

CMSC 330: Organization of Programming Languages

Closures (Implementing Higher Order Functions)

Returning Functions as Results

- ▶ In OCaml you can **pass functions as arguments** to **map**, **fold**, etc. and you can **return functions as results**

```
# let pick_fn n =  
    let plus3 x = x + 3 in  
    let plus4 x = x + 4 in  
    if n > 0 then plus3 else plus4  
val pick_fn : int -> (int->int) = <fun>
```

```
# let g = pick_fn 2;;  
val g : int -> int = <fun>  
# g 4;;      (* evaluates to 7 *)
```

Multi-argument Functions

- ▶ Consider a rewriting of the prior code (above)

```
let pick_fn n =  
    if n > 0 then (fun x->x+3) else (fun x->x+4)
```

- ▶ Here's another version

```
let pick_fn n =  
    (fun x -> if n > 0 then x+3 else x+4)
```

Currying



- ▶ We just saw a way for a **function to take multiple arguments!**
 - I.e., **no separate concept** of **multi-argument functions** – can encode one as a *function that takes a single argument and returns a function that takes the rest*
- ▶ This encoding is called **currying** the function
 - Named after the logician **Haskell B. Curry**.
 - three programming languages are named after him: Haskell, Brook, and Curry

Curried Functions In OCaml

- ▶ OCaml syntax defaults to currying. E.g.,

```
let add x y = x + y
```

- is identical to all of the following:

```
let add = (fun x -> (fun y -> x + y))  
let add = (fun x y -> x + y)  
let add x = (fun y -> x+y)
```

- `add` has type `int -> (int -> int)`
- `add 3` has type `int -> int`
 - ▶ `add 3` is a function that adds 3 to its argument
- `(add 3) 4 = 7`

Syntax Conventions for Currying

- ▶ Because currying is so common, OCaml uses the following conventions:
 - `->` associates from the right
 - Thus `int -> int -> int` is the same as
 - `int -> (int -> int)`
 - function application associates from the left
 - Thus `add 3 4` is the same as
 - `(add 3) 4`

Quiz 1: Which f definition is equivalent?

`let f a b = a / b;;`

A. `let f b = fun a -> a / b;;`

B. `let f = fun a -> (fun b -> a / b) ;;`

C. `let f = fun a | b -> a / b;;`

D. `let f (a, b) = a / b;;`

Quiz 1: Which f definition is equivalent?

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A. `let f b = fun a -> a / b;;`

B. `let f = fun a -> (fun b -> a / b) ;;`

C. `let f = fun a | b -> a / b;;`

D. `let f (a, b) = a / b;;`

Quiz 2: What is enabled by currying?

- A. Passing functions as arguments
- B. Passing only a portion of the expected arguments
- C. Naming arguments
- D. Recursive functions

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Multiple Arguments, Partial Application

- ▶ Another way for passing multiple arguments is using tuples
 - `let f (a,b) = a / b (* int*int -> int *)`
 - `let f a b = a / b (* int-> int-> int *)`
- ▶ Is there a benefit to using currying instead?
 - Supports **partial application** – useful when you want to provide some arguments now, the rest later

Closure

OCaml Example

```
let foo x =  
  let bar = fun y -> x + y in  
  bar  
;;
```

foo 10 = ?

(fun y -> x + y) 10?

Where is **x**?

Another Example

```
let x = 1 in
  let f = fun y -> x in
    let x = 2 in
      f 0
```

What does this expression should evaluate to?

- A. 1
- B. 2

Another Example

```
let x = 1 in
  let f = fun y -> x in
    let x = 2 in
      f 0
```

What does this expression should evaluate to?

- A. 1
- B. 2

Scope

► **Dynamic scope**

- The body of a function is evaluated in the current dynamic environment at the time the function is **called**, not the old dynamic environment that existed at the time the function was defined.

