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 $\{1.x_1 \mapsto u_1, 2.x_2 \mapsto u_2\}$	pattern-matching on sum
	|	case t of $\{\langle x_1, x_2 \rangle \mapsto u\}$	pattern-matching on product
	|	case t of $\{$roll$_R$ $x \mapsto u\}$	unroll for recursive types
	|	alloc$_A$ d . t	allocate data
	|	t ◁ ()	fill destination with unit
	|	t ◁ u	fill terminal-type destination
	|	t ◁ Ur u	fill destination with exponential
	|	t ◁ 1.d . u	fill sum-type destination with variant 1
	|	t ◁ 2.d . u	fill sum-type destination with variant 2
	|	t ◁ $\langle d_1, d_2 \rangle$. u	fill product-type destination
	|	t ◁ 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	
	|	$\langle l_1, l_2 \rangle$	
	|	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
	|	λ x:A . t	lambda abstraction
	|	h	heap value

label, l	::=		memory address

labels	::=		
	|	l	
	|	l, labels	
	|	$\bar{l}$	M

| $\bar{l}$, labels   M

label_set, L ::=   set of used labels
| $\emptyset$
| {labels}
| $L_1 \sqcup L_2$
| (L) S

heap_affect, ha   ::=   heap cell
| $l \triangleleft v$
| $\bar{l} \triangleleft \bar{v}$ 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   ::=
| $\bot$ bottom type
| 1   unit type
| R   recursive type bound to a name
| $A \otimes B$ product type
| $A \oplus B$ sum type
| $A \multimap B$ linear function type
| $\lfloor A \rfloor$ destination type
| !A   exponential
| (A)   S
| $W[r := A]$ M

type_with_hole, W   ::=
| $\bot$ bottom type
| r   type hole in recursive definition
| 1   unit type
| R   recursive type bound to a name
| $W_1 \otimes W_2$ product type
| $W_1 \oplus W_2$ sum type
| $W_1 \multimap W_2$ linear function type
| $\lfloor W \rfloor$ destination type
| !W   exponential
| (W)   S

rec_type_bound, R   ::=   recursive type bound to a name

rec_type_def   ::=
| $\mu \, r \, . \, W$

type_affect, ta	::=		type affectation
	$\vert$	$\mathsf{x} : \mathsf{A}$	var
	$\vert$	$l : \mathsf{A}$	label
	$\vert$	$\bar{l} : \bar{\mathsf{A}}$	generic for multiple occurences

type_affects	::=		type affectations
	$\vert$	ta	
	$\vert$	$\mathsf{ta}, \mathsf{type\_affects}$	

typing_context, Γ, $\mho$, Φ, Ψ	::=		typing context
	$\vert$	$\emptyset$	
	$\vert$	$\{\mathsf{type\_affects}\}$	
	$\vert$	$\Gamma_1 \sqcup \Gamma_2$	

types, $\bar{\mathsf{A}}$	::=		
	$\vert$	$\cdot$	empty type list
	$\vert$	A	
	$\vert$	$\mathsf{A} \;\; \mathsf{types}$	

| command | ::= | |
| | $\vert$ | $\mathbb{H} \underset{L}{\Diamond} \mathsf{t}$ |

heap_constructor, C	::=	
	$\vert$	$\{()\}$
	$\vert$	$\{\, \mathsf{Ur} \,\}$
	$\vert$	$\{1.\}$
	$\vert$	$\{2.\}$
	$\vert$	$\{\langle , \rangle\}$
	$\vert$	$\{\, \mathsf{roll}\,\mathsf{R}\}$

