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 $\{\text{Ur } x \mapsto u\}$		pattern-matching on exponentiated value
	|	case t of $\{1.x_1 \mapsto u_1, 2.x_2 \mapsto u_2\}$		pattern-matching on sum
	|	case t of $\{\langle x_1, x_2\rangle \mapsto u\}$		pattern-matching on product
	|	case t of $\{\text{roll}_R\ x \mapsto u\}$		unroll for recursive types
	|	$\text{alloc}_A\ d\,.\,t$		allocate data
	|	$t \lhd ()$		fill destination with unit
	|	$t \lhd u$		fill terminal-type destination
	|	$t \lhd \text{Ur } u$		fill destination with exponential
	|	$t \lhd 1.d\,.\,u$		fill sum-type destination with variant 1
	|	$t \lhd 2.d\,.\,u$		fill sum-type destination with variant 2
	|	$t \lhd \langle d_1, d_2\rangle\,.\,u$		fill product-type destination
	|	$t \lhd \text{roll}_R\ d\,.\,u$		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		
	|	$1.l$		
	|	$2.l$		
	|	$\langle l_1, l_2\rangle$		
	|	$\text{roll}_R\ l$		
	|	$C\bar{l}$	M	generic for all the cases above
val, v	::=			unreducible value
	|	•		no-effect effect
	|	$\lfloor l \rfloor$		address of an allocated memory area
	|	$\lambda x{:}A\,.\,t$		lambda abstraction
	|	h		heap value
label, l	::=			memory address
labels	::=			
	|	l		
	|	l bar		
	|	l, labels		

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

type_affect, ta	::=		type affectation
	|	$x : A$	var
	|	$l : A$	label
	|	$\bar{l} : \bar{A}$	generic for multiple occurences
type_affects	::=		type affectations
	|	ta	
	|	ta, type_affects	
typing_context, Γ, $\mho$, Φ, Ψ	::=		typing context
	|	$\emptyset$	
	|	{type_affects}	
	|	$\Gamma_1 \sqcup \Gamma_2$	
types, $\bar{A}$	::=		
	|	.	empty type list
	|	A	
	|	A types	
command	::=		
	|	$\mathbb{H} \mid_L \mathsf{t}$	
heap_constructor, C	::=		
	|	{()}	
	|	{ Ur }	
	|	{1.}	
	|	{2.}	
	|	$\{\langle,\rangle\}$	
	|	{ roll R}	
judg	::=		
	|	$l \in$ names (Φ)	
	|	$l \notin$ names (Φ)	
	|	type_affect $\in \Gamma$	
	|	names $(\Gamma) \cap$ names (D) $= \emptyset$	
	|	names $(\Phi) \sqcup$ names $(\Psi) = L$	
	|	$l \in L$	
	|	$l \notin L$	
	|	heap_affect $\in \mathbb{H}$	
	|	A = B	
	|	t = u	
	|	Γ = D	
	|	R $\overset{\text{fix}}{=}$ rec_type_def	
	|	C : $\bar{A} \xrightharpoonup{c}$ A	
	|	Φ ; Ψ ; $\mho$; $\Gamma \vdash$ command : A	
	|	$\Phi \vdash \mathbb{H}$	
	|	Φ ; Ψ ; $\mho$; $\Gamma \vdash$ t : A	
	|	command $\Downarrow$ command$'$	

terminals ::=
| $()$
| $\mapsto$
| $\star$
| $\circledast$
| $\oplus$
| $\multimap$
| $:=$
| $\vdash$
| $\sqcup$
| $;$
| $\cap$
| $\emptyset$
| $\longrightarrow$
| $\triangleright$
| $\neq$
| $\in$
| $\notin$
| \n
| $\langle$
| $\rangle$
| 1.
| 2.
| Ur
| $\triangleleft$
| $|$
| $\oslash$
| $\overset{c}{\lrcorner}$
| $=$
| $\Downarrow$
| $\ldots$
| $\overset{\mathsf{fix}}{=}$
| $\bot$
| $\bullet$

formula ::=
| judgement

Ctx ::=
| $l \in \mathsf{names}(\Phi)$
| $l \notin \mathsf{names}(\Phi)$
| type_affect $\in \Gamma$
| $\mathsf{names}(\Gamma_1) \cap \mathsf{names}(\Gamma_2) = \emptyset$ $\quad$ Γ_1 and Γ_2 are disjoint typing contexts with no clashi

