salt3: Blocks

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

Syntax

$$x \qquad \text{(variables, } \mathcal{V})$$

$$n \qquad \text{(integers, } \mathbb{Z})$$

$$w ::= x \mid * \, w \qquad \text{(place expression, } \mathcal{W})$$

$$e ::= \text{()} \mid n \mid \text{copy } w \mid w \mid \& \, w \mid \&\text{mut } w \mid w = e \mid \{\, p \,\} \qquad \text{(expressions, } \mathcal{E})$$

$$s ::= \text{let } x = e \mid \text{let mut } x = e \mid e \qquad \text{(statements, } \mathcal{S})$$

$$p ::= e \mid s \; ; \; p \qquad \text{(programs, } \mathcal{P})$$

Typing

$$l \qquad \text{(lifetimes, Lt)}$$

$$t ::= \text{()} \mid \text{i32} \mid \text{\& } w \mid \text{\&mut } w \qquad \text{(types, } \mathcal{T})$$

$$\tilde{t} ::= \lfloor t \rfloor \mid t \qquad \text{(partial types, } \tilde{\mathcal{T}})$$

$$m ::= \text{imm} \mid \text{mut} \qquad \text{(mutability)}$$

$$u ::= \langle \tilde{t} \rangle_l^m \qquad \text{(slot types, } \mathbb{S}_{\mathcal{T}})$$

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

$$\text{copyable}(t) \qquad \text{(copyability)}$$

$$\Gamma \vdash \text{readable}(w) \qquad \text{(readability)}$$

$$\Gamma \vdash \text{writable}(w) \qquad \text{(writability)}$$

$$\Gamma \vdash \text{mutable}(w) \qquad \text{(mutability)}$$

$$\Gamma \vdash \tilde{t} \approx \tilde{t} \qquad \text{(type compatibility)}$$

$$\Gamma \vdash \tilde{t} : l \qquad \text{(lifetimes)}$$

$$\Gamma \vdash w : u \qquad \text{(place expressions)}$$

$$\Gamma \vdash \langle e : t \rangle_l \dashv \Gamma \qquad \text{(expressions)}$$

$$\Gamma \vdash \langle s \rangle_l \dashv \Gamma \qquad \text{(statments)}$$

$$\Gamma \vdash \langle p : t \rangle_l \dashv \Gamma \qquad \text{(programs)}$$

$$\frac{(x \mapsto \langle \tilde{t} \rangle_l^m) \in \Gamma}{\Gamma \vdash x : \langle \tilde{t} \rangle_l^m} \ \text{VAR} \qquad\qquad \frac{\Gamma \vdash w : \langle \& \, x \rangle_{l_1}^{m_1} \qquad \Gamma \vdash x : \langle \tilde{t} \rangle_{l_2}^{m_2}}{\Gamma \vdash *w : \langle \tilde{t} \rangle_{l_2}^{m_2}} \ \text{DEREF}$$

$$\frac{\Gamma \vdash w : \langle \text{\&mut} \, x \rangle_{l_1}^{m_1} \qquad \Gamma \vdash x : \langle \tilde{t} \rangle_{l_2}^{m_2}}{\Gamma \vdash *w : \langle \tilde{t} \rangle_{l_2}^{m_2}} \ \text{MUTDEREF} \qquad\qquad \frac{}{\Gamma \vdash \langle () : () \rangle_l \dashv \Gamma} \ \text{UNIT}$$

$$\frac{n \in \mathbb{Z}}{\Gamma \vdash \langle n : \texttt{i32} \rangle_l \dashv \Gamma} \ \text{INT} \qquad \frac{\nexists y, j.(y \mapsto \langle \text{\&mut} \, *^j x \rangle_l^m) \in \Gamma}{\Gamma \vdash \textsf{readable}(*^k x)} \ \text{READABLE} \qquad \frac{}{\textsf{copyable}\,(\,()\,)} \ \text{COPYUNIT}$$

$$\frac{}{\textsf{copyable}\,(\texttt{i32})} \ \text{COPYINT} \qquad\qquad \frac{}{\textsf{copyable}\,(\& \, w)} \ \text{COPYREF}$$

