CS443: Compiler Construction

Lecture 11: Environments and DeBruijn Indices

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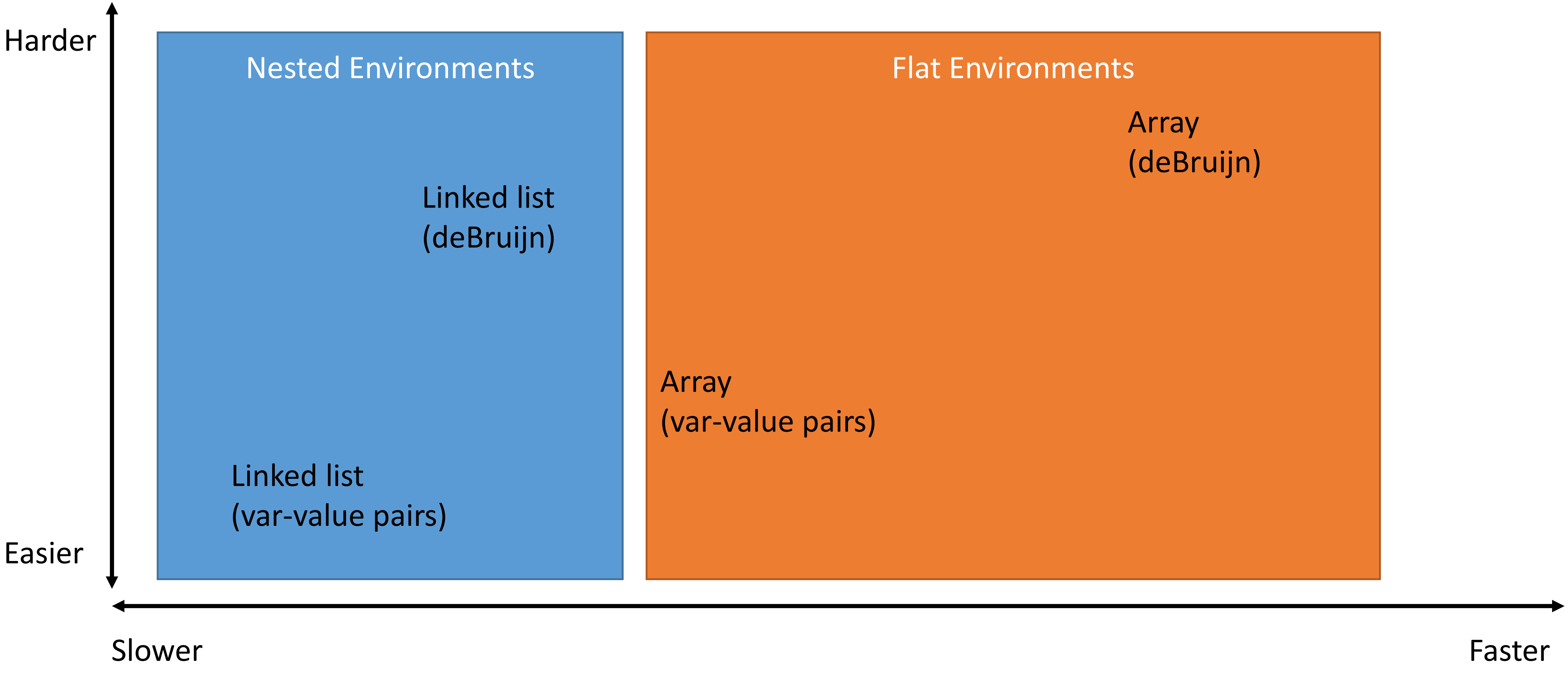
Based on material from Steve Chong, Steve Zdancewic, and Greg Morrisett

