`salt3`: Blocks

`CS392-M1`: *Rust, In Practice and in Theory*

Syntax

$$
\begin{aligned}
&x && \text{(variables, } \mathcal{V}\text{)}\\
&n && \text{(integers, } \mathbb{Z}\text{)}\\
w &::= x \mid \texttt{*}\, w && \text{(place expression, } \mathcal{W}\text{)}\\
e &::= \texttt{()} \mid n \mid w \mid \texttt{\&}\, w \mid \texttt{\&mut}\, w \mid \texttt{copy}\, w \mid w \,\texttt{=}\, e \mid \texttt{\{}\, p\, \texttt{\}} && \text{(expressions, } \mathcal{E}\text{)}\\
s &::= e \mid \texttt{let}\, x \,\texttt{=}\, e \mid \texttt{let mut}\, x \,\texttt{=}\, e && \text{(statements, } \mathcal{S}\text{)}\\
p &::= e \mid s \,\texttt{;}\, p && \text{(programs, } \mathcal{P}\text{)}
\end{aligned}
$$

Typing

$$
\begin{array}{rlr}
l & & \text{(lifetimes, Lt)} \\
t & ::= \texttt{()} \mid \texttt{i32} \mid \texttt{\&}\ w \mid \texttt{\&mut}\ w & \text{(types, } \mathcal{T}\text{)} \\
\tilde{t} & ::= \lfloor t \rfloor \mid t & \text{(partial types, } \tilde{\mathcal{T}}\text{)} \\
m & ::= \mathsf{imm} \mid \mathsf{mut} & \text{(mutability)} \\
u & ::= \langle \tilde{t} \rangle_l^m & \text{(slot types, } \mathbb{S}_{\mathcal{T}}\text{)}
\end{array}
$$

$$
\Gamma \in \mathcal{V} \mapsto \mathbb{S}_{\mathcal{T}} \qquad \text{(contexts)}
$$

$$
\begin{array}{lr}
\mathsf{copyable}(t) & \text{(copyability)} \\
\Gamma \vdash w : u & \text{(place expressions)} \\
\Gamma \vdash \mathsf{readable}(w) & \text{(readability)} \\
\Gamma \vdash \mathsf{writable}(w) & \text{(writability)} \\
\Gamma \vdash \tilde{t} \approx \tilde{t} & \text{(type compatibility)} \\
\Gamma \vdash \langle e : t \rangle_l \dashv \Gamma & \text{(expressions)} \\
\Gamma \vdash \langle s \rangle_l \dashv \Gamma & \text{(statments)} \\
\Gamma \vdash \langle p : t \rangle_l \dashv \Gamma & \text{(programs)}
\end{array}
$$

$$
\frac{(x \mapsto \langle \tilde{t} \rangle_l^m) \in \Gamma}{\Gamma \vdash x : \langle \tilde{t} \rangle_l^m}\ \text{(var)}
$$

$$
\frac{\Gamma \vdash w_1 : \langle \texttt{\&}\ w_2 \rangle_{l_1}^{m_1} \qquad \Gamma \vdash w_2 : \langle t \rangle_{l_2}^{m_2}}{\Gamma \vdash \texttt{*}\ w_1 : \langle t \rangle_{l_2}^{m_2}}\ \text{(deref)}
$$

$$
\frac{}{\Gamma \vdash \langle \texttt{()} : \texttt{()} \rangle_l \dashv \Gamma}\ \text{(unit)}
$$

$$
\frac{n \in \mathbb{Z}}{\Gamma \vdash \langle n : \texttt{i32} \rangle_l \dashv \Gamma}\ \text{(int)}
$$

$$
\frac{\nexists y, l.(y \mapsto \texttt{\&mut}\ \texttt{*}^l x) \in \Gamma}{\Gamma \vdash \mathsf{readable}(\texttt{*}^k x)}\ \text{(readable)}
$$

$$\frac{}{\mathsf{copyable}(\texttt{()})}\ (\text{copy-unit})$$

$$\frac{}{\mathsf{copyable}(\texttt{i32})}\ (\text{copy-int})$$

$$\frac{}{\mathsf{copyable}(\texttt{\&}\ w)}\ (\text{copy-brw})$$

$$\frac{\Gamma \vdash w : \langle t \rangle^{m}_{l_1} \qquad \Gamma \vdash \mathsf{readable}(w) \qquad \mathsf{copyable}(t)}{\Gamma \vdash \langle \mathsf{copy}\ w : t \rangle_{l_2} \dashv \Gamma}\ (\text{place-copy})$$