$$\frac{\Gamma \vdash w : \langle t \rangle_{l_1}^m \qquad \Gamma \vdash \textsf{readable}(w) \qquad \textsf{copyable}\,(t)}{\Gamma \vdash \langle \textsf{copy} \, w : t \rangle_{l_2} \dashv \Gamma} \ \text{PLACECOPY}$$

$$\frac{\Gamma \vdash \textsf{readable}(*^k x) \qquad \nexists y, j.(y \mapsto \langle \& \, *^j x \rangle_l^m) \in \Gamma}{\Gamma \vdash \textsf{writable}(*^k x)} \ \text{WRITABLE}$$

$$\frac{\Gamma \vdash x : \langle \text{\&mut} \, w \rangle_{l_1}^m \qquad \Gamma \vdash \textsf{writable}(x)}{\Gamma \vdash \langle x : \text{\&mut} \, w \rangle_{l_2} \dashv \Gamma[x \mapsto \langle \lfloor \text{\&mut} \, w \rfloor \rangle_{l_1}^m]} \ \text{PLACEMOVE} \qquad \frac{\Gamma \vdash w : \langle t \rangle_{l_1}^m \qquad \Gamma \vdash \textsf{readable}(w)}{\Gamma \vdash \langle \& \, w : \& \, w \rangle_{l_2} \dashv \Gamma} \ \text{REF}$$

$$\frac{(x \mapsto \langle t \rangle_l^{\textsf{mut}}) \in \Gamma}{\Gamma \vdash \textsf{mutable}(x)} \ \text{MUTVAR} \qquad \frac{(x \mapsto \langle \text{\&mut} \, w \rangle_l^m) \in \Gamma \qquad \Gamma \vdash \textsf{mutable}(*^k w)}{\Gamma \vdash \textsf{mutable}(*^{k+1} x)} \ \text{MUTDEREF}$$

$$\frac{\Gamma \vdash w : \langle t \rangle_{l_1}^{\textsf{mut}} \qquad \Gamma \vdash \textsf{writable}(w) \qquad \Gamma \vdash \textsf{mutable}(w)}{\Gamma \vdash \langle \text{\&mut} \, w : \text{\&mut} \, w \rangle_{l_2} \dashv \Gamma} \ \text{MUTREF} \qquad \frac{}{\Gamma \vdash () \approx ()} \ \approx\text{-UNIT}$$

$$\frac{}{\Gamma \vdash \texttt{i32} \approx \texttt{i32}} \ \approx\text{-INT} \qquad \frac{\Gamma \vdash w_1 : \langle \tilde{t}_1 \rangle_{l_1}^{m_1} \qquad \Gamma \vdash w_2 : \langle \tilde{t}_2 \rangle_{l_2}^{m_2} \qquad \Gamma \vdash \tilde{t}_1 \approx \tilde{t}_2}{\Gamma \vdash \& \, w_1 \approx \& \, w_2} \ \approx\text{-REF}$$

$$\frac{\Gamma \vdash w_1 : \langle \tilde{t}_1 \rangle_{l_1}^{m_1} \qquad \Gamma \vdash w_2 : \langle \tilde{t}_2 \rangle_{l_2}^{m_2} \qquad \Gamma \vdash \tilde{t}_1 \approx \tilde{t}_2}{\Gamma \vdash \text{\&mut} \, w_1 \approx \text{\&mut} \, w_2} \ \approx\text{-MUTREF} \qquad \frac{\Gamma \vdash t_1 \approx \tilde{t}_2}{\Gamma \vdash \lfloor t_1 \rfloor \approx \tilde{t}_2} \ \approx\text{-PARTIAL}_1$$

