Compiler Construction

Lecture 10: Interpreter 3

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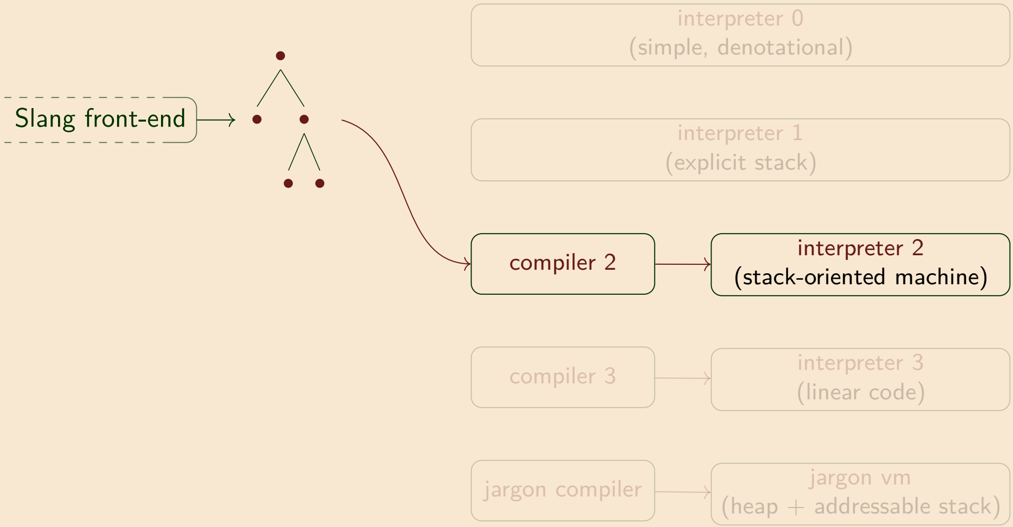
Reminder: the derivation



Slang front-end

interpreter 0
(simple, denotational)

interpreter 1
(explicit stack)

compiler 2

interpreter 2
(stack-oriented machine)

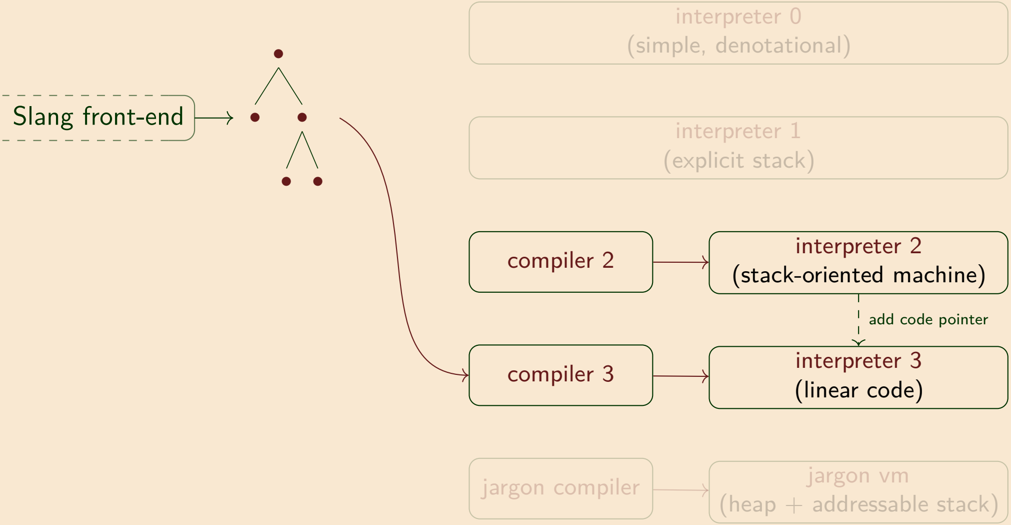
compiler 3

interpreter 3
(linear code)

jargon compiler

jargon vm
(heap + addressable stack)

