Compiler Construction

Lecture 10: Interpreter 3

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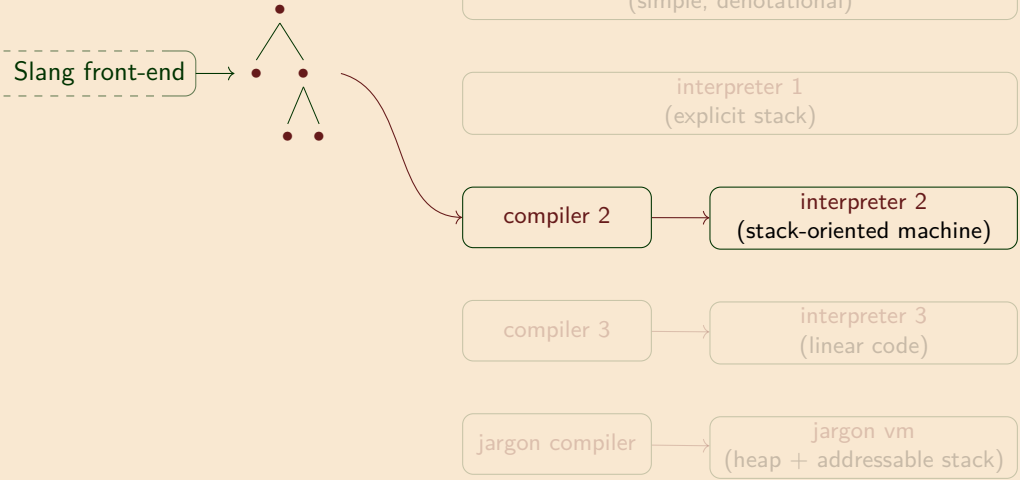
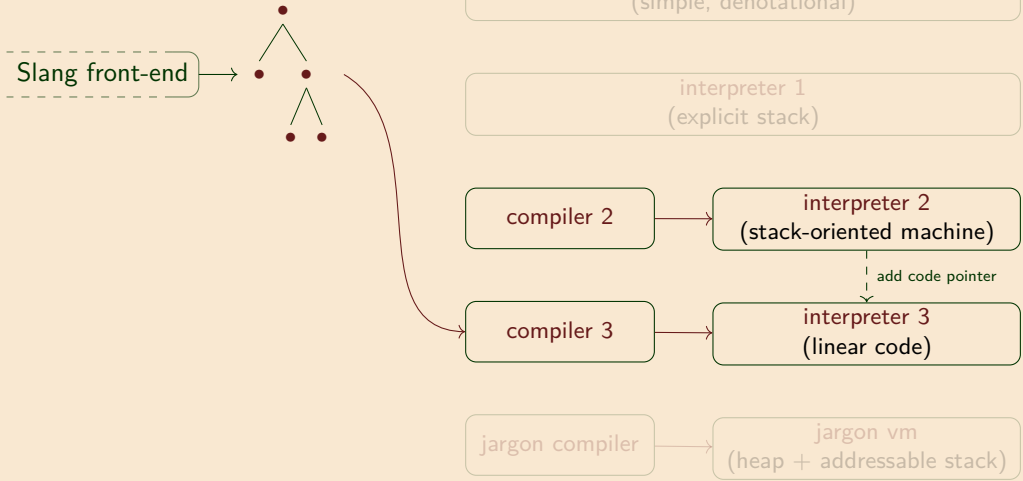
Lent 2025

Reminder: the derivation



Reminder: the derivation



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)
```

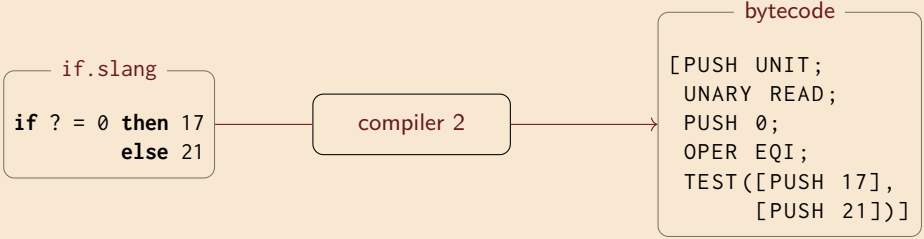
bytecode

```
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
```

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)]
 | ...
```

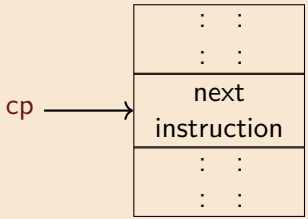


(WHILE also takes code arguments)

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.