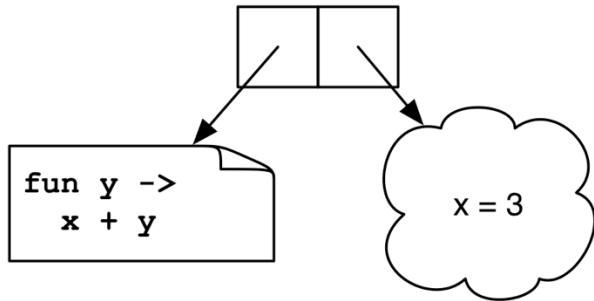
► **Lexical scope**

- The body of a function is evaluated in the old dynamic environment that existed at the time the function was **defined**, not the current environment when the function is called.

Closure

```
let foo x =  
  let bar y = x + y  
in  
bar ;;
```

foo 3 Closure

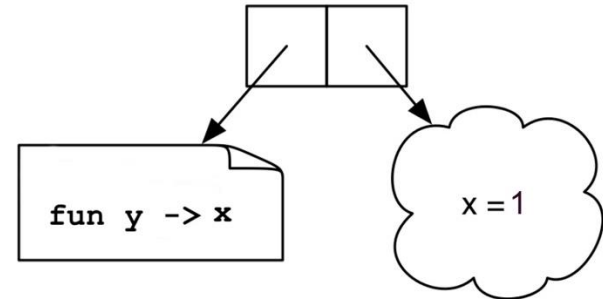


Function

Environment

```
let x = 1 in  
let f = fun y -> x  
in  
let x = 2 in  
f 0
```

Closure



Function

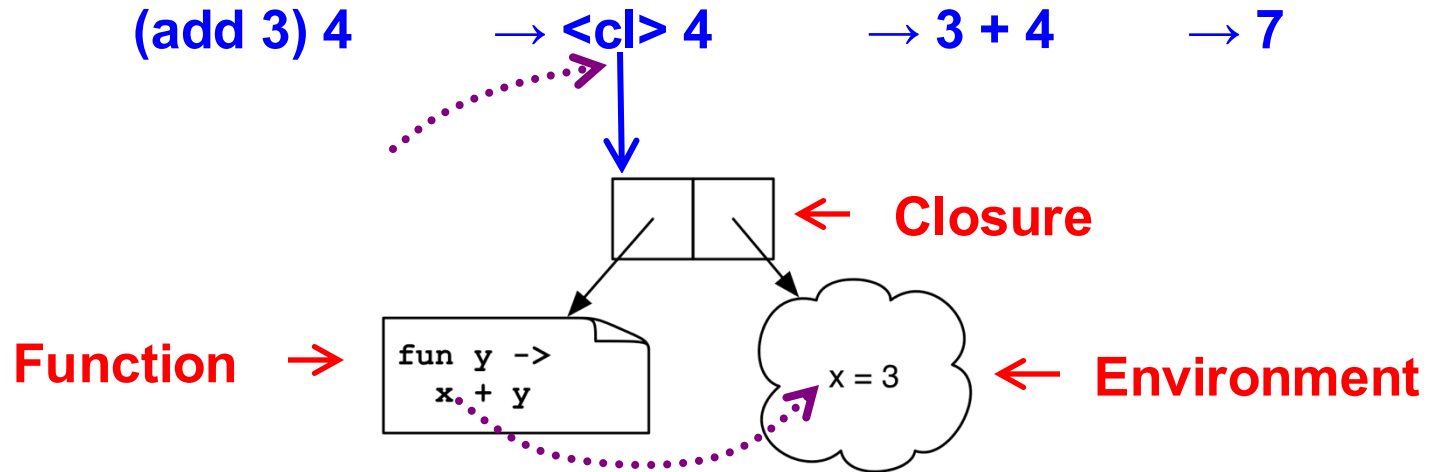
Environment

Closures Implement Static Scoping

- ▶ An **environment** is a mapping from variable names to values
 - Just like a stack frame
- ▶ A **closure** is a pair (f, e) consisting of function code f and an environment e
- ▶ When you invoke a closure, f is evaluated using e to look up variable bindings

Example – Closure 1

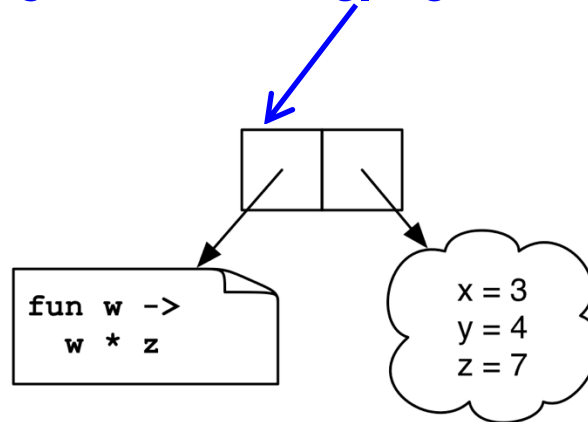
```
let add x = (fun y -> x + y)
```



Example – Closure 2

```
let mult_sum (x, y) =  
  let z = x + y in  
  fun w -> w * z
```

`(mult_sum (3, 4)) 5` \rightarrow `<cl> 5` \rightarrow `5 * 7` \rightarrow `35`



Quiz 3: What is x?

```
let a = 0;;  
let b = 10;;  
let f () = a + b;;  
let b = 5;;  
let x = f ();;
```

- A. 15
- B. 1
- C. 10
- D. Error - variable name conflicts

Quiz 3: What is x?

```
let a = 0;;  
let b = 10;;  
let f () = a + b;;  
let b = 5;;  
let x = f ();;
```

A. 15

B. 1

C. 10

D. Error - variable name conflicts

Quiz 4: What is z?

```
let f x = fun y -> x - y in
  let g = f 2 in
  let x = 3 in
  let z = g 4 in
z;;
```

A. -2

B. 7

C. -1

D. Type Error – insufficient arguments

Quiz 4: What is z?

```
let f x = fun y -> x - y in
let g = f 2 in
let x = 3 in
let z = g 4 in
z;;
```

A. -2

B. 7

C. -1

D. Type Error – insufficient arguments

Quiz 5: What does this evaluate to?

```
let f x = x+1 in  
  let g = f in  
    g (fun i -> i+1) 10
```

- A. Type Error
- B. 1
- C. 2
- D. 3

Quiz 5: What does this evaluate to?

```
let f x = x+1 in  
let g = f in  
(g (fun i -> i+1) ) 10
```

- A. **Type Error** – Too many arguments passed to g (application is *left associative*)
- B. 1
- C. 2
- D. 3


Higher-Order Functions in C

- ▶ C supports **function pointers**, but does not support closures

```
typedef int (*int_func) (int);  
void app(int_func f, int *a, int n) {  
    for (int i = 0; i < n; i++)  
        a[i] = f(a[i]);  
}  
int add_one(int x) { return x + 1; }  
int main() {  
    int a[] = {5, 6, 7};  
    app(add_one, a, 3);  
}
```

Java Example

```
public class Test{
    public void doSomething(){
        int a = 10; //must be final
        Runnable runnable = new Runnable(){
            public void run(){
                int b = a + 1;
                System.out.println(b);
            }
        };
        (new Thread(runnable)).start(); //runs later
        //a = 100; //not allowed
    }
    public static void main(String[] args){
        Test t = new Test();
        t.doSomething();
    }
} // a=10 is removed from the stack here
```



Needed later,
makes copy of a

Java 8 Supports Lambda Expressions

- ▶ Ocaml's

`fun (a, b) -> a + b`

- ▶ Is like the following in Java 8

`(a, b) -> a + b`

- ▶ Java 8 supports closures, and variations on this syntax