$termvar$, x term variable

$index$, i, j, k, n, m, p, id

$$
\begin{array}{lll}
T & ::= & \\
 & | & \mathbf{bool} \\
 & | & \mathbf{int} \\
 & | & \langle T_1, .., T_n \rangle \\
 & | & T@r \\
 & | & T@(r_1, .., r_n) \\
 & | & \mathbf{coloring}\,(r) \\
 & | & \mathbf{exists}\, r_1, .., r_n.(T_1, .., T_m), \Phi, Q \rightarrow \mathbf{Tr}
\end{array}
$$

$$
\begin{array}{lll}
\mathit{flist} & ::= & \\
 & | & \{\mathit{fdef}_1, .., \mathit{fdef}_n\}
\end{array}
$$

$$
\begin{array}{lll}
\mathit{fdef} & ::= & \\
 & | & \mathbf{function}
\end{array}
$$

$$
\begin{array}{lll}
r & ::= &
\end{array}
$$

$$
\begin{array}{lll}
\Gamma & ::= & \\
 & | & \{(e_1 : T_1), .., (e_n : T_n)\} \\
 & | & \varnothing
\end{array}
$$

$$
\begin{array}{lll}
\Omega & ::= & \\
 & | & \{\omega_1, .., \omega_n\} \\
 & | & \varnothing
\end{array}
$$

$$
\begin{array}{lll}
rs & ::= & \\
 & | & \{r_1, .., r_n\} \\
 & | & \varnothing
\end{array}
$$

$$
\begin{array}{lll}
\omega & ::= & \\
 & | & r_1 \leq r_2 \\
 & | & r_1 * r_2
\end{array}
$$

$$
\begin{array}{lll}
\Phi & ::= & \\
 & | & \{\phi_1, .., \phi_n\} \\
 & | & \varnothing
\end{array}
$$

$$
\begin{array}{lll}
\phi & ::= & \\
 & | & \mathbf{reads}\,(r) \\
 & | & \mathbf{writes}\,(r) \\
 & | & \mathbf{reducesid}\,(r)
\end{array}
$$

$$
\begin{array}{lll}
Q & ::= & \\
 & | & \{q_1, .., q_n\}
\end{array}
$$

$$
\begin{array}{lll}
q & ::= & \\
 & | & \mathbf{atomic}\,(r)
\end{array}
$$

	$\mid$ **simult** (r)	
ρ	::=	
v	::=	
	$\mid$ bv	
	$\mid$ iv	
	$\mid$ $\langle v_1, v_2 \rangle$	
	$\mid$ **null**	
	$\mid$ **l**	
	$\mid$ $\langle\langle \rho_1, .., \rho_n, v \rangle\rangle$	
bv	::=	
	$\mid$ **true**	constant true
	$\mid$ **false**	constant false
iv	::=	
	$\mid$ 0	
	$\mid$ **S** iv	
e	::=	
	$\mid$ x	
	$\mid$ iv	
	$\mid$ bv	
	$\mid$ $\langle e1, .., en \rangle$	
	$\mid$ $e\ iv$	
	$\mid$ id	
	$\mid$ **new** $T@r$	
	$\mid$ **null** $T@r$	
	$\mid$ **isnull** (e)	
	$\mid$ **upregion** $(e, r1, .., rn)$	
	$\mid$ **downregion** $(e, r1, .., rn)$	
	$\mid$ **read** (e)	
	$\mid$ **write** (e_1, e_2)	
	$\mid$ **reduce** (id, e_1, e_2)	
	$\mid$ **newcolor** r	
	$\mid$ **color** (e_1, e_2, e_3)	
	$\mid$ $e_1 + e_2$	
	$\mid$ $e_1 < e_2$	
	$\mid$ **let** $id : T = e_1 \in e_2$	
	$\mid$ **if b then** $c0$ **else** $c1$	conditional
	$\mid$ $id[r_1, .., r_n](e_1, .., e_m)$	
	$\mid$ **partition** r_p **using** e_1 **as** $r_1, .., r_n \in e_2$	
	$\mid$ **pack** e_1 **as** $T[r_1, .., r_n]$	
	$\mid$ **unpack** e_1 **as** $id : T[r_1, .., r_n] \in e_2$	
	$\mid$ **function** $id[r_1, .., r_n](e_1, .., e_m)$	