LabelSet ::=
| $\mathsf{names}(\Phi) \sqcup \mathsf{names}(\Psi) = L$
| $l \in L$
| $l \notin L$

Heap ::=

	|	heap_affect $\in \mathbb{H}$	
Eq	::=		
	|	A $=$ B	
	|	t $=$ u	
	|	Γ $=$ D	
Ty	::=		
	|	R $\overset{\text{fix}}{=}$ rec_type_def	
	|	C : $\bar{\mathsf{A}} \xrightarrow{c}$ A	Heap constructor C builds a value of type A given a
	|	Φ ; Ψ ; $\mho$; $\Gamma \vdash$ command : A	
	|	$\Phi \vdash \mathbb{H}$	$\mathbb{H}$ is a well-typed heap given heap typing context Φ
	|	Φ ; Ψ ; $\mho$; $\Gamma \vdash$ t : A	t is a well-typed term of type A given heap typing c
Sem	::=		
	|	command $\Downarrow$ command$'$	t reduces to t', with heap growing from H to H'
judgement	::=		
	|	Ctx	
	|	LabelSet	
	|	Heap	
	|	Eq	
	|	Ty	
	|	Sem	
user_syntax	::=		
	|	metavariable	
	|	term	
	|	var_sub	
	|	var_subs	
	|	heap_val	
	|	val	
	|	*label*	
	|	labels	
	|	*label_set*	
	|	heap_affect	
	|	heap_affects	
	|	heap_context	
	|	type	
	|	type_with_hole	
	|	rec_type_bound	
	|	rec_type_def	
	|	type_affect	
	|	type_affects	
	|	typing_context	
	|	types	
	|	command	
	|	heap_constructor	
	|	judg	
	|	terminals	

$\boxed{l \in \mathsf{names}(\Phi)}$

$\boxed{l \notin \mathsf{names}(\Phi)}$

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

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

$\boxed{\mathsf{names}(\Phi) \sqcup \mathsf{names}(\Psi) = L}$

$\boxed{l \in L}$

$\boxed{l \notin L}$

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

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

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

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

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

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

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

$$\frac{}{\{1.\} : \mathsf{A} \overset{\mathsf{c}}{\rightharpoonup} \mathsf{A} \oplus \mathsf{B}} \quad \textsc{TyCtor\_V1}$$

$$\frac{}{\{2.\} : \mathsf{B} \overset{\mathsf{c}}{\rightharpoonup} \mathsf{A} \oplus \mathsf{B}} \quad \textsc{TyCtor\_V2}$$

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

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

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

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

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

$\boxed{\Phi \vdash \mathbb{H}}$ $\mathbb{H}$ is a well-typed heap given heap typing context Φ

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

$$\frac{\begin{array}{l}\Phi \vdash \mathbb{H} \\ \Phi \,;\, \Psi \,;\, \mho \,;\, \Gamma \vdash \mathsf{v} : \mathsf{A}\end{array}}{\Phi \sqcup \{l : \mathsf{A}\} \vdash \mathbb{H} \sqcup \{l \triangleleft \mathsf{v}\}} \quad \textsc{TyHeap\_Val}$$

$\boxed{\Phi \,;\, \Psi \,;\, \mho \,;\, \Gamma \vdash \mathsf{t} : \mathsf{A}}$ t is a well-typed term of type A given heap typing context Φ, unrestricted typing cont

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

$$\frac{l \notin \mathsf{names}(\Phi)}{\Phi \;;\; \{l : \mathsf{A}\} \;;\; \mho \;;\; \emptyset \vdash \lfloor l \rfloor : \lfloor \mathsf{A} \rfloor} \quad \textsc{TyTerm\_LDest}$$

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

$$\frac{\mathsf{C} : \bar{\mathsf{A}} \stackrel{\mathsf{c}}{\rightharpoonup} \mathsf{A}}{\Phi \sqcup \{\bar{l} : \bar{\mathsf{A}}\} \;;\; \emptyset \;;\; \mho \;;\; \emptyset \vdash \mathsf{C}\bar{l} : \mathsf{A}} \quad \textsc{TyTerm\_HeapVal}$$