Reminder: the derivation



Slang front-end

interpreter 0
(simple, denotational)

interpreter 1
(explicit stack)

compiler 2

interpreter 2
(stack-oriented machine)

add code pointer

compiler 3

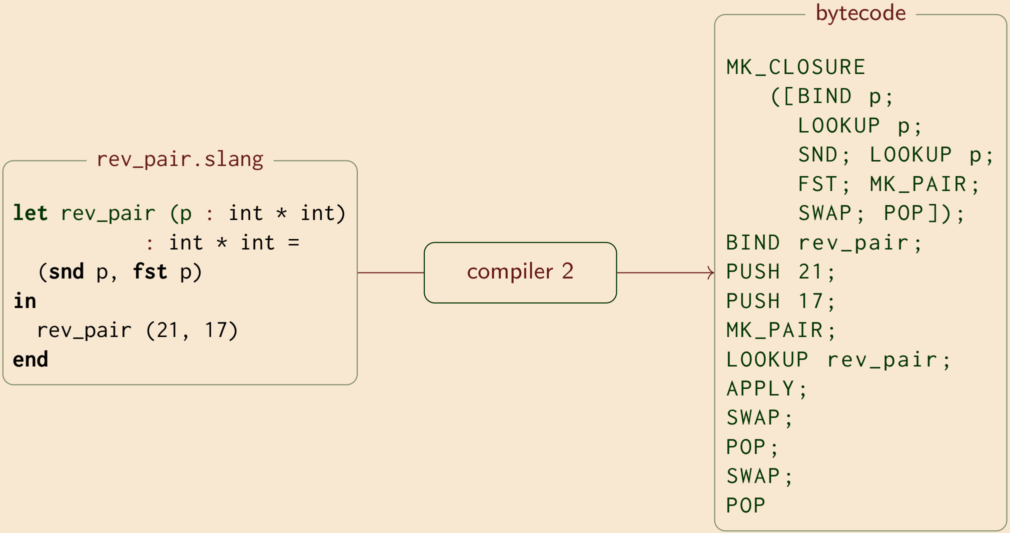
interpreter 3
(linear code)

jargon compiler

jargon vm
(heap + addressable stack)

Non-linear code

Nested code in interpreter 2: closures



rev_pair.slang

```
let rev_pair (p : int * int)
             : int * int =
  (snd p, fst p)
in
  rev_pair (21, 17)
end
```

compiler 2

bytecode

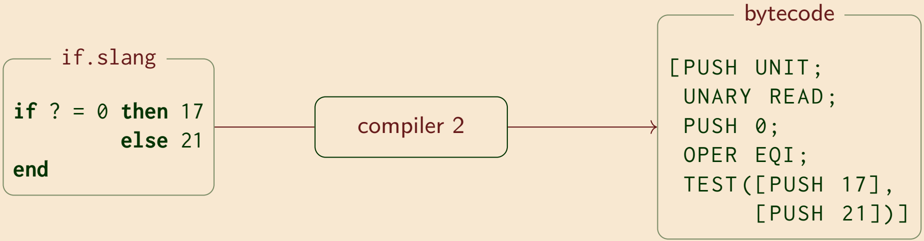
```
MK_CLOSURE
   ([BIND p;
     LOOKUP p;
     SND; LOOKUP p;
     FST; MK_PAIR;
     SWAP; POP]);
BIND rev_pair;
PUSH 21;
PUSH 17;
MK_PAIR;
LOOKUP rev_pair;
APPLY;
SWAP;
POP;
SWAP;
POP
```

This is about MK_CLOSURE taking instruction arguments

Nested code in interpreter 2: conditionals

```
type instruction = ... | TEST of code * code | WHILE of code * code | ...
and code = instruction list

let rec compile = function
 | If(l, e1, e2, e3) → (compile e1) @ [TEST(l, compile e2, compile e3)]
 | ...
```



```
if ? = 0 then 17
         else 21
end
```

```
[PUSH UNIT;
 UNARY READ;
 PUSH 0;
 OPER EQI;
 TEST([PUSH 17],
      [PUSH 21])]
```

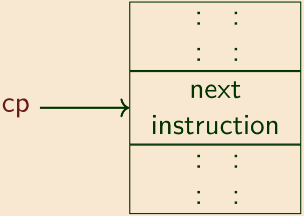
(WHILE also takes code arguments)

Linearise code

Interpreter 2 copies code on the code stack.

We want to introduce a global instruction array indexed by a code pointer (cp).

At runtime the cp points at the next instruction to be executed.

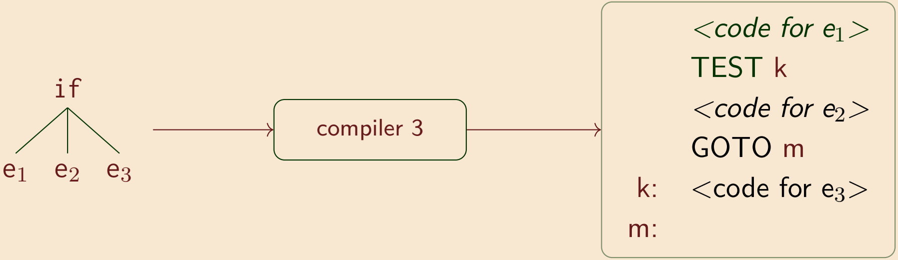


New instructions:

