Polymorphism

Concepts of Programming Languages
Lecture 4

CAS CS 320

Practice Problem

```
let k = fun x -> (fun y -> x) in
let x = 3 + k k 2 3 4 in
k x (k x)
```

1 k 3 6 6 6

Would UTop throw a type error on the above expressions? If not, what does it evaluate to?

Answer

```
let k = fun x -> fun y -> x in
let x = 3 + k k 2 3 4 in
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```

Practice Problem

Implement the function

```
val bitonic : int -> int -> int -> int list
```

so that **bitonic i j k** is a list of consecutive integers from **i** to **j** to **k**, e.g.,

```
bitonic 1 5 3 = [1;2;3;4;5;4;3]
```

Outline

- Discuss **polymorphism** in general
- Demo **examples** of polymorphic functions

Polymorphism

Recall: Polymorphism and Lists

```
let rec length l =
  match l with
  | [] -> 0
  | x :: xs -> 1 + length xs
```

What is the type of the length function?

Does this function depend on the values in the list?

Recall: The List Type

`[1;2;3]`	`["1";"2";"3"]`	`[[1;1];[2;2];[3;3]]`
`int list`	`string list`	`int list list`

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A function on lists is *polymorphic* (with respect to the list parameter) if it can be apply to a list parametrized by *any* type

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`["1";"2";"3"]` **string list**

`[[1;1];[2;2];[3;3]]` **int list list**

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For this, we need *type parameters* to stand for *any* type:

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`'a, 'b, 'c,...`

Not all functions are polymorphic

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let rec sum l =
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OCaml's type inference is good at "guessing" when functions are polymorphic

Example

Implement the function

reverse : 'a list -> 'a list

such that ***reverse l*** *is the same as* ***l*** *but in reverse order*

High Level

```
let rec rev_int (l : int list) : int list =
  match l with
  | [] -> []
  | x :: l -> rev l @ [x]

let rec rev_string (l : string list) : string list =
  match l with
  | [] -> []
  | x :: l -> rev l @ [x]

let _ = assert (rev_int [1;2;3] = [3;2;1])
let _ = assert (rev_string ["1";"2";"3"] = ["3";"2";"1"])
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Copy/pasting code is *time consuming* and *error prone*

Polymorphism allows for better code reuse. The *same* function can be applied in multiple contexts

Basic Example

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let id = fun x -> x
let a = id 0
let b = id (0 = 0)
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*But if we type-check, what should be the type of **id**?*

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1. **Ad Hoc Polymorphism:** The ability to overload function names so that different types can share interfaces

our focus

2. **Parametric polymorphism:** The ability to define functions that are *agnostic* to (parts of) the types, giving it more reusability

Ad Hoc Polymorphism

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let add (x : float) (y : float) = x +. y
let add (x : string) (y : string) = x ^ y
(* This doesn't work in OCaml... *)
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Ad hoc polymorphism is essentially **function overloading**

Functions can be defined and used for different types of inputs

Then we can define code against *interfaces* (this is common in object oriented programming)

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For example, we can write a single identity function and use it in multiple contexts

Type Parameters

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let id : 'a -> 'a = fun x -> x
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Type parameters are instantiated at particular types according to the context

Looking Ahead: Quantification

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In reality, types variables in OCaml are **quantified**

Just like with expression variables, we don't like *unbound* type variables

We read this "**id** has type **t -> t** for any type **t**"

Polymorphism and Type Inference

(int -> 'a) -> (int -> 'a)

```
fun f -> (fun x -> f (x + 1))
```

In OCaml, the type of an expression depends on how its subexpressions are *used*

OCaml can figure out what is the "most" polymorphic type we can give to an expression

This is called **type inference**

demo

(remove)

There are many subtleties to this...

Subtlety 1: Type Annotations

```
let rec rev ('a list) : 'a list =
  match l with
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let id : 'a -> 'a = fun x -> x
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Parametric polymorphism is *not* just removing type annotations

There are PLs *without* polymorphism *or* type annotations

There are PLs *with* polymorphism that *require* type annotations

Subtlety 2: Type Inference

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We will take up this topic at the end of the course

Subtlety 3: Dynamic Dispatch

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let to_string (x : 'a) : string = ...
(* This is not possible in OCaml *)
```

Parametric polymorphism cannot be used for *dispatch*

We can't write a polymorphic function that "checks the type" to see what to do

Practice Problem

```
let rec f x = f (f (x + 1)) in f
```

What is the type of the above OCaml expressions?

Answer

```
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```

Aside: Parametricity

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Can you write function of type ***'a -> 'a****?*

fun x -> x

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Can you write a another?

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Can you write a another?

Parametricity refers the (very cool) observation that polymorphic types often restrict the kinds of functions you can write in a *mathematically rigorous sense*

Summary

Polymorphism allows functions to be agnostic to (parts of) the types of its parameters

Parametric polymorphism does not allow for dynamic dispatch, it must given the *same* implementation at any particular type