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

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

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

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

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

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

$$\frac{\begin{array}{l}\Phi \;;\; \Psi_1 \;;\; \mho \;;\; \Gamma_1 \vdash \mathsf{t} : \mathsf{A}_1 \oplus \mathsf{A}_2 \\ \Phi \;;\; \Psi_2 \;;\; \mho \;;\; \Gamma_2 \sqcup \{\mathsf{x}_1 : \mathsf{A}_1\} \vdash \mathsf{u}_1 : \mathsf{B} \\ \Phi \;;\; \Psi_2 \;;\; \mho \;;\; \Gamma_2 \sqcup \{\mathsf{x}_2 : \mathsf{A}_2\} \vdash \mathsf{u}_2 : \mathsf{B} \\ \mathsf{names}(\Gamma_1) \cap \mathsf{names}(\Gamma_2) = \emptyset \\ \mathsf{names}(\Psi_1) \cap \mathsf{names}(\Psi_2) = \emptyset\end{array}}{\Phi \;;\; \Psi_1 \sqcup \Psi_2 \;;\; \mho \;;\; \Gamma_1 \sqcup \Gamma_2 \vdash \mathsf{case}\,\mathsf{t}\,\mathsf{of}\,\{1.\mathsf{x}_1 \mapsto \mathsf{u}_1, 2.\mathsf{x}_2 \mapsto \mathsf{u}_2\} : \mathsf{B}} \quad \textsc{TyTerm\_PatS}$$

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

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

$$\frac{\Phi\ ;\ \Psi\ ;\ \mho\ ;\ \Gamma \sqcup \{d : \lfloor A \rfloor\} \vdash t : \bot}{\Phi\ ;\ \Psi\ ;\ \mho\ ;\ \Gamma \vdash \mathsf{alloc}_{A}\ d\,.\,t : A}\ \textsc{TyTerm\_Alloc}$$

$$\frac{\Phi\ ;\ \Psi\ ;\ \mho\ ;\ \Gamma \vdash t : \lfloor 1 \rfloor}{\Phi\ ;\ \Psi\ ;\ \mho\ ;\ \Gamma \vdash t \triangleleft () : \bot}\ \textsc{TyTerm\_FillU}$$

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

$$\frac{\begin{array}{l}\Phi\ ;\ \Psi_1\ ;\ \mho\ ;\ \Gamma \vdash t : \lfloor !A \rfloor \\ \Phi\ ;\ \emptyset\ ;\ \mho\ ;\ \emptyset \vdash u : A\end{array}}{\Phi\ ;\ \Psi_1\ ;\ \mho\ ;\ \Gamma \vdash t \triangleleft \mathsf{Ur}\ u : \bot}\ \textsc{TyTerm\_FillE}$$

$$\frac{\begin{array}{l}\Phi\ ;\ \Psi_1\ ;\ \mho\ ;\ \Gamma_1 \vdash t : \lfloor A_1 \oplus A_2 \rfloor \\ \Phi\ ;\ \Psi_2\ ;\ \mho\ ;\ \Gamma_2 \sqcup \{d' : \lfloor A_1 \rfloor\} \vdash u : B \\ \mathsf{names}\,(\Gamma_1) \cap \mathsf{names}\,(\Gamma_2) = \emptyset \\ \mathsf{names}\,(\Psi_1) \cap \mathsf{names}\,(\Psi_2) = \emptyset\end{array}}{\Phi\ ;\ \Psi_1 \sqcup \Psi_2\ ;\ \mho\ ;\ \Gamma_1 \sqcup \Gamma_2 \vdash t \triangleleft 1.d'\,.\,u : B}\ \textsc{TyTerm\_FillV1}$$

$$\frac{\begin{array}{l}\Phi\ ;\ \Psi_1\ ;\ \mho\ ;\ \Gamma_1 \vdash t : \lfloor A_1 \oplus A_2 \rfloor \\ \Phi\ ;\ \Psi_2\ ;\ \mho\ ;\ \Gamma_2 \sqcup \{d' : \lfloor A_2 \rfloor\} \vdash u : B \\ \mathsf{names}\,(\Gamma_1) \cap \mathsf{names}\,(\Gamma_2) = \emptyset \\ \mathsf{names}\,(\Psi_1) \cap \mathsf{names}\,(\Psi_2) = \emptyset\end{array}}{\Phi\ ;\ \Psi_1 \sqcup \Psi_2\ ;\ \mho\ ;\ \Gamma \vdash t \triangleleft 2.d'\,.\,u : B}\ \textsc{TyTerm\_FillV2}$$

