CSE 130

Programming Languages

Lecture: Polymorphism

Ranjit Jhala
UC San Diego

Example: Calculator Revisited

```
type expr =
   | Num of int
   | Div of expr * expr
```

Can you write a function?

```
val eval : expr -> int
```

In Class Exercise

```
type expr =
   | Num of int
   | Div of expr * expr
```

Write an Evaluation function

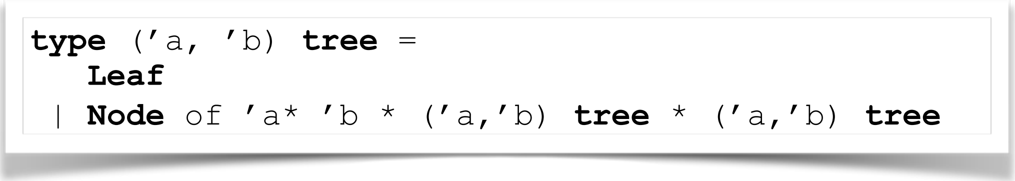
```
val eval : expr -> int option
```

That returns *None* if a div-by-zero occurs

Moral

Failure ***is*** an Option!

Datatypes with many type variables



```
type ('a, 'b) tree =
   Leaf
 | Node of 'a* 'b * ('a,'b) tree * ('a,'b) tree
```

Datatypes with many type variables

- Multiple type variables

```
type ('a,'b) tree =
  Leaf
| Node of 'a* 'b * ('a,'b) tree * ('a,'b) tree
```

- Type is instantiated for each use:

Node(“alice”, 2, Leaf, Leaf)

Node(“charlie”, 3, Leaf, Leaf)

Node(“bob”, 13,
, Node(“alice”, 2, Leaf, Leaf)
, Node(“charlie”, 3, Leaf, Leaf))

Datatypes with many type variables

- Multiple type variables

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type ('a,'b) tree =
  Leaf
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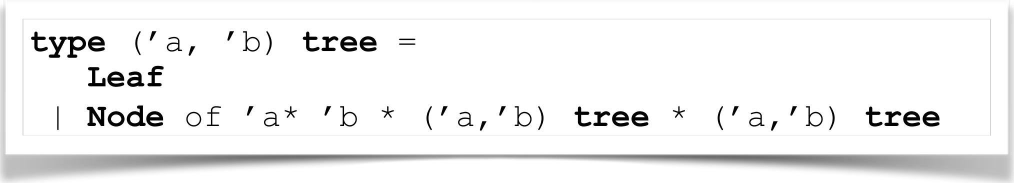
- Type is instantiated for each use:

Node(“alice”, 2, Leaf, Leaf)

Node(“charlie”, 3, Leaf, Leaf)

Node(“bob”, 13,
, Node(“alice”, 2, Leaf, Leaf)
, Node(3, “charlie”, Leaf, Leaf))

Binary Search Trees



```
type ('a, 'b) tree =
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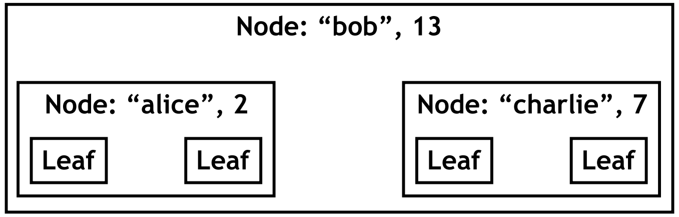
 | Node of 'a* 'b * ('a,'b) tree * ('a,'b) tree
```

Node (key, value, left, right)

BST Property:

keys in left < key < keys in right

BST Property: *keys in left < key < keys in right*



```
Node(“bob”, 13
    , Node(“alice”, 2, Leaf, Leaf)
    , Node(“charlie”, 3, Leaf, Leaf))
```

In-Class Exercise!

BST Property: *keys in left < key < keys in right*

```
type (’a, ’b) tree =
    Leaf
  | Node of ’a* ’b * (’a,’b) tree * (’a,’b) tree
```

Write a function to lookup keys…

```
val lookup: ’a ->(’a,’b)tree ->’b option
```

Polymorphic Data Structures

- Container data structures independent of type !
- Appropriate type is instantiated at each use:

’a list
(’a , ’b) tree
(’a , ’b) hashtbl …

- Static type checking catches errors early
  - Cannot add int key to string hashtable
- Generics: in Java,C#,VB (borrowed from ML)

Type Inference

How DOES Ocaml figure out all the types ?!

