

1 Syntax

$e ::= c \in \mathbb{Z}$ $ x \in \text{Var}$ $ e_1 + e_2$ $ \lambda x. s$ $ e_1(e_2)$ $ \text{alloc}$ $ e.f$ $ f \text{ in } e$	$e_e ::= \cdot +_1 e$ $ \cdot +_2 \cdot$ $ @_1(e_2)$ $ @_2$ $ @_3$ $ \cdot f$ $ f \text{ in }_1 \cdot$	$s \in \text{stat} ::= \text{skip}$ $ s_1; s_2$ $ x := e$ $ \text{if } (e > 0) s_1 s_2$ $ \text{while } (e > 0) s$ $ \text{return } e$ $ e_1.f := e_2$ $ \text{delete } e.f$	$s_e ::= x :=_1 \cdot$ $ \cdot;_1 s_2$ $ \text{if }_1 s_1 s_2$ $ \text{while}_1 (e > 0) s$ $ \text{while}_2 (e > 0) s$ $ \text{return}_1 \cdot$ $ \cdot f :=_1 e_2$ $ \cdot f :=_2 \cdot$ $ \text{delete}_1 \cdot f$
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2 Semantics

2.1 Expressions

$$\frac{\text{RED-CONST}(c)}{H_e, \ell_e, \ell_c, c \Downarrow H_e, \ell_e, c} \quad \frac{\text{RED-VAR-LOCAL}(x)}{H_e, \ell_e, \ell_c, x \Downarrow H_e, \ell_e, \ell_c[x]} \quad x \in \text{dom}(H_e[\ell_c])$$

$$\frac{\text{RED-VAR-GLOBAL}(x)}{H_e, \ell_e, \ell_c, x \Downarrow H_e, \ell_e, E[x]} \quad x \in \text{dom}(H_e[\ell_e]) \wedge x \notin \text{dom}(H_e[\ell_c])$$

$$\frac{\text{RED-VAR-UNDEF}(x)}{H_e, \ell_e, \ell_c, x \Downarrow \text{err}} \quad x \notin \text{dom}(H_e[\ell_e]) \wedge x \notin \text{dom}(H_e[\ell_c])$$

$$\frac{\text{RED-ADD}(e_1, e_2)}{H_e, \ell_e, \ell_c, e_1 \Downarrow r \quad \ell_c, r, \cdot +_1 e_2 \Downarrow r'}{H_e, \ell_e, \ell_c, e_1 + e_2 \Downarrow r'} \quad \frac{\text{RED-ADD-1}(e_2)}{H_e, \ell_e, \ell_c, e_2 \Downarrow r \quad v_1, r, \cdot +_2 \cdot \Downarrow r'}{\ell_c, (H_e, \ell_e, v_1), \cdot +_1 e_2 \Downarrow r'}$$

$$\frac{\text{RED-ADD-2}}{v_1, (H_e, \ell_e, v_2), \cdot +_2 \cdot \Downarrow H_e, \ell_e, v_1 + v_2}$$