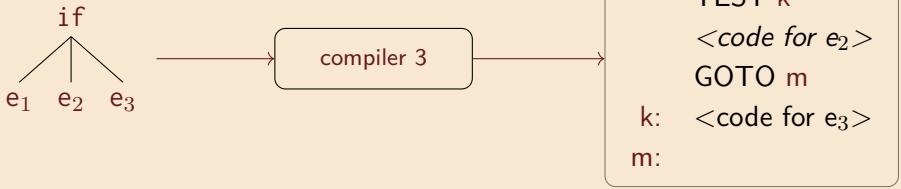


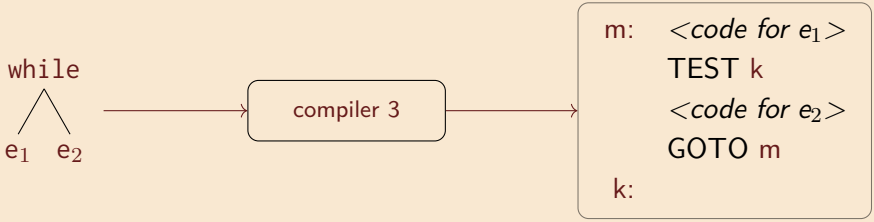
New instructions:

`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




while
e1 e2
compiler 3
m: <code for e1>
TEST k
<code for e2>
GOTO m
k:

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

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)
```

bytecode

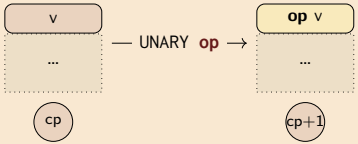
```
    MK_CLOSURE(rev_pair)
    BIND rev_pair
    PUSH 21
    PUSH 17
    MK_PAIR
    LOOKUP rev_pair
    APPLY
    SWAP
    POP
    HALT
LABEL rev_pair:
    BIND p
    LOOKUP p
    SND
    LOOKUP p
    FST
    MK_PAIR
    SWAP
    POP
    RETURN
```

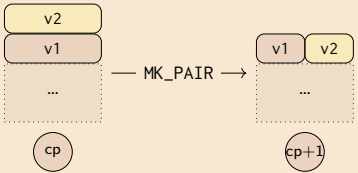
Interpreter 3: execution

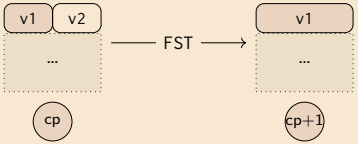
Interpreter 3: stack manipulation

```
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)
 | ...
```

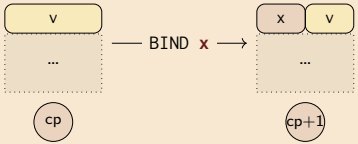
```
let step (cp, evs) = match get_instruction cp, evs with
  | UNARY op,          V v::evs → (cp+1, V(do_unary(op, v))::evs)
  | MK_PAIR,    V v2::V v1::evs → (cp+1, V(PAIR(v1, v2))::evs)
  | FST,    V(PAIR (v, _))::evs → (cp+1, V v::evs)
  | ...
```

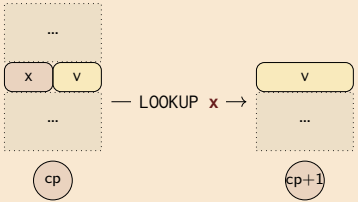




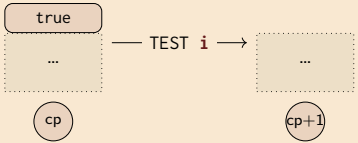


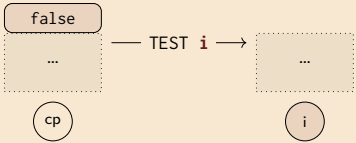
```
let step (cp, evs) = match get_instruction cp, evs with
 | BIND x,            V v::evs → (cp+1, EV [(x, v)]::evs)
 | LOOKUP x,                evs → (cp+1, V(search(evs, x))::evs)
 | ...
```

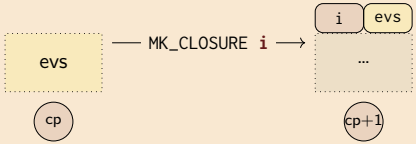




```
let step (cp, evs) =  match get_instruction cp, evs with
| TEST (_, Some _),  V(BOOL true)::evs → (cp+1, evs)
| TEST (_, Some i), V(BOOL false)::evs → (i,    evs)
| MK_CLOSURE i   ,                  evs → (cp+1, V(CLOSURE
                                                (i,evs_to_env evs))::evs)
|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

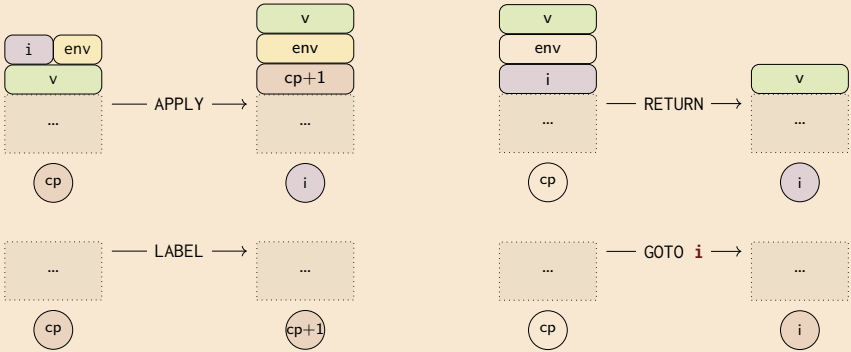






Interpreter 3: applications and control flow


```
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)
```



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**