$$\frac{}{\langle \textsc{literal}(v), \xi, \phi, \rho\rangle \Downarrow \langle v, \xi, \phi, \rho\rangle} \quad (\textsc{Literal})$$

$$\frac{x \in \operatorname{dom} \rho}{\langle \textsc{var}(x), \xi, \phi, \rho\rangle \Downarrow \langle \rho(x), \xi, \phi, \rho\rangle} \quad (\textsc{FormalVar})$$

$$\frac{x \notin \operatorname{dom} \rho \qquad x \in \operatorname{dom} \xi}{\langle \textsc{var}(x), \xi, \phi, \rho\rangle \Downarrow \langle \xi(x), \xi, \phi, \rho\rangle} \quad (\textsc{GlobalVar})$$

$$\frac{x \in \operatorname{dom} \rho \qquad \langle e, \xi, \phi, \rho\rangle \Downarrow \langle v, \xi', \phi, \rho'\rangle}{\langle \textsc{set}(x, e), \xi, \phi, \rho\rangle \Downarrow \langle v, \xi', \phi, \rho'\{x \mapsto v\}\rangle} \quad (\textsc{FormalAssign})$$

$$\frac{x \notin \operatorname{dom} \rho \qquad x \in \operatorname{dom} \xi \qquad \langle e, \xi, \phi, \rho\rangle \Downarrow \langle v, \xi', \phi, \rho'\rangle}{\langle \textsc{set}(x, e), \xi, \phi, \rho\rangle \Downarrow \langle v, \xi'\{x \mapsto v\}, \phi, \rho'\rangle} \quad (\textsc{GlobalAssign})$$

$$\frac{\langle e_1, \xi, \phi, \rho\rangle \Downarrow \langle v_1, \xi', \phi, \rho'\rangle \qquad v_1 \neq 0 \qquad \langle e_2, \xi', \phi, \rho'\rangle \Downarrow \langle v_2, \xi'', \phi, \rho''\rangle}{\langle \textsc{if}(e_1, e_2, e_3), \xi, \phi, \rho\rangle \Downarrow \langle v_2, \xi'', \phi, \rho''\rangle} \quad (\textsc{IfTrue})$$

$$\frac{\langle e_1, \xi, \phi, \rho\rangle \Downarrow \langle v_1, \xi', \phi, \rho'\rangle \qquad v_1 = 0 \qquad \langle e_3, \xi', \phi, \rho'\rangle \Downarrow \langle v_3, \xi'', \phi, \rho''\rangle}{\langle \textsc{if}(e_1, e_2, e_3), \xi, \phi, \rho\rangle \Downarrow \langle v_3, \xi'', \phi, \rho''\rangle} \quad (\textsc{IfFalse})$$

$$\frac{\begin{array}{c}\langle e_1, \xi, \phi, \rho\rangle \Downarrow \langle v_1, \xi', \phi, \rho'\rangle \qquad v_1 \neq 0 \\ \langle e_2, \xi', \phi, \rho'\rangle \Downarrow \langle v_2, \xi'', \phi, \rho''\rangle \qquad \langle \textsc{while}(e_1, e_2), \xi'', \phi, \rho''\rangle \Downarrow \langle v_3, \xi''', \phi, \rho'''\rangle\end{array}}{\langle \textsc{while}(e_1, e_2), \xi, \phi, \rho\rangle \Downarrow \langle v_3, \xi''', \phi, \rho'''\rangle} \quad (\textsc{WhileIterate})$$

$$\frac{\langle e_1, \xi, \phi, \rho\rangle \Downarrow \langle v_1, \xi', \phi, \rho'\rangle \qquad v_1 = 0}{\langle \textsc{while}(e_1, e_2), \xi, \phi, \rho\rangle \Downarrow \langle 0, \xi', \phi, \rho'\rangle} \quad (\textsc{WhileEnd})$$

$$\frac{}{\langle \textsc{begin}(), \xi, \phi, \rho\rangle \Downarrow \langle 0, \xi, \phi, \rho\rangle} \quad (\textsc{EmptyBegin})$$

$$\frac{\begin{array}{c}\langle e_1, \xi_0, \phi, \rho_0\rangle \Downarrow \langle v_1, \xi_1, \phi, \rho_1\rangle \\ \langle e_2, \xi_1, \phi, \rho_1\rangle \Downarrow \langle v_2, \xi_2, \phi, \rho_2\rangle \\ \vdots \\ \langle e_n, \xi_{n-1}, \phi, \rho_{n-1}\rangle \Downarrow \langle v_n, \xi_n, \phi, \rho_n\rangle\end{array}}{\langle \textsc{begin}(e_1, e_2, \ldots, e_n), \xi_0, \phi, \rho_0\rangle \Downarrow \langle v_n, \xi_n, \phi, \rho_n\rangle} \quad (\textsc{Begin})$$

$$\frac{\begin{array}{c}\phi(f) = \textsc{user}(\langle x_1, \ldots, x_n\rangle, e) \\ x_1, \ldots, x_n \text{ all distinct} \\ \langle e_1, \xi_0, \phi, \rho_0\rangle \Downarrow \langle v_1, \xi_1, \phi, \rho_1\rangle \\ \vdots \\ \langle e_n, \xi_{n-1}, \phi, \rho_{n-1}\rangle \Downarrow \langle v_n, \xi_n, \phi, \rho_n\rangle \\ \langle e, \xi_n, \phi, \{x_1 \mapsto v_1, \ldots, x_n \mapsto v_n\}\rangle \Downarrow \langle v, \xi', \phi, \rho'\rangle\end{array}}{\langle \textsc{apply}(f, e_1, \ldots, e_n), \xi_0, \phi, \rho_0\rangle \Downarrow \langle v, \xi', \phi, \rho_n\rangle} \quad (\textsc{ApplyUser})$$

Figure 1.4: Summary of operational semantics (expressions)