$$\frac{\Gamma \vdash \mathsf{readable}(\texttt{*}^{k} x) \qquad \nexists y, l.(y \mapsto \texttt{\&}\ \texttt{*}^{l} x) \in \Gamma}{\Gamma \vdash \mathsf{writable}(\texttt{*}^{k} x)}\ (\text{writable})$$

$$\frac{\Gamma \vdash x : \langle \texttt{\&mut}\ w \rangle^{m}_{l_1} \qquad \Gamma \vdash \mathsf{writable}(x)}{\Gamma \vdash \langle x : \texttt{\&mut}\ w \rangle_{l_2} \dashv \Gamma[x \mapsto \lfloor \texttt{\&mut}\ w \rfloor]}\ (\text{place-move})$$

$$\frac{\Gamma \vdash w : \langle t \rangle^{m}_{l_1} \qquad \Gamma \vdash \mathsf{readable}(w)}{\Gamma \vdash \langle \texttt{\&}\ w : \texttt{\&}\ w \rangle_{l_2} \dashv \Gamma}\ (\text{brw})$$

$$\frac{\Gamma \vdash w : \langle t \rangle^{\mathsf{mut}}_{l_1} \qquad \Gamma \vdash \mathsf{writable}(w) \qquad \Gamma \vdash \mathsf{mutable}(w)}{\Gamma \vdash \langle \texttt{\&mut}\ w : \texttt{\&mut}\ w \rangle_{l_2} \dashv \Gamma}\ (\text{mut-brw})$$

$$\frac{}{\Gamma \vdash \texttt{i32} \approx \texttt{i32}}\ (\approx\text{-int})$$

$$\frac{}{\Gamma \vdash \texttt{()} \approx \texttt{()}}\ (\approx\text{-unit})$$

$$\frac{\Gamma \vdash w_1 : \langle \tilde{t}_1 \rangle^{m_1}_{l_1} \qquad \Gamma \vdash w_2 : \langle \tilde{t}_2 \rangle^{m_2}_{l_2} \qquad \Gamma \vdash \tilde{t}_1 \approx \tilde{t}_2}{\Gamma \vdash \texttt{\&}\ w_1 \approx \texttt{\&}\ w_2}\ (\approx\text{-brw})$$

$$\frac{\Gamma \vdash w_1 : \langle \tilde{t}_1 \rangle^{m_1}_{l_1} \qquad \Gamma \vdash w_2 : \langle \tilde{t}_2 \rangle^{m_2}_{l_2} \qquad \Gamma \vdash \tilde{t}_1 \approx \tilde{t}_2}{\Gamma \vdash \texttt{\&mut}\ w_1 \approx \texttt{\&mut}\ w_2}\ (\approx\text{-mbrw})$$

$$\frac{\Gamma \vdash t_1 \approx \tilde{t}_2}{\Gamma \vdash \lfloor t_1 \rfloor \approx \tilde{t}_2}\ (\approx\text{-partial}_1)$$

$$\frac{\Gamma \vdash \tilde{t}_1 \approx t_2}{\Gamma \vdash \tilde{t}_1 \approx \lfloor t_2 \rfloor}\ (\approx\text{-partial}_2)$$

$$\begin{aligned} \mathsf{write}(\Gamma, x, t) &= \Gamma[x \mapsto t] \\ \mathsf{write}(\Gamma, \texttt{*}^{k+1} x, t) &= \mathsf{write}(\Gamma, \texttt{*}^{k} w, t) \quad \text{where} \quad (x \mapsto \texttt{\&mut}\ w^{m}) \in \Gamma \end{aligned}$$

$$\mathsf{replace}(\texttt{\&*}^{k+1}w_1, w_1, \texttt{\&[mut]}w_2) = \texttt{\&*}^{k}w_2$$

$$\mathsf{replace}(\texttt{\&mut *}^{k+1}w_1, w_1, \texttt{\&[mut]}w_2) = \texttt{\&mut *}^{k}w_2$$

$$\mathsf{replace}(t_1, w, t_2) = t_1$$

$$\mathsf{replace}(\lfloor t_1 \rfloor, w, t_2) = \lfloor \mathsf{replace}(t_1, w, t_2) \rfloor$$

$$\mathsf{replace}(\Gamma, w, t_2) = \{x \mapsto \mathsf{replace}(\tilde{t}_1, w, t_2) : (x \mapsto \tilde{t}_1) \in \Gamma\}$$

$$\mathsf{update}(\Gamma, w, t_2) = \mathsf{replace}(\mathsf{write}(\Gamma, w, t_2), w, t_2)$$