`LABEL L`	Associate label L with this location in the code array
`GOTO L`	Set the cp to the code address associated with L

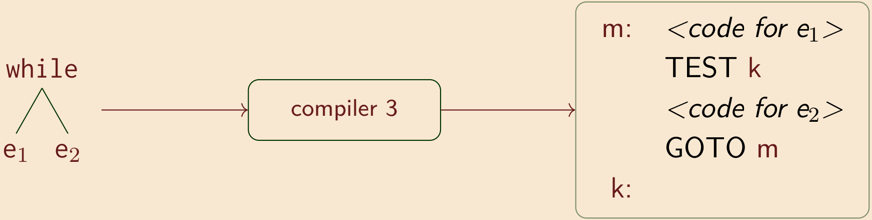
Linear code

Compile conditionals, loops



```
      <code for e1>
      TEST k
      <code for e2>
      GOTO m
k:    <code for e3>
m:
```

Compile loops



```
m:   <code for e_1>
     TEST k
     <code for e_2>
     GOTO m
k:
```

`if ? = 0 then 17 else 21 end`

Non-linear code

Linear code

● ● ●

Compilation

Execution

Interpreter 2

```
PUSH UNIT
UNARY READ
PUSH 0
OPER EQI
TEST(
   [PUSH 17],
   [PUSH 21]
)
```

Interpreter 3

```
PUSH UNIT
UNARY READ
PUSH 0
OPER EQI
TEST L0
PUSH 17
GOTO L1
LABEL L0
PUSH 21
LABEL L1
HALT
```

Symbolic
code locations

Interpreter 3 (loaded)

```
 0   PUSH UNIT
 1   UNARY READ
 2   PUSH 0
 3   OPER EQI
 4   TEST L0 = 7
 5   PUSH 17
 6   GOTO L1 = 9
 7   LABEL L0
 8   PUSH 21
 9   LABEL L1
10   HALT
```

Numeric
code locations

Interpreter 3: compilation

Data types: interpreter 2 *vs* interpreter 3

Non-linear code

Linear code

Compilation

● ○ ○ ○

Execution

interp_2.mli

```
type value =
| ...
| CLOSURE of bool * closure
and closure = instruction list * env
and instruction =
| PUSH of value     | LOOKUP of var
| POP               | BIND of var
| FST               | SND
| APPLY
| MK_PAIR           | MK_INL
| MK_CLOSURE of instruction list
| ...
```

interp_3.mli

```
type label = string
type location = label * address option

type value =
| ...
| CLOSURE of location * env

and instruction =
   | PUSH of value     | LOOKUP of var
   | POP               | BIND of var
   | FST               | SND
   | APPLY             | RETURN
   | MK_PAIR           | MK_INL
   | MK_CLOSURE of location

   | GOTO of location   | LABEL of label
```

Code locations:		
	("L",None):	not yet loaded (assigned numeric address)
	("L",Some i):	label "L" has been assigned numeric address i

Compilation of `if`: interpreter 2 *vs* interpreter 3

interp_2.ml

```
let rec compile = function
 | If (l, e1, e2, e3) → compile e1 @ [TEST(l, compile e2, compile e3)]
 ...
```

interp_3.ml

```
let rec comp = function
  | If(l, e1, e2, e3) → let else_label = new_label () in
                        let after_else_label = new_label () in
                        let defs1, c1 = comp e1 in
                        let defs2, c2 = comp e2 in
                        let defs3, c3 = comp e3 in
                        (defs1 @ defs2 @ defs3,
                         (c1
                          @ [TEST(l, (else_label, None))]
                          @ c2
                          @ [GOTO (l, (after_else_label, None));
                             LABEL(l, else_label)]
                          @ c3
                          @ [LABEL (l, after_else_label)]))
```