$$\begin{array}{c}
\frac{\text{RED-LAMBDA}(x, s)}{H_e, \ell_e, \ell_c, \lambda x. s \Downarrow H_e, \ell_e, (\ell_c, \lambda x. s)} \\
\frac{\text{RED-APP}(e_1, e_2)}{H_e, \ell_e, \ell_c, e_1 \Downarrow r \quad \ell_c, r, @_1(e_2) \Downarrow r' \quad \frac{}{H_e, \ell_e, \ell_c, e_1(e_2) \Downarrow r'}} \\
\frac{\text{RED-APP-1}(e_2)}{H_e, \ell_e, \ell_c, e_2 \Downarrow r \quad \ell'_c, x, s, r, @_2 \Downarrow r' \quad \frac{}{\ell_c, (H_e, \ell_e, (\ell'_c, \lambda x. s)), @_1(e_2) \Downarrow r'}} \\
\frac{\text{RED-APP-2}(s)}{H_e, \ell'_c \leftarrow C[x \leftarrow v], \ell_e, \ell'_c, s \Downarrow r \quad \ell'_c = \text{fresh}(H_e) \quad C = H_e[\ell_c] \quad r, @_3 \Downarrow r' \quad \frac{}{\ell_c, x, s, (H_e, \ell_e, v), @_2 \Downarrow r'}}{\text{RED-APP-3-RET} \quad \frac{}{\text{ret}(H_e, \ell_e, v), @_3 \Downarrow H_e, \ell_e, l}} \\
\frac{\text{RED-APP-3-NO-RET}}{H_e, \ell_e, \ell_c, @_3 \Downarrow \text{err}} \quad \frac{\text{RED-NEW-OBJ} \quad \ell = \text{fresh}(H)}{H, H_e, \ell_e, \ell_c, \text{alloc} \Downarrow H[\ell \leftarrow \{\}], H_e, \ell_e, l} \\
\frac{\text{RED-FIELD}(e, f)}{H, H_e, \ell_e, \ell_c, e \Downarrow r \quad r, .f \Downarrow r' \quad \frac{}{H, H_e, \ell_e, \ell_c, e.f \Downarrow r'}} \\
\frac{\text{RED-FIELD-1}(f)}{(H, H_e, \ell_e, \ell), .f \Downarrow H, H_e, \ell_e, H[\ell][f]} \quad \ell.f \in \text{dom}^2(H) \\
\frac{\text{RED-IN}(f, e)}{H, H_e, \ell_e, \ell_c, e \Downarrow r \quad r, f \text{in}_1. \Downarrow r' \quad \frac{}{H, H_e, \ell_e, \ell_c, f \text{in } e \Downarrow r'}} \\
\frac{\text{RED-IN-1-TRUE}(f)}{(H, H_e, \ell_e, \ell), f \text{in}_1. \Downarrow H, H_e, \ell_e, 1} \quad \ell.f \in \text{dom}^2(H) \\
\frac{\text{RED-IN-1-FALSE}(f)}{(H, H_e, \ell_e, \ell), f \text{in}_1. \Downarrow H, H_e, \ell_e, 0} \quad \ell.f \notin \text{dom}^2(H)
\end{array}$$

2.2 Statements

$$\begin{array}{c}
\text{RED-SKIP} \\
\frac{}{H_e, \ell_e, \ell_c, \text{skip} \Downarrow H_e, \ell_e, \ell_c} \\
\\
\text{RED-SEQ}(s_1, s_2) \\
\frac{H_e, \ell_e, \ell_c, s_1 \Downarrow r \quad r, \cdot;_1 s_2 \Downarrow r'}{H_e, \ell_e, \ell_c, s_1; s_2 \Downarrow r'} \\
\\
\text{RED-SEQ-1}(s_2) \\
\frac{H_e, \ell_e, \ell_c, s_2 \Downarrow r}{H_e, \ell_e, \ell_c, \cdot;_1 s_2 \Downarrow r} \\
\\
\text{RED-ASN}(x, e) \\
\frac{H_e, \ell_e, \ell_c, e \Downarrow r \quad \ell_c, r, x :=_1 \cdot \Downarrow r'}{H_e, \ell_e, \ell_c, x := e \Downarrow r'} \\
\\
\text{RED-ASN-1}(x) \\
\frac{\ell'_e = \text{fresh}(H_e) \quad E = H_e[\ell_e]}{\ell_c, (H_e, \ell_e, v), x :=_1 \cdot \Downarrow H_e[\ell'_e \leftarrow E[x \leftarrow v]], \ell'_e, \ell_c} \quad x \notin \text{dom}(H_e[\ell_c]) \\
\\
\text{RED-ASN-1-LOCAL}(x) \\
\frac{\ell'_c = \text{fresh}(H_e) \quad C = H_e[\ell_c]}{\ell_c, (H_e, \ell_e, v), x :=_1 \cdot \Downarrow H_e[\ell'_c \leftarrow C[x \leftarrow v]], \ell_e, \ell'_c} \quad x \in \text{dom}(C) \\
\\
\text{RED-IF}(e, s_1, s_2) \\
\frac{H_e, \ell_e, \ell_c, e \Downarrow r \quad \ell_c, r, \text{if}_1 s_1 s_2 \Downarrow r'}{H_e, \ell_e, \ell_c, \text{if}(e > 0) s_1 s_2 \Downarrow r'} \\
\\
\text{RED-IF-1-POS}(s_1, s_2) \\
\frac{H_e, \ell_e, \ell_c, s_1 \Downarrow r}{\ell_c, (H_e, \ell_e, v), \text{if}_1 s_1 s_2 \Downarrow r} \quad v > 0 \\
\\
\text{RED-IF-1-NEG}(s_1, s_2) \\
\frac{H_e, \ell_e, \ell_c, s_2 \Downarrow r}{\ell_c, (H_e, \ell_e, v), \text{if}_1 s_1 s_2 \Downarrow r} \quad v \leq 0 \\
\\
\text{RED-WHILE}(e, s) \\
\frac{H_e, \ell_e, \ell_c, e \Downarrow r \quad \ell_c, r, \text{while}_1(e > 0) s \Downarrow r'}{H_e, \ell_e, \ell_c, \text{while}(e > 0) s \Downarrow r'} \\
\\
\text{RED-WHILE-1-NEG}(e, s) \\
\frac{}{\ell_c, (H_e, \ell_e, v), \text{while}_1(e > 0) s \Downarrow H_e, \ell_e, \ell_c} \quad v \leq 0 \\
\\
\text{RED-WHILE-1-POS}(e, s) \\
\frac{H_e, \ell_e, \ell_c, s \Downarrow r \quad r, \text{while}_2(e > 0) s \Downarrow r'}{\ell_c, (H_e, \ell_e, v), \text{while}_1(e > 0) s \Downarrow r'} \quad v > 0 \\
\\
\text{RED-WHILE-2}(e, s) \\
\frac{H_e, \ell_e, \ell_c, \text{while}(e > 0) s \Downarrow r}{H_e, \ell_e, \ell_c, \text{while}_2(e > 0) s \Downarrow r} \\
\\
\text{RED-RETURN}(e) \\
\frac{H_e, \ell_e, \ell_c, e \Downarrow r \quad r, \text{return}_1 \cdot \Downarrow r'}{H_e, \ell_e, \ell_c, \text{return } e \Downarrow r'} \\
\\
\text{RED-RETURN-1} \\
\frac{}{(\ell_c, (H_e, \ell_e, v), \text{return}_1 \cdot \Downarrow \text{ret}(H_e, \ell_e, v))}
\end{array}$$

