Pixy formal semantics

A. Finn Hackett, Reed Mullanix

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1 Term language

$\langle expr \rangle ::= \langle number \rangle$
$\quad | \quad \langle var \rangle$
$\quad | \quad$ nil
$\quad | \quad$? $\langle expr \rangle$
$\quad | \quad$ if $\langle expr \rangle$ then $\langle expr \rangle$ else $\langle expr \rangle$
$\quad | \quad \langle expr \rangle$ fby $\langle expr \rangle$
$\quad | \quad \langle expr \rangle$ where $\langle wheredecls \rangle$
$\quad | \quad$ next $\langle expr \rangle$
$\quad | \quad \langle var \rangle$ ($\langle exprlist \rangle$)
$\quad | \quad \langle expr \rangle$ + $\langle expr \rangle$
$\quad | \quad \langle expr \rangle$ - $\langle expr \rangle$
$\quad | \quad \langle expr \rangle$ * $\langle expr \rangle$
$\quad | \quad \langle expr \rangle$ / $\langle expr \rangle$
$\quad | \quad \langle expr \rangle$ .. $\langle expr \rangle$
$\quad | \quad$ ($\langle exprlist \rangle$)
$\quad | \quad$ len $\langle expr \rangle$
$\quad | \quad$ [$\langle exprlist \rangle$] $\langle expr \rangle$

$\langle exprlist \rangle ::= \langle expr \rangle$, $\langle exprlist \rangle \mid \langle expr \rangle$

$\langle varlist \rangle ::= \langle var \rangle$, $\langle varlist \rangle \mid \langle var \rangle$

$\langle wheredecl \rangle ::= \langle var \rangle$ = $\langle expr \rangle$
$\quad | \quad \langle var \rangle$ ($\langle varlist \rangle$) = $\langle expr \rangle$
$\quad | \quad$ ($\langle varlist \rangle$) = $\langle expr \rangle$

$\langle wheredecls \rangle ::= \langle wheredecl \rangle; \langle wheredecls \rangle \mid \langle wheredecl \rangle$

2 Init rules

$$\frac{F \vdash E \overset{init}{\Rightarrow} S}{F \vdash ?E \overset{init}{\Rightarrow} S}[\texttt{Init} - \texttt{check}]$$

$$\frac{\begin{array}{c} F \vdash L \overset{init}{\Rightarrow} S_l \\ F \vdash R \overset{init}{\Rightarrow} S_r \end{array}}{F \vdash L \text{ fby } R \overset{init}{\Rightarrow} false, S_l, S_r}[\texttt{Init} - \texttt{fby}]$$

$$\frac{\begin{array}{c} F \vdash C \overset{init}{\Rightarrow} S_c \\ F \vdash T \overset{init}{\Rightarrow} S_t \\ F \vdash F \overset{init}{\Rightarrow} S_f \end{array}}{F \vdash \text{if } C \text{ then } T \text{ else } F \overset{init}{\Rightarrow} S_c, S_t, S_f}[\texttt{Init} - \texttt{ite}]$$

$$\frac{F \vdash E \overset{init}{\Rightarrow} S}{F \vdash \text{next } E \overset{init}{\Rightarrow} false, S}[\texttt{Init} - \texttt{next}]$$

$$\frac{F \vdash E_n \overset{wheredecl}{\Rightarrow} F'}{F \vdash n = E; E_n \overset{wheredecl}{\Rightarrow} F'}[\texttt{WhereInit} - \texttt{v} - \texttt{decl}]$$

$$\frac{F \vdash E_n \overset{wheredecl}{\Rightarrow} F'}{F \vdash f(A) = E; E_n \overset{wheredecl}{\Rightarrow} f \to \langle A, E \rangle, F'}[\texttt{WhereInit} - \texttt{fn} - \texttt{decl}]$$

$$\frac{}{F \vdash \overset{wheredecl}{\Rightarrow} F}[\texttt{WhereInit} - \texttt{empty} - \texttt{decl}]$$