formula	::=		
	| *judgement*		judgement
	| $\neg$*formula*	M	negated formula
	| (*formula*)	M	bracketed
	| $\forall_i.\phi \in \Phi$	M	for all variables in domain of G
	| $\exists_i.\phi \in \Phi$	M	for all variables in domain of G
	| $\forall_i.\omega \in \mathbf{P}$	M	for all variables in domain of G
	| $\exists_i.\omega \in \mathbf{P}$	M	for all variables in domain of G
	| $\forall_i$.*formula*	M	for all variables in domain of G
	| $\exists_i$.*formula*	M	for all variables in domain of G
	| $\Gamma(id)$		lookup
	| $formula_1 = formula_2$		equality
	| $formula_1 \wedge formula_2$		equality
	| $\bigwedge_i$.*formula*	M	for all variables in domain of G
	| $formula_1 \cap formula_2$	M	for all variables in domain of G
	| $formula_1 \cup formula_2$	M	for all variables in domain of G
	| $formula_1 \subseteq formula_2$	M	for all variables in domain of G
	| $\Gamma, \Phi, \Omega \rightarrow T$		impl
	| ϕ		
	| ω		
	| Ω		
	| Φ		
	| $\Phi[r_1/r'_1, .., r_n/r'_n]$		
	| $T[r_1/r'_1, .., r_n/r'_n]$		
	| $\Gamma[r_1/r'_1, .., r_n/r'_n]$		
	| $O[r_1/r'_1, .., r_n/r'_n]$		
	| $regions\_of(\Gamma, T)$		
	| $regions\_of(\Gamma, T1, T_2)$		
	| *rs*		

terminals	::=	
	| $\exists$	
	| $\forall$	
	| $\in$	
	| ω	
	| ϕ	
	| ρ	
	| $\vee$	
	| $\wedge$	
	| $\neg$	
	| $*$	
	| $\leq$	
	| $\longrightarrow$	
	| $\rightarrow$	
	| $\Rightarrow$	
	| λ	

	$\mapsto$
	$\vdash$
	$\varnothing$
	$\times$
	$<:$
	$\langle$
	$\rangle$
	$<$
	$\Downarrow$
	σ
	Γ
	ε

Jtype	::=		
	|	$\Gamma, \Phi, \Omega \vdash e : T$	Typing

judgement	::=	
	|	*Jtype*

user_syntax	::=	
	|	*termvar*
	|	*index*
	|	T
	|	*flist*
	|	*fdef*
	|	r
	|	Γ
	|	Ω
	|	*rs*
	|	ω
	|	Φ
	|	ϕ
	|	Q
	|	q
	|	ρ
	|	v
	|	*bv*
	|	*iv*
	|	e
	|	*formula*
	|	*terminals*

$\boxed{\Gamma, \Phi, \Omega \vdash e : T}$ Typing

$$\frac{\begin{array}{l}\Gamma, \Phi, \Omega \vdash e_1 : T@(r_1, .., r_n) \\ \forall_i . \mathbf{reads}\,(r_i) \in \Phi'\end{array}}{\Gamma, \Phi, \Omega \vdash \mathbf{read}\,(e_1) : T} \quad \text{T\_Read}$$

$$\frac{\begin{array}{l}\Gamma, \Phi, \Omega \vdash e_1 : T@(r_1, .., r_n) \\ \Gamma, \Phi, \Omega \vdash e_2 : T \\ \forall_i . \mathbf{writes}\,(r_i) \in \Phi'\end{array}}{\Gamma, \Phi, \Omega \vdash \mathbf{write}\,(e_1, e_2) : T@(r_1, .., r_n)} \quad \text{T\_Write}$$

$$\frac{\begin{array}{l}\{(e_1 : T_1), (e_2 : T_2)\}, \varnothing, \varnothing \to T \\ \Gamma, \Phi, \Omega \vdash e_1 : T@(r_1, .., r_n) \\ \Gamma, \Phi, \Omega \vdash e_2 : T \\ \forall_i . \mathbf{reducesid}\,(r_i) \in \Phi'\end{array}}{\Gamma, \Phi, \Omega \vdash \mathbf{reduce}\,(id, e_1, e_2) : T_1@(r_1, .., r_n)}\ \text{T\_Reduce}$$

$$\frac{}{\Gamma, \Phi, \Omega \vdash \mathbf{new}\ T@r : T@r}\