19-1

Cryptol

"State"

Mutation

– "there are places that store stuff at different points in time"

Math	C
$x = 14$	$x = 14$
$y = x + 17$	$y = x + 17$
$z = x + 12$	$x = 16$
$f(x) = x + 21$	$z = y + 1$
$q = f(z)$	

$x = 16$

Math is inherently timeless parallel

C has no substitution

C requires time

C is inherently sequential

$(f \quad e_1 \quad e_2)$

$v_f \quad v_1 \quad v_2$

$M[x \leftarrow v_1][y \leftarrow v_2]$

(parallel = things can happen at same time but you'll never know)

((--x, printf)(,
("%d", x++)
x)

(Concurrency := things happen at same time and you know it)

State-ISWIM

$M = \ldots \mid (\text{set! } X\ M) \mid (M; M)$

$E = \ldots \mid (\text{set! } X\ E) \mid (E; M)$

$E[(\text{set! } X\ V_2)] \longmapsto$

$E[(\lambda X.m)\ V_1] \longmapsto E[m[X \leftarrow V_1]]$

$E[V; M] \longmapsto E[M]$

((λX.
(set! X 2);
X)
3)

$\rightarrow$ (set! 3 2);
3

$\rightarrow$ (set! X 2);
3

19-2 expr $M = \ldots \mid (\text{set! } M\ M) \mid (M ; M) \mid \sigma$

σ = some set distinct from variables $V = \ldots \mid \sigma$

"pointers" "addresses"

eval-context $E = \ldots \mid (\text{set! } E\ M) \mid (\text{set! } V\ E) \mid (E ; M)$

In Normal ISWIM $\mapsto$ was a relation on M

program $P = \Sigma / M$ $\Sigma = \emptyset \mid \Sigma[\sigma \mapsto V]$

In state-ISWIM $\mapsto$ is a relation on P

$\Sigma / E[(\lambda X. M)\ V] \mapsto \Sigma' / E[M[X \leftarrow \sigma_f]]$

$\Sigma' = \Sigma[\sigma_f \mapsto V]$

Java-way $\Sigma / E[\sigma\ V] \mapsto$ σ_f is fresh in Σ

if $\Sigma(\sigma) = (\lambda X. M)$

C-way $\Sigma / E[\text{deref } \sigma] \mapsto \Sigma / E[\Sigma(\sigma)]$

$\Sigma / E[(\text{set! } \sigma\ V)] \mapsto \Sigma[\sigma \mapsto V] / E[V]$

$\Sigma / E[V ; M] \mapsto \Sigma / E[M]$

$V = \ldots \mid (\text{kont } E)$

$\Sigma / E[\text{call/cc } V] \mapsto \Sigma / E[V\ (\text{kont } E)]$

$\Sigma / E[(\text{kont } E')\ V] \mapsto \Sigma / E'[V]$

19-3

$$\text{eval}(M) = \text{if } \emptyset / M \mapsto^* \Sigma / V$$
$$\text{then} \quad b \quad \text{if } V \in b$$
$$\text{`fun} \quad \text{if } V \in \lambda X.\cancel{M}$$

$$\emptyset / ((\lambda X.\ (\text{set! } X\ (+\ X\ 1));\ ((\lambda Y.\ (\text{set! } Y\ (+\ X\ 1));\ (+\ Y\ X))\ 4))\ 2)$$

$$\mapsto \quad \emptyset[\sigma_0 \mapsto 2] / (\text{set! } \sigma_0\ (+\ \sigma_0\ 1));$$
$$① \; ((\lambda Y.\ (\text{set! } Y\ (+\ \sigma_0\ 1))\ (+\ Y\ \sigma_0))\ 4)$$

$$\mapsto \quad \emptyset[\sigma_0 \mapsto 2][\sigma_0 \mapsto 3] / ①$$

$$\mapsto \quad \emptyset[\sigma_0 \mapsto 2][\sigma_0 \mapsto 3][\sigma_1 \mapsto 4] / (\text{set! } \sigma_1\ (+\ \sigma_0\ 1));\ (+\ \sigma_1\ \sigma_0)$$

