$metavariable, x, xs, y, uf, f, d$

term, t, u	::=			term
	|	x		variable
	|	v		value
	|	t u		application
	|	t ; u		effect execution
	|	case t of $\{() \mapsto$ u$\}$		pattern-matching on unit
	|	case t of $\{$ Ur $x \mapsto$ u$\}$		pattern-matching on exponentiated value
	|	case t of $\{$ inl $x_1 \mapsto$ u_1, inr $x_2 \mapsto$ $u_2\}$		pattern-matching on sum
	|	case t of $\{\langle x_1, x_2\rangle \mapsto$ u$\}$		pattern-matching on product
	|	case t of $\{\mathsf{roll}_{R}\ x \mapsto$ u$\}$		unroll for recursive types
	|	$\mathsf{alloc}_{A}\ d$. t		allocate data
	|	t $\triangleleft$ ()		fill destination with unit
	|	t $\triangleleft$ u		fill terminal-type destination
	|	t $\triangleleft$ Ur u		fill destination with exponential
	|	t $\triangleleft$ inl d . u		fill sum-type destination with variant 1
	|	t $\triangleleft$ inr d . u		fill sum-type destination with variant 2
	|	t $\triangleleft$ $\langle d_1, d_2\rangle$. u		fill product-type destination
	|	t $\triangleleft$ $\mathsf{roll}_{R}\ d$. u		fill destination with recursive type
	|	(t)	S	
	|	t [var_subs]	M	
var_sub, vs	::=			variable substitution
	|	x := t		
var_subs	::=			variable substitutions
	|	vs		
	|	vs, var_subs		
heap_val, h	::=			
	|	()		
	|	Ur ℓ		
	|	inl ℓ		
	|	inr ℓ		
	|	$\langle \ell_1, \ell_2\rangle$		
	|	$\mathsf{roll}_{R}\ \ell$		
	|	C $\bar{\ell}$	M	generic for all the cases above
val, v	::=			unreducible value
	|	$\bullet$		no-effect effect
	|	$\lfloor \ell \rfloor$		address of an allocated memory area
	|	$\lambda\, x$:A . t		lambda abstraction
	|	h		heap value
$label, \ell$	::=			memory address
labels	::=			
	|	ℓ		
	|	ℓ, labels		
	|	$\bar{\ell}$	M	

	|	$\bar{\ell}$, labels	M	
$\mathit{label\_set}$, L	::=			set of used labels
	|	$\emptyset$		
	|	{labels}		
	|	$L_1 \sqcup L_2$		
heap_affect, ha	::=			heap cell
	|	$\ell \lhd \mathsf{v}$		
	|	$\bar{\ell} \lhd \bar{\mathsf{v}}$	M	generic for multiple occurences
heap_affects	::=			heap cells
	|	ha		
	|	ha, heap_affects		
heap_context, $\mathbb{H}$	::=			heap contents
	|	$\emptyset$		
	|	{heap_affects}		
	|	$\mathbb{H}_1 \sqcup \mathbb{H}_2$		
type, A, B	::=			
	|	$\perp$		bottom type
	|	1		unit type
	|	R		recursive type bound to a name
	|	$\mathsf{A} \otimes \mathsf{B}$		product type
	|	$\mathsf{A} \oplus \mathsf{B}$		sum type
	|	$\mathsf{A} \multimap \mathsf{B}$		linear function type
	|	$\lfloor \mathsf{A} \rfloor$		destination type
	|	!A		exponential
	|	(A)	S	
	|	$\mathsf{W}[r := \mathsf{A}]$	M	
type_with_hole, W	::=			
	|	r		type hole in recursive definition
	|	$\perp$		bottom type
	|	1		unit type
	|	R		recursive type bound to a name
	|	$\mathsf{W}_1 \otimes \mathsf{W}_2$		product type
	|	$\mathsf{W}_1 \oplus \mathsf{W}_2$		sum type
	|	$\mathsf{W}_1 \multimap \mathsf{W}_2$		linear function type
	|	$\lfloor \mathsf{W} \rfloor$		destination type
	|	!W		exponential
	|	(W)	S	
rec_type_bound, R	::=			recursive type bound to a name
rec_type_def	::=			
	|	$\mu\, r\,.\,\mathsf{W}$		

type_affect, ta ::=
| x : A
| ℓ : A
| $\bar{\ell}$: $\bar{\mathsf{A}}$

type_affects ::=
| ta
| ta, type_affects

typing_context, Γ, $\mho$, Φ, Ψ, $\Psi^{\mathbb{H}}$, Ψ^{t} ::=
| $\emptyset$
| $\{$type_affects$\}$
| $\Gamma_1 \sqcup \Gamma_2$

types, $\bar{\mathsf{A}}$ ::=
| $\cdot$
| A
| A types

command ::=
| $L \,|\, \mathbb{H} \,|\, \mathrm{t}$

heap_constructor, C ::=
| ()
| Ur
| inl
| inr
| $\langle , \rangle$
| roll R

judg ::=
| $\ell \in \mathcal{N}(\Phi)$
| $\ell \notin \mathcal{N}(\Phi)$
| type_affect $\in \Gamma$
| $\mathcal{N}(\Gamma_1) \cap \mathcal{N}(\Gamma_2) = \emptyset$
| $\mathcal{N}(\Gamma_1) \cap \mathcal{N}(\Gamma_2) = \emptyset \wedge \mathcal{N}(\Gamma_1) \cap \mathcal{N}(\Gamma_3) = \emptyset \wedge \mathcal{N}(\Gamma_2) \cap \mathcal{N}(\Gamma_3) =$
| $\mathcal{N}(\Phi) \sqcup \mathcal{N}(\Psi) \subset L$
| $\mathcal{N}(\Phi) \sqcup \mathcal{N}(\Psi^{\mathbb{H}}) \sqcup \mathcal{N}(\Psi^{\mathrm{t}}) \subset L$
| $\ell \in L$
| $\ell \notin L$
| heap_affect $\in \mathbb{H}$
| A = B
| t = u
| Γ = D
| $\{\ell \triangleleft \mathrm{v}', \bar{\ell} \triangleleft \bar{\mathrm{v}}\} = \mathsf{deepCopy}(L, \lfloor \ell \rfloor, \mathrm{v})$
| R $\overset{\mathsf{fix}}{=}$ rec_type_def
| A is destination-free
| C : $\bar{\mathsf{A}} \overset{\mathsf{c}}{\rightharpoondown}$ A
| Φ ; $\Psi^{\mathbb{H}} \uplus \Psi^{\mathrm{t}}$; $\mho$; $\Gamma \vdash$ command : A

