| | | | |
|---|---|---|---|
| termvar, $x$, $y$, $d$ | | | Term-level variable |
| holevar, $h$ | | | Hole |
| term_value, $v$ | ::= | | Term value |
| | $\mid$ $\langle v_1 \,{}_{9}\, \overline{v_2} \rangle_{H}$ | | Ampar |
| | $\mid$ $@h$ | | Destination |
| | $\mid$ $()$ | | Unit |
| | $\mid$ $\mathsf{Inl}\; v$ | | Left variant for sum |
| | $\mid$ $\mathsf{Inr}\; v$ | | Right variant for sum |
| | $\mid$ $(v_1\,,\,v_2)$ | | Product |
| | $\mid$ $\mathsf{E}_m\; v$ | | Exponential |
| | $\mid$ $\lambda x\,.\,t$ | | Linear function |
| | $\mid$ $(v)$ | S | |
| $\overline{\text{extended\_value}}$, $\overline{v}$ | ::= | | Store value |
| | $\mid$ $v$ | | Term value |
| | $\mid$ $h$ | | Hole |
| | $\mid$ $\mathsf{Inl}\; \overline{v}$ | | Left variant with val or hole |
| | $\mid$ $\mathsf{Inr}\; \overline{v}$ | | Right variant with val or hole |
| | $\mid$ $(\overline{v_1}\,,\,\overline{v_2})$ | | Product with val or hole |
| | $\mid$ $\mathsf{E}_m\; \overline{v}$ | | Exponential with val or hole |
| | $\mid$ $(\overline{v})$ | S | |
| | $\mid$ $\overline{v}[e]$ | M | |
| term, $t$, $u$ | ::= | | Term |
| | $\mid$ $v$ | | Term value |
| | $\mid$ $x$ | | Variable |
| | $\mid$ $t \succ u$ | | Application |
| | $\mid$ $t \succ \mathbf{case}\; () \mapsto u$ | | Pattern-match on unit |
| | $\mid$ $t \succ \mathbf{case}\; \{\, \mathsf{Inl}\; x_1 \mapsto u_1\,,\; \mathsf{Inr}\; x_2 \mapsto u_2 \,\}$ | | Pattern-match on sum |
| | $\mid$ $t \succ \mathbf{case}\; (x_1\,,\,x_2) \mapsto u$ | | Pattern-match on product |
| | $\mid$ $t \succ \mathbf{case}\; \mathsf{E}_m\; x \mapsto u$ | | Pattern-match on exponential |
| | $\mid$ $t \succ \mathbf{mapL}\; x \mapsto u$ | | Map over the left side of the ampar |
| | $\mid$ $\mathbf{to}_{\ltimes}\; t$ | | Wrap t into a trivial ampar |
| | $\mid$ $\mathbf{from}_{\ltimes}\; t$ | | Extract value from trivial ampar |
| | $\mid$ $\mathbf{alloc}_{A}$ | | Return a fresh "identity" ampar object |
| | $\mid$ $t \triangleleft ()$ | | Fill destination with unit |
| | $\mid$ $t \triangleleft \mathsf{Inl}$ | | Fill destination with left variant |
| | $\mid$ $t \triangleleft \mathsf{Inr}$ | | Fill destination with right variant |
| | $\mid$ $t \triangleleft (,)$ | | Fill destination with product constructor |
| | $\mid$ $t \triangleleft \mathsf{E}_m$ | | Fill destination with exponential constructor |
| | $\mid$ $t \triangleleft\!\bullet\; u$ | | Fill destination with root of ampar u |
| | $\mid$ $(t)$ | S | |
| | $\mid$ $t[sub]$ | M | |
| sub | ::= | | Variable substitution |
| | $\mid$ $x := v$ | | |
| | $\mid$ $sub_1, sub_2$ | | |
| | $\mid$ $sub$ | S | |
| effect, $e$ | ::= | | Effect |
| | $\mid$ $\varepsilon$ | | No effect |
| | $\mid$ $h := \overline{v}$ | | |
| | $\mid$ $e_1 \cdot e_2$ | | |
| | $\mid$ $e$ | S | |

