Semantics (Large-Step and Small)

$$
\begin{array}{rcl}
v_* \in V & ::= & n \mid \mathit{true} \mid \mathit{false} \mid (\lambda x.M) \mid (\text{pair } V\ V) \mid (\text{inl } V) \mid (\text{inr } V) \mid \sigma \\
\\
e_* \in M & ::= & V \mid \\
& & (\text{op } M\ M) \mid \\
& & (\text{if } M\ M\ M) \mid \\
& & (M\ M) \mid \\
& & x \mid \\
& & (\text{box } M) \mid (\text{unbox } M) \mid (\text{set-box! } M\ M) \mid \\
& & (\text{pair } M\ M) \mid (\text{fst } M) \mid (\text{snd } M) \mid \\
& & (\text{inl } M) \mid (\text{inr } M) \mid (\text{match } M\ M\ M)
\end{array}
$$

Large-step (for an eager language with boxes):

$$v; \Sigma \Downarrow v; \Sigma \qquad \text{(VAL)}$$

$$\frac{e_1; \Sigma_0 \Downarrow n_1; \Sigma_1 \qquad e_2; \Sigma_1 \Downarrow n_2; \Sigma_2}{(\text{op } e_1\ e_2); \Sigma_0 \Downarrow \overline{\text{op}}(n_1, n_2); \Sigma_2} \qquad \text{(ARITH)}$$

$$\frac{e_c; \Sigma_0 \Downarrow \mathit{true}; \Sigma_1 \qquad e_t; \Sigma_1 \Downarrow v; \Sigma_2}{(\text{if } e_c\ e_t\ e_f); \Sigma_0 \Downarrow v; \Sigma_2} \qquad \text{(IF-TRUE)}$$

$$\frac{e_c; \Sigma_0 \Downarrow \mathit{false}; \Sigma_1 \qquad e_f; \Sigma_1 \Downarrow v; \Sigma_2}{(\text{if } e_c\ e_t\ e_f); \Sigma_0 \Downarrow v; \Sigma_2} \qquad \text{(IF-FALSE)}$$

$$\frac{e_f; \Sigma_0 \Downarrow (\lambda x.e_b); \Sigma_1 \qquad e_a; \Sigma_1 \Downarrow v_a; \Sigma_2 \qquad e_b[x \leftarrow v_a]; \Sigma_2 \Downarrow v; \Sigma_3}{(e_f e_a); \Sigma_0 \Downarrow v; \Sigma_3} \qquad (\beta_v)$$

$$\frac{e; \Sigma_0 \Downarrow v; \Sigma_1 \qquad \sigma \notin \text{dom}(\Sigma_1)}{(\text{box } e); \Sigma_0 \Downarrow \sigma; \Sigma_1, \sigma \leftarrow v} \qquad \text{(BOX)}$$

$$\frac{e; \Sigma_0 \Downarrow \sigma; \Sigma_1 \qquad \Sigma_1(\sigma) = v}{(\text{unbox } e); \Sigma_0 \Downarrow v; \Sigma_1} \qquad \text{(UNBOX)}$$

$$\frac{e_1; \Sigma_0 \Downarrow \sigma; \Sigma_1 \qquad e_2; \Sigma_1 \Downarrow v; \Sigma_2}{(\text{set-box! } e_1\ e_2); \Sigma_0 \Downarrow v; \Sigma_2, \sigma \leftarrow v} \qquad \text{(SET-BOX!)}$$

$$\frac{e_1; \Sigma_0 \Downarrow v_1; \Sigma_1 \qquad e_2; \Sigma_1 \Downarrow v_2; \Sigma_2}{(\text{pair } e_1\ e_2); \Sigma_0 \Downarrow (\text{pair } v_1\ v_2); \Sigma_2} \qquad \text{(PAIR)}$$

$$\frac{e; \Sigma_0 \Downarrow (\text{inl } v_\ell); \Sigma_1 \qquad e_\ell; \Sigma_1 \Downarrow (\lambda x.e_b); \Sigma_2 \qquad e_b[x \leftarrow v_\ell]; \Sigma_2 \Downarrow v; \Sigma_3}{(\text{match } e\ e_\ell\ e_r); \Sigma_0 \Downarrow v; \Sigma_3} \qquad \text{(MATCH-LEFT)}$$

$$\frac{e; \Sigma_0 \Downarrow (\text{inr } v_r); \Sigma_1 \qquad e_r; \Sigma_1 \Downarrow (\lambda x.e_b); \Sigma_2 \qquad e_b[x \leftarrow v_r]; \Sigma_2 \Downarrow v; \Sigma_3}{(\text{match } e\ e_\ell\ e_r); \Sigma_0 \Downarrow v; \Sigma_3} \qquad \text{(MATCH-RIGHT)}$$

Small-step (with continuations as well as boxes).

$$v_* \in V \quad ::= \quad \ldots \mid (\widehat{\lambda} E)$$

$$e_* \in M \quad ::= \quad \ldots \mid (\text{call/cc } M)$$

$$\begin{aligned} E \quad ::= \quad & [\,] \mid \\ & (\text{if } E\ M\ M) \mid \\ & (\text{pair } E\ M) \mid (\text{pair } V\ E) \mid (\text{fst } E) \mid (\text{snd } E) \mid \\ & (\text{inl } E) \mid (\text{inr } E) \mid (\text{match } E\ M\ M) \mid (\text{match (inl } V)\ E\ M) \mid (\text{match (inr } V)\ M\ E) \mid \\ & (\text{box } E) \mid (\text{unbox } E) \mid (\text{set-box! } E\ M) \mid (\text{set-box! } V\ E) \mid \\ & (E\ M) \mid (V\ E) \mid \\ & (\text{call/cc } E) \end{aligned}$$

$$E[(\text{if } \mathit{true}\ e_t\ e_f)]; \Sigma \to E[e_t]; \Sigma \qquad (\textsc{if-true})$$

$$E[(\text{if } \mathit{false}\ e_t\ e_f)]; \Sigma \to E[e_f]; \Sigma \qquad (\textsc{if-false})$$

$$E[(\text{match (inl } v)\ (\lambda x.e_b)\ e_r)]; \Sigma \to E[e_b[x \leftarrow v]]; \Sigma \qquad (\textsc{match-left})$$

$$E[(\text{match (inr } v)\ e_\ell\ (\lambda x.e_b))]; \Sigma \to E[e_b[x \leftarrow v]]; \Sigma \qquad (\textsc{match-right})$$

$$E[(\text{box } v)]; \Sigma \to E[\sigma]; \Sigma, \sigma \leftarrow v \qquad (\sigma \notin \text{dom}(\Sigma)) \qquad (\textsc{box})$$

$$E[(\text{unbox } \sigma)]; \Sigma \to E[v]; \Sigma \qquad (v = \Sigma(\sigma)) \qquad (\textsc{unbox})$$

$$E[(\text{set-box! } \sigma\ v)]; \Sigma \to E[v]; \Sigma, \sigma \leftarrow v \qquad (\textsc{set-box!})$$

$$E[((\lambda x.e)\ v)]; \Sigma \to E[e[x \leftarrow v]]; \Sigma \qquad (\beta_v)$$

$$E[(\text{call/cc } (\lambda x.e))]; \Sigma \to E[e[x \leftarrow (\widehat{\lambda} E)]]; \Sigma \qquad (\textsc{call/cc})$$

$$E[((\widehat{\lambda} E')\ v)]; \Sigma \to E'[v]; \Sigma \qquad (\textsc{cont})$$