| $\Phi\ ;\ \Psi \vdash \mathbb{H}$
| $\Phi\ ;\ \Psi\ ;\ \mho\ ;\ \Gamma \vdash \mathsf{t} : \mathsf{A}$
| command $\Downarrow$ command$'$

terminals ::=
| $()$
| $\mapsto$
| $\oplus$
| $\multimap$
| $:=$
| $\vdash$
| $\sqcup$
| $\emptyset$
| $\neq$
| $\in$
| $\notin$
| \n
| $\langle$
| $\rangle$
| inl
| inr
| Ur
| $\triangleleft$
| $|$
| $\overset{\mathsf{c}}{\angle}$
| $=$
| $\Downarrow$
| $\overset{\mathsf{fix}}{=}$
| $\bot$
| $\bullet$
| $\subset$
| $;$
| $\mathcal{N}$
| $\bar{\ell}$
| $\bar{\mathsf{v}}$

formula ::=
| judgement

Ctx ::=
| $\ell \in \mathcal{N}(\Phi)$
| $\ell \notin \mathcal{N}(\Phi)$
| type_affect $\in \Gamma$
| $\mathcal{N}(\Gamma_1) \cap \mathcal{N}(\Gamma_2) = \emptyset$ Γ_1 and Γ_2 are disj
| $\mathcal{N}(\Gamma_1) \cap \mathcal{N}(\Gamma_2) = \emptyset \wedge \mathcal{N}(\Gamma_1) \cap \mathcal{N}(\Gamma_3) = \emptyset \wedge \mathcal{N}(\Gamma_2) \cap \mathcal{N}(\Gamma_3) = \emptyset$ Γ_1, Γ_2 and Γ_3 are f

LabelSet ::=
| $\mathcal{N}(\Phi) \sqcup \mathcal{N}(\Psi) \subset L$
| $\mathcal{N}(\Phi) \sqcup \mathcal{N}(\Psi^{\mathbb{H}}) \sqcup \mathcal{N}(\Psi^{\mathsf{t}}) \subset L$
| $\ell \in L$

	$\vert$	$\ell = \mathsf{fresh}(L)$	
Heap	::=		
	$\vert$	heap_affect $\in \mathbb{H}$	
Eq	::=		
	$\vert$	$\mathsf{A} = \mathsf{B}$	
	$\vert$	$\mathsf{t} = \mathsf{u}$	
	$\vert$	$\Gamma = \mathsf{D}$	
Copy	::=		
	$\vert$	$\{\ell \triangleleft \mathsf{v}', \bar{\ell} \triangleleft \bar{\mathsf{v}}\} = \mathsf{deepCopy}(L, \lfloor \ell \rfloor, \mathsf{v})$	Deep-copy v into the memory tree with root ℓ a
Ty	::=		
	$\vert$	$\mathsf{R} \overset{\mathsf{fix}}{=}$ rec_type_def	
	$\vert$	A is destination-free	A is destination-free
	$\vert$	$\mathsf{C} : \bar{\mathsf{A}} \overset{\mathsf{c}}{\multimap} \mathsf{A}$	Heap constructor C builds a value of type A giv
	$\vert$	$\Phi \,;\, \Psi^{\mathbb{H}} \sqcup \Psi^{\mathsf{t}} \,;\, \mho \,;\, \Gamma \vdash \mathsf{command} : \mathsf{A}$	
	$\vert$	$\Phi \,;\, \Psi \vdash \mathbb{H}$	
	$\vert$	$\Phi \,;\, \Psi \,;\, \mho \,;\, \Gamma \vdash \mathsf{t} : \mathsf{A}$	
Sem	::=		
	$\vert$	$\mathsf{command} \Downarrow \mathsf{command}'$	
judgement	::=		
	$\vert$	Ctx	
	$\vert$	LabelSet	
	$\vert$	Heap	
	$\vert$	Eq	
	$\vert$	Copy	
	$\vert$	Ty	
	$\vert$	Sem	
user_syntax	::=		
	$\vert$	*metavariable*	
	$\vert$	term	
	$\vert$	var_sub	
	$\vert$	var_subs	
	$\vert$	heap_val	
	$\vert$	val	
	$\vert$	*label*	
	$\vert$	labels	
	$\vert$	*label_set*	
	$\vert$	heap_affect	
	$\vert$	heap_affects	
	$\vert$	heap_context	
	$\vert$	type	
	$\vert$	type_with_hole	
	$\vert$	rec_type_bound	

| rec_type_def
| type_affect
| type_affects
| typing_context
| types
| command
| heap_constructor
| judg
| terminals

$\boxed{\ell \in \mathcal{N}(\Phi)}$

$\boxed{\ell \notin \mathcal{N}(\Phi)}$

$\boxed{\mathsf{type\_affect} \in \Gamma}$

$\boxed{\mathcal{N}(\Gamma_1) \cap \mathcal{N}(\Gamma_2) = \emptyset}$ Γ_1 and Γ_2 are disjoint typing contexts with no clashing variable names or labels

$\boxed{\mathcal{N}(\Gamma_1) \cap \mathcal{N}(\Gamma_2) = \emptyset \wedge \mathcal{N}(\Gamma_1) \cap \mathcal{N}(\Gamma_3) = \emptyset \wedge \mathcal{N}(\Gamma_2) \cap \mathcal{N}(\Gamma_3) = \emptyset}$ Γ_1, Γ_2 and Γ_3 are fully disjoint typing cont

$\boxed{\mathcal{N}(\Phi) \sqcup \mathcal{N}(\Psi) \subset L}$

$\boxed{\mathcal{N}(\Phi) \sqcup \mathcal{N}(\Psi^{\mathbb{H}}) \sqcup \mathcal{N}(\Psi^{\mathsf{t}}) \subset L}$