$$\frac{\begin{array}{c} F \vdash E \overset{init}{\Rightarrow} s \\ F \vdash E_n \overset{whereinit}{\Rightarrow} S \end{array}}{F \vdash n = E; E_n \overset{whereinit}{\Rightarrow} \langle nil, s \rangle, S}[\texttt{WhereInit} - \texttt{v} - \texttt{init}]$$

$$\frac{F \vdash E_n \overset{whereinit}{\Rightarrow} S}{F \vdash f(A) = E; E_n \overset{whereinit}{\Rightarrow} S}[\texttt{WhereInit} - \texttt{fn} - \texttt{init}]$$

$$\frac{}{F \vdash \stackrel{whereinit}{\Rightarrow} \emptyset}[\texttt{WhereInit} - \texttt{empty} - \texttt{init}]$$

$$\frac{\begin{array}{c} F \vdash E_s \stackrel{wheredecl}{\Rightarrow} F' \\ F' \vdash E \stackrel{init}{\Rightarrow} S_e \\ F' \vdash E_s \stackrel{whereinit}{\Rightarrow} S \end{array}}{F \vdash E \,\text{where}\, E_s \stackrel{init}{\Rightarrow} S_e, S}[\texttt{Init} - \texttt{where}]$$

$$\frac{\begin{array}{c} F \vdash A \stackrel{init}{\Rightarrow} S \\ F \vdash A_n \stackrel{applyinit}{\Rightarrow} S_n \end{array}}{F \vdash A, A_n \stackrel{applyinit}{\Rightarrow} S, S_n}[\texttt{ApplyInit} - \texttt{arg}]$$

$$\frac{}{F \vdash \stackrel{applyinit}{\Rightarrow} \emptyset}[\texttt{ApplyInit} - \texttt{empty}]$$

$$\frac{\begin{array}{c} F(f) = \langle \_, E \rangle \\ F \vdash E \stackrel{init}{\Rightarrow} S_e \\ F \vdash A \stackrel{applyinit}{\Rightarrow} S \end{array}}{F \vdash f(A) \stackrel{init}{\Rightarrow} S_e, S}[\texttt{Init} - \texttt{apply}]$$

$$\frac{}{F \vdash \_ \stackrel{init}{\Rightarrow} \emptyset}[\texttt{Init} - \texttt{literal}]$$

$$\frac{\begin{array}{c} F \vdash L \stackrel{init}{\Rightarrow} S_l \\ F \vdash R \stackrel{init}{\Rightarrow} S_r \end{array}}{F \vdash L \ \_ \ R \stackrel{init}{\Rightarrow} S_l, S_r}[\texttt{Init} - \texttt{binop}]$$

3 Data type sizing

4 Evaluation rules

$$\frac{\begin{array}{c} S; F; M \vdash E \Downarrow V; S' \\ V \neq nil \end{array}}{S; F; M \vdash ?E \Downarrow true; S'}[\texttt{Eval} - \texttt{check} - \texttt{true}]$$

$$\frac{S; F; M \vdash E \Downarrow nil; S'}{S; F; M \vdash\, ?E \Downarrow false; S'}[\texttt{Eval} - \texttt{check} - \texttt{false}]$$

$$\frac{\begin{array}{c} S_c; F; M \vdash C \Downarrow true; S_c' \\ S_t; F; M \vdash T \Downarrow V; S_t' \\ S_f; F; M \vdash F \not\Downarrow nil; S_f' \end{array}}{S_c, S_t, S_f; F; M \vdash \text{if } C \text{ then } T \text{ else } F \Downarrow V; S_c', S_t', S_f'}[\texttt{Eval} - \texttt{ite} - \texttt{true}]$$

$$\frac{\begin{array}{c} S_c; F; M \vdash C \Downarrow false; S_c' \\ S_t; F; M \vdash T \not\Downarrow nil; S_t' \\ S_f; F; M \vdash F \Downarrow V; S_f' \end{array}}{S_c, S_t, S_f; F; M \vdash \text{if } C \text{ then } T \text{ else } F \Downarrow V; S_c', S_t', S_f'}[\texttt{Eval} - \texttt{ite} - \texttt{false}]$$