judg	::=	
	$\vert$	$l \in \mathsf{names}\,(\Phi)$
	$\vert$	$l \notin \mathsf{names}\,(\Phi)$
	$\vert$	$\mathsf{type\_affect} \in \Gamma$
	$\vert$	$\mathsf{names}\,(\Gamma) \cap \mathsf{names}\,(\mathsf{D}) = \emptyset$
	$\vert$	$\mathsf{names}\,(\Phi) \sqcup \mathsf{names}\,(\Psi) \subset L$
	$\vert$	$l \in L$
	$\vert$	$l \notin L$
	$\vert$	$\mathsf{heap\_affect} \in \mathbb{H}$
	$\vert$	$\mathsf{A} = \mathsf{B}$
	$\vert$	$\mathsf{t} = \mathsf{u}$
	$\vert$	$\Gamma = \mathsf{D}$
	$\vert$	$\mathsf{R} \overset{\mathsf{fix}}{=} \mathsf{rec\_type\_def}$
	$\vert$	$\mathsf{C} : \bar{\mathsf{A}} \overset{\mathsf{c}}{\rightharpoondown} \mathsf{A}$
	$\vert$	$\Phi \,;\, \Psi \,;\, \mho \,;\, \Gamma \vdash \mathsf{command} : \mathsf{A}$
	$\vert$	$\Phi \,;\, \Psi \vdash \mathbb{H}$
	$\vert$	$\Phi \,;\, \Psi \,;\, \mho \,;\, \Gamma \vdash \mathsf{t} : \mathsf{A}$
	$\vert$	$\mathsf{command} \;\; \Downarrow \;\; \mathsf{command}'$

terminals ::=
| ()
| ↦
| ⋆
| ⊛
| ⊕
| ⊸
| :=
| ⊢
| ⊔
| ;
| ∩
| ∅
| ⟶
| ▷
| ≠
| ∈
| ∉
| \n
| ⟨
| ⟩
| 1.
| 2.
| Ur
| ◁
| |
| ⊘
| $\stackrel{c}{\llcorner}$
| =
| ⟹
| ...
| $\stackrel{\text{fix}}{=}$
| ⊥
| •
| ⊂

formula ::=
| judgement

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

LabelSet ::=
| $\mathsf{names}\,(\Phi) \sqcup \mathsf{names}\,(\Psi) \subset L$
| $l \in L$
| $l = \mathsf{fresh}(\mathbb{L} \setminus L)$

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Heap	::=		
	|	heap_affect $\in \mathbb{H}$	

Eq	::=	
	|	$A = B$
	|	$t = u$
	|	$\Gamma = D$

Ty	::=		
	|	$R \overset{\text{fix}}{=}$ rec_type_def	
	|	$C : \bar{A} \overset{c}{\multimap} A$	Heap constructor C builds a value of type A given a
	|	$\Phi \;;\; \Psi \;;\; \mho \;;\; \Gamma \vdash$ command $: A$	
	|	$\Phi \;;\; \Psi \vdash \mathbb{H}$	$\mathbb{H}$ is a well-typed heap given heap typing context Φ
	|	$\Phi \;;\; \Psi \;;\; \mho \;;\; \Gamma \vdash t : A$	t is a well-typed term of type A given heap typing c

Sem	::=	
	|	command $\Downarrow$ command$'$

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

$$\quad\quad | \quad \mathsf{terminals}$$

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

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

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

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

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

$\boxed{l \in L}$

$\boxed{l = \mathsf{fresh}(\mathbb{L} \setminus L)}$

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

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

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

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

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

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

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

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

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

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

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

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

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

$$\frac{\begin{array}{c} \mathsf{names}\,(\Phi) \sqcup \mathsf{names}\,(\Psi) \subset L \\ \Phi \ ; \ \Psi \vdash \mathbb{H} \\ \Phi \ ; \ \Psi \ ; \ \mho \ ; \ \Gamma \vdash \mathsf{t} : \mathsf{A} \end{array}}{\Phi \ ; \ \Psi \ ; \ \mho \ ; \ \Gamma \vdash \mathbb{H} \underset{L}{\diamondsuit} \mathsf{t} : \mathsf{A}} \quad \text{TyCommand\_Def}$$