How to represent environments

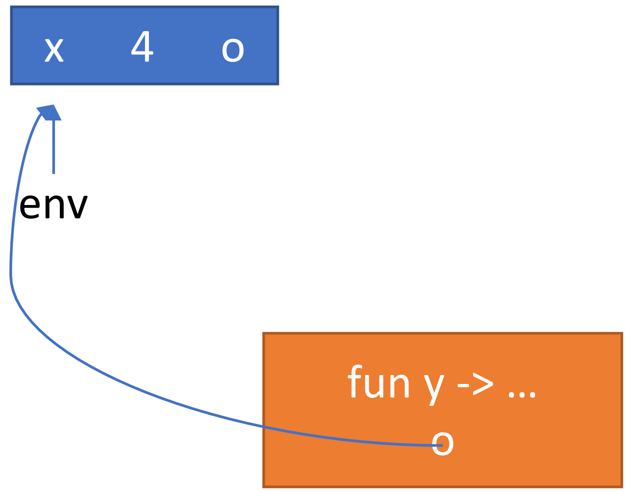
- Considerations:
  - Optimization: we don't need to store all variables in the environment, just those that might "escape" (be used in nested functions)
  - Data structure: lookup should be fast (asymptotic and constant factors)

Data Structures for Environments



Nested Environments

```
(((fun x -> (fun y -> (fun z -> x + y + z) 21) 17) 4
```



Nested Environments

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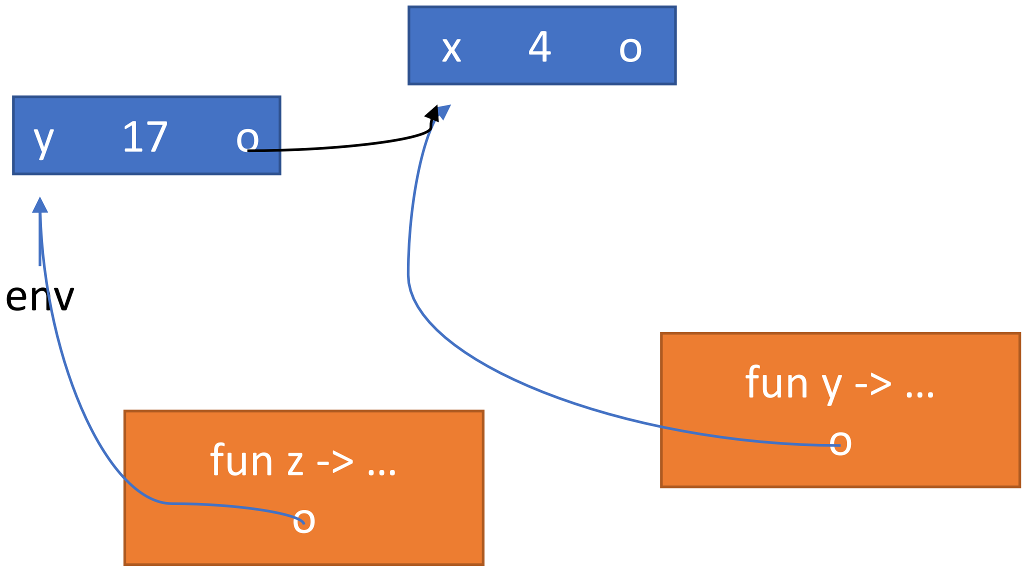