$$\frac{\begin{array}{c} S_c; F; M \vdash C \Downarrow nil; S_c' \\ S_t; F; M \vdash T \not\Downarrow nil; S_t' \\ S_f; F; M \vdash F \not\Downarrow nil; S_f' \end{array}}{S_c, S_t, S_f; F; M \vdash \text{if } C \text{ then } T \text{ else } F \Downarrow nil; S_c', S_t', S_f'}[\texttt{Eval} - \texttt{ite} - \texttt{nil}]$$

$$\frac{\begin{array}{c} S_c; F; M \vdash C \not\Downarrow nil; S_c' \\ S_t; F; M \vdash T \not\Downarrow nil; S_t' \\ S_f; F; M \vdash F \not\Downarrow nil; S_f' \end{array}}{S_c, S_t, S_f; F; M \vdash \text{if } C \text{ then } T \text{ else } F \not\Downarrow nil; S_c', S_t', S_f'}[\texttt{Eval} - \texttt{ite} - \texttt{C}]$$

$$\frac{\begin{array}{c} S_l; F; M \vdash E_l \Downarrow V; S_l' \\ V \neq nil \\ S_r; F; M \vdash E_r \not\Downarrow nil; S_r' \end{array}}{false, S_l, S_r; F; M \vdash E_l \text{ fby } E_r \Downarrow V; true, S_l', S_r'}[\texttt{Eval} - \texttt{fby} - \texttt{before}]$$

$$\frac{\begin{array}{c} S_l; F; M \vdash E_l \Downarrow nil; S_l' \\ S_r; F; M \vdash E_r \not\Downarrow nil; S_r' \end{array}}{false, S_l, S_r; F; M \vdash E_l \text{ fby } E_r \Downarrow nil; false, S_l', S_r'}[\texttt{Eval} - \texttt{fby} - \texttt{before} - \texttt{nil}]$$

$$\frac{\begin{array}{c} S_l; F; M \vdash E_l \not\Downarrow nil; S_l' \\ S_r; F; M \vdash E_r \Downarrow V; S_r' \end{array}}{true, S_l, S_r; F; M \vdash E_l \text{ fby } E_r \Downarrow V; true, S_l', S_r'}[\texttt{Eval} - \texttt{fby} - \texttt{after}]$$

$$\frac{\begin{array}{c} S_l; F; M \vdash E_l \not\Downarrow nil; S'_l \\ S_r; F; M \vdash E_r \not\Downarrow nil; S'_r \end{array}}{c, S_l, S_r; F; M \vdash E_l \text{ fby } E_r \Downarrow nil; c, S'_l, S'_r} [\texttt{Eval} - \texttt{fby} - \texttt{C}]$$

$$\frac{S_n; F; M \vdash E_n \stackrel{names}{\Rightarrow} F'; M'}{\langle v, \_ \rangle, S_n; F; M \vdash n = E; E_n \stackrel{names}{\Rightarrow} F'; n \to v, M'} [\texttt{WhereNames} - \texttt{v} - \texttt{decl}]$$

$$\frac{S; f \to \langle A, E \rangle, F; M \vdash E_v \stackrel{names}{\Rightarrow} F'; M'}{S; F; M \vdash f(A) = E; E_n \stackrel{names}{\Rightarrow} F'; M'} [\texttt{WhereNames} - \texttt{fn} - \texttt{decl}]$$

$$\frac{}{\emptyset; F; M \vdash \stackrel{names}{\Rightarrow} F'; M'} [\texttt{WhereNames} - \texttt{empty}]$$

$$\frac{s; F; M \vdash E \Downarrow v; s' S_n; F; M \vdash E_n \stackrel{values}{\Rightarrow} S'_n}{\langle \_, s \rangle, S_n; F; M \vdash n = E; E_n \stackrel{values}{\Rightarrow} \langle v, s' \rangle, S'_n} [\texttt{WhereVal} - \texttt{v} - \texttt{decl}]$$

$$\frac{S; F; M \vdash E_n \stackrel{values}{\Rightarrow} S'}{S; F; M \vdash f(A) = E; E_n \stackrel{values}{\Rightarrow} S'} [\texttt{WhereVal} - \texttt{fn} - \texttt{decl}]$$