$\boxed{\ell \in L}$

$\boxed{\ell = \mathsf{fresh}(L)}$

$\boxed{\mathsf{heap\_affect} \in \mathbb{H}}$

$\boxed{\mathsf{A} = \mathsf{B}}$

$\boxed{\mathsf{t} = \mathsf{u}}$

$\boxed{\Gamma = \mathsf{D}}$

$\boxed{\{\ell \triangleleft \mathsf{v}', \bar{\ell} \triangleleft \bar{\mathsf{v}}\} = \mathsf{deepCopy}(L, \lfloor \ell \rfloor, \mathsf{v})}$ Deep-copy v into the memory tree with root ℓ and fresh labels $\bar{\ell}$

$\boxed{\mathsf{R} \overset{\mathsf{fix}}{=} \mathsf{rec\_type\_def}}$

$\boxed{\mathsf{A} \text{ is destination-free}}$ A is destination-free

$\boxed{\mathsf{C} : \bar{\mathsf{A}} \overset{\mathsf{c}}{\rightharpoonup} \mathsf{A}}$ Heap constructor C builds a value of type A given arguments of type $\bar{\mathsf{A}}$

$$\frac{}{() : \cdot \overset{\mathsf{c}}{\rightharpoonup} 1} \quad \textsc{TyCtor\_U}$$

$$\frac{}{\mathsf{inl} : \mathsf{A} \overset{\mathsf{c}}{\rightharpoonup} \mathsf{A} \oplus \mathsf{B}} \quad \textsc{TyCtor\_Inl}$$

$$\frac{}{\mathsf{inr} : \mathsf{B} \overset{\mathsf{c}}{\rightharpoonup} \mathsf{A} \oplus \mathsf{B}} \quad \textsc{TyCtor\_Inr}$$

$$\frac{}{\langle , \rangle : \mathsf{A} \ \ \mathsf{B} \overset{\mathsf{c}}{\rightharpoonup} \mathsf{A} \otimes \mathsf{B}} \quad \textsc{TyCtor\_P}$$

$$\frac{}{\mathsf{Ur} \ : \mathsf{A} \overset{\mathsf{c}}{\rightharpoonup} !\mathsf{A}} \quad \textsc{TyCtor\_E}$$

$$\frac{\mathsf{R} \overset{\mathsf{fix}}{=} \mu\, r\, .\, \mathsf{W}}{\mathsf{roll}\ \mathsf{R} : \mathsf{W}[r := \mathsf{R}] \overset{\mathsf{c}}{\rightharpoonup} \mathsf{R}} \quad \textsc{TyCtor\_R}$$

$\boxed{\Phi \,;\, \Psi^{\mathbb{H}} \sqcup \Psi^{\mathsf{t}} \,;\, \mho \,;\, \Gamma \vdash \mathsf{command} : \mathsf{A}}$

$$\frac{\begin{array}{l}\mathcal{N}(\Psi^{\mathbb{H}}) \cap \mathcal{N}(\Psi^{\mathsf{t}}) = \emptyset \\ \mathcal{N}(\Phi) \sqcup \mathcal{N}(\Psi^{\mathbb{H}}) \sqcup \mathcal{N}(\Psi^{\mathsf{t}}) \subset L \\ \Phi \,;\, \Psi^{\mathbb{H}} \vdash \mathbb{H} \\ \Phi \,;\, \Psi^{\mathsf{t}} \,;\, \mho \,;\, \Gamma \vdash \mathsf{t} : \mathsf{A}\end{array}}{\Phi \,;\, \Psi^{\mathbb{H}} \sqcup \Psi^{\mathsf{t}} \,;\, \mho \,;\, \Gamma \vdash L \,|\, \mathbb{H} \,|\, \mathsf{t} : \mathsf{A}} \quad \textsc{TyCommand\_Def}$$

$\boxed{\Phi \,;\, \Psi \vdash \mathbb{H}}$

$$\frac{}{\emptyset \,;\, \emptyset \vdash \emptyset} \quad \textsc{TyHeap\_Empty}$$

$$\frac{\begin{array}{l}\mathcal{N}(\Psi_1) \cap \mathcal{N}(\Psi_2) = \emptyset \\ \Phi \,;\, \Psi_1 \vdash \mathbb{H} \\ \Phi \,;\, \Psi_2 \,;\, \emptyset \,;\, \emptyset \vdash \mathsf{v} : \mathsf{A}\end{array}}{\Phi \sqcup \{\ell : \mathsf{A}\} \,;\, \Psi_1 \sqcup \Psi_2 \vdash \mathbb{H} \sqcup \{\ell \triangleleft \mathsf{v}\}} \quad \textsc{TyHeap\_Val}$$

$\boxed{\Phi \,;\, \Psi \,;\, \mho \,;\, \Gamma \vdash \mathsf{t} : \mathsf{A}}$

$$\frac{}{\Phi \,;\, \emptyset \,;\, \mho \,;\, \emptyset \vdash \bullet : \bot} \quad \textsc{TyTerm\_NoEff}$$

$$\frac{\ell \notin \mathcal{N}(\Phi)}{\Phi \,;\, \{\ell : \mathsf{A}\} \,;\, \mho \,;\, \emptyset \vdash \lfloor \ell \rfloor : \lfloor \mathsf{A} \rfloor} \quad \textsc{TyTerm\_LDest}$$

$$\frac{\Phi \,;\, \Psi \,;\, \mho \,;\, \Gamma \sqcup \{x : \mathsf{A}\} \vdash \mathsf{t} : \mathsf{B}}{\Phi \,;\, \Psi \,;\, \mho \,;\, \Gamma \vdash \lambda\, x{:}\mathsf{A} \,.\, \mathsf{t} : \mathsf{A} \multimap \mathsf{B}} \quad \textsc{TyTerm\_Lam}$$

$$\frac{\mathsf{C} : \bar{\mathsf{A}} \xrightarrow{\mathsf{c}} \mathsf{A}}{\Phi \sqcup \{\bar{\ell} : \bar{\mathsf{A}}\} \,;\, \emptyset \,;\, \mho \,;\, \emptyset \vdash \mathsf{C}\,\bar{\ell} : \mathsf{A}} \quad \textsc{TyTerm\_HeapVal}$$

$$\frac{}{\Phi \,;\, \emptyset \,;\, \mho \,;\, \{x : \mathsf{A}\} \vdash x : \mathsf{A}} \quad \textsc{TyTerm\_Id}$$