Nested Environments

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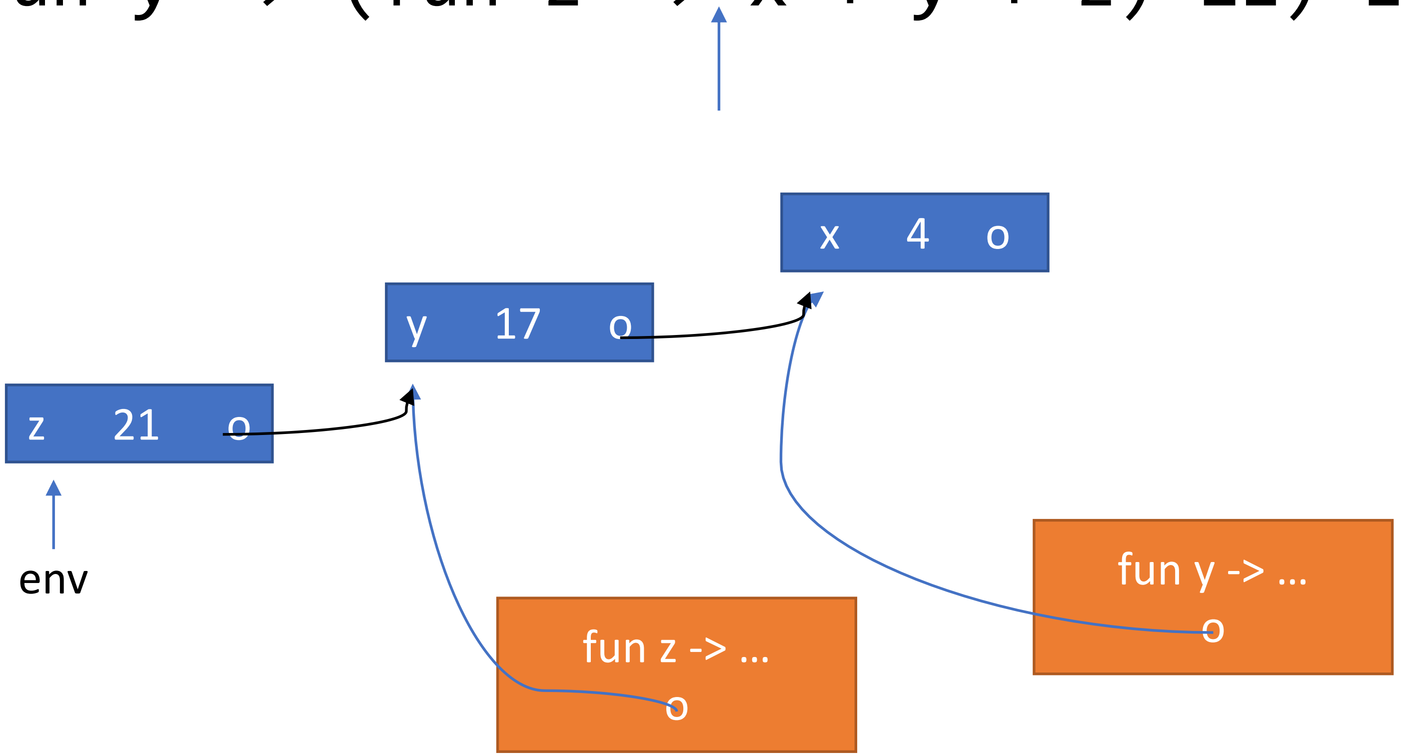