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

$$\frac{}{\emptyset \ ; \ \Psi \vdash \emptyset} \quad \text{TyHeap\_Empty}$$

$$\frac{\begin{array}{c} \Phi \ ; \ \Psi \vdash \mathbb{H} \\ \Phi \ ; \ \Psi \ ; \ \emptyset \ ; \ \emptyset \vdash \mathsf{v} : \mathsf{A} \end{array}}{\Phi \sqcup \{l : \mathsf{A}\} \ ; \ \Psi \vdash \mathbb{H} \sqcup \{l \triangleleft \mathsf{v}\}} \quad \text{TyHeap\_Val}$$

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

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

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$$\frac{l \notin \mathsf{names}\,(\Phi)}{\Phi \,;\, \{l : A\} \,;\, \mho \,;\, \emptyset \vdash \lfloor l \rfloor : \lfloor A \rfloor} \quad \text{TYTERM\_LDEST}$$

$$\frac{\Phi \,;\, \Psi \,;\, \mho \,;\, \Gamma \sqcup \{x : A\} \vdash t : B}{\Phi \,;\, \Psi \,;\, \mho \,;\, \Gamma \vdash \lambda x{:}A.t : A \multimap B} \quad \text{TYTERM\_LAM}$$

$$\frac{C : \bar{A} \overset{c}{\multimap} A}{\Phi \sqcup \{\bar{l} : \bar{A}\} \,;\, \emptyset \,;\, \mho \,;\, \emptyset \vdash C\bar{l} : A} \quad \text{TYTERM\_HEAPVAL}$$

$$\frac{}{\Phi \,;\, \emptyset \,;\, \mho \,;\, \{x : A\} \vdash x : A} \quad \text{TYTERM\_ID}$$

$$\frac{}{\Phi \,;\, \emptyset \,;\, \mho \sqcup \{x : A\} \,;\, \emptyset \vdash x : A} \quad \text{TYTERM\_ID'}$$

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

$$\frac{\begin{array}{c} \Phi \,;\, \Psi_1 \,;\, \mho \,;\, \Gamma_1 \vdash t : \bot \\ \Phi \,;\, \Psi_2 \,;\, \mho \,;\, \Gamma_2 \vdash u : B \\ \mathsf{names}\,(\Gamma_1) \cap \mathsf{names}\,(\Gamma_2) = \emptyset \\ \mathsf{names}\,(\Psi_1) \cap \mathsf{names}\,(\Psi_2) = \emptyset \end{array}}{\Phi \,;\, \Psi_1 \sqcup \Psi_2 \,;\, \mho \,;\, \Gamma_1 \sqcup \Gamma_2 \vdash t \,;\, u : B} \quad \text{TYTERM\_WITHEFF}$$

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

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

$$\frac{\begin{array}{c} \Phi \,;\, \Psi_1 \,;\, \mho \,;\, \Gamma_1 \vdash t : A_1 \oplus A_2 \\ \Phi \,;\, \Psi_2 \,;\, \mho \,;\, \Gamma_2 \sqcup \{x_1 : A_1\} \vdash u_1 : B \\ \Phi \,;\, \Psi_2 \,;\, \mho \,;\, \Gamma_2 \sqcup \{x_2 : A_2\} \vdash u_2 : B \\ \mathsf{names}\,(\Gamma_1) \cap \mathsf{names}\,(\Gamma_2) = \emptyset \\ \mathsf{names}\,(\Psi_1) \cap \mathsf{names}\,(\Psi_2) = \emptyset \end{array}}{\Phi \,;\, \Psi_1 \sqcup \Psi_2 \,;\, \mho \,;\, \Gamma_1 \sqcup \Gamma_2 \vdash \mathsf{case}\,t\,\mathsf{of}\,\{1.x_1 \mapsto u_1, 2.x_2 \mapsto u_2\} : B} \quad \text{TYTERM\_PATS}$$