$$\frac{\begin{array}{l}\Phi\ ;\ \Psi_1\ ;\ \mho\ ;\ \Gamma_1 \vdash t : \lfloor A_1 \otimes A_2 \rfloor \\ \Phi\ ;\ \Psi_2\ ;\ \mho\ ;\ \Gamma_2 \sqcup \{d_1 : \lfloor A_1 \rfloor, d_2 : \lfloor A_2 \rfloor\} \vdash u : B \\ \mathsf{names}\,(\Gamma_1) \cap \mathsf{names}\,(\Gamma_2) = \emptyset \\ \mathsf{names}\,(\Psi_1) \cap \mathsf{names}\,(\Psi_2) = \emptyset\end{array}}{\Phi\ ;\ \Psi_1 \sqcup \Psi_2\ ;\ \mho\ ;\ \Gamma_1 \sqcup \Gamma_2 \vdash t \triangleleft \langle d_1, d_2 \rangle\,.\,u : B}\ \textsc{TyTerm\_FillP}$$

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

$\boxed{\mathsf{command} \Downarrow \mathsf{command}'}$ t reduces to t', with heap growing from H to H'

$$\frac{}{\mathbb{H}|_{L} \bullet \ \Downarrow\ \mathbb{H}|_{L} \bullet}\ \textsc{SemOp\_NoEff}\ \textit{(value)}$$

$$\frac{}{\mathbb{H}|_{L} \lfloor l \rfloor \ \Downarrow\ \mathbb{H}|_{L} \lfloor l \rfloor}\ \textsc{SemOp\_LDest}\ \textit{(value)}$$

$$\frac{}{\mathbb{H}|_{L} \lambda x{:}A\,.\,t \ \Downarrow\ \mathbb{H}|_{L} \lambda x{:}A\,.\,t}\ \textsc{SemOp\_Lam}\ \textit{(value)}$$

$$\frac{}{\mathbb{H}|_{L} C\bar{l} \ \Downarrow\ \mathbb{H}|_{L} C\bar{l}}\ \textsc{SemOp\_HeapVal}\ \textit{(value)}$$

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

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

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

$$\dfrac{\begin{array}{c}\mathbb{H}_0 \mid_{L_0} \mathsf{t} \Downarrow \mathbb{H}_1 \sqcup \{l \triangleleft \mathsf{v}_1\} \mid_{L_1} 1.l \\ \mathbb{H}_1 \sqcup \{l \triangleleft \mathsf{v}_1\} \mid_{L_1} \mathsf{u}_1[\mathsf{x}_1 := \mathsf{v}] \Downarrow \mathbb{H}_2 \mid_{L_2} \mathsf{v}_2\end{array}}{\mathbb{H}_0 \mid_{L_0} \mathsf{case}\;\mathsf{t}\;\mathsf{of}\;\{1.\mathsf{x}_1 \mapsto \mathsf{u}_1, 2.\mathsf{x}_2 \mapsto \mathsf{u}_2\} \Downarrow \mathbb{H}_2 \mid_{L_2} \mathsf{v}_2}\ \textsc{SemOp\_PatV1}$$

$$\dfrac{\begin{array}{c}\mathbb{H}_0 \mid_{L_0} \mathsf{t} \Downarrow \mathbb{H}_1 \sqcup \{l \triangleleft \mathsf{v}_1\} \mid_{L_1} 2.l \\ \mathbb{H}_1 \sqcup \{l \triangleleft \mathsf{v}_1\} \mid_{L_1} \mathsf{u}_2[\mathsf{x}_2 := \mathsf{v}] \Downarrow \mathbb{H}_2 \mid_{L_2} \mathsf{v}_2\end{array}}{\mathbb{H}_0 \mid_{L_0} \mathsf{case}\;\mathsf{t}\;\mathsf{of}\;\{1.\mathsf{x}_1 \mapsto \mathsf{u}_1, 2.\mathsf{x}_2 \mapsto \mathsf{u}_2\} \Downarrow \mathbb{H}_2 \mid_{L_2} \mathsf{v}_2}\ \textsc{SemOp\_PatV2}$$