$$\frac{}{\Gamma \vdash \texttt{i32} : l}\ \text{(int-lftm)}$$

$$\frac{\Gamma \vdash w : \langle t \rangle_{l_1}^{m} \qquad l_1 \leq l_2}{\Gamma \vdash \texttt{\&}\ w : l_2}\ \text{(brw-lftm)}$$

$$\frac{\Gamma \vdash w : \langle t \rangle_{l_1}^{m} \qquad l_1 \leq l_2}{\Gamma \vdash \texttt{\&mut}\ w : l_2}\ \text{(mut-brw-lftm)}$$

$$\frac{\begin{array}{c}\Gamma_1 \vdash w : \langle \tilde{t}_1 \rangle_{l_1}^{\mathsf{mut}} \qquad \Gamma_1 \vdash e : t_2 \dashv \Gamma_2 \qquad \Gamma_2 \vdash \tilde{t}_1 \approx t_2 \\ \Gamma_2 \vdash t_2 : l_1 \qquad \Gamma_3 = \mathsf{update}(\Gamma, w, t_2) \qquad \Gamma_3 \vdash \mathsf{writable}(w)\end{array}}{\Gamma_1 \vdash \langle w \texttt{ = } e : \texttt{()} \rangle_{l_2} \dashv \Gamma_3}\ \text{(assign)}$$

$$\mathsf{drop}(\Gamma, l) = \Gamma \setminus \{x \mapsto \langle \tilde{t} \rangle_{l}^{m} : (x \mapsto \langle \tilde{t} \rangle_{l}^{m}) \in \Gamma\}$$

$$\frac{\Gamma_1 \vdash \langle p : t \rangle_{l+1} \dashv \Gamma_2 \qquad \Gamma_2 \vdash t : l}{\Gamma_1 \vdash \langle \texttt{\{}\ p\ \texttt{\}} : t \rangle_{l} \dashv \mathsf{drop}(\Gamma_2, l+1)}\ \text{(block)}$$

$$\frac{\Gamma_1 \vdash \langle e : t \rangle_{l} \dashv \Gamma_2}{\Gamma_1 \vdash \langle e \rangle_{l} \dashv \Gamma_2}\ \text{(expr-stmt)}$$

$$\frac{\Gamma_1 \vdash \langle e : t \rangle_{l} \dashv \Gamma_2 \qquad x \notin \mathsf{dom}(\Gamma_2)}{\Gamma_1 \vdash \langle \texttt{let}\ x \texttt{ = } e \rangle_{l} \dashv \Gamma_2[x \mapsto \langle t \rangle_{l}^{\mathsf{imm}}]}\ \text{(let)}$$

$$\frac{\Gamma_1 \vdash \langle e : t \rangle_{l} \dashv \Gamma_2 \qquad x \notin \mathsf{dom}(\Gamma_2)}{\Gamma_1 \vdash \langle \texttt{let mut}\ x \texttt{ = } e \rangle_{l} \dashv \Gamma_2[x \mapsto \langle t \rangle_{l}^{\mathsf{mut}}]}\ \text{(let-mut)}$$

$$\frac{\Gamma_1 \vdash \langle s \rangle_{l} \dashv \Gamma_2 \qquad \Gamma_2 \vdash \langle p : t \rangle_{l} \dashv \Gamma_3}{\Gamma_1 \vdash \langle s\ \texttt{;}\ p : t \rangle_{l} \dashv \Gamma_3}\ \text{(prog)}$$

Evaluation

$$
\begin{aligned}
\ell &::= \ell_x && \text{(locations, } \mathcal{L}\text{)}\\
v &::= \texttt{()} \mid n \mid \ell && \text{(values, } \mathbb{V}\text{)}\\
\tilde{v} &::= \bot \mid v && \text{(partial values, } \tilde{\mathbb{V}}\text{)}\\
r &::= \langle \tilde{v} \rangle_l && \text{(slot types, } \mathbb{S}_{\mathbb{V}}\text{)}
\end{aligned}
$$

$$
S \in \mathcal{L} \mapsto \mathbb{S}_{\mathbb{V}} \qquad \text{(store)}
$$

$$
\begin{aligned}
&\langle\, S \,,\, e \;\Downarrow\; S \,,\, v \,\rangle_l && \text{(expressions)}\\
&\langle\, S \,,\, s \;\Downarrow S \,\rangle_l && \text{(statements)}\\
&\langle\, S \,,\, p \;\Downarrow\; S \,,\, v \,\rangle_l && \text{(programs)}
\end{aligned}
$$