Compilation of `lambda`: interpreter 2 *vs* interpreter 3

interp_2.ml

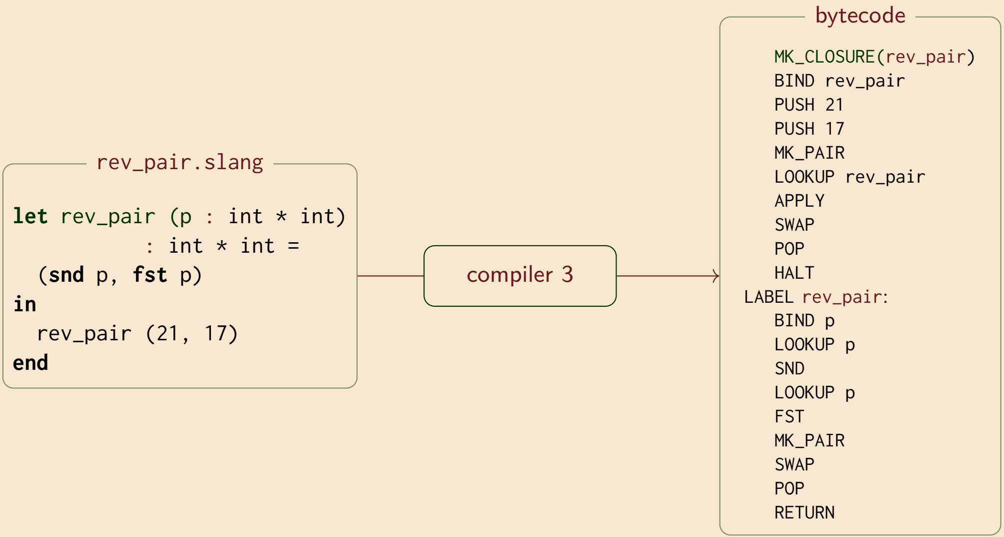
```
let rec compile = function
 | Lambda(l, x, e) → [MK_CLOSURE(l, BIND(l,x) :: compile e @ leave_scope l)]
 ...
```

interp_3.ml

```
let rec comp = function
 | Lambda(l, x, e) → let defs, c = comp e in
                     let f = new_label () in
                     let def = [LABEL (l,f); BIND(l,x)]
                               @ c @ [SWAP l; POP l; RETURN l]
                       in (def @ defs, [MK_CLOSURE(l, (f, None))])
...
let compile e =
    let defs, c = comp e in
    c         (* body of program *)
    @ [HALT]  (* stop the interpreter *)
    @ defs    (* the function definitions *)
```

(NB: `defs` are definitions to add after `HALT`)

Example: compiled code for rev_pair.slang



rev_pair.slang

```
let rev_pair (p : int * int)
           : int * int =
  (snd p, fst p)
in
  rev_pair (21, 17)
end
```

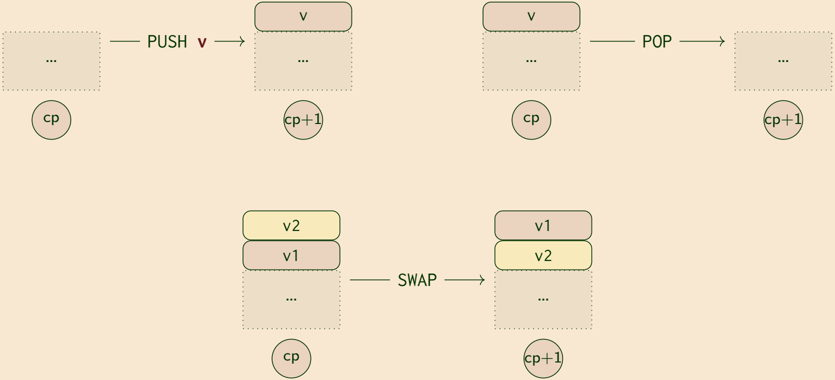
bytecode

```
   MK_CLOSURE(rev_pair)
   BIND rev_pair
   PUSH 21
   PUSH 17
   MK_PAIR
   LOOKUP rev_pair
   APPLY
   SWAP
   POP
   HALT
LABEL rev_pair:
   BIND p
   LOOKUP p
   SND
   LOOKUP p
   FST
   MK_PAIR
   SWAP
   POP
   RETURN
```

Interpreter 3: execution

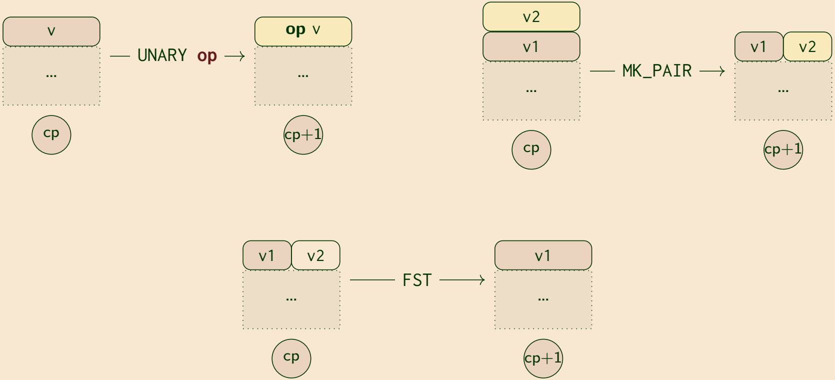
Interpreter 3: stack manipulation

```
let step (cp, evs) = match (get_instruction cp, evs) with
 | PUSH v,                   evs → (cp+1, V v::evs)
 | POP,                   s::evs → (cp+1, evs)
 | SWAP,              s1::s2::evs → (cp+1, s2::s1::evs)
 | ...
```



