are built.

You might be familiar with types if you've ever taken a semantics course before.

- *is happy*: $\langle e, t \rangle$
- *Henning*: e

- Haskell has a more complex and powerful type-system than the one you might be used to from formal semantics.
    - Formal semantics typically uses the *simply-typed lambda calculus* as a basis.
    - Haskell is based on System F, i.e., the *polymorphic lambda calculus*, which allows for universal quantification over types.
    - Various *language extensions* exist to make Haskell's type system even more powerful (dependent types, linear types, etc).
    - In this course, we won't go much beyond simple types and some basic polymorphism.

Getting information about types

You can find out the type of any haskell expression quite easily using the `:type` command in GHCi:

```
ghci> :t "hello haskell!"
"hello haskell!" :: String
ghci> :t 'a'
'a' :: Char
```

- Note that single characters are enclosed in single quotes.
- The double colon `::` is interpreted as *has the type*.

We explicitly annotate expressons with their type using `::`.

```
ghci> :t ("hello haskell!" :: String)
"hello haskell!" :: String
```

If we annotate an expression with the wrong type, we'll get an error:

```
ghci> :t ("hello haskell!" :: Char)
<interactive>:1:2: error:
    • Couldn't match type ‘[Char]’ with ‘Char’
      Expected: Char
        Actual: String
```

`String` is actually a name for a *complex type*, `[Char]`.

That is to say, strings in haskell are actually just *lists of characters*.

In general, for any type `a`, the type `[a]` is the type of a list of things of type `a`.

We can print strings to the standard output in GHCi using the `putStrLn` or `putStr` functions.

```
ghci> putStrLn "hello haskell!"
hello haskell!
```

Examine the type of `putStrLn`. You'll notice something quite interesting.

```
ghci> :t putStrLn
putStrLn :: String -> IO ()
```

In Haskell, we use arrow notation for function types (we'll come back to this later). `IO ()` is a special type to indicate that the program has some effect beyond evaluation of functions and arguments.

```haskell
  -- print1.hs

module Print1 where

main :: IO ()
main = putStrLn "hello world!"
```

If we load `print1.hs` from GHCi and execute `main`, *hello world!* will be printed to the standard output.

In haskell `main` is the default action when building an executable, or running it in GHCi, and it must always be of type `IO ()`.

Input/output is much more complicated in Haskell than in most other programming languages, since it involves exploiting Haskell's type system to reason about *side effects*. This will be a topic for later in the semester.

Concatenating strings

There are two functions for concatenating strings in the haskell prelude:

```
(++) :: [a] -> [a] -> [a]
concat :: [[a]] -> [a]
```

- `++` is an infix operator, whereas ~concat is just an ordinary function.
- Note that `a` in the type signature is a *type variable*. Free variables in type signatures are implicitly universally quantified in Haskell.
- This means that both `++` and `concat` are *polymorphic* functions; they can be used to combine lists more generally.

In formal semantics, functional types are often written using angled-brackets (e.g., $\langle e, t\rangle$), following the convention used by (Heim, Irene and Kratzer, Angelika, 1998).

Haskell uses arrow notation, which is more commonly found in the computer science/programming language literature, although some semantics texts use arrow notation (Carpenter, Bob, 1998).

Arrow notation in Haskell is *right associative*:

- `a -> b -> c` $\iff$ `a -> (b -> c)`

Types primer ii

Let's look again at the type for list concatenation:

```
(++) :: [a] -> [a] -> [a]
```

- `(->)` is a type *constructor*. It takes two types `a`, `b` and returns the type of a function from as to bs.
- One important feature of haskell is the possibility of defining arbitrary constructors; `([.])` takes a type `a` and returns the type of a list of as.
- Remember, free type variables are implicitly universally quanitified, which means that list concatenation is defined for something of type `[a]`, where `a` can be *any type*.

Strings as lists of chars

```
"hello haskell!"
['h','e','l','l','o',' ','h','a','s','k','e','l','l','!']
```

- Strings surrounded by double quotes are really just *syntactic sugar* for lists of characters.
- Syntactic sugar is just a notational convention built into the language that makes our lives as programmers easier.
- Lists are actually also syntactic sugar! We'll learn what lists really are in a bit.

What do you think the following evaluates to?

```
[1,2,3] ++ [4,5,6]
```

What happens if we try to evaluate the following:

```
"hello" ++ [4,5,6]
```

More list manipulation

```
ghci> head "Henning"
'H'
ghci> tail "Henning"
"enning"
ghci> take 0 "Henning"
""
ghci> take 3 "Henning"
"Hen"
ghci> drop 3 "Henning"
"ning"
ghci> "Henning" !! 2
'n'
```

What happens when you run the following in GHCi:

```
ghci> "yo" !! 2
```

Let's examine the type of `!!`; as expected, its a function from a list of as, to an integer, to an a.

```
(!!) :: [a] -> Int -> a
```

Note however, that this isn't a *total* function; there are some lists and integers for which this function will be undefined.

Partial functions in haskell are considered *unsafe*, because the type system doesn't prevent us from providing an illicit value as an argument to the function.

Building lists with `cons`

The final list manipulation function we'll look at is an important one: `cons`.