| | | | | |
|---|---|---|---|---|
| $\mathsf{type}$, $\mathsf{A}$, $\mathsf{B}$ | ::= | | | Type |
| | \| | $\mathsf{1}$ | | Unit |
| | \| | $\mathsf{A}_1 \oplus \mathsf{A}_2$ | | Sum |
| | \| | $\mathsf{A}_1 \otimes \mathsf{A}_2$ | | Product |
| | \| | $!_m \mathsf{A}$ | | Exponential |
| | \| | $\mathsf{A}_1 \ltimes \mathsf{A}_2$ | | Ampar type (consuming $\mathsf{A}_1$ yields $\mathsf{A}_2$) |
| | \| | $\mathsf{A}_1 \ {}_m\!\!\to \mathsf{A}_2$ | | Linear function |
| | \| | $\lfloor \mathsf{A} \rfloor_m$ | | Destination |
| | \| | $(\mathsf{A})$ | S | |
| $\mathit{multiplicity}$, $m$ | ::= | | | Multiplicity (Semiring with product $\cdot$) |
| | \| | $\nu$ | | Born now. Identity of the product |
| | \| | $\uparrow$ | | One scope older |
| | \| | $\infty$ | | Infinitely old / static. Absorbing for product |
| | \| | $m_1 \cdot m_2$ | | Semiring product |
| | \| | $(m)$ | S | |
| typing_context, $\Delta$ | ::= | | | Typing context |
| | \| | $\Gamma$ | | |
| | \| | $\mathrm{H}$ | | |
| | \| | $\Gamma \sqcup \mathrm{H}$ | | |
| pos_context, $\Gamma$ | ::= | | | Positive typing context |
| | \| | $\emptyset$ | | |
| | \| | {pos_assigns} | | |
| | \| | $\Gamma_1 \sqcup \Gamma_2$ | | |
| | \| | $-\mathrm{H}$ | | |
| | \| | $m \cdot \Gamma$ | | Increase age of bindings by $m$ |
| | \| | $(\Gamma)$ | S | |
| pos_assign, pa | ::= | | | Positive type assignment |
| | \| | $+\mathsf{x} :_m \mathsf{A}$ | | Variable |
| | \| | $+\mathtt{h} :_m \mathsf{A}$ | | Destination |
| pos_assigns | ::= | | | Positive type assignments |
| | \| | pa | | |
| | \| | pa, pos_assigns | | |
| neg_assign, na | ::= | | | Negative type assignment |
| | \| | $-\mathtt{h} :_m \mathsf{A}$ | | Hole |
| neg_assigns | ::= | | | Negative type assignments |
| | \| | na | | |
| | \| | na, neg_assigns | | |
| neg_context, $\mathrm{H}$ | ::= | | | Negative typing context |
| | \| | $\emptyset$ | | |
| | \| | {neg_assigns} | | |
| | \| | $\mathrm{H}_1 \sqcup \mathrm{H}_2$ | | |
| | \| | $-\Gamma$ | | |
| | \| | $m \cdot \mathrm{H}$ | | Increase age of bindings by $m$ |
| | \| | $(\mathrm{H})$ | S | |

| | | | |
|---|---|---|---|
| eff_app | ::= | | Effect application |
| | \| | e, $\overline{v}_H$ | |
| | \| | **apply** (eff_app) | |
| | \| | e $\hat{\cdot}$ eff_app | |
| terminals | ::= | | |
| | \| | $\multimap$ | |
| | \| | $\rtimes$ | |
| | \| | $\mapsto$ | |
| | \| | $()$ | |
| | \| | **Inl** | |
| | \| | **Inr** | |
| | \| | $(,)$ | |
| | \| | $\triangleleft$ | |
| | \| | $\triangleleft\!\bullet$ | |
| | \| | $:=$ | |
| | \| | $\cdot$ | |
| | \| | $\sqcup$ | |
| | \| | $\emptyset$ | |
| | \| | $\exists$ | |
| | \| | $\neq$ | |
| | \| | $\leq$ | |
| | \| | $\in$ | |
| | \| | $\notin$ | |
| | \| | $\subset$ | |
| | \| | $\mathcal{N}$ | |
| | \| | $\vdash$ | |
| | \| | $\Vdash$ | |
| | \| | $\mid$ | |
| | \| | $\Downarrow$ | |
| formula | ::= | | |
| | \| | judgement | |
| Ctx | ::= | | |
| | \| | $x \in \mathcal{N}(\Delta)$ | |
| | \| | $h \in \mathcal{N}(\Delta)$ | |
| | \| | $x \notin \mathcal{N}(\Delta)$ | |
| | \| | $h \notin \mathcal{N}(\Delta)$ | |
| | \| | **fresh** $x$ | |
| | \| | **fresh** $h$ | |
| | \| | pos_assign $\in \Gamma$ | |
| | \| | neg_assign $\in H$ | |
| | \| | **onlyPositive** $(\Delta)$ | |
| | \| | **onlyNegative** $(\Delta)$ | |
| Eq | ::= | | |
| | \| | $A_1 = A_2$ | |
| | \| | $A_1 \neq A_2$ | |
| | \| | $t = u$ | |
| | \| | $t \neq u$ | |
| | \| | $\Delta_1 = \Delta_2$ | |
| | \| | $\mathcal{N}(\Delta_1) \cap \mathcal{N}(\Delta_2) = \emptyset$ | |