$$\dfrac{\begin{array}{c}\mathbb{H}_0 \mid_{L_0} \mathsf{t} \Downarrow \mathbb{H}_1 \sqcup \{l_1 \triangleleft \mathsf{v}_{11}, l_2 \triangleleft \mathsf{v}_{12}\} \mid_{L_1} \langle l_1, l_2\rangle \\ \mathbb{H}_1 \sqcup \{l_1 \triangleleft \mathsf{v}_{11}, l_2 \triangleleft \mathsf{v}_{12}\} \mid_{L_1} \mathsf{u}[\mathsf{x}_1 := \mathsf{v}_1, \mathsf{x}_2 := \mathsf{v}_2] \Downarrow \mathbb{H}_2 \mid_{L_2} \mathsf{v}_2\end{array}}{\mathbb{H}_0 \mid_{L_0} \mathsf{case}\;\mathsf{t}\;\mathsf{of}\;\{\langle \mathsf{x}_1, \mathsf{x}_2\rangle \mapsto \mathsf{u}\} \Downarrow \mathbb{H}_2 \mid_{L_2} \mathsf{v}_2}\ \textsc{SemOp\_PatP}$$

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

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

$$\dfrac{\begin{array}{l}l \notin L_0 \\ \mathbb{H}_0 \mid_{L_0 \sqcup \{l\}} \mathsf{t}[\mathsf{d} := \lfloor l \rfloor] \Downarrow \mathbb{H}_1 \sqcup \{l \triangleleft \mathsf{v}_1\} \mid_{L_1} \bullet\end{array}}{\mathbb{H}_0 \mid_{L_0} \mathsf{alloc}_{\mathsf{A}}\;\mathsf{d}\,.\,\mathsf{t} \Downarrow \mathbb{H}_1 \sqcup \{l \triangleleft \mathsf{v}_1\} \mid_{L_1} \mathsf{v}_1}\ \textsc{SemOp\_Alloc}$$

$$\frac{\mathbb{H}_0 \mid_{L_0} \mathsf{t} \Downarrow \mathbb{H}_1 \mid_{L_1} \lfloor l \rfloor}{\mathbb{H}_0 \mid_{L_0} \mathsf{t} \triangleleft () \Downarrow \mathbb{H}_1 \sqcup \{ l \triangleleft () \} \mid_{L_1} \bullet} \quad \textsc{SemOp\_FillU}$$

$$\frac{\begin{array}{c}\mathbb{H}_0 \mid_{L_0} \mathsf{t} \Downarrow \mathbb{H}_1 \mid_{L_1} \lfloor l \rfloor \\ \mathbb{H}_1 \mid_{L_1} \mathsf{u} \Downarrow \mathbb{H}_2 \mid_{L_2} \mathsf{v}_2\end{array}}{\mathbb{H}_0 \mid_{L_0} \mathsf{t} \triangleleft \mathsf{u} \Downarrow \mathbb{H}_2 \sqcup \{ l \triangleleft \mathsf{v}_2 \} \mid_{L_2} \bullet} \quad \textsc{SemOp\_FillL}$$

$$\frac{\begin{array}{c}\mathbb{H}_0 \mid_{L_0} \mathsf{t} \Downarrow \mathbb{H}_1 \mid_{L_1} \lfloor l \rfloor \\ \mathbb{H}_1 \mid_{L_1} \mathsf{u} \Downarrow \mathbb{H}_2 \mid_{L_2} \mathsf{v}_2\end{array}}{\mathbb{H}_0 \mid_{L_0} \mathsf{t} \triangleleft \mathsf{Ur}\ \mathsf{u} \Downarrow \mathbb{H}_2 \sqcup \{ l \triangleleft \mathsf{Ur}\ l', l' \triangleleft \mathsf{v}_2 \} \mid_{L_2} \bullet} \quad \textsc{SemOp\_FillE}$$