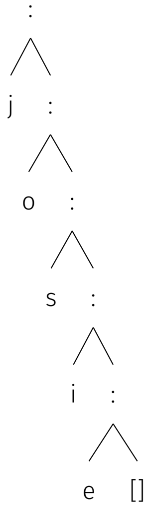
```
ghci> 'h' : []
[h]
ghci> 'h' : "enning"
"henning"
```

In haskell, lists are built up by successive application of `cons`:

```
'h' : ('e' : ('n' : ('n' : ('i' : ('n' : ('g' : []))))))
```

Since `:` is right associative we can drop the parentheses.

Lists in haskell are therefore *singly-linked lists of characters*.


:
j
:
o
:
s
:
i
:
e
[]

- For most industrial applications, singly-linked lists of chars would be a terrible choice.
- On the other hand, this means that strings ”come for free” on the basis of chars and extremely general list manipulation functions.
- For anything we do in this class, performance won’t be an issue. For serious work with strings, the standard is the Haskell `text` library.

Prolegomenon to types

- In preparation for next week's class with type.
- Types are syntactic categories used to restrict what counts as a valid expression.
- Basic ingredients:
    - A set of primitive types.
    - A recursive rule for constructing complex (i.e., functional) types.
    - Rules for computing the type of a complex expression from the types of its parts.

- Let's keep things simple, and start with just two primitive types:

$$\mathbf{Typ} := \{\mathtt{Int}, \mathtt{Bool}\}$$

- We'll assume that integers are possible values and have the type `Int`:

$$73 :: \mathtt{Int}$$

- We'll also assume two primitive values with the type `Bool`:

$$\mathbf{true} :: \mathtt{Bool}, \mathbf{false} :: \mathtt{Bool}$$

We'll now state a recursive rule for complex (functional) types, using the Haskell convention for types.

- If $\mathtt{a} \in \mathbf{Typ}$, then $\mathtt{a}$ is a type.
- If $\mathtt{a}$ is a type, and $\mathtt{b}$ is a type, then $\mathtt{a} \to \mathtt{b}$ is a type.
- Nothing else is a type.

This means that we have many complex types like the following:

- $(\mathtt{Bool} \to \mathtt{Bool}) \to \mathtt{Int}$
- $\mathtt{Int} \to \mathtt{Int}$

- We can assign some useful operations their types:

$$(+) :: \texttt{Int} \to \texttt{Int} \to \texttt{Int}$$

$$(-) :: \texttt{Int} \to \texttt{Int} \to \texttt{Int}$$

$$\textbf{factorial} :: \texttt{Int} \to \texttt{Int}$$

$$\textbf{odd} :: \texttt{Int} \to \texttt{Bool}$$

$$\textbf{even} :: \texttt{Int} \to \texttt{Bool}$$

$$\textbf{and} :: \texttt{Bool} \to \texttt{Bool} \to \texttt{Bool}$$

Functional applications: Let $\beta :: \mathsf{a} \rightarrow \mathsf{b}$, $\alpha :: \mathsf{a}$ be an expression of the SLTC. $\beta(\alpha)$ is an expression of type b.

Abstractions: Let $\beta :: \mathsf{b}$ be an expression of the SLTC, and υ a variable of type a. $\lambda\upsilon.\beta$ is an expression of type $\mathsf{a} \rightarrow \mathsf{b}$.

Can you infer the types of the following expressions? Go step by step.

$$\mathbf{and}(\mathbf{odd}(4))(t)$$

$$\lambda x.\mathbf{odd}(\mathbf{factorial}(x))$$

$$\lambda f.f(\lambda x.(+)(x)(2))$$

Often, you can *infer* the type of an expression without specifying the type of all of its sub-parts.

When you try to compile a haskell source file, or evaluate an expression in GHCi, the compiler will attempt to check that it is well-typed, by inferring the types of any expressions that don't have an explicit type provided.

Since haskell's type system is more expressive than we have here, the type-inference algorithm is quite complicated (the compiler is based on an algorithm called *Hindley-Milner*).

In a first order type-system, we can only state typed identity functions.

What is the type of *the* identity function?

$$\lambda x.x :: ?$$

Consider the following functions:

$$\mathbf{not} :: \texttt{Bool} \rightarrow \texttt{Bool}$$

$$\mathbf{not}' :: \lambda f.\lambda x.\mathbf{not}(f(x))$$

$$\mathbf{not}'' :: \lambda r.\lambda x.\lambda y.\mathbf{not}(r(x)(y))$$

- What are the types of not’ and not”?
- Is there a way of expressing all three functions as a single-operation? If not, why not?

Remember the expression ω:

$$(\lambda x.xx)(\lambda x.xx)$$

- Try to give it a concrete type.
- This problem is related to the lack of Turing completeness of the SLTC.
- On the other hand, because the SLTC is relatively constrained it has some extremely nice logical properties:
    - The SLTC is a sound and complete logic.
    - *Type-checking* (checking whether an expression is well-typed), and *type inference* are decidable.

- Next time we’ll learn much more about Haskell’s type system.
- Haskell’s type system is more expressive than the SLTC - we can do everything we can in the SLTC and more.
- We’ll learn about *polymorphic functions* corresponding *polymorphic datatypes*; a first step in understanding the kinds of powerful abstractions that Haskell provides to reason about computation.

$\mathcal{F}in$

References

Carpenter, Bob (1998). *Type-Logical Semantics*, MIT Press.

Heim, Irene and Kratzer, Angelika (1998). *Semantics in Generative Grammar*, Blackwell.