$$\frac{\text{RED-FIELD-ASN}(e_1, f, e_2) \quad H, H_e, \ell_e, \ell_c, e_1 \Downarrow r \quad \ell_c, r, .f :=_1 e_2 \Downarrow r'}{H, H_e, \ell_e, \ell_c, e_1 .f := e_2 \Downarrow r'}$$

$$\frac{\text{RED-FIELD-ASN-1}(f, e_2) \quad H, H_e, \ell_e, \ell_c, e_2 \Downarrow r \quad \ell_c, \ell, r, .f :=_2 \cdot \Downarrow r'}{\ell_c, (H, H_e, \ell_e, \ell), .f :=_1 e_2 \Downarrow r'}$$

$$\frac{\text{RED-FIELD-ASN-2}(f) \quad o = H[\ell] \quad H' = H[\ell \leftarrow o[f \leftarrow v]] \quad \ell \in \text{dom}(H)}{\ell_c, \ell, (H, H_e, \ell_e, v), .f :=_2 \cdot \Downarrow H', H_e, \ell_e, \ell_c}$$

$$\frac{\text{RED-DELETE}(e, f) \quad H, H_e, \ell_e, \ell_c, e \Downarrow r \quad \ell_c, r, \text{delete}_1 .f \Downarrow r'}{H, H_e, \ell_e, \ell_c, \text{delete } e .f \Downarrow r'}$$

$$\frac{\text{RED-DELETE-1}(f) \quad o = H[\ell] \quad H' = H[\ell \leftarrow o \setminus f]}{\ell_c, (H, H_e, \ell_e, \ell), \text{delete}_1 .f \Downarrow H', H_e, \ell_e, \ell_c} \quad \ell \in \text{dom}(H)$$

2.3 Aborting Rules

$$\frac{\text{RED-ERROR-EXPR}(e) \quad \sigma, e \Downarrow \text{err}}{\text{abort } \sigma \wedge \text{-intercept}_e \sigma} \quad \frac{\text{RED-ERROR-STAT}(s) \quad \sigma, s \Downarrow \text{err}}{\text{abort } \sigma}$$

$$\frac{\sigma = C[\text{err}]}{\text{abort } \sigma} \quad \frac{}{\text{intercept}_{@_3} \text{ret}(H_e, \ell_e, v)}$$