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

$$\text{write}(\Gamma, x, t) = \Gamma[x \mapsto \langle t \rangle_l^m] \quad \text{where} \quad (x \mapsto \langle \cdot \rangle_l^m) \in \Gamma$$
$$\text{write}(\Gamma, *^{k+1}x, t) = \text{write}(\Gamma, *^k w, t) \quad \text{where} \quad (x \mapsto \langle \&\text{mut } w \rangle_l^m) \in \Gamma$$

$$\text{replace}(\&\, *^{k+1}w_1, w_1, \&\, w_2) = \&\, *^k w_2$$
$$\text{replace}(\&\, *^{k+1}w_1, w_1, \&\text{mut } w_2) = \&\, *^k w_2$$
$$\text{replace}(\&\text{mut } *^{k+1}w_1, w_1, \&\, w_2) = \&\text{mut } *^k w_2$$
$$\text{replace}(\&\text{mut } *^{k+1}w_1, w_1, \&\text{mut } w_2) = \&\text{mut } *^k w_2$$
$$\text{replace}(t_1, w, t_2) = t_1$$
$$\text{replace}(\lfloor t_1 \rfloor, w, t_2) = \lfloor \text{replace}(t_1, w, t_2) \rfloor$$
$$\text{replace}(\Gamma, w, t_2) = \{x \mapsto \langle \text{replace}(\tilde{t}_1, w, t_2) \rangle_l^m : (x \mapsto \langle \tilde{t}_1 \rangle_l^m) \in \Gamma\}$$

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

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

$$\frac{}{\Gamma \vdash \texttt{i32} : l} \text{ INTLFTM} \qquad \frac{G \vdash w : \langle t \rangle_{l_1}^m \quad l_1 \leq l_2}{\Gamma \vdash \&\, w : l_2} \text{ REFLTFM}$$

$$\frac{\Gamma \vdash w : \langle t \rangle_{l_1}^m \quad l_1 \leq l_2}{\Gamma \vdash \&\text{mut } w : l_2} \text{ MUTREFLFTM}$$

$$\frac{\Gamma_1 \vdash w : \langle \tilde{t}_1 \rangle_{l_1}^{\text{mut}} \quad \Gamma_1 \vdash e : t_2 \dashv \Gamma_2 \quad \Gamma_2 \vdash \tilde{t}_1 \approx t_2}{\Gamma_2 \vdash t_2 : l_1 \quad \Gamma_3 = \text{update}(\Gamma, w, t_2) \quad \Gamma_3 \vdash \text{writable}(w)} \text{ ASSIGN} \\ \frac{}{\Gamma_1 \vdash \langle w = e : () \rangle_{l_2} \dashv \Gamma_3}$$

$$\frac{\Gamma_1 \vdash \langle p : t \rangle_{l+1} \dashv \Gamma_2 \quad \Gamma_2 \vdash t : l}{\Gamma_1 \vdash \langle \{ p \} : t \rangle_l \dashv \text{drop}(\Gamma_2, l+1)} \text{ BLOCK} \qquad \frac{\Gamma_1 \vdash \langle e : t \rangle_l \dashv \Gamma_2 \quad x \notin \text{dom}(\Gamma_2)}{\Gamma_1 \vdash \langle \texttt{let } x = e \rangle_l \dashv \Gamma_2[x \mapsto \langle t \rangle_l^{\text{imm}}]} \text{ LET}$$

$$\frac{\Gamma_1 \vdash \langle e : t \rangle_l \dashv \Gamma_2 \quad x \notin \text{dom}(\Gamma_2)}{\Gamma_1 \vdash \langle \texttt{let mut } x = e \rangle_l \dashv \Gamma_2[x \mapsto \langle t \rangle_l^{\text{mut}}]} \text{ LETMUT} \qquad \frac{\Gamma_1 \vdash \langle e : t \rangle_l \dashv \Gamma_2}{\Gamma_1 \vdash \langle e \rangle_l \dashv \Gamma_2} \text{ EXPRSTMT}$$

$$\frac{\Gamma_1 \vdash \langle s \rangle_l \dashv \Gamma_2 \quad \Gamma_2 \vdash \langle p : t \rangle_l \dashv \Gamma_3}{\Gamma_1 \vdash \langle s \, ; \, p : t \rangle_l \dashv \Gamma_3} \text{ PROG}$$