| | | |
|---|---|---|
| Ty | ::= | |
| | \| | $\Delta \Vdash \overline{v} : \mathbf{A}$ |
| | \| | $\Gamma \vdash t : \mathbf{A}$ |
| Sem | ::= | |
| | \| | $\mathsf{eff\_app}_1 = \mathsf{eff\_app}_2$ (we assume effect lists are $\varepsilon$-terminated) |
| | \| | $t \Downarrow v \mid e$ |
| judgement | ::= | |
| | \| | Ctx |
| | \| | Eq |
| | \| | Ty |
| | \| | Sem |
| user_syntax | ::= | |
| | \| | termvar |
| | \| | holevar |
| | \| | term_value |
| | \| | extended_value |
| | \| | term |
| | \| | sub |
| | \| | effect |
| | \| | type |
| | \| | *multiplicity* |
| | \| | typing_context |
| | \| | pos_context |
| | \| | pos_assign |
| | \| | pos_assigns |
| | \| | neg_assign |
| | \| | neg_assigns |
| | \| | neg_context |
| | \| | eff_app |
| | \| | terminals |

$\boxed{x \in \mathcal{N}(\Delta)}$

$\boxed{h \in \mathcal{N}(\Delta)}$

$\boxed{x \notin \mathcal{N}(\Delta)}$

$\boxed{h \notin \mathcal{N}(\Delta)}$

$\boxed{\mathbf{fresh}\ x}$

$\boxed{\mathbf{fresh}\ h}$

$\boxed{\mathsf{pos\_assign} \in \Gamma}$

$\boxed{\mathsf{neg\_assign} \in H}$

$\boxed{\mathbf{onlyPositive}(\Delta)}$

$\boxed{\mathbf{onlyNegative}(\Delta)}$

$\boxed{\mathbf{A}_1 = \mathbf{A}_2}$

$\boxed{\mathbf{A}_1 \neq \mathbf{A}_2}$

$\boxed{t = u}$

$\boxed{t \neq u}$

$\boxed{\Delta_1 = \Delta_2}$

$\boxed{\mathcal{N}(\Delta_1) \cap \mathcal{N}(\Delta_2) = \emptyset}$

$\boxed{\Delta \Vdash \overline{v} : A}$

$$\frac{}{\emptyset \mathbin{\scriptstyle\sqcup} \{-h :_{\nu} A\} \Vdash h : A}\ \textsc{TyValExt\_Hole}$$

$$\frac{}{\{+h :_{m} A\} \mathbin{\scriptstyle\sqcup} \emptyset \Vdash @h : \lfloor A \rfloor_{m}}\ \textsc{TyValExt\_Dest}$$

$$\frac{}{\emptyset \mathbin{\scriptstyle\sqcup} \emptyset \Vdash () : 1}\ \textsc{TyValExt\_Unit}$$

$$\frac{\Gamma \mathbin{\scriptstyle\sqcup} H \Vdash \overline{v} : A_1}{\Gamma \mathbin{\scriptstyle\sqcup} H \Vdash \mathsf{Inl}\,\overline{v} : A_1 \oplus A_2}\ \textsc{TyValExt\_Inl}$$

$$\frac{\Gamma \mathbin{\scriptstyle\sqcup} H \Vdash \overline{v} : A_2}{\Gamma \mathbin{\scriptstyle\sqcup} H \Vdash \mathsf{Inr}\,\overline{v} : A_1 \oplus A_2}\ \textsc{TyValExt\_Inr}$$