$$\frac{}{\emptyset; F; M \vdash \stackrel{values}{\Rightarrow} \emptyset} [\texttt{WhereVal} - \texttt{empty}]$$

$$\frac{\begin{array}{c} S; F; M \vdash E_s \stackrel{names}{\Rightarrow} F_i; M_i \\ S; F_i; M_i \vdash E_s \stackrel{values}{\Rightarrow} S' \\ S_e; F_i; M_i \vdash E \Downarrow V; S'_e \end{array}}{S_e, S; F; M \vdash E \text{ where } E_s \Downarrow V; S'_e, S'} [\texttt{Eval} - \texttt{where}]$$

$$\frac{\begin{array}{c} S; F; M \vdash E_s \stackrel{names}{\Rightarrow} F_i; M_i \\ S; F_i; M_i \vdash E_s \stackrel{values}{\Rightarrow} S' \\ S_e; F_i; M_i \vdash E \not\Downarrow nil; S'_e \end{array}}{S_e, S; F; M \vdash E \text{ where } E_s \not\Downarrow nil; S'_e, S'} [\texttt{Eval} - \texttt{where} - \texttt{C}]$$

$$\frac{\begin{array}{c} S; F; M \vdash E \Downarrow V; S' \\ V \neq nil \end{array}}{\langle false, nil \rangle, S; F; M \vdash \text{next } E \Downarrow nil; \langle true, V \rangle, S'} [\texttt{Eval} - \texttt{next} - \texttt{before}]$$

$$\frac{S; F; M \vdash E \Downarrow nil; S'}{\langle false, nil \rangle, S; F; M \vdash \text{next } E \Downarrow nil; \langle false, nil \rangle, S'} [\texttt{Eval} - \texttt{next} - \texttt{before} - \texttt{nil}]$$

$$\frac{\begin{array}{c} v \neq nil \\ S; F; M \vdash E \Downarrow V; S' \end{array}}{\langle true, v \rangle, S; F; M \vdash \text{next } E \Downarrow v; \langle true, V \rangle, S'} [\texttt{Eval} - \texttt{next} - \texttt{after}]$$

$$\frac{S; F; M \vdash E \Downarrow V; S'}{\langle true, nil \rangle, S; F; M \vdash \text{next } E \Downarrow V; \langle true, nil \rangle, S'} [\texttt{Eval} - \texttt{next} - \texttt{after} - \texttt{nil}]$$

$$\frac{S; F; M \vdash E \not\Downarrow nil; S'}{\langle c, v \rangle, S; F; M \vdash \text{next } E \not\Downarrow nil; \langle c, v \rangle, S'} [\texttt{Eval} - \texttt{next} - \texttt{C}]$$

$$\frac{}{\emptyset; F; M \vdash nil \Downarrow nil; \emptyset} [\texttt{Eval} - \texttt{nil}]$$

$$\frac{}{\emptyset; F; M \vdash nil \not\Downarrow nil; \emptyset} [\texttt{Eval} - \texttt{nil} - \texttt{C}]$$

$$\frac{N \in \mathbb{R}}{\emptyset; F; M \vdash N \Downarrow N; \emptyset} [\texttt{Eval} - \texttt{num}]$$

$$\frac{N \in \mathbb{R}}{\emptyset; F; M \vdash N \not\Downarrow nil; \emptyset} [\texttt{Eval} - \texttt{num} - \texttt{C}]$$

$$\frac{M(I) = V}{\emptyset; F; M \vdash I \Downarrow V; \emptyset} [\texttt{Eval} - \texttt{id}]$$

$$\frac{M(I) = V}{\emptyset; F; M \vdash I \not\Downarrow nil; \emptyset} [\texttt{Eval} - \texttt{id} - \texttt{C}]$$

$$\frac{E \in \{true, false\}}{\emptyset; F; M \vdash E \Downarrow E; \emptyset} [\texttt{Eval} - \texttt{boolean}]$$

$$\frac{E \in \{true, false\}}{\emptyset; F; M \vdash E \Downarrow\!\!\!\!\!\Downarrow\, nil; \emptyset}[\texttt{Eval} - \texttt{boolean} - \texttt{C}]$$