Polymorphic Types

- Polymorphic types are tricky
- Not always obvious from staring at code
- How to ensure correctness ?
- Types (almost) never entered w/ program!

Polymorphic Type Inference

- Computing the types of all expressions
  - At compile time : statically Typed
- Each binding is processed in order
  - Types are computed for each binding
  - For expression and variable bound to
  - Types used for subsequent bindings
- Unlike values (determined at run-time)

Polymorphic Type Inference

- Every expression accepted by ML must have a valid inferred type
- Can have no idea what a function does, but still know its exact type
- A function may never (or sometimes terminate), but will still have a valid type

Example 1

```
let x = 2 + 3;;

let y = string_of_int x;;
```

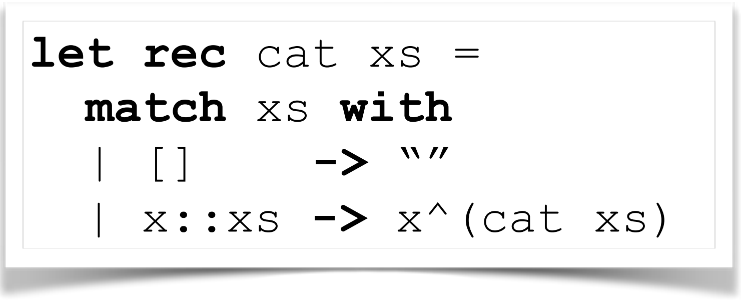
Example 2

```
let x = 2 + 3;;

let y = string_of_int x;;

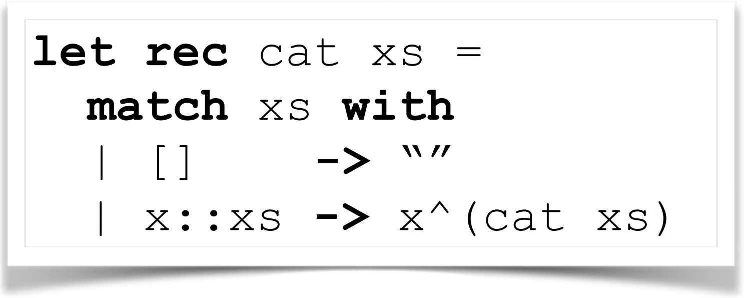
let inc y = x + y;;
```

Example 5



```
let rec cat xs =
  match xs with
   | []     -> “”
   | x::xs  -> x^(cat xs)
```

ML doesn’t know what function does, or even that it finishes only its type!



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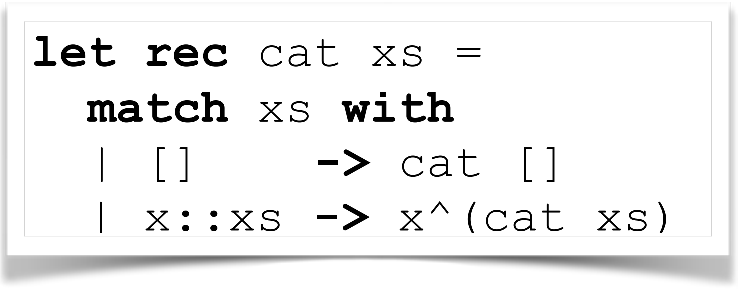

```
let rec cat xs =
  match xs with
   | []     -> cat []
   | x::xs  -> x^(cat xs)
```

Example 5

```
let rec map f xs =
  match xs with
   | []       -> []
   | x::xs’  ->(f x)::(map f xs’)
```

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let rec map f xs =
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```

“Generalize” Unconstrained Vars

```
(‘a->‘b) -> ‘a list -> ‘b list
```

Example 7

```
let rec fold f cur xs =
  match xs with
     []       -> cur
   | x::xs’  -> fold f (f cur x) xs’
```

Example 11

```
let foo1 f g x =
  if f x
  then x
  else g x
```

Example 12

```
let foo2 f g x =
  if f x
  then x
  else foo2 f g (g x)
```