$$\frac{\begin{array}{l}\Gamma_1 \mathbin{\scriptstyle\sqcup} H_1 \Vdash \overline{v_1} : A_1\\ \Gamma_2 \mathbin{\scriptstyle\sqcup} H_2 \Vdash \overline{v_2} : A_2\\ \mathcal{N}(\Gamma_1 \mathbin{\scriptstyle\sqcup} H_1) \cap \mathcal{N}(\Gamma_2 \mathbin{\scriptstyle\sqcup} H_2) = \emptyset\end{array}}{\Gamma_1 \sqcup \Gamma_2 \mathbin{\scriptstyle\sqcup} H_1 \sqcup H_2 \Vdash (\overline{v_1}\,,\,\overline{v_2}) : A_1 \otimes A_2}\ \textsc{TyValExt\_Prod}$$

$$\frac{\Gamma \mathbin{\scriptstyle\sqcup} H \Vdash \overline{v} : A}{m{\cdot}\Gamma \mathbin{\scriptstyle\sqcup} m{\cdot}H \Vdash \mathsf{E}_{m}\,\overline{v} : !_{m}A}\ \textsc{TyValExt\_Exp}$$

$$\frac{\begin{array}{l}-H \mathbin{\scriptstyle\sqcup} \emptyset \Vdash v_1 : A_1\\ \Gamma_2 \mathbin{\scriptstyle\sqcup} H \Vdash \overline{v_2} : A_2\end{array}}{\Gamma_2 \mathbin{\scriptstyle\sqcup} \emptyset \Vdash \langle v_1 \,,\, \overline{v_2}\rangle_{H} : A_1 \ltimes A_2}\ \textsc{TyValExt\_Ampar}$$

$$\frac{\Gamma \sqcup \{+x :_{m} A_1\} \vdash t : A_2}{\Gamma \mathbin{\scriptstyle\sqcup} \emptyset \Vdash \lambda x\,.\,t : A_1 \,{}_{m}\!\!\to A_2}\ \textsc{TyValExt\_Lambda}$$

$\boxed{\Gamma \vdash t : A}$

$$\frac{\Gamma \mathbin{\scriptstyle\sqcup} \emptyset \Vdash v : A}{\Gamma \vdash v : A}\ \textsc{TyTerm\_Val}$$

$$\frac{}{\{+x :_{\nu} A\} \vdash x : A}\ \textsc{TyTerm\_VarNow}$$

$$\frac{}{\{+x :_{\infty} A\} \vdash x : A}\ \textsc{TyTerm\_VarInf}$$

$$\frac{\begin{array}{l}\Gamma_1 \vdash t : A_1\\ \Gamma_2 \vdash u : A_1 \,{}_{m}\!\!\to A_2\\ \mathcal{N}(\Gamma_1) \cap \mathcal{N}(\Gamma_2) = \emptyset\end{array}}{m{\cdot}\Gamma_1 \sqcup \Gamma_2 \vdash t \succ u : A_2}\ \textsc{TyTerm\_App}$$

$$\frac{\begin{array}{l}\Gamma_1 \vdash t : 1\\ \Gamma_2 \vdash u : B\\ \mathcal{N}(\Gamma_1) \cap \mathcal{N}(\Gamma_2) = \emptyset\end{array}}{\Gamma_1 \sqcup \Gamma_2 \vdash t \succ \mathsf{case}\; () \mapsto u : B}\ \textsc{TyTerm\_PatUnit}$$

$$\frac{\begin{array}{l}\Gamma_1 \vdash t : A_1 \oplus A_2\\ \Gamma_2 \sqcup \{+x_1 :_{m} A_1\} \vdash u_1 : B\\ \Gamma_2 \sqcup \{+x_2 :_{m} A_2\} \vdash u_2 : B\\ \mathcal{N}(\Gamma_1) \cap \mathcal{N}(\Gamma_2) = \emptyset\end{array}}{m{\cdot}\Gamma_1 \sqcup \Gamma_2 \vdash t \succ \mathsf{case}\; \{\, \mathsf{Inl}\, x_1 \mapsto u_1\,,\ \mathsf{Inr}\, x_2 \mapsto u_2 \,\} : B}\ \textsc{TyTerm\_PatSum}$$