$$\frac{\begin{array}{c} \Phi \,;\, \Psi_1 \,;\, \mho \,;\, \Gamma_1 \vdash t : A_1 \otimes A_2 \\ \Phi \,;\, \Psi_2 \,;\, \mho \,;\, \Gamma_2 \sqcup \{x_1 : A_1, x_2 : A_2\} \vdash u : B \\ \mathsf{names}\,(\Gamma_1) \cap \mathsf{names}\,(\Gamma_2) = \emptyset \\ \mathsf{names}\,(\Psi_1) \cap \mathsf{names}\,(\Psi_2) = \emptyset \end{array}}{\Phi \,;\, \Psi_1 \sqcup \Psi_2 \,;\, \mho \,;\, \Gamma_1 \sqcup \Gamma_2 \vdash \mathsf{case}\,t\,\mathsf{of}\,\{\langle x_1, x_2 \rangle \mapsto u\} : B} \quad \text{TYTERM\_PATP}$$

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

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

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

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

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

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

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

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

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

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

$$\frac{}{\mathbb{H} \diamondsuit_L \bullet \quad \Downarrow \quad \mathbb{H} \diamondsuit_L \bullet} \quad \text{SemOp\_NoEff} \; \textit{(value)}$$

$$\frac{}{\mathbb{H} \diamondsuit_L \lfloor l \rfloor \quad \Downarrow \quad \mathbb{H} \diamondsuit_L \lfloor l \rfloor} \quad \text{SemOp\_LDest} \; \textit{(value)}$$

$$\frac{}{\mathbb{H} \diamondsuit_L \lambda x{:}A.t \quad \Downarrow \quad \mathbb{H} \diamondsuit_L \lambda x{:}A.t} \quad \text{SemOp\_Lam} \; \textit{(value)}$$

$$\frac{}{\mathbb{H} \diamondsuit_L \mathsf{C}\bar{l} \quad \Downarrow \quad \mathbb{H} \diamondsuit_L \mathsf{C}\bar{l}} \quad \text{SemOp\_HeapVal} \; \textit{(value)}$$

$$\frac{\mathbb{H}_0 \underset{L_0}{\diamondsuit} t \;\Downarrow\; \mathbb{H}_1 \underset{L_1}{\diamondsuit} \lambda x{:}A.\,t' \qquad \mathbb{H}_1 \underset{L_1}{\diamondsuit} u \;\Downarrow\; \mathbb{H}_2 \underset{L_2}{\diamondsuit} v_2 \qquad \mathbb{H}_2 \underset{L_2}{\diamondsuit} t'[x := v_2] \;\Downarrow\; \mathbb{H}_3 \underset{L_3}{\diamondsuit} v_3}{\mathbb{H}_0 \underset{L_0}{\diamondsuit} t\,u \;\Downarrow\; \mathbb{H}_3 \underset{L_3}{\diamondsuit} v_3} \;\; \textsc{SemOp\_App}$$

$$\frac{\mathbb{H}_0 \underset{L_0}{\diamondsuit} t \;\Downarrow\; \mathbb{H}_1 \underset{L_1}{\diamondsuit} () \qquad \mathbb{H}_1 \underset{L_1}{\diamondsuit} u \;\Downarrow\; \mathbb{H}_2 \underset{L_2}{\diamondsuit} v_2}{\mathbb{H}_0 \underset{L_0}{\diamondsuit} \mathsf{case}\,t\,\mathsf{of}\,\{() \mapsto u\} \;\Downarrow\; \mathbb{H}_2 \underset{L_2}{\diamondsuit} v_2} \;\; \textsc{SemOp\_PatU}$$

$$\frac{\mathbb{H}_0 \underset{L_0}{\diamondsuit} t \;\Downarrow\; \mathbb{H}_1 \sqcup \{l \triangleleft v_1\} \underset{L_1}{\diamondsuit} \mathsf{Ur}\,l \qquad \mathbb{H}_1 \sqcup \{l \triangleleft v_1\} \underset{L_1}{\diamondsuit} u[x := v_1] \;\Downarrow\; \mathbb{H}_2 \underset{L_2}{\diamondsuit} v_2}{\mathbb{H}_0 \underset{L_0}{\diamondsuit} \mathsf{case}\,t\,\mathsf{of}\,\{\mathsf{Ur}\,x \mapsto u\} \;\Downarrow\; \mathbb{H}_2 \underset{L_2}{\diamondsuit} v_2} \;\; \textsc{SemOp\_PatE}$$