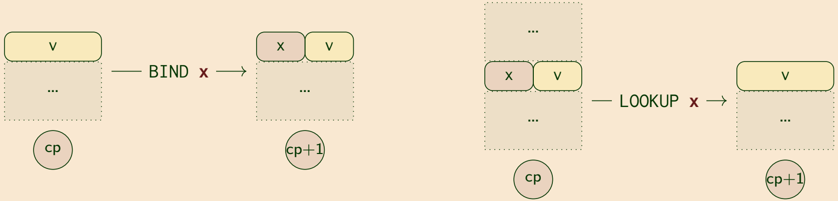
Interpreter 3: pairs and primitives

```
let step (cp, evs) = match (get_instruction cp, evs) with
 | UNARY op,          V v::evs → (cp+1, V(do_unary(op, v))::evs)
 | MK_PAIR,    V v2::V v1::evs → (cp+1, V(PAIR(v1, v2))::evs)
 | FST,    V(PAIR (v, _))::evs → (cp+1, V v::evs)
 | ...
```



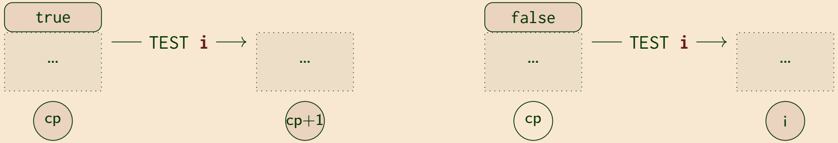
Interpreter 3: environments

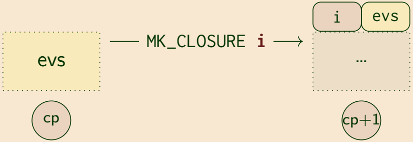
```
let step (cp, evs) = match (get_instruction cp, evs) with
 | BIND x,            V v::evs → (cp+1, EV([(x, v)])::evs)
 | LOOKUP x,              evs → (cp+1, V(search(evs, x))::evs)
 | ...
```



Interpreter 3: closures and conditionals

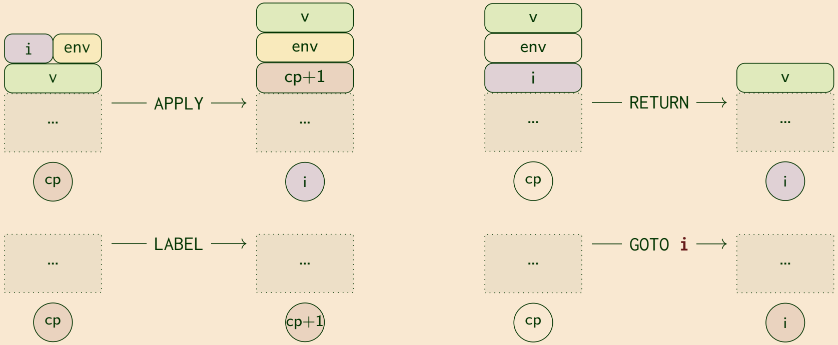
```
let step (cp, evs) =  match (get_instruction cp, evs) with
| TEST (_, Some _),  V(BOOL true)::evs → (cp+1, evs)
| TEST (_, Some i), V(BOOL false)::evs → (i,    evs)
| MK_CLOSURE i   ,                 evs → (cp+1, V(CLOSURE
                                             (i,evs_to_env evs))::evs)
| ...
```





Interpreter 3: applications and control flow

```
let step (cp, evs) = match (get_instruction cp, evs) with
| APPLY,  V(CLOSURE ((_, Some i), e))
                             ::V v::evs → (i, V v::EV e::RA(cp+1)::evs)
| RETURN,             V v::_::RA i::evs → (i, V v::evs)
| LABEL l,                          evs → (cp+1, evs)
| GOTO (_, Some i),                 evs → (i, evs)
```



Observations

The machine is **becoming simpler** (no OCaml stack; no nested code)

The treatment of **environments** is still very **inefficient**

It still pushes **complex values on the stack**, unlike most virtual machines

It still uses **OCaml's memory management** to manipulate complex values

Next time: **Jargon VM**