$$\frac{\begin{array}{l}\Gamma_1 \vdash t : A_1 \otimes A_2\\ \Gamma_2 \sqcup \{+x_1 :_{m} A_1, +x_2 :_{m} A_2\} \vdash u : B\\ \mathcal{N}(\Gamma_1) \cap \mathcal{N}(\Gamma_2) = \emptyset\end{array}}{m{\cdot}\Gamma_1 \sqcup \Gamma_2 \vdash t \succ \mathsf{case}\; (x_1\,,\,x_2) \mapsto u : B}\ \textsc{TyTerm\_PatProd}$$

$$\frac{\Gamma_1 \vdash \mathsf{t} : {!_{m'}}\mathsf{A} \qquad \Gamma_2 \sqcup \{{+}\mathsf{x} :_{m \cdot m'} \mathsf{A}_1\} \vdash \mathsf{u} : \mathsf{B} \qquad \mathcal{N}(\Gamma_1) \cap \mathcal{N}(\Gamma_2) = \emptyset}{m{\cdot}\Gamma_1 \sqcup \Gamma_2 \vdash \mathsf{t} \succ \mathsf{case}\ \mathsf{E}_{m'}\, \mathsf{x} \mapsto \mathsf{u} : \mathsf{B}} \quad \textsc{TyTerm\_PatExp}$$

$$\frac{\Gamma_1 \vdash \mathsf{t} : \mathsf{A}_1 \ltimes \mathsf{A}_2 \qquad {\uparrow}{\cdot}\Gamma_2 \sqcup \{{+}\mathsf{x} :_{\nu} \mathsf{A}_1\} \vdash \mathsf{u} : \mathsf{B} \qquad \mathcal{N}(\Gamma_1) \cap \mathcal{N}(\Gamma_2) = \emptyset}{\Gamma_1 \sqcup \Gamma_2 \vdash \mathsf{t} \succ \mathsf{mapL}\, \mathsf{x} \mapsto \mathsf{u} : \mathsf{B} \ltimes \mathsf{A}_2} \quad \textsc{TyTerm\_MapAmpar}$$

$$\frac{\Gamma_1 \vdash \mathsf{t} : \lfloor \mathsf{A}_2 \rfloor_m \qquad \Gamma_2 \vdash \mathsf{u} : \mathsf{A}_1 \ltimes \mathsf{A}_2 \qquad \mathcal{N}(\Gamma_1) \cap \mathcal{N}(\Gamma_2) = \emptyset}{\Gamma_1 \sqcup ({\uparrow}{\cdot}m){\cdot}\Gamma_2 \vdash \mathsf{t} \triangleleft\!\bullet\, \mathsf{u} : \mathsf{A}_1} \quad \textsc{TyTerm\_FillComp}$$

$$\frac{\Gamma \vdash \mathsf{t} : \lfloor \mathbf{1} \rfloor_m}{\Gamma \vdash \mathsf{t} \triangleleft () : \mathbf{1}} \quad \textsc{TyTerm\_FillUnit}$$

$$\frac{\Gamma \vdash \mathsf{t} : \lfloor \mathsf{A}_1 \oplus \mathsf{A}_2 \rfloor_m}{\Gamma \vdash \mathsf{t} \triangleleft \mathsf{Inl} : \lfloor \mathsf{A}_1 \rfloor_m} \quad \textsc{TyTerm\_FillInl}$$

$$\frac{\Gamma \vdash \mathsf{t} : \lfloor \mathsf{A}_1 \oplus \mathsf{A}_2 \rfloor_m}{\Gamma \vdash \mathsf{t} \triangleleft \mathsf{Inr} : \lfloor \mathsf{A}_2 \rfloor_m} \quad \textsc{TyTerm\_FillInr}$$

$$\frac{\Gamma \vdash \mathsf{t} : \lfloor \mathsf{A}_1 \otimes \mathsf{A}_2 \rfloor_m}{\Gamma \vdash \mathsf{t} \triangleleft (,) : \lfloor \mathsf{A}_1 \rfloor_m \otimes \lfloor \mathsf{A}_2 \rfloor_m} \quad \textsc{TyTerm\_FillProd}$$

$$\frac{\Gamma \vdash \mathsf{t} : \lfloor {!_{m'}}\mathsf{A} \rfloor_m}{\Gamma \vdash \mathsf{t} \triangleleft \mathsf{E}_m : \lfloor \mathsf{A} \rfloor_{m \cdot m'}} \quad \textsc{TyTerm\_FillExp}$$