$$\mapsto \quad \emptyset[\sigma_0 \mapsto 2][\sigma_0 \mapsto 3][\sigma_1 \mapsto 4][\sigma_1 \mapsto 5] / (+\ \sigma_0\ \sigma_1)$$

$$\mapsto \quad \text{''} \quad / 8$$

$$\text{lookup}(\Sigma, \sigma) = \Sigma(\sigma)$$
$$\text{lookup}(\Sigma[\sigma_0 \mapsto V], \sigma_0) = V$$
$$\text{lookup}(\Sigma[\sigma_0 \mapsto V], \sigma_1) = \text{lookup}(\Sigma, \sigma_1)$$

$$\text{extend}(\Sigma, \sigma, V)$$
$$\text{extend}(\emptyset, \sigma, V) = \emptyset[\sigma \mapsto V]$$
$$\text{extend}(\Sigma[\sigma_0 \mapsto V_0], \sigma_0, V_1) = \Sigma[\sigma_0 \mapsto V_1]$$

$$\Sigma[\sigma_0 \mapsto V_0] \ldots [\sigma_n \mapsto V_n] \;/\; M$$
$$\longmapsto \Sigma \;/\; M$$
$$\text{if } \sigma_0 \ldots \sigma_n \notin \mathrm{LIVE}(M)$$

$$
\begin{aligned}
\mathrm{LIVE}(X) &= \emptyset \qquad\qquad \sigma = \{\sigma\} \\
(M\ N) &= LV(M) \cup LV(N) \\
(\lambda X.M) &= LV(M) \\
(o^n\ M \ldots) &= LV(M) \cup \ldots \\
(\text{set!}\ M\ N) &= LV(M) \cup LV(n) \\
(M;\ N) &= \;\text{''}
\end{aligned}
$$

C E S K

control, env, store, continuation

$C = M \qquad E = \emptyset \mid E[X \mapsto \sigma]$

$S = \emptyset \mid S[\sigma \mapsto V]$

$K = mt \mid fun(N, E, K) \mid arg(V, K)$

$M = \ldots \mid (\text{set!}\ X\ M) \qquad \mid \text{set!}(\cancel{N,}E, K) \mid \text{set!}(\sigma, K)$

$\mid seq(N, E, K)$

$$
\begin{aligned}
&\langle X, E, S, K\rangle \longmapsto \langle E(X), E, S, K\rangle \\
&\langle \sigma, E, S, K\rangle \longmapsto \langle S(\sigma), E, S, K\rangle \\
&\langle (M\ N), E, S, K\rangle \longmapsto \langle M, E, S, fun(N, E, K)\rangle \\
&\langle V, E, S, fun(N, E', K)\rangle \longmapsto \langle N, E', S, arg(V, K)\rangle \\
&\langle \lambda X.M, E, S, K\rangle \longmapsto \langle clo(\lambda X.M, E), E, S, K\rangle \\
&\langle V, E, S, arg(clo(\lambda X.M, E'), K)\rangle \\
&\qquad \longmapsto \langle M, E'[X \mapsto \sigma_f], S[\sigma_f \mapsto V], K\rangle \\
&\langle (\text{set!}\ \sigma\ M), E, S, K\rangle \\
&\qquad \longmapsto \langle M, E, S, \text{set!}(\sigma, K)\rangle \\
&\langle V, E, S, \text{set!}(\sigma, K)\rangle \\
&\qquad \longmapsto \langle V, E, S[\sigma \mapsto V], K\rangle \\
&\langle M;N, E, S, K\rangle \longmapsto \langle M, E, S, seg(N, E, K)\rangle \\
&\langle V, E, S, seg(N, E', K)\rangle \longmapsto \langle N, E', S, K\rangle
\end{aligned}
$$