$$\frac{}{\Phi \,;\, \emptyset \,;\, \mho \sqcup \{x : \mathsf{A}\} \,;\, \emptyset \vdash x : \mathsf{A}} \quad \textsc{TyTerm\_Id'}$$

$$\frac{\begin{array}{l}\Phi \,;\, \Psi_1 \,;\, \mho \,;\, \Gamma_1 \vdash \mathsf{t} : \mathsf{A} \multimap \mathsf{B} \\ \Phi \,;\, \Psi_2 \,;\, \mho \,;\, \Gamma_2 \vdash \mathsf{u} : \mathsf{A} \\ \mathcal{N}(\Gamma_1) \cap \mathcal{N}(\Gamma_2) = \emptyset \\ \mathcal{N}(\Psi_1) \cap \mathcal{N}(\Psi_2) = \emptyset\end{array}}{\Phi \,;\, \Psi_1 \sqcup \Psi_2 \,;\, \mho \,;\, \Gamma_1 \sqcup \Gamma_2 \vdash \mathsf{t}\;\mathsf{u} : \mathsf{B}} \quad \textsc{TyTerm\_App}$$

$$\frac{\begin{array}{l}\Phi \,;\, \Psi_1 \,;\, \mho \,;\, \Gamma_1 \vdash \mathsf{t} : \bot \\ \Phi \,;\, \Psi_2 \,;\, \mho \,;\, \Gamma_2 \vdash \mathsf{u} : \mathsf{B} \\ \mathcal{N}(\Gamma_1) \cap \mathcal{N}(\Gamma_2) = \emptyset \\ \mathcal{N}(\Psi_1) \cap \mathcal{N}(\Psi_2) = \emptyset\end{array}}{\Phi \,;\, \Psi_1 \sqcup \Psi_2 \,;\, \mho \,;\, \Gamma_1 \sqcup \Gamma_2 \vdash \mathsf{t} \,;\, \mathsf{u} : \mathsf{B}} \quad \textsc{TyTerm\_EffThen}$$

$$\frac{\begin{array}{l}\Phi \,;\, \Psi_1 \,;\, \mho \,;\, \Gamma_1 \vdash \mathsf{t} : \mathsf{1} \\ \Phi \,;\, \Psi_2 \,;\, \mho \,;\, \Gamma_2 \vdash \mathsf{u} : \mathsf{A} \\ \mathcal{N}(\Gamma_1) \cap \mathcal{N}(\Gamma_2) = \emptyset \\ \mathcal{N}(\Psi_1) \cap \mathcal{N}(\Psi_2) = \emptyset\end{array}}{\Phi \,;\, \Psi_1 \sqcup \Psi_2 \,;\, \mho \,;\, \Gamma_1 \sqcup \Gamma_2 \vdash \mathsf{case}\,\mathsf{t}\,\mathsf{of}\,\{() \mapsto \mathsf{u}\} : \mathsf{A}} \quad \textsc{TyTerm\_PatU}$$

$$\frac{\begin{array}{l}\Phi \,;\, \Psi_1 \,;\, \mho \,;\, \Gamma_1 \vdash \mathsf{t} : !\mathsf{A} \\ \Phi \,;\, \Psi_2 \,;\, \mho \sqcup \{x : \mathsf{A}\} \,;\, \Gamma_2 \vdash \mathsf{u} : \mathsf{B} \\ \mathcal{N}(\Gamma_1) \cap \mathcal{N}(\Gamma_2) = \emptyset \\ \mathcal{N}(\Psi_1) \cap \mathcal{N}(\Psi_2) = \emptyset\end{array}}{\Phi \,;\, \Psi_1 \sqcup \Psi_2 \,;\, \mho \,;\, \Gamma_1 \sqcup \Gamma_2 \vdash \mathsf{case}\,\mathsf{t}\,\mathsf{of}\,\{\mathsf{Ur}\; x \mapsto \mathsf{u}\} : \mathsf{B}} \quad \textsc{TyTerm\_PatE}$$

$$\dfrac{\begin{array}{l}\Phi \,;\, \Psi_1 \,;\, \mho \,;\, \Gamma_1 \vdash \mathsf{t} : \mathsf{A}_1 \oplus \mathsf{A}_2 \\ \Phi \,;\, \Psi_2 \,;\, \mho \,;\, \Gamma_2 \sqcup \{x_1 : \mathsf{A}_1\} \vdash \mathsf{u}_1 : \mathsf{B} \\ \Phi \,;\, \Psi_2 \,;\, \mho \,;\, \Gamma_2 \sqcup \{x_2 : \mathsf{A}_2\} \vdash \mathsf{u}_2 : \mathsf{B} \\ \mathcal{N}(\Gamma_1) \cap \mathcal{N}(\Gamma_2) = \emptyset \\ \mathcal{N}(\Psi_1) \cap \mathcal{N}(\Psi_2) = \emptyset \end{array}}{\Phi \,;\, \Psi_1 \sqcup \Psi_2 \,;\, \mho \,;\, \Gamma_1 \sqcup \Gamma_2 \vdash \mathsf{case}\,\mathsf{t}\,\mathsf{of}\,\{\,\mathsf{inl}\ x_1 \mapsto \mathsf{u}_1,\ \mathsf{inr}\ x_2 \mapsto \mathsf{u}_2\} : \mathsf{B}} \quad \text{TyTerm\_PatS}$$

$$\dfrac{\begin{array}{l}\Phi \,;\, \Psi_1 \,;\, \mho \,;\, \Gamma_1 \vdash \mathsf{t} : \mathsf{A}_1 \otimes \mathsf{A}_2 \\ \Phi \,;\, \Psi_2 \,;\, \mho \,;\, \Gamma_2 \sqcup \{x_1 : \mathsf{A}_1, x_2 : \mathsf{A}_2\} \vdash \mathsf{u} : \mathsf{B} \\ \mathcal{N}(\Gamma_1) \cap \mathcal{N}(\Gamma_2) = \emptyset \\ \mathcal{N}(\Psi_1) \cap \mathcal{N}(\Psi_2) = \emptyset \end{array}}{\Phi \,;\, \Psi_1 \sqcup \Psi_2 \,;\, \mho \,;\, \Gamma_1 \sqcup \Gamma_2 \vdash \mathsf{case}\,\mathsf{t}\,\mathsf{of}\,\{\langle x_1, x_2\rangle \mapsto \mathsf{u}\} : \mathsf{B}} \quad \text{TyTerm\_PatP}$$