$$
\frac{}{x \rightsquigarrow \ell_x}\ \text{(loc-var)}
$$

$$
\frac{w \rightsquigarrow \ell_x \qquad (\ell_x \mapsto \ell_y) \in S}{\texttt{*}\, w \rightsquigarrow \ell_y}\ \text{(loc-drf)}
$$

$$
\frac{}{\langle\, S \,,\, \texttt{()} \;\Downarrow\; S \,,\, \texttt{()} \,\rangle_l}\ \text{(unit)}
$$

$$
\frac{n \in \mathbb{Z}}{\langle\, S \,,\, n \;\Downarrow\; S \,,\, n \,\rangle_l}\ \text{(int)}
$$

$$
\frac{w \rightsquigarrow \ell_x \qquad (\ell_x \mapsto \langle v \rangle_{l_1}) \in S}{\langle\, S \,,\, \texttt{copy}\; w \;\Downarrow\; S \,,\, v \,\rangle_{l_2}}\ \text{(place-copy)}
$$

$$
\frac{w \rightsquigarrow \ell_x \qquad (\ell_x \mapsto \langle v \rangle_{l_1}) \in S}{\langle\, S \,,\, w \;\Downarrow\; S[\ell_x \mapsto \langle \bot \rangle_{l_1}] \,,\, v \,\rangle_{l_2}}\ \text{(move)}
$$

$$
\frac{w \rightsquigarrow \ell}{\langle\, S \,,\, \texttt{\&}\, w \;\Downarrow\; S \,,\, \ell \,\rangle_l}\ \text{(brw)}
$$

$$
\frac{w \rightsquigarrow \ell}{\langle\, S \,,\, \texttt{\&mut}\; w \;\Downarrow\; S \,,\, \ell \,\rangle_l}\ \text{(mut-brw)}
$$

$$\frac{w \rightsquigarrow \ell_x \qquad (\ell_x \mapsto \langle \tilde{v} \rangle_{l_1}) \in S_1 \qquad \langle\, S_1 \,,\, e \,\Downarrow\, S_2 \,,\, v \,\rangle_{l_2}}{\langle\, S_1 \,,\, w \texttt{ = } e \,\Downarrow\, S_2[\ell_x \mapsto \langle v \rangle_{l_1}] \,,\, \texttt{()} \,\rangle_{l_2}} \text{(assign)}$$

$$\mathsf{drop}(S, l) = S \setminus \{\ell \mapsto \langle \tilde{v} \rangle_l : (\ell \mapsto \langle \tilde{v} \rangle_l) \in S\}$$

$$\frac{\langle\, S_1 \,,\, p \,\Downarrow\, S_2 \,,\, v \,\rangle_{l+1}}{\langle\, S_1 \,,\, \texttt{\{}\ p\ \texttt{\}} \,\Downarrow\, \mathsf{drop}(S_2, l+1) \,,\, v \,\rangle_l} \text{(block)}$$

$$\frac{\langle\, S_1 \,,\, e \,\Downarrow\, S_2 \,,\, v \,\rangle_l}{\langle\, S_1 \,,\, e \,\Downarrow\, S_2 \,\rangle_l} \text{(expr-stmt)}$$

$$\frac{\langle\, S_1 \,,\, e \,\Downarrow\, S_2 \,,\, v \,\rangle_l}{\langle\, S_1 \,,\, \texttt{let}\ x \texttt{ = } e \,\Downarrow\, S_2[\ell_x \mapsto \langle v \rangle_l] \,\rangle_l} \text{(let)}$$

$$\frac{\langle\, S_1 \,,\, e \,\Downarrow\, S_2 \,,\, v \,\rangle_l}{\langle\, S_1 \,,\, \texttt{let mut}\ x \texttt{ = } e \,\Downarrow\, S_2[\ell_x \mapsto \langle v \rangle_l] \,\rangle_l} \text{(let-mut)}$$

$$\frac{\langle\, S_1 \,,\, e \,\Downarrow\, S_2 \,,\, v \,\rangle_l}{\langle\, S_1 \,,\, e \,\Downarrow\, S_2 \,\rangle_l} \text{(expr-stmt)}$$

$$\frac{\langle\, S_1 \,,\, s \,\Downarrow\, S_2 \,\rangle_l \qquad \langle\, S_2 \,,\, p \,\Downarrow\, S_3 \,,\, v \,\rangle_l}{\langle\, S_1 \,,\, s \texttt{ ; } p \,\Downarrow\, S_3 \,,\, v \,\rangle_l} \text{(prog)}$$