$$\frac{\begin{array}{c} S; F; M \vdash E \Downarrow V; S' \\ A_n; S_n; F; M \vdash E_n \overset{arg}{\Rightarrow} M_i; S'_n \end{array}}{A, A_n; S, S_n; F; M \vdash E, E_n \overset{arg}{\Rightarrow} A \to V, M_i; S', S'_n}[\texttt{Apply} - \texttt{arg}]$$

$$\frac{}{\emptyset; \emptyset; F; M \vdash \overset{arg}{\Rightarrow} \emptyset; \emptyset}[\texttt{Apply} - \texttt{arg} - \texttt{empty}]$$

$$\frac{\begin{array}{c} S; F; M \vdash E \Downarrow\!\!\!\!\!\Downarrow\, nil; S' \\ A_n; S_n; F; M \vdash E_n \overset{argC}{\Rightarrow} M_i; S'_n \end{array}}{A, A_n; S, S_n; F; M \vdash E, E_n \overset{argC}{\Rightarrow} A \to nil, M_i; S', S'_n}[\texttt{Apply} - \texttt{arg} - \texttt{C}]$$

$$\frac{}{\emptyset; \emptyset; F; M \vdash \overset{argC}{\Rightarrow} \emptyset; \emptyset}[\texttt{Apply} - \texttt{arg} - \texttt{empty} - \texttt{C}]$$

$$\frac{\begin{array}{c} F(f) = \langle A, E \rangle \\ A; S; F; M \vdash a \overset{arg}{\Rightarrow} M_i; S' \\ S_e; F; M_i \vdash E \Downarrow V; S'_e \end{array}}{S_e, S; F; M \vdash f(a) \Downarrow V; S'_e, S'}[\texttt{Eval} - \texttt{apply}]$$

$$\frac{\begin{array}{c} F(f) = \langle A, E \rangle \\ A; S; F; M \vdash a \overset{argC}{\Rightarrow} M_i; S' \\ S_e; F; M_i \vdash E \Downarrow\!\!\!\!\!\Downarrow\, nil; S'_e \end{array}}{S_e, S; F; M \vdash f(a) \Downarrow nil; S'_e, S'}[\texttt{Eval} - \texttt{apply} - \texttt{C}]$$

$$\frac{\begin{array}{c} L, R \in \mathbb{R} \\ V = L + R \end{array}}{L + R \overset{binop}{\Rightarrow} V}[\texttt{Binop} - \texttt{plus}]$$

$$\frac{\begin{array}{c} L, R \in \mathbb{R} \\ V = L - R \end{array}}{L - R \overset{binop}{\Rightarrow} V}[\texttt{Binop} - \texttt{minus}]$$

$$\frac{\begin{array}{c} L, R \in \mathbb{R} \\ V = L * R \end{array}}{L * R \stackrel{binop}{\Rightarrow} V} [\texttt{Binop} - \texttt{times}]$$

$$\frac{\begin{array}{c} L, R \in \mathbb{R} \\ V = L/R \end{array}}{L/R \stackrel{binop}{\Rightarrow} V} [\texttt{Binop} - \texttt{divide}]$$

$$\frac{\begin{array}{c} S_l; F; M \vdash L_e \Downarrow L_v; S_l' \\ S_r; F; M \vdash R_e \Downarrow R_v; S_l' \\ L_v \; B \; R_v \stackrel{binop}{\Rightarrow} V \end{array}}{S_l, S_r; F; M \vdash L_e \; B \; R_e \Downarrow V; S_l', S_r'} [\texttt{Eval} - \texttt{binop}]$$

$$\frac{\begin{array}{c} S_l; F; M \vdash L_e \Downarrow\!\!\!\!/ \; nil; S_l' \\ S_r; F; M \vdash R_e \Downarrow\!\!\!\!/ \; nil; S_l' \end{array}}{S_l, S_r; F; M \vdash L_e \; B \; R_e \Downarrow\!\!\!\!/ \; nil; S_l', S_r'} [\texttt{Eval} - \texttt{binop} - \texttt{C}]$$