$$\frac{\begin{array}{l} l' \notin L_1 \\ \mathbb{H}_0 \mid_{L_0} \mathsf{t} \Downarrow \mathbb{H}_1 \mid_{L_1} \lfloor l \rfloor \\ \mathbb{H}_1 \mid_{L_1 \sqcup \{l'\}} \mathsf{u}[\mathsf{d} := \lfloor l' \rfloor] \Downarrow \mathbb{H}_2 \sqcup \{ l' \triangleleft \mathsf{v}_1 \} \mid_{L_2} \mathsf{v}_2\end{array}}{\mathbb{H}_0 \mid_{L_0} \mathsf{t} \triangleleft 1.\mathsf{d}\,.\,\mathsf{u} \Downarrow \mathbb{H}_2 \sqcup \{ l \triangleleft 1.l', l' \triangleleft \mathsf{v}_1 \} \mid_{L_2} \mathsf{v}_2} \quad \textsc{SemOp\_FillV1}$$

$$\frac{\begin{array}{l} l' \notin L_1 \\ \mathbb{H}_0 \mid_{L_0} \mathsf{t} \Downarrow \mathbb{H}_1 \mid_{L_1} \lfloor l \rfloor \\ \mathbb{H}_1 \mid_{L_1 \sqcup \{l'\}} \mathsf{u}[\mathsf{d} := \lfloor l' \rfloor] \Downarrow \mathbb{H}_2 \sqcup \{ l' \triangleleft \mathsf{v}_1 \} \mid_{L_2} \mathsf{v}_2\end{array}}{\mathbb{H}_0 \mid_{L_0} \mathsf{t} \triangleleft 2.\mathsf{d}\,.\,\mathsf{u} \Downarrow \mathbb{H}_2 \sqcup \{ l \triangleleft 2.l', l' \triangleleft \mathsf{v}_1 \} \mid_{L_2} \mathsf{v}_2} \quad \textsc{SemOp\_FillV2}$$

$$\frac{\begin{array}{l} l_1 \notin L_1 \\ l_1 \notin L_1 \\ \mathbb{H}_0 \mid_{L_0} \mathsf{t} \Downarrow \mathbb{H}_1 \mid_{L_1} \lfloor l \rfloor \\ \mathbb{H}_1 \mid_{L_1 \sqcup \{l_1, l_2\}} \mathsf{u}[\mathsf{d}_1 := \lfloor l_1 \rfloor, \mathsf{d}_2 := \lfloor l_2 \rfloor] \Downarrow \mathbb{H}_2 \sqcup \{ l_1 \triangleleft \mathsf{v}_{11}, l_2 \triangleleft \mathsf{v}_{12} \} \mid_{L_2} \mathsf{v}_2\end{array}}{\mathbb{H}_0 \mid_{L_0} \mathsf{t} \triangleleft \langle \mathsf{d}_1, \mathsf{d}_2 \rangle\,.\,\mathsf{u} \Downarrow \mathbb{H}_2 \sqcup \{ l \triangleleft \langle l_1, l_2 \rangle, l_1 \triangleleft \mathsf{v}_{11}, l_2 \triangleleft \mathsf{v}_{12} \} \mid_{L_2} \mathsf{v}_2} \quad \textsc{SemOp\_FillP}$$

$$\frac{\begin{array}{l} l' \notin L_1 \\ \mathbb{H}_0 \mid_{L_0} \mathsf{t} \Downarrow \mathbb{H}_1 \mid_{L_1} \lfloor l \rfloor \\ \mathbb{H}_1 \mid_{L_1 \sqcup \{l'\}} \mathsf{u}[\mathsf{d} := \lfloor l' \rfloor] \Downarrow \mathbb{H}_2 \sqcup \{ l' \triangleleft \mathsf{v}_1 \} \mid_{L_2} \mathsf{v}_2\end{array}}{\mathbb{H}_0 \mid_{L_0} \mathsf{t} \triangleleft \mathsf{roll}_{\mathsf{R}}\ \mathsf{d}\,.\,\mathsf{u} \Downarrow \mathbb{H}_2 \sqcup \{ l \triangleleft \mathsf{roll}_{\mathsf{R}}\ l', l' \triangleleft \mathsf{v}_1 \} \mid_{L_2} \mathsf{v}_2} \quad \textsc{SemOp\_FillR}$$

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Definition rules:        50 good    0 bad
Definition rule clauses: 151 good    0 bad
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