$$\frac{\mathbb{H}_0 \underset{L_0}{\diamondsuit} t \;\Downarrow\; \mathbb{H}_1 \sqcup \{l \triangleleft v_1\} \underset{L_1}{\diamondsuit} 1.l \qquad \mathbb{H}_1 \sqcup \{l \triangleleft v_1\} \underset{L_1}{\diamondsuit} u_1[x_1 := v] \;\Downarrow\; \mathbb{H}_2 \underset{L_2}{\diamondsuit} v_2}{\mathbb{H}_0 \underset{L_0}{\diamondsuit} \mathsf{case}\,t\,\mathsf{of}\,\{1.x_1 \mapsto u_1, 2.x_2 \mapsto u_2\} \;\Downarrow\; \mathbb{H}_2 \underset{L_2}{\diamondsuit} v_2} \;\; \textsc{SemOp\_PatV1}$$

$$\frac{\mathbb{H}_0 \underset{L_0}{\diamondsuit} t \;\Downarrow\; \mathbb{H}_1 \sqcup \{l \triangleleft v_1\} \underset{L_1}{\diamondsuit} 2.l \qquad \mathbb{H}_1 \sqcup \{l \triangleleft v_1\} \underset{L_1}{\diamondsuit} u_2[x_2 := v] \;\Downarrow\; \mathbb{H}_2 \underset{L_2}{\diamondsuit} v_2}{\mathbb{H}_0 \underset{L_0}{\diamondsuit} \mathsf{case}\,t\,\mathsf{of}\,\{1.x_1 \mapsto u_1, 2.x_2 \mapsto u_2\} \;\Downarrow\; \mathbb{H}_2 \underset{L_2}{\diamondsuit} v_2} \;\; \textsc{SemOp\_PatV2}$$

$$\frac{\mathbb{H}_0 \underset{L_0}{\diamondsuit} t \;\Downarrow\; \mathbb{H}_1 \sqcup \{l_1 \triangleleft v_{11}, l_2 \triangleleft v_{12}\} \underset{L_1}{\diamondsuit} \langle l_1, l_2 \rangle \qquad \mathbb{H}_1 \sqcup \{l_1 \triangleleft v_{11}, l_2 \triangleleft v_{12}\} \underset{L_1}{\diamondsuit} u[x_1 := v_1, x_2 := v_2] \;\Downarrow\; \mathbb{H}_2 \underset{L_2}{\diamondsuit} v_2}{\mathbb{H}_0 \underset{L_0}{\diamondsuit} \mathsf{case}\,t\,\mathsf{of}\,\{\langle x_1, x_2 \rangle \mapsto u\} \;\Downarrow\; \mathbb{H}_2 \underset{L_2}{\diamondsuit} v_2} \;\; \textsc{SemOp\_PatP}$$

$$\frac{\mathbb{H}_0 \underset{L_0}{\diamondsuit} t \;\Downarrow\; \mathbb{H}_1 \sqcup \{l \triangleleft v_1\} \underset{L_1}{\diamondsuit} \underset{R}{\mathsf{roll}}\,l \qquad \mathbb{H}_1 \sqcup \{l \triangleleft v_1\} \underset{L_1}{\diamondsuit} u[x := v_1] \;\Downarrow\; \mathbb{H}_2 \underset{L_2}{\diamondsuit} v_2}{\mathbb{H}_0 \underset{L_0}{\diamondsuit} \mathsf{case}\,t\,\mathsf{of}\,\{\underset{R}{\mathsf{roll}}\,x \mapsto u\} \;\Downarrow\; \mathbb{H}_2 \underset{L_2}{\diamondsuit} v_2} \;\; \textsc{SemOp\_PatR}$$