$$\dfrac{\begin{array}{l}\mathsf{R} \overset{\mathsf{fix}}{=} \mu\, r \,.\, \mathsf{W} \\ \Phi \,;\, \Psi_1 \,;\, \mho \,;\, \Gamma_1 \vdash \mathsf{t} : \mathsf{R} \\ \Phi \,;\, \Psi_2 \,;\, \mho \,;\, \Gamma_2 \sqcup \{x : \mathsf{W}[r := \mathsf{R}]\} \vdash \mathsf{u} : \mathsf{B} \\ \mathcal{N}(\Gamma_1) \cap \mathcal{N}(\Gamma_2) = \emptyset \\ \mathcal{N}(\Psi_1) \cap \mathcal{N}(\Psi_2) = \emptyset \end{array}}{\Phi \,;\, \Psi_1 \sqcup \Psi_2 \,;\, \mho \,;\, \Gamma_1 \sqcup \Gamma_2 \vdash \mathsf{case}\ \mathsf{t}\ \mathsf{of}\ \{\underset{\mathsf{R}}{\mathsf{roll}}\ x \mapsto \mathsf{u}\} : \mathsf{B}} \quad \text{TyTerm\_PatR}$$

$$\dfrac{\Phi \,;\, \Psi \,;\, \mho \,;\, \Gamma \sqcup \{d : \lfloor \mathsf{A} \rfloor\} \vdash \mathsf{t} : \bot}{\Phi \,;\, \Psi \,;\, \mho \,;\, \Gamma \vdash \underset{\mathsf{A}}{\mathsf{alloc}}\ d \,.\, \mathsf{t} : \mathsf{A}} \quad \text{TyTerm\_Alloc}$$

$$\dfrac{\Phi \,;\, \Psi \,;\, \mho \,;\, \Gamma \vdash \mathsf{t} : \lfloor 1 \rfloor}{\Phi \,;\, \Psi \,;\, \mho \,;\, \Gamma \vdash \mathsf{t} \triangleleft () : \bot} \quad \text{TyTerm\_FillU}$$

$$\dfrac{\begin{array}{l}\Phi \,;\, \Psi_1 \,;\, \mho \,;\, \Gamma_1 \vdash \mathsf{t} : \lfloor \mathsf{A} \rfloor \\ \Phi \,;\, \Psi_2 \,;\, \mho \,;\, \Gamma_2 \vdash \mathsf{u} : \mathsf{A} \\ \mathcal{N}(\Gamma_1) \cap \mathcal{N}(\Gamma_2) = \emptyset \\ \mathcal{N}(\Psi_1) \cap \mathcal{N}(\Psi_2) = \emptyset \end{array}}{\Phi \,;\, \Psi_1 \sqcup \Psi_2 \,;\, \mho \,;\, \Gamma_1 \sqcup \Gamma_2 \vdash \mathsf{t} \triangleleft \mathsf{u} : \bot} \quad \text{TyTerm\_FillL}$$

$$\dfrac{\begin{array}{l}\mathsf{A} \text{ is destination-free} \\ \Phi \,;\, \Psi_1 \,;\, \mho \,;\, \Gamma \vdash \mathsf{t} : \lfloor !\mathsf{A} \rfloor \\ \Phi \,;\, \emptyset \,;\, \mho \,;\, \emptyset \vdash \mathsf{u} : \mathsf{A} \end{array}}{\Phi \,;\, \Psi_1 \,;\, \mho \,;\, \Gamma \vdash \mathsf{t} \triangleleft \mathsf{Ur}\ \mathsf{u} : \bot} \quad \text{TyTerm\_FillE}$$

$$\dfrac{\begin{array}{l}\Phi \,;\, \Psi_1 \,;\, \mho \,;\, \Gamma_1 \vdash \mathsf{t} : \lfloor \mathsf{A}_1 \oplus \mathsf{A}_2 \rfloor \\ \Phi \,;\, \Psi_2 \,;\, \mho \,;\, \Gamma_2 \sqcup \{d' : \lfloor \mathsf{A}_1 \rfloor\} \vdash \mathsf{u} : \mathsf{B} \\ \mathcal{N}(\Gamma_1) \cap \mathcal{N}(\Gamma_2) = \emptyset \\ \mathcal{N}(\Psi_1) \cap \mathcal{N}(\Psi_2) = \emptyset \end{array}}{\Phi \,;\, \Psi_1 \sqcup \Psi_2 \,;\, \mho \,;\, \Gamma_1 \sqcup \Gamma_2 \vdash \mathsf{t} \triangleleft \mathsf{inl}\, d' \,.\, \mathsf{u} : \mathsf{B}} \quad \text{TyTerm\_FillInl}$$

$$\dfrac{\begin{array}{l}\Phi \,;\, \Psi_1 \,;\, \mho \,;\, \Gamma_1 \vdash \mathsf{t} : \lfloor \mathsf{A}_1 \oplus \mathsf{A}_2 \rfloor \\ \Phi \,;\, \Psi_2 \,;\, \mho \,;\, \Gamma_2 \sqcup \{d' : \lfloor \mathsf{A}_2 \rfloor\} \vdash \mathsf{u} : \mathsf{B} \\ \mathcal{N}(\Gamma_1) \cap \mathcal{N}(\Gamma_2) = \emptyset \\ \mathcal{N}(\Psi_1) \cap \mathcal{N}(\Psi_2) = \emptyset \end{array}}{\Phi \,;\, \Psi_1 \sqcup \Psi_2 \,;\, \mho \,;\, \Gamma \vdash \mathsf{t} \triangleleft \mathsf{inr}\, d' \,.\, \mathsf{u} : \mathsf{B}} \quad \text{TyTerm\_FillInr}$$