Evaluation

$$\ell ::= \ell_x \qquad \text{(locations, } \mathcal{L})$$

$$v ::= \text{()} \mid n \mid \ell \qquad \text{(values, } \mathbb{V})$$

$$\tilde{v} ::= \bot \mid v \qquad \text{(partial values, } \tilde{\mathbb{V}})$$

$$r ::= \langle \tilde{v} \rangle_l \qquad \text{(slot types, } \mathbb{S}_{\mathbb{V}})$$

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

$$S \vdash \langle e \Downarrow v \rangle_l \dashv S \qquad \text{(expressions)}$$

$$S \vdash \langle s \rangle_l \dashv S \qquad \text{(statements)}$$

$$S \vdash \langle p \Downarrow v \rangle_l \dashv S \qquad \text{(programs)}$$

$$\frac{}{S \vdash x \rightsquigarrow \ell_x} \text{ LOCVAR} \qquad\qquad \frac{S \vdash w \rightsquigarrow \ell_x \qquad (\ell_x \mapsto \langle \ell_y \rangle_l) \in S}{S \vdash * w \rightsquigarrow \ell_y} \text{ LOCDEREF}$$

$$\frac{}{S \vdash \langle () \Downarrow () \rangle_l \dashv S} \text{ UNIT} \qquad\qquad \frac{n \in \mathbb{Z}}{S \vdash \langle n \Downarrow n \rangle_l \dashv S} \text{ INT}$$

$$\frac{S \vdash w \rightsquigarrow \ell_x \qquad (\ell_x \mapsto \langle v \rangle_{l_1}) \in S}{S \vdash \langle \texttt{copy } w \Downarrow v \rangle_{l_2} \dashv S} \text{ PLACECOPY} \qquad \frac{S \vdash w \rightsquigarrow \ell_x \qquad (\ell_x \mapsto \langle v \rangle_{l_1}) \in S}{S \vdash \langle w \Downarrow v \rangle_{l_2} \dashv S[\ell_x \mapsto \langle \bot \rangle_{l_1}]} \text{ MOVE}$$

$$\frac{S \vdash w \rightsquigarrow \ell_x}{S \vdash \langle \texttt{\& } w \Downarrow \ell_x \rangle_l \dashv S} \text{ REF} \qquad\qquad \frac{S \vdash w \rightsquigarrow \ell_x}{S \vdash \langle \texttt{\&mut } w \Downarrow \ell_x \rangle_l \dashv S} \text{ MUTREF}$$

$$\frac{S \vdash w \rightsquigarrow \ell_x \qquad (\ell_x \mapsto \langle \tilde{v} \rangle_{l_1}) \in S_1 \qquad S_1 \vdash \langle e \Downarrow v \rangle_{l_2} \dashv S_2}{S_1 \vdash \langle w = e \Downarrow () \rangle_{l_2} \dashv S_2[\ell_x \mapsto \langle v \rangle_{l_1}]} \text{ ASSIGN}$$

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

$$\frac{S_1 \vdash \langle p \Downarrow v \rangle_{l+1} \dashv S_2}{S_1 \vdash \{ p \} \Downarrow v \dashv \text{drop}(S_2, l+1)} \text{ BLOCK} \qquad \frac{S_1 \vdash \langle e \Downarrow v \rangle_l \dashv S_2}{S_1 \vdash \langle \texttt{let } x = e \rangle_l \dashv S_2[\ell_x \mapsto \langle v \rangle_l]} \text{ LET}$$

$$\frac{S_1 \vdash \langle e \Downarrow v \rangle \dashv S_2}{S_1 \vdash \langle \texttt{let mut } x = e \rangle \dashv S_2[\ell_x \mapsto \langle v \rangle_l]} \text{ LETMUT} \qquad \frac{S_1 \vdash \langle e \Downarrow v \rangle_l \dashv S_2}{S_1 \vdash \langle e \rangle_l \dashv S_2} \text{ EXPRSTMT}$$

$$\frac{S_1 \vdash \langle s \rangle_l \dashv S_2 \qquad S_2 \vdash \langle p \Downarrow v \rangle_l \dashv S_3}{S_1 \vdash \langle s \texttt{ ; } p \Downarrow v \rangle_l \dashv S_3} \text{ PROG}$$