Nested Environments

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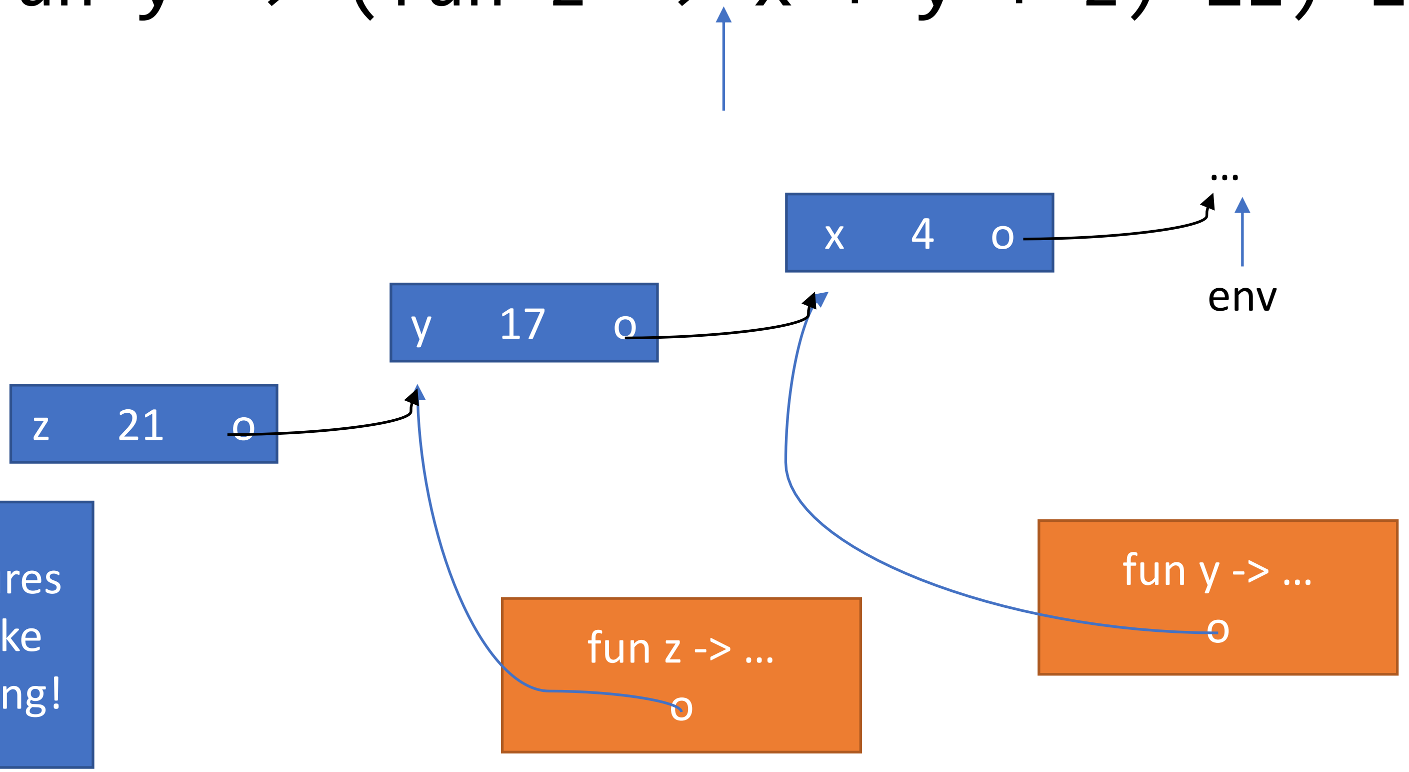


Environments in closures are still there—just like functional programming!

Extend and Lookup for Nested Envs

```
__extend_env(env, var, val):
  env new_node = new env(var, val, env)
  return new_node

__lookup(env, var):
  while(env.var != var && env != NULL):
    env = env.next
  return env.val
```

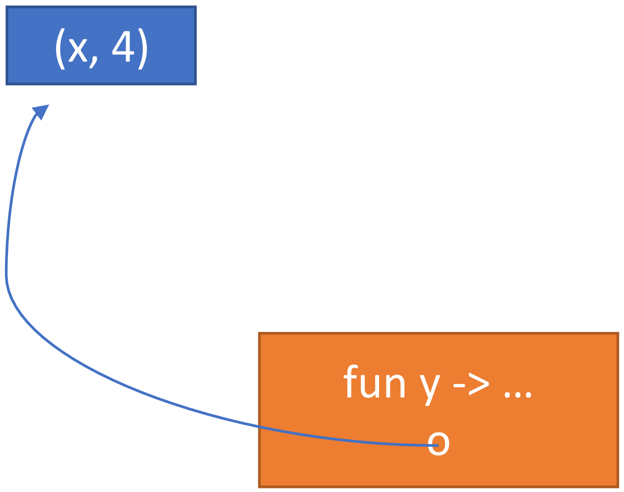
For recursive functions, can just make the closure and “backpatch” it later

```
let rec fact n = if n <= 1 then n else n * (fact (n – 1))

int fact__body(env env, int n) {
  env = __extend_env(env, “n”, n);
  …
}
closure fact_clos = __mk_clos(fact__body, env));
env = __extend_env(env, “fact”, fact_clos);
fact_clos.clos_env = env;
```