$$\dfrac{\begin{array}{l}\Phi \,;\, \Psi_1 \,;\, \mho \,;\, \Gamma_1 \vdash \mathsf{t} : \lfloor \mathsf{A}_1 \otimes \mathsf{A}_2 \rfloor \\ \Phi \,;\, \Psi_2 \,;\, \mho \,;\, \Gamma_2 \sqcup \{d_1 : \lfloor \mathsf{A}_1 \rfloor, d_2 : \lfloor \mathsf{A}_2 \rfloor\} \vdash \mathsf{u} : \mathsf{B} \\ \mathcal{N}(\Gamma_1) \cap \mathcal{N}(\Gamma_2) = \emptyset \\ \mathcal{N}(\Psi_1) \cap \mathcal{N}(\Psi_2) = \emptyset \end{array}}{\Phi \,;\, \Psi_1 \sqcup \Psi_2 \,;\, \mho \,;\, \Gamma_1 \sqcup \Gamma_2 \vdash \mathsf{t} \triangleleft \langle d_1, d_2 \rangle \,.\, \mathsf{u} : \mathsf{B}} \quad \text{TyTerm\_FillP}$$

$$\dfrac{\begin{array}{l} \mathsf{R} \overset{\mathsf{fix}}{=} \mu\, r\,.\,\mathsf{W} \\ \Phi\ ;\ \Psi_1\ ;\ \mho\ ;\ \Gamma_1 \vdash \mathsf{t} : \lfloor \mathsf{R} \rfloor \\ \Phi\ ;\ \Psi_2\ ;\ \mho\ ;\ \Gamma_2 \sqcup \{ d : \lfloor \mathsf{W}[r := \mathsf{R}] \rfloor \} \vdash \mathsf{u} : \mathsf{B} \\ \mathcal{N}(\Gamma_1) \cap \mathcal{N}(\Gamma_2) = \emptyset \\ \mathcal{N}(\Psi_1) \cap \mathcal{N}(\Psi_2) = \emptyset \end{array}}{\Phi\ ;\ \Psi_1 \sqcup \Psi_2\ ;\ \mho\ ;\ \Gamma_1 \sqcup \Gamma_2 \vdash \mathsf{t} \triangleleft \underset{\mathsf{R}}{\mathsf{roll}}\ d\,.\,\mathsf{u} : \mathsf{B}} \quad \textsc{TyTerm\_FillR}$$

$\boxed{\mathsf{command} \Downarrow \mathsf{command}'}$

$$\dfrac{}{L \mid \mathbb{H} \mid \bullet \ \Downarrow\ L \mid \mathbb{H} \mid \bullet} \quad \textsc{SemOp\_NoEff}\ \textit{(value)}$$

$$\dfrac{}{L \mid \mathbb{H} \mid \lfloor \ell \rfloor \ \Downarrow\ L \mid \mathbb{H} \mid \lfloor \ell \rfloor} \quad \textsc{SemOp\_LDest}\ \textit{(value)}$$

$$\dfrac{}{L \mid \mathbb{H} \mid \lambda\, x{:}\mathsf{A}\,.\,\mathsf{t} \ \Downarrow\ L \mid \mathbb{H} \mid \lambda\, x{:}\mathsf{A}\,.\,\mathsf{t}} \quad \textsc{SemOp\_Lam}\ \textit{(value)}$$

$$\dfrac{}{L \mid \mathbb{H} \mid \mathsf{C}\,\bar{\ell} \ \Downarrow\ L \mid \mathbb{H} \mid \mathsf{C}\,\bar{\ell}} \quad \textsc{SemOp\_HeapVal}\ \textit{(value)}$$

$$\dfrac{\begin{array}{c} L_0 \mid \mathbb{H}_0 \mid \mathsf{t} \ \Downarrow\ L_1 \mid \mathbb{H}_1 \mid \lambda\, x{:}\mathsf{A}\,.\,\mathsf{t}' \\ L_1 \mid \mathbb{H}_1 \mid \mathsf{u} \ \Downarrow\ L_2 \mid \mathbb{H}_2 \mid \mathsf{v}_2 \\ L_2 \mid \mathbb{H}_2 \mid \mathsf{t}'\,[x := \mathsf{v}_2] \ \Downarrow\ L_3 \mid \mathbb{H}_3 \mid \mathsf{v}_3 \end{array}}{L_0 \mid \mathbb{H}_0 \mid \mathsf{t}\ \mathsf{u} \ \Downarrow\ L_3 \mid \mathbb{H}_3 \mid \mathsf{v}_3} \quad \textsc{SemOp\_App}$$

$$\dfrac{\begin{array}{c} L_0 \mid \mathbb{H}_0 \mid \mathsf{t} \ \Downarrow\ L_1 \mid \mathbb{H}_1 \mid () \\ L_1 \mid \mathbb{H}_1 \mid \mathsf{u} \ \Downarrow\ L_2 \mid \mathbb{H}_2 \mid \mathsf{v}_2 \end{array}}{L_0 \mid \mathbb{H}_0 \mid \mathsf{case}\,\mathsf{t}\,\mathsf{of}\,\{ () \mapsto \mathsf{u} \} \ \Downarrow\ L_2 \mid \mathbb{H}_2 \mid \mathsf{v}_2} \quad \textsc{SemOp\_PatU}$$

$$\dfrac{\begin{array}{c} L_0 \mid \mathbb{H}_0 \mid \mathsf{t} \ \Downarrow\ L_1 \mid \mathbb{H}_1 \sqcup \{ \ell \triangleleft \mathsf{v}_1 \} \mid \mathsf{Ur}\ \ell \\ L_1 \mid \mathbb{H}_1 \mid \mathsf{u}\,[x := \mathsf{v}_1] \ \Downarrow\ L_2 \mid \mathbb{H}_2 \mid \mathsf{v}_2 \end{array}}{L_0 \mid \mathbb{H}_0 \mid \mathsf{case}\,\mathsf{t}\,\mathsf{of}\,\{ \mathsf{Ur}\ x \mapsto \mathsf{u} \} \ \Downarrow\ L_2 \mid \mathbb{H}_2 \mid \mathsf{v}_2} \quad \textsc{SemOp\_PatE}$$