$$\frac{\mathbb{H}_0 \underset{L_0}{\diamondsuit} t \;\Downarrow\; \mathbb{H}_1 \underset{L_1}{\diamondsuit} \bullet \qquad \mathbb{H}_1 \underset{L_1}{\diamondsuit} u \;\Downarrow\; \mathbb{H}_2 \underset{L_2}{\diamondsuit} v_2}{\mathbb{H}_0 \underset{L_0}{\diamondsuit} t\,;\,u \;\Downarrow\; \mathbb{H}_2 \underset{L_2}{\diamondsuit} v_2} \;\; \textsc{SemOp\_WithEff}$$

$$\frac{l = \mathsf{fresh}(\mathbb{L} \setminus L_0) \qquad \mathbb{H}_0 \underset{L_0 \sqcup \{l\}}{\diamondsuit} t[d := \lfloor l \rfloor] \;\Downarrow\; \mathbb{H}_1 \sqcup \{l \triangleleft v_1\} \underset{L_1}{\diamondsuit} \bullet}{\mathbb{H}_0 \underset{L_0}{\diamondsuit} \underset{A}{\mathsf{alloc}}\,d.\,t \;\Downarrow\; \mathbb{H}_1 \sqcup \{l \triangleleft v_1\} \underset{L_1}{\diamondsuit} v_1} \;\; \textsc{SemOp\_Alloc}$$

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

$$\frac{\begin{array}{c} \mathbb{H}_0 \underset{L_0}{\Diamond}\, t \;\;\Downarrow\;\; \mathbb{H}_1 \underset{L_1}{\Diamond}\, \lfloor l \rfloor \\[4pt] \mathbb{H}_1 \underset{L_1}{\Diamond}\, u \;\;\Downarrow\;\; \mathbb{H}_2 \underset{L_2}{\Diamond}\, v_2 \end{array}}{\mathbb{H}_0 \underset{L_0}{\Diamond}\, t \triangleleft u \;\;\Downarrow\;\; \mathbb{H}_2 \sqcup \{l \triangleleft v_2\} \underset{L_2}{\Diamond}\, \bullet} \;\; \textsc{SemOp\_FillL}$$

$$\frac{\begin{array}{c} \mathbb{H}_0 \underset{L_0}{\Diamond}\, t \;\;\Downarrow\;\; \mathbb{H}_1 \underset{L_1}{\Diamond}\, \lfloor l \rfloor \\[4pt] \mathbb{H}_1 \underset{L_1}{\Diamond}\, u \;\;\Downarrow\;\; \mathbb{H}_2 \underset{L_2}{\Diamond}\, v_2 \end{array}}{\mathbb{H}_0 \underset{L_0}{\Diamond}\, t \triangleleft \mathsf{Ur}\, u \;\;\Downarrow\;\; \mathbb{H}_2 \sqcup \{l \triangleleft \mathsf{Ur}\, l',\, l' \triangleleft v_2\} \underset{L_2}{\Diamond}\, \bullet} \;\; \textsc{SemOp\_FillE}$$

$$\frac{\begin{array}{c} l' = \mathsf{fresh}(\mathbb{L} \setminus L_1) \\[2pt] \mathbb{H}_0 \underset{L_0}{\Diamond}\, t \;\;\Downarrow\;\; \mathbb{H}_1 \underset{L_1}{\Diamond}\, \lfloor l \rfloor \\[4pt] \mathbb{H}_1 \underset{L_1 \sqcup \{l'\}}{\Diamond}\, u[d := \lfloor l' \rfloor] \;\;\Downarrow\;\; \mathbb{H}_2 \sqcup \{l' \triangleleft v_1\} \underset{L_2}{\Diamond}\, v_2 \end{array}}{\mathbb{H}_0 \underset{L_0}{\Diamond}\, t \triangleleft 1.d.u \;\;\Downarrow\;\; \mathbb{H}_2 \sqcup \{l \triangleleft 1.l',\, l' \triangleleft v_1\} \underset{L_2}{\Diamond}\, v_2} \;\; \textsc{SemOp\_FillV1}$$