Flat Environments

```
(((fun x -> (fun y -> (fun z -> x + y + z) 21) 17) 4
```



Flat Environments

```
(((fun x -> (fun y -> (fun z -> x + y + z) 21) 17) 4
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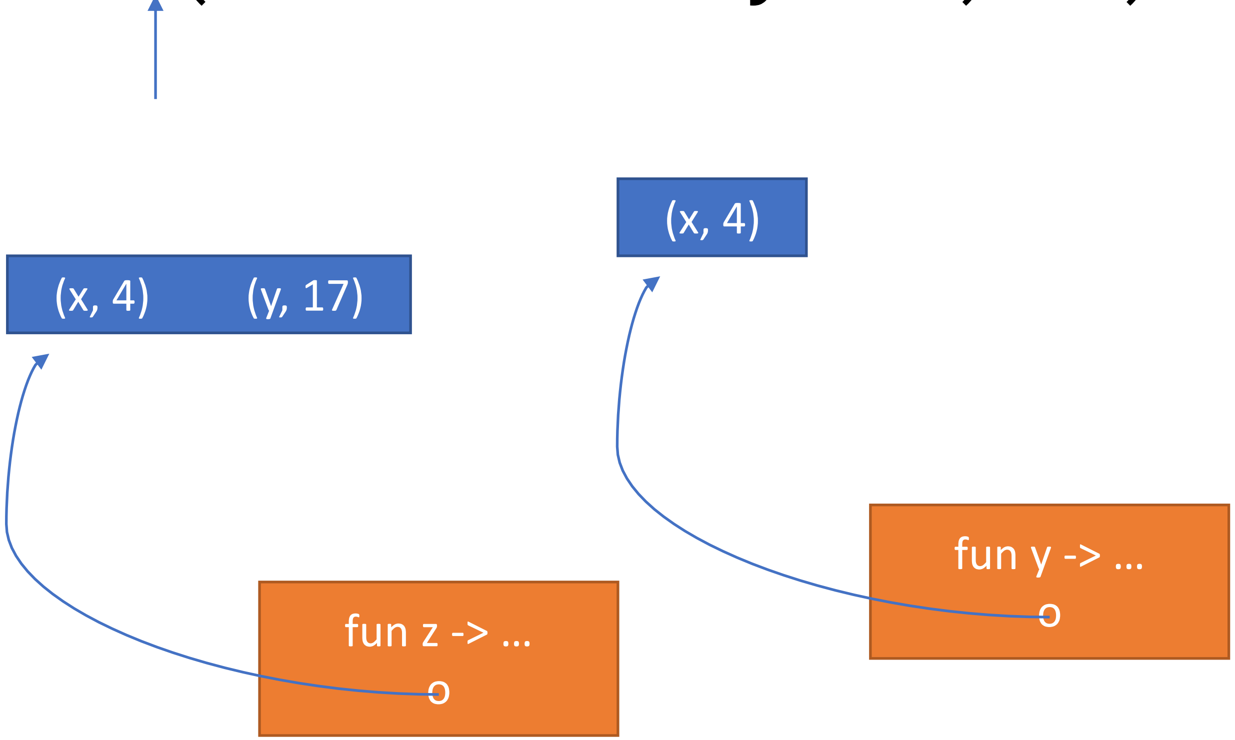


Pro: Faster lookup
Con: Slower construction

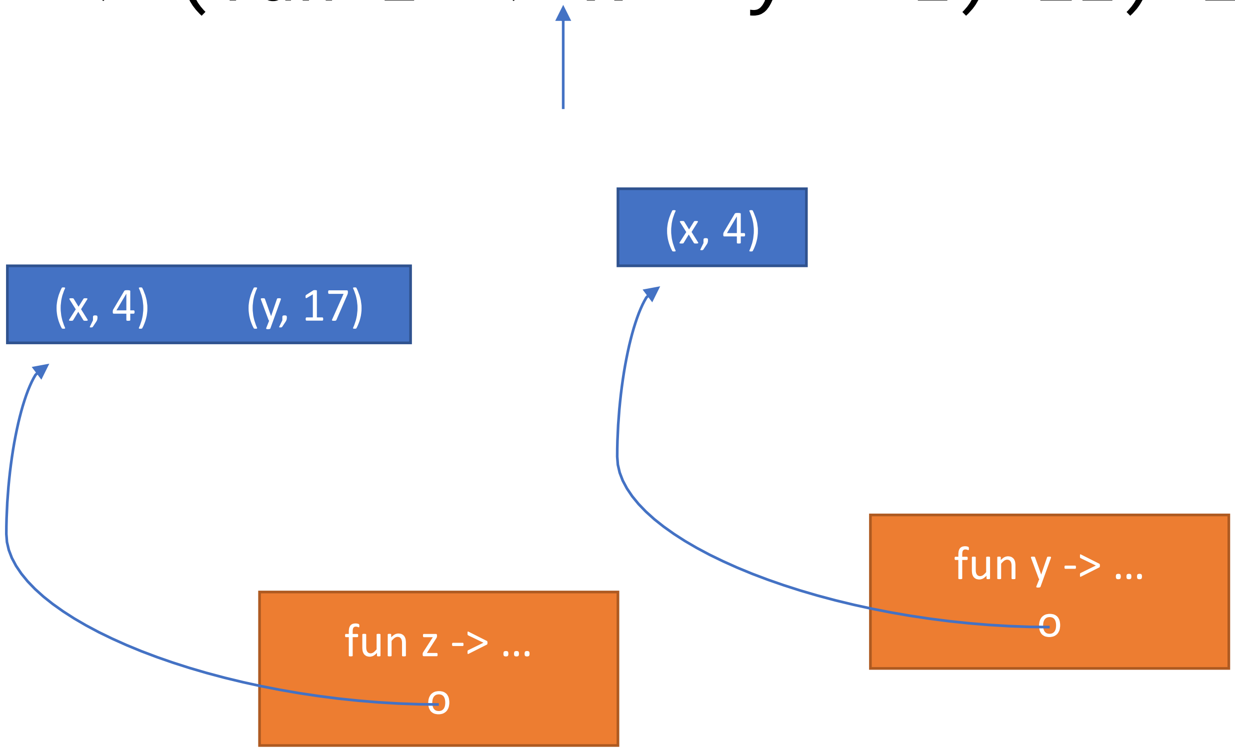
Extend and Lookup for Flat Envs