$$\dfrac{\begin{array}{c} L_0 \mid \mathbb{H}_0 \mid \mathsf{t} \ \Downarrow\ L_1 \mid \mathbb{H}_1 \sqcup \{ \ell \triangleleft \mathsf{v}_1 \} \mid \mathsf{inl}\ \ell \\ L_1 \mid \mathbb{H}_1 \mid \mathsf{u}_1\,[x_1 := \mathsf{v}_1] \ \Downarrow\ L_2 \mid \mathbb{H}_2 \mid \mathsf{v}_2 \end{array}}{L_0 \mid \mathbb{H}_0 \mid \mathsf{case}\,\mathsf{t}\,\mathsf{of}\,\{ \mathsf{inl}\ x_1 \mapsto \mathsf{u}_1,\ \mathsf{inr}\ x_2 \mapsto \mathsf{u}_2 \} \ \Downarrow\ L_2 \mid \mathbb{H}_2 \mid \mathsf{v}_2} \quad \textsc{SemOp\_PatInl}$$

$$\dfrac{\begin{array}{c} L_0 \mid \mathbb{H}_0 \mid \mathsf{t} \ \Downarrow\ L_1 \mid \mathbb{H}_1 \sqcup \{ \ell \triangleleft \mathsf{v}_1 \} \mid \mathsf{inr}\ \ell \\ L_1 \mid \mathbb{H}_1 \mid \mathsf{u}_2\,[x_2 := \mathsf{v}_1] \ \Downarrow\ L_2 \mid \mathbb{H}_2 \mid \mathsf{v}_2 \end{array}}{L_0 \mid \mathbb{H}_0 \mid \mathsf{case}\,\mathsf{t}\,\mathsf{of}\,\{ \mathsf{inl}\ x_1 \mapsto \mathsf{u}_1,\ \mathsf{inr}\ x_2 \mapsto \mathsf{u}_2 \} \ \Downarrow\ L_2 \mid \mathbb{H}_2 \mid \mathsf{v}_2} \quad \textsc{SemOp\_PatInr}$$

$$\dfrac{\begin{array}{c} L_0 \mid \mathbb{H}_0 \mid \mathsf{t} \ \Downarrow\ L_1 \mid \mathbb{H}_1 \sqcup \{ \ell_1 \triangleleft \mathsf{v}_{11}, \ell_2 \triangleleft \mathsf{v}_{12} \} \mid \langle \ell_1, \ell_2 \rangle \\ L_1 \mid \mathbb{H}_1 \mid \mathsf{u}\,[x_1 := \mathsf{v}_{11}, x_2 := \mathsf{v}_{12}] \ \Downarrow\ L_2 \mid \mathbb{H}_2 \mid \mathsf{v}_2 \end{array}}{L_0 \mid \mathbb{H}_0 \mid \mathsf{case}\,\mathsf{t}\,\mathsf{of}\,\{ \langle x_1, x_2 \rangle \mapsto \mathsf{u} \} \ \Downarrow\ L_2 \mid \mathbb{H}_2 \mid \mathsf{v}_2} \quad \textsc{SemOp\_PatP}$$

$$\dfrac{\begin{array}{c} L_0 \mid \mathbb{H}_0 \mid \mathsf{t} \ \Downarrow\ L_1 \mid \mathbb{H}_1 \sqcup \{ \ell \triangleleft \mathsf{v}_1 \} \mid \underset{\mathsf{R}}{\mathsf{roll}}\ \ell \\ L_1 \mid \mathbb{H}_1 \mid \mathsf{u}\,[x := \mathsf{v}_1] \ \Downarrow\ L_2 \mid \mathbb{H}_2 \mid \mathsf{v}_2 \end{array}}{L_0 \mid \mathbb{H}_0 \mid \mathsf{case}\ \mathsf{t}\ \mathsf{of}\ \{ \underset{\mathsf{R}}{\mathsf{roll}}\ x \mapsto \mathsf{u} \} \ \Downarrow\ L_2 \mid \mathbb{H}_2 \mid \mathsf{v}_2} \quad \textsc{SemOp\_PatR}$$

$$\dfrac{\begin{array}{c} L_0 \mid \mathbb{H}_0 \mid \mathsf{t} \ \Downarrow\ L_1 \mid \mathbb{H}_1 \mid \bullet \\ L_1 \mid \mathbb{H}_1 \mid \mathsf{u} \ \Downarrow\ L_2 \mid \mathbb{H}_2 \mid \mathsf{v}_2 \end{array}}{L_0 \mid \mathbb{H}_0 \mid \mathsf{t}\ ;\ \mathsf{u} \ \Downarrow\ L_2 \mid \mathbb{H}_2 \mid \mathsf{v}_2} \quad \textsc{SemOp\_EffThen}$$

$$\dfrac{\begin{array}{l} \ell = \mathsf{fresh}(L_0) \\ L_0 \sqcup \{\ell\} \mid \mathbb{H}_0 \mid \mathsf{t}\,[d := \lfloor \ell \rfloor] \ \Downarrow\ L_1 \mid \mathbb{H}_1 \sqcup \{ \ell \triangleleft \mathsf{v}_1 \} \mid \bullet \end{array}}{L_0 \mid \mathbb{H}_0 \mid \underset{\mathsf{A}}{\mathsf{alloc}}\ d\,.\,\mathsf{t} \ \Downarrow\ L_1 \mid \mathbb{H}_1 \mid \mathsf{v}_1} \quad \textsc{SemOp\_Alloc}$$

$$\frac{L_0 \mid \mathbb{H}_0 \mid \mathsf{t} \;\Downarrow\; L_1 \mid \mathbb{H}_1 \mid \lfloor \ell \rfloor}{L_0 \mid \mathbb{H}_0 \mid \mathsf{t} \lhd () \;\Downarrow\; L_1 \mid \mathbb{H}_1 \sqcup \{\ell \lhd ()\} \mid \bullet} \quad \textsc{SemOp\_FillU}$$

$$\frac{\begin{array}{l} L_0 \mid \mathbb{H}_0 \mid \mathsf{t} \;\Downarrow\; L_1 \mid \mathbb{H}_1 \mid \lfloor \ell \rfloor \\ L_1 \mid \mathbb{H}_1 \mid \mathsf{u} \;\Downarrow\; L_2 \mid \mathbb{H}_2 \mid \mathsf{v}_2 \\ \{\ell \lhd \mathsf{v}_3, \bar{\ell} \lhd \bar{\mathsf{v}}\} = \mathsf{deepCopy}(L_2, \lfloor \ell \rfloor, \mathsf{v}_2) \end{array}}{L_0 \mid \mathbb{H}_0 \mid \mathsf{t} \lhd \mathsf{u} \;\Downarrow\; L_2 \sqcup \{\bar{\ell}\} \mid \mathbb{H}_2 \sqcup \{\ell \lhd \mathsf{v}_3, \bar{\ell} \lhd \bar{\mathsf{v}}\} \mid \bullet} \quad \textsc{SemOp\_FillL}$$

