-1

$M := X \mid b \mid \lambda X.M \mid (o^n M \ldots) \mid M\ N$ $\qquad V := b \mid \lambda X.M$ $\qquad \beta_v : (\lambda X M)V \to M[X \leftarrow V]$ $\qquad \Delta : (o^n b \ldots) \Rightarrow \delta(o^n, b \ldots)$

$E = \bullet \mid E\ N \mid V\ E \mid o^n\ V \ldots\ E\ M \ldots$

$K = ret \mid fn(N, K) \mid ar(V, K) \mid pr(o^n, \langle V \ldots \rangle, \langle M \ldots \rangle, K)$

"stack" — Continuation = future of computation

CK -

$\langle M\ N, K \rangle \mapsto_{CK} \langle M, fn(N, K) \rangle$

$\langle V, fn(N, K) \rangle \mapsto_{CK} \langle N, ar(V, K) \rangle$

$\langle V, ar(\lambda X.M, K) \rangle \mapsto_{CK} \langle M[X \leftarrow V], K \rangle$

$P \mapsto_{CK} \cdots \mapsto_{CK} \langle X, K \rangle$ X is unbound

$\langle (((((\lambda X.(\lambda Y.(\lambda Z.\ P)))\ 4)\ 5)\ 6),\ K \rangle$

$\mapsto_{CK}^*$

$\langle P[X \leftarrow 6][Y \leftarrow 5][Z \leftarrow 4],\ K \rangle$

$P = X$ $\qquad P = ((\lambda \_.\ 9)\ (\lambda B.(X(YZ))$

CEK → environment $\qquad \Sigma = \bullet \mid \Sigma[X \mapsto V]$ $\qquad [X \mapsto V] \in \Sigma$

broken CEK - PHP - maths - elisp - shells

$\langle X, \Sigma, K \rangle \mapsto_{CEK} \langle V, \Sigma, K \rangle$ where

$\langle M\ N, \Sigma, K \rangle \mapsto_{CEK} \langle M, \Sigma, fn(N, K) \rangle$

$\langle V, \Sigma, fn(N, K) \rangle \mapsto_{CEK} \langle N, \Sigma, ar(V, K) \rangle$

$\langle V, \Sigma, ar(\lambda X.M, K) \rangle \mapsto_{CEK} \langle M, \Sigma[X \mapsto V], K \rangle$

dynamic scope — the place where variables are bound

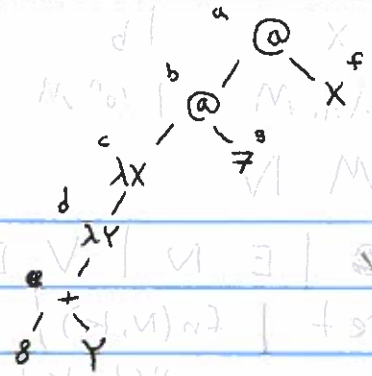
→ depends on execution

JS: $o.m(a) = o[m](o, a)$

$o[m](a)$ — $o[m](this, a)$

9-2

$(((\lambda X.(\lambda Y.\ 8 + Y))\ 7)\ X)$



$\langle a, \text{env}, ret \rangle$

$\langle b, \circ, fn(f, ret) \rangle$

$\langle c, \circ, fn(g, fn(f, ret)) \rangle$

$\langle g, \circ, ar(c, fn(f, ret)) \rangle$

$\langle d, \circ[X \mapsto 7], fn(f, ret) \rangle$

$\langle f, \circ[X \mapsto 7], ar(d, ret) \rangle$

$\langle 7, \circ[X \mapsto 7], ar(d, ret) \rangle$

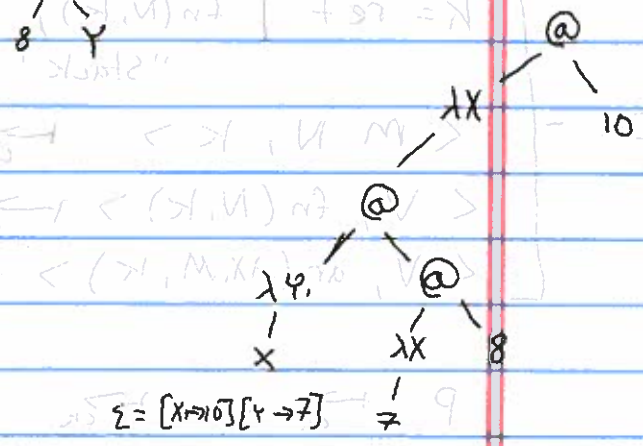
$\langle e, \circ[X \mapsto 7][Y \mapsto 7], ret \rangle$

$= \langle 8 + Y, \overbrace{\quad}^{1}, ret \rangle$

$\langle Y, \circ[X \mapsto 7][Y \mapsto 7], pr(+, \langle 8 \rangle, \langle\rangle, ret) \rangle$

$\langle 7, \text{''}, \langle\rangle, \text{''} \rangle$

$\langle 15, \text{''}, ret \rangle$



CEK $K = ret \mid fn(N, \Sigma, K) \mid ar(V, K)$

$\langle X, \Sigma, K \rangle \longmapsto_{CEK} \langle V, \Sigma, K \rangle$ where $[X \mapsto V] \in \Sigma$

$\langle M\ N, \Sigma, K \rangle \longmapsto_{CEK} \langle M, \Sigma, fn(N, \Sigma, K) \rangle$

$\langle V, \Sigma, fn(N, \Sigma', K) \rangle \longmapsto_{CEK} \langle N, \Sigma', ar(V, K) \rangle$

$\langle V, \Sigma, ar(\lambda X.M, K) \rangle \longmapsto_{CEK} \langle M, \circ [X \mapsto V], K \rangle$

~~$V = b \mid \lambda X.M$~~

$V = b \mid clo(\lambda X.M, \Sigma)$

static scope

$\langle \lambda X.M, \Sigma, K \rangle \longmapsto_{CEK} \langle clo(\lambda X.M, \Sigma), \Sigma, K \rangle$

$\langle V, \Sigma, ar(clo(\lambda X.M, \Sigma'), K) \rangle$

$\longmapsto_{CEK} \langle M, \Sigma'[X \mapsto V], K \rangle$

9-3

Implementing Σ

$$\langle X, \Sigma, K \rangle \mapsto \langle V, \Sigma, K \rangle$$

$$[X \mapsto V] \in \Sigma$$

Closure = clo $(\lambda X.\ M,\ \Sigma)$

- $\lambda X.\ M$: code pointer
- Σ : variable mapping
- flat closure

X

$\Sigma = [X]$

movq %rdx ← %rcx[0]

flat closure = Σ is an array of the mentioned variable

$\lambda X. \ldots X \ldots Y \ldots Z \ldots$ $\quad \Sigma = [X, Y, Z]$ or $[Y, X, Z]$

rcx[0] rcx[8] rcx[16]

nested closure

Σ = pointer to the last fun call

$\Sigma = [X, Y, \bullet] \to [Z, A, B, \bullet] \to [C, \bullet]$

X, Y, Z

rcx[0] rcx[8] rcx[8][0]