$$\frac{}{\emptyset \vdash \mathsf{alloc}_{\mathsf{A}} : \lfloor \mathsf{A} \rfloor_{\nu} \ltimes \mathsf{A}} \quad \textsc{TyTerm\_Alloc}$$

$$\frac{\Gamma \vdash \mathsf{t} : \mathsf{A}}{\Gamma \vdash \mathsf{to}_{\ltimes}\, \mathsf{t} : \mathbf{1} \ltimes \mathsf{A}} \quad \textsc{TyTerm\_ToAmpar}$$

$$\frac{\Gamma \vdash \mathsf{t} : \mathbf{1} \ltimes \mathsf{A}}{\Gamma \vdash \mathsf{from}_{\ltimes}\, \mathsf{t} : \mathsf{A}} \quad \textsc{TyTerm\_FromAmpar}$$

$\boxed{\mathsf{eff\_app}_1 = \mathsf{eff\_app}_2}$ (we assume effect lists are $\varepsilon$-terminated)

$$\frac{}{\mathsf{apply}\,(\varepsilon,\ \overline{\mathsf{v}}_{\mathrm{H}}) = \varepsilon,\ \overline{\mathsf{v}}_{\mathrm{H}}} \quad \textsc{EffApp\_NoEff}$$

$$\frac{\mathrm{h} \notin \mathcal{N}(\mathrm{H})}{\mathsf{apply}\,(\mathrm{h} \coloneqq \overline{\mathsf{v}'} \cdot \mathsf{e},\ \overline{\mathsf{v}}_{\mathrm{H}}) = \mathrm{h} \coloneqq \overline{\mathsf{v}'}\ \hat{\cdot}\ \mathsf{apply}\,(\mathsf{e},\ \overline{\mathsf{v}}_{\mathrm{H}})} \quad \textsc{EffApp\_Skip}$$

$$\frac{}{\mathsf{apply}\,(\mathrm{h} \coloneqq () \cdot \mathsf{e},\ \overline{\mathsf{v}}_{\mathrm{H} \sqcup \{-\mathrm{h} :_{\nu} \mathbf{1}\}}) = \mathsf{apply}\,(\mathsf{e},\ \overline{\mathsf{v}}[\mathrm{h} \coloneqq ()]_{\mathrm{H}})} \quad \textsc{EffApp\_FillUnit}$$

$$\frac{}{\mathsf{apply}\,(\mathrm{h} \coloneqq \mathsf{Inl}\,\mathrm{h}' \cdot \mathsf{e},\ \overline{\mathsf{v}}_{\mathrm{H} \sqcup \{-\mathrm{h} :_{\nu} \mathsf{A}_1 \oplus \mathsf{A}_2\}}) = \mathsf{apply}\,(\mathsf{e},\ \overline{\mathsf{v}}[\mathrm{h} \coloneqq \mathsf{Inl}\,\mathrm{h}']_{\mathrm{H} \sqcup \{-\mathrm{h}' :_{\nu} \mathsf{A}_1\}})} \quad \textsc{EffApp\_FillInl}$$

$$\frac{}{\mathsf{apply}\,(\mathrm{h} \coloneqq \mathsf{Inr}\,\mathrm{h}' \cdot \mathsf{e},\ \overline{\mathsf{v}}_{\mathrm{H} \sqcup \{-\mathrm{h} :_{\nu} \mathsf{A}_1 \oplus \mathsf{A}_2\}}) = \mathsf{apply}\,(\mathsf{e},\ \overline{\mathsf{v}}[\mathrm{h} \coloneqq \mathsf{Inr}\,\mathrm{h}']_{\mathrm{H} \sqcup \{-\mathrm{h}' :_{\nu} \mathsf{A}_2\}})} \quad \textsc{EffApp\_FillInr}$$

$$\frac{}{\mathsf{apply}\,(\mathrm{h} \coloneqq (\mathrm{h}_1\ ,\ \mathrm{h}_2) \cdot \mathsf{e},\ \overline{\mathsf{v}}_{\mathrm{H} \sqcup \{-\mathrm{h} :_{\nu} \mathsf{A}_1 \otimes \mathsf{A}_2\}}) = \mathsf{apply}\,(\mathsf{e},\ \overline{\mathsf{v}}[\mathrm{h} \coloneqq (\mathrm{h}_1\ ,\ \mathrm{h}_2)]_{\mathrm{H} \sqcup \{-\mathrm{h}_1 :_{\nu} \mathsf{A}_1, -\mathrm{h}_2 :_{\nu} \mathsf{A}_2\}})} \quad \textsc{EffApp\_FillProd}$$