$$\frac{\begin{array}{l} L_0 \mid \mathbb{H}_0 \mid \mathsf{t} \;\Downarrow\; L_1 \mid \mathbb{H}_1 \mid \lfloor \ell \rfloor \\ L_1 \mid \mathbb{H}_1 \mid \mathsf{u} \;\Downarrow\; L_2 \mid \mathbb{H}_2 \mid \mathsf{v}_2 \\ \ell' = \mathsf{fresh}(L_2) \\ \{\ell' \lhd \mathsf{v}_3, \bar{\ell} \lhd \bar{\mathsf{v}}\} = \mathsf{deepCopy}(L_2 \sqcup \{\ell'\}, \lfloor \ell' \rfloor, \mathsf{v}_2) \end{array}}{L_0 \mid \mathbb{H}_0 \mid \mathsf{t} \lhd \mathsf{Ur}\ \mathsf{u} \;\Downarrow\; L_2 \sqcup \{\ell', \bar{\ell}\} \mid \mathbb{H}_2 \sqcup \{\ell \lhd \mathsf{Ur}\ \ell', \ell' \lhd \mathsf{v}_3, \bar{\ell} \lhd \bar{\mathsf{v}}\} \mid \bullet} \quad \textsc{SemOp\_FillE}$$

$$\frac{\begin{array}{l} \ell' = \mathsf{fresh}(L_1) \\ L_0 \mid \mathbb{H}_0 \mid \mathsf{t} \;\Downarrow\; L_1 \mid \mathbb{H}_1 \mid \lfloor \ell \rfloor \\ L_1 \sqcup \{\ell'\} \mid \mathbb{H}_1 \mid \mathsf{u}[d := \lfloor \ell' \rfloor] \;\Downarrow\; L_2 \mid \mathbb{H}_2 \sqcup \{\ell' \lhd \mathsf{v}_1\} \mid \mathsf{v}_2 \end{array}}{L_0 \mid \mathbb{H}_0 \mid \mathsf{t} \lhd \mathsf{inl}\, d \,.\, \mathsf{u} \;\Downarrow\; L_2 \mid \mathbb{H}_2 \sqcup \{\ell \lhd \mathsf{inl}\ \ell', \ell' \lhd \mathsf{v}_1\} \mid \mathsf{v}_2} \quad \textsc{SemOp\_FillInl}$$

$$\frac{\begin{array}{l} \ell' = \mathsf{fresh}(L_1) \\ L_0 \mid \mathbb{H}_0 \mid \mathsf{t} \;\Downarrow\; L_1 \mid \mathbb{H}_1 \mid \lfloor \ell \rfloor \\ L_1 \sqcup \{\ell'\} \mid \mathbb{H}_1 \mid \mathsf{u}[d := \lfloor \ell' \rfloor] \;\Downarrow\; L_2 \mid \mathbb{H}_2 \sqcup \{\ell' \lhd \mathsf{v}_1\} \mid \mathsf{v}_2 \end{array}}{L_0 \mid \mathbb{H}_0 \mid \mathsf{t} \lhd \mathsf{inr}\, d \,.\, \mathsf{u} \;\Downarrow\; L_2 \mid \mathbb{H}_2 \sqcup \{\ell \lhd \mathsf{inr}\ \ell', \ell' \lhd \mathsf{v}_1\} \mid \mathsf{v}_2} \quad \textsc{SemOp\_FillInr}$$

$$\frac{\begin{array}{l} \ell_1 = \mathsf{fresh}(L_1) \\ \ell_2 = \mathsf{fresh}(L_1 \sqcup \{\ell_1\}) \\ L_0 \mid \mathbb{H}_0 \mid \mathsf{t} \;\Downarrow\; L_1 \mid \mathbb{H}_1 \mid \lfloor \ell \rfloor \\ L_1 \sqcup \{\ell_1, \ell_2\} \mid \mathbb{H}_1 \mid \mathsf{u}[d_1 := \lfloor \ell_1 \rfloor, d_2 := \lfloor \ell_2 \rfloor] \;\Downarrow\; L_2 \mid \mathbb{H}_2 \sqcup \{\ell_1 \lhd \mathsf{v}_{11}, \ell_2 \lhd \mathsf{v}_{12}\} \mid \mathsf{v}_2 \end{array}}{L_0 \mid \mathbb{H}_0 \mid \mathsf{t} \lhd \langle d_1, d_2 \rangle \,.\, \mathsf{u} \;\Downarrow\; L_2 \mid \mathbb{H}_2 \sqcup \{\ell \lhd \langle \ell_1, \ell_2 \rangle, \ell_1 \lhd \mathsf{v}_{11}, \ell_2 \lhd \mathsf{v}_{12}\} \mid \mathsf{v}_2} \quad \textsc{SemOp\_FillP}$$

$$\frac{\begin{array}{l} \ell' = \mathsf{fresh}(L_1) \\ L_0 \mid \mathbb{H}_0 \mid \mathsf{t} \;\Downarrow\; L_1 \mid \mathbb{H}_1 \mid \lfloor \ell \rfloor \\ L_1 \sqcup \{\ell'\} \mid \mathbb{H}_1 \mid \mathsf{u}[d := \lfloor \ell' \rfloor] \;\Downarrow\; L_2 \mid \mathbb{H}_2 \sqcup \{\ell' \lhd \mathsf{v}_1\} \mid \mathsf{v}_2 \end{array}}{L_0 \mid \mathbb{H}_0 \mid \mathsf{t} \lhd \underset{\mathsf{R}}{\mathsf{roll}}\ d \,.\, \mathsf{u} \;\Downarrow\; L_2 \mid \mathbb{H}_2 \sqcup \{\ell \lhd \underset{\mathsf{R}}{\mathsf{roll}}\ \ell', \ell' \lhd \mathsf{v}_1\} \mid \mathsf{v}_2} \quad \textsc{SemOp\_FillR}$$

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Definition rules:         50 good     0 bad
Definition rule clauses: 157 good     0 bad
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