```
__extend_env(env, var, val):
  env new_env = new (env[env.length + 1])
  env[0] = (var, val)
  env[1:] = copy(env)
  return env

__lookup(env, var):
  i = 0
  while(env[i].var != var && i < env.length):
    i++
  return env[i].val
```

Optimization: We don't need to add z to the environment!

```
(((fun x -> (fun y -> (fun z -> x + y + z) 21) 17) 4
```



Optimizations for flat environments

- You can just produce the environment when you need it for a closure (assuming you know all the values you need to build it)
  - … and you can easily include only the free variables in the body.

Alternate way of thinking of flat environments: the closure *is* the environment

```
(((fun x -> (fun y -> x + (fun z -> y + z) 21) 17) 4
```

Side bonus: special case for recursive closures so we don't have to backpatch

But getting back to the fact that lookup is still O(n) in the size of the environment…

deBruijn Indices Track Number of Binders

```
(((fun x -> (fun y -> (fun z -> x + y + z) 21) 17) 4
```

deBruijn Indices Track Number of Binders

```
(((fun   -> (fun   -> (fun   ->   +   +  ) 21) 17) 4
```

deBruijn Indices Track Number of Binders

```
(((fun -> (fun -> (fun -> 2 + 1 + 0) 21) 17) 4
```

deBruijn Indices: Example

```
let x = 1 in x +
                (let y = 2 in
                   (let x = 3 in x + y)
                   + y)
```

```
let = 1 in 0 +
              (let = 2 in
                 (let = 3 in 0 + 1)
                 + 0)
```

Note: Same binder can have different indices at different points in the program!

deBruijn Indices: Another Example