$$\frac{\Gamma' \sqcup \mathrm{H}' \Vdash \overline{\mathsf{v}'} : \mathsf{A} \qquad \mathcal{N}(\mathrm{H} \sqcup \{-\mathrm{h} :_{\nu} \mathsf{A}\}) \cap \mathcal{N}(\mathrm{H}') = \emptyset}{\mathsf{apply}\,(\mathrm{h} \coloneqq \overline{\mathsf{v}'} \cdot \mathsf{e},\ \overline{\mathsf{v}}_{\mathrm{H} \sqcup \{-\mathrm{h} :_{\nu} \mathsf{A}\}}) = \mathsf{apply}\,(\mathsf{e},\ \overline{\mathsf{v}}[\mathrm{h} \coloneqq \overline{\mathsf{v}'}]_{\mathrm{H} \sqcup \mathrm{H}'})} \quad \textsc{EffApp\_FillComp} \quad \text{(Encompasses all other } \textsc{Fill} \text{ rules)}$$

$\boxed{\mathsf{t} \Downarrow \mathsf{v} \mid \mathsf{e}}$

$$\frac{}{\mathsf{v} \Downarrow \mathsf{v} \mid \varepsilon}\ \textsc{BigStep\_Val}$$

$$\frac{\begin{array}{c}\mathsf{t}_1 \Downarrow \mathsf{v}_1 \mid \mathsf{e}_1 \\ \mathsf{t}_2 \Downarrow \lambda x\,.\,\mathsf{u} \mid \mathsf{e}_2 \\ \mathsf{u}[x \coloneqq \mathsf{v}_1] \Downarrow \mathsf{v}_3 \mid \mathsf{e}_3\end{array}}{\mathsf{t}_1 \succ \mathsf{t}_2 \Downarrow \mathsf{v}_3 \mid \mathsf{e}_1 \cdot \mathsf{e}_2 \cdot \mathsf{e}_3}\ \textsc{BigStep\_App}$$

$$\frac{\begin{array}{c}\mathsf{t}_1 \Downarrow () \mid \mathsf{e}_1 \\ \mathsf{t}_2 \Downarrow \mathsf{v}_2 \mid \mathsf{e}_2\end{array}}{\mathsf{t}_1 \succ \mathbf{case}\ () \mapsto \mathsf{t}_2 \Downarrow \mathsf{v}_2 \mid \mathsf{e}_1 \cdot \mathsf{e}_2}\ \textsc{BigStep\_PatUnit}$$

$$\frac{\begin{array}{c}\mathsf{t} \Downarrow \mathbf{Inl}\ \mathsf{v}_1 \mid \mathsf{e}_1 \\ \mathsf{u}_1[x_1 \coloneqq \mathsf{v}_1] \Downarrow \mathsf{v}_2 \mid \mathsf{e}_2\end{array}}{\mathsf{t} \succ \mathbf{case}\ \{\, \mathbf{Inl}\ x_1 \mapsto \mathsf{u}_1 ,\ \mathbf{Inr}\ x_2 \mapsto \mathsf{u}_2 \,\} \Downarrow \mathsf{v}_2 \mid \mathsf{e}_1 \cdot \mathsf{e}_2}\ \textsc{BigStep\_PatInl}$$

$$\frac{\begin{array}{c}\mathsf{t} \Downarrow \mathbf{Inr}\ \mathsf{v}_1 \mid \mathsf{e}_1 \\ \mathsf{u}_2[x_2 \coloneqq \mathsf{v}_1] \Downarrow \mathsf{v}_2 \mid \mathsf{e}_2\end{array}}{\mathsf{t} \succ \mathbf{case}\ \{\, \mathbf{Inl}\ x_1 \mapsto \mathsf{u}_1 ,\ \mathbf{Inr}\ x_2 \mapsto \mathsf{u}_2 \,\} \Downarrow \mathsf{v}_2 \mid \mathsf{e}_1 \cdot \mathsf{e}_2}\ \textsc{BigStep\_PatInr}$$

