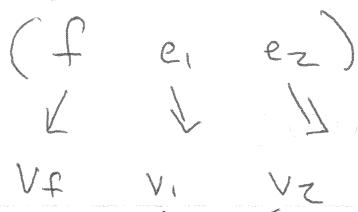


Mutation - "Here are places that store stuff at different points in time"

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

Math is inherently timeless parallel

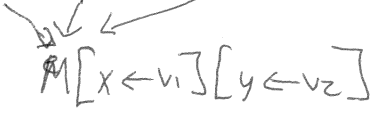
C has no substitution
C requires time
C is inherently sequential



```

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

```



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

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

State - ISWIM

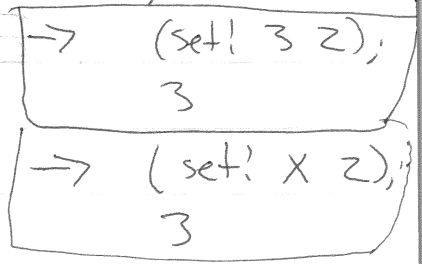
$M = \dots \mid (\text{set! } X \ M) \mid (M; M)$
 $E = \dots \mid (\text{set! } X \ E) \mid (E; M)$

```

( (-X,
  (set! X Z);
  X)
  3)

```

$E[(\text{set! } X \ v_2)] \Leftrightarrow$
 $E[(-X, m) \ v_1] \Leftrightarrow E[M[x \leftarrow v_1]]$
 $E[V; M] \Leftrightarrow E[M]$



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

$\sigma =$ some set distinct from variables $V = \dots \mid \sigma$
"pointers" "addresses"

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

In Normal ISWIM \mapsto was a relation on M

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

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 $\Sigma / E[\sigma V] \mapsto \sigma_f$ is fresh in Σ
if $\Sigma(\sigma) = (\lambda X. M)$

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

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

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



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

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

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

19-3/

eval (m) = if $\emptyset / M \mapsto^* \Sigma / V$

then b if $V \in b$
'fun if $V \in \lambda X, M$

$\emptyset / ((\lambda X, (set! X (+ X 1)))$
 $(\lambda Y, (set! Y (+ X 1))$
 $(+ Y X)$
 $Y))$ \mapsto $\emptyset [\sigma_0 \mapsto 2] /$
 $(set! \sigma_0 (+ \sigma_0 1))$
 $\textcircled{1} \left[\begin{array}{l} (\lambda Y, (set! Y (+ \sigma_0 1)) \\ (+ Y \sigma_0)) \\ Y \end{array} \right]$
 \Downarrow

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

\Downarrow
 $\emptyset [\sigma_0 \mapsto 2] [\sigma_0 \mapsto 3] [\sigma_1 \mapsto 4] [\sigma_1 \mapsto 5] / (+ \sigma_0 \sigma_1)$
 \mapsto
 $" / 8$

lookup (Σ, σ) = $\Sigma(\sigma)$

lookup ($\Sigma [\sigma_0 \mapsto V], \sigma_0$) = V

lookup ($\Sigma [\sigma_0 \mapsto V], \sigma_1$) = lookup (Σ, σ_1)

extend (Σ, σ, V)

extend (\emptyset, σ, V) = $\emptyset [\sigma \mapsto V]$

extend ($\Sigma [\sigma_0 \mapsto V_0], \sigma_0, V_1$) = $\Sigma [\sigma_0 \mapsto V_1]$

19-4/

$$\Sigma [\sigma_0 \mapsto V_0] \dots [\sigma_n \mapsto V_n] / M$$

$$\mapsto \Sigma / M$$

if $\sigma_0 \dots \sigma_n \notin \text{LIVE}(M)$

$$\text{LIVE}(X) = \emptyset \quad \sigma = \{\sigma\}$$

$$(M N) = \text{LV}(M) \cup \text{LV}(N)$$

$$(\lambda X.M) = \text{LV}(M)$$

$$(\sigma^n M \dots) = \text{LV}(M) \cup \dots$$

$$(\text{set! } M N) = \text{LV}(M) \cup \text{LV}(N)$$

$$(M; N) = \dots$$

C	E	S	k	$C = M$	$E = \emptyset$	$ E[X \mapsto \sigma]$
\downarrow	\downarrow	\downarrow	\downarrow		$S = \emptyset$	$ S[\sigma \mapsto V]$
control	env	store	continuation			
				$k = mt$	$ \text{fun}(N, E, k)$	$ \text{arg}(V, k)$
				$M = \dots$	$ (\text{set! } X M)$	$ \text{set!}(M, E, k)$
						$ \text{set!}(\sigma, k)$
						$ \text{seg}(N, E, k)$

- $\langle X, E, S, k \rangle \mapsto \langle E(X), E, S, k \rangle$
- $\langle \sigma, E, S, k \rangle \mapsto \langle S(\sigma), E, S, k \rangle$
- $\langle (M N), E, S, k \rangle \mapsto \langle M, E, S, \text{fun}(N, E, k) \rangle$
- $\langle V, E, S, \text{fun}(N, E', k) \rangle \mapsto \langle N, E', S, \text{arg}(V, k) \rangle$
- $\langle \lambda X.M, E, S, k \rangle \mapsto \langle \text{clo}(\lambda X.M, E), E, S, k \rangle$
- $\langle V, E, S, \text{arg}(\overset{\text{clo}}{\lambda X.M}, E', k) \rangle$
- $\mapsto \langle M, E' [X \mapsto \sigma], S[\sigma \mapsto V], k \rangle$
- $\langle (\text{set! } \sigma M), E, S, k \rangle$
- $\mapsto \langle M, E, S, \text{set!}(\sigma, k) \rangle$
- $\langle V, E, S, \text{set!}(\sigma, k) \rangle$
- $\mapsto \langle V, E, S[\sigma \mapsto V], k \rangle$
- $\langle M; N, E, S, k \rangle \mapsto \langle M, E, S, \text{seg}(N, E, k) \rangle$
- $\langle V, E, S, \text{seg}(N, E', k) \rangle \mapsto \langle N, E', S, k \rangle$