$$\frac{\begin{array}{c} l' = \mathsf{fresh}(\mathbb{L} \setminus L_1) \\[2pt] \mathbb{H}_0 \underset{L_0}{\Diamond}\, t \;\;\Downarrow\;\; \mathbb{H}_1 \underset{L_1}{\Diamond}\, \lfloor l \rfloor \\[4pt] \mathbb{H}_1 \underset{L_1 \sqcup \{l'\}}{\Diamond}\, u[d := \lfloor l' \rfloor] \;\;\Downarrow\;\; \mathbb{H}_2 \sqcup \{l' \triangleleft v_1\} \underset{L_2}{\Diamond}\, v_2 \end{array}}{\mathbb{H}_0 \underset{L_0}{\Diamond}\, t \triangleleft 2.d.u \;\;\Downarrow\;\; \mathbb{H}_2 \sqcup \{l \triangleleft 2.l',\, l' \triangleleft v_1\} \underset{L_2}{\Diamond}\, v_2} \;\; \textsc{SemOp\_FillV2}$$

$$\frac{\begin{array}{c} l_1 = \mathsf{fresh}(\mathbb{L} \setminus L_1) \\[2pt] l_2 = \mathsf{fresh}(\mathbb{L} \setminus (L_1 \sqcup \{l_1\})) \\[2pt] \mathbb{H}_0 \underset{L_0}{\Diamond}\, t \;\;\Downarrow\;\; \mathbb{H}_1 \underset{L_1}{\Diamond}\, \lfloor l \rfloor \\[4pt] \mathbb{H}_1 \underset{L_1 \sqcup \{l_1, l_2\}}{\Diamond}\, u[d_1 := \lfloor l_1 \rfloor,\, d_2 := \lfloor l_2 \rfloor] \;\;\Downarrow\;\; \mathbb{H}_2 \sqcup \{l_1 \triangleleft v_{11},\, l_2 \triangleleft v_{12}\} \underset{L_2}{\Diamond}\, v_2 \end{array}}{\mathbb{H}_0 \underset{L_0}{\Diamond}\, t \triangleleft \langle d_1, d_2 \rangle.u \;\;\Downarrow\;\; \mathbb{H}_2 \sqcup \{l \triangleleft \langle l_1, l_2 \rangle,\, l_1 \triangleleft v_{11},\, l_2 \triangleleft v_{12}\} \underset{L_2}{\Diamond}\, v_2} \;\; \textsc{SemOp\_FillP}$$

$$\frac{\begin{array}{c} l' = \mathsf{fresh}(\mathbb{L} \setminus L_1) \\[2pt] \mathbb{H}_0 \underset{L_0}{\Diamond}\, t \;\;\Downarrow\;\; \mathbb{H}_1 \underset{L_1}{\Diamond}\, \lfloor l \rfloor \\[4pt] \mathbb{H}_1 \underset{L_1 \sqcup \{l'\}}{\Diamond}\, u[d := \lfloor l' \rfloor] \;\;\Downarrow\;\; \mathbb{H}_2 \sqcup \{l' \triangleleft v_1\} \underset{L_2}{\Diamond}\, v_2 \end{array}}{\mathbb{H}_0 \underset{L_0}{\Diamond}\, t \triangleleft \underset{\mathsf{R}}{\mathsf{roll}}\, d.u \;\;\Downarrow\;\; \mathbb{H}_2 \sqcup \{l \triangleleft \underset{\mathsf{R}}{\mathsf{roll}}\, l',\, l' \triangleleft v_1\} \underset{L_2}{\Diamond}\, v_2} \;\; \textsc{SemOp\_FillR}$$

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