$$\frac{\begin{array}{c}\mathsf{t} \Downarrow (\mathsf{v}_1 , \mathsf{v}_2) \mid \mathsf{e}_1 \\ \mathsf{u}[x_1 \coloneqq \mathsf{v}_1, x_2 \coloneqq \mathsf{v}_2] \Downarrow \mathsf{v}_2 \mid \mathsf{e}_2\end{array}}{\mathsf{t} \succ \mathbf{case}\ (x_1 , x_2) \mapsto \mathsf{u} \Downarrow \mathsf{v}_2 \mid \mathsf{e}_1 \cdot \mathsf{e}_2}\ \textsc{BigStep\_PatProd}$$

$$\frac{\begin{array}{c}\mathsf{t} \Downarrow \langle \mathsf{v}_1 , \overline{\mathsf{v}_2} \rangle_{H} \mid \mathsf{e}_1 \\ \mathsf{u}[x \coloneqq \mathsf{v}_1] \Downarrow \mathsf{v}_3 \mid \mathsf{e}_2 \\ \mathsf{e}_3, \overline{\mathsf{v}_4}_{H'} = \mathbf{apply}\ (\mathsf{e}_2, \overline{\mathsf{v}_2}_{H})\end{array}}{\mathsf{t} \succ \mathbf{mapL}\ x \mapsto \mathsf{u} \Downarrow \langle \mathsf{v}_3 , \overline{\mathsf{v}_4} \rangle_{H'} \mid \mathsf{e}_1 \cdot \mathsf{e}_3}\ \textsc{BigStep\_MapAmpar}$$

$$\frac{\mathbf{fresh}\ h}{\mathbf{alloc}_{A} \Downarrow \langle @h , h \rangle_{\{-h :_{\nu} A\}} \mid \varepsilon}\ \textsc{BigStep\_Alloc}$$

$$\frac{\mathsf{t} \Downarrow \mathsf{v} \mid \mathsf{e}}{\mathbf{to}_{\rtimes}\ \mathsf{t} \Downarrow \langle () , \mathsf{v} \rangle_{\emptyset} \mid \mathsf{e}}\ \textsc{BigStep\_ToAmpar}$$

$$\frac{\mathsf{t} \Downarrow \langle () , \mathsf{v} \rangle_{\emptyset} \mid \mathsf{e}}{\mathbf{from}_{\rtimes}\ \mathsf{t} \Downarrow \mathsf{v} \mid \mathsf{e}}\ \textsc{BigStep\_FromAmpar}$$

$$\frac{\mathsf{t} \Downarrow @h \mid \mathsf{e}}{\mathsf{t} \triangleleft () \Downarrow () \mid \mathsf{e} \cdot h \coloneqq ()}\ \textsc{BigStep\_FillUnit}$$

$$\frac{\begin{array}{c}\mathsf{t} \Downarrow @h \mid \mathsf{e} \\ \mathbf{fresh}\ h'\end{array}}{\mathsf{t} \triangleleft \mathbf{Inl} \Downarrow @h' \mid \mathsf{e} \cdot h \coloneqq \mathbf{Inl}\ h'}\ \textsc{BigStep\_FillInl}$$

$$\frac{\mathsf{t} \Downarrow @h \mid \mathsf{e}}{\mathsf{t} \triangleleft \mathbf{Inr} \Downarrow @h' \mid \mathsf{e} \cdot h \coloneqq \mathbf{Inr}\ h'}\ \textsc{BigStep\_FillInr}$$

$$\frac{\begin{array}{c}\mathsf{t} \Downarrow @h \mid \mathsf{e} \\ \mathbf{fresh}\ h_1 \\ \mathbf{fresh}\ h_2\end{array}}{\mathsf{t} \triangleleft (,) \Downarrow (@h_1 , @h_2) \mid \mathsf{e} \cdot h \coloneqq (h_1 , h_2)}\ \textsc{BigStep\_FillProd}$$

$$\frac{\begin{array}{c}\mathsf{t} \Downarrow @h \mid \mathsf{e}_1 \\ \mathsf{u} \Downarrow \langle \mathsf{v}_1 , \overline{\mathsf{v}_2} \rangle_{H} \mid \mathsf{e}_2\end{array}}{\mathsf{t} \triangleleft\!\bullet \mathsf{u} \Downarrow \mathsf{v}_1 \mid \mathsf{e}_1 \cdot \mathsf{e}_2 \cdot h \coloneqq \overline{\mathsf{v}_2}}\ \textsc{BigStep\_FillComp}$$

```
Definition rules:          49 good     0 bad
Definition rule clauses:  117 good     0 bad
```