```
let x = 1 in
let add = fun y -> x + y in
let two = add 1 in
two

let = 1 in
let = fun -> 1 + 0 in
let = 0 1 in
0
```

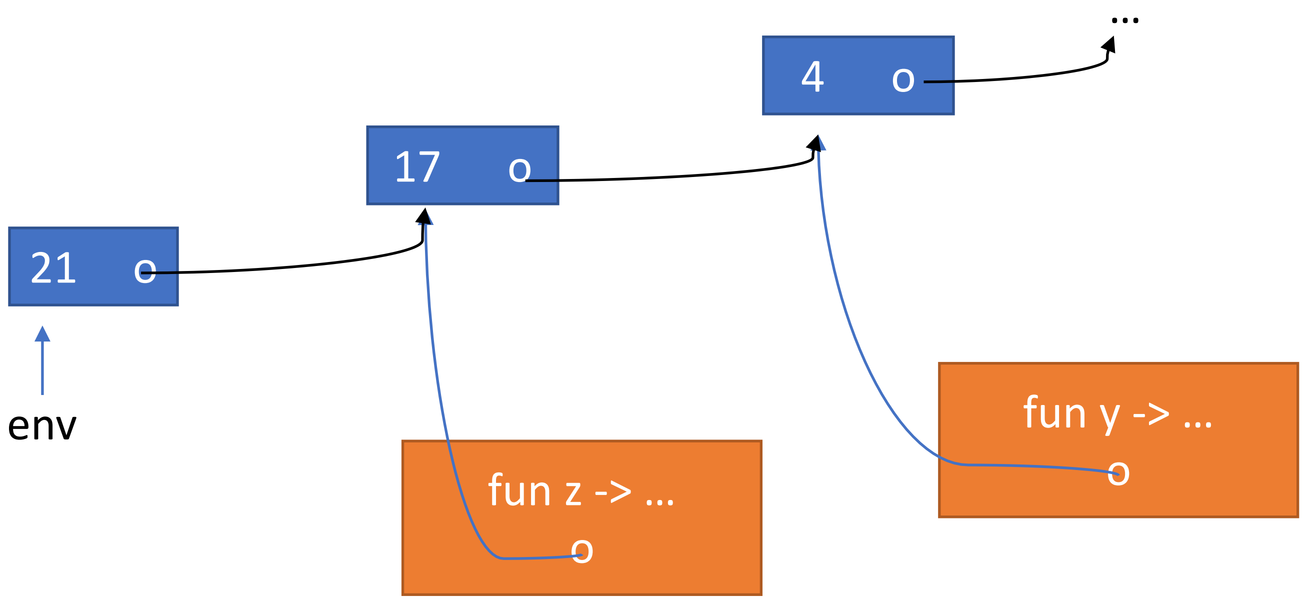
For recursive functions, consider “let rec” to bind the function name in the body

```
let rec fact n = if n <= 1 then n else n * (fact (n – 1))

let rec = if 0 <= 1 then 0 else 0 * (1 (0 – 1))
```

Nested Environments with deBruijn Indices

(((fun -> (fun -> (fun -> 2 + 1 + 0) 21) 17) 4



Extend and Lookup for Nested Envs (deBruijn)

```
__extend_env(env, val):
  env new_node = new env(val, env)
  return new_node

__lookup(env, ind):
  while(ind > 0):
    env = env.next
    ind--
  return env.val
```

Extend and Lookup for Flat Envs (deBruijn)

```
__extend_env(env, val):
 env new_env = new (env[env.length + 1])
  env[0] = val
  env[1:] = copy(env)
  return env

__lookup(env, ind):
  return env[ind]
```

Compromise: Keep variable names, but remember their deBruijn index while compiling

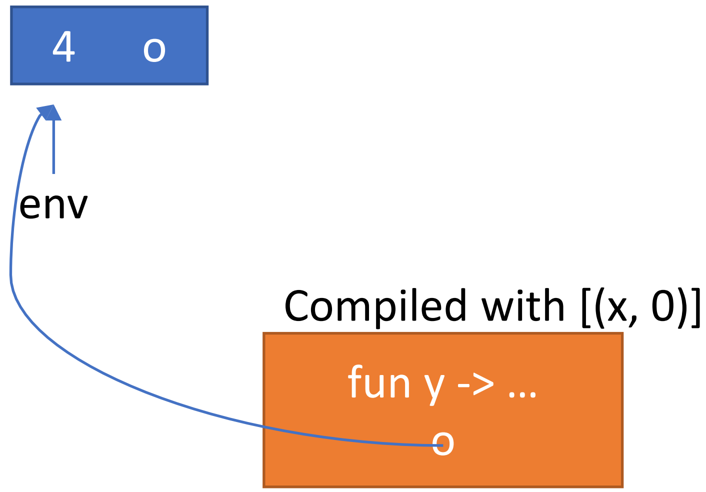
“Environment record”

```
compile_exp : (string * int) list -> ML.Ast.t_exp ->
  C.Ast.p_stmt_list * C.Ast.p_exp * closure list
```

- Con: Have to keep environment record in sync with environment
- Pro: Way easier to debug

Nested Environments (Compromise)

```
(((fun x -> (fun y -> (fun z -> x + y + z) 21) 17) 4
```



Nested Environments (Compromise)

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```

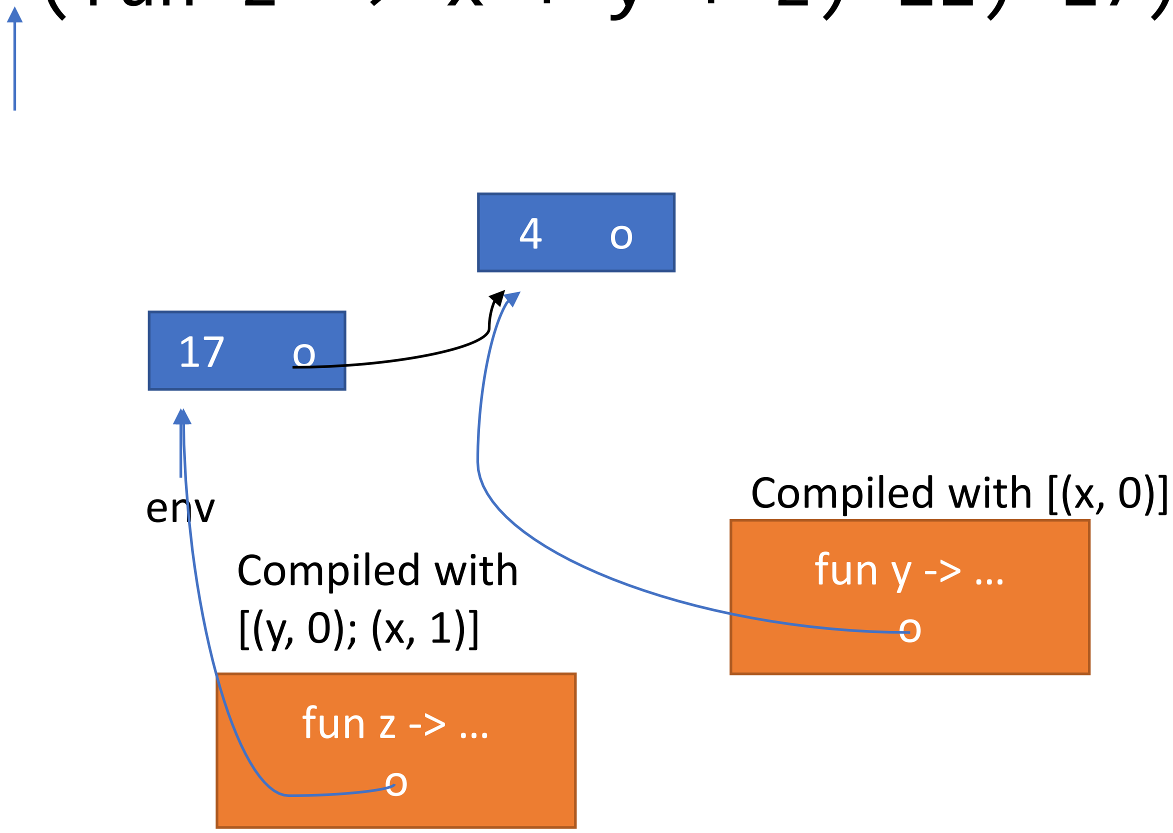

Recursive functions (compromise)

```
let rec fact n = if n <= 1 then n else n * (fact (n – 1))
```

1. Extend environment, environment record with placeholder
2. Compile function with extended env. record
3. Make closure with placeholder-extended environment
4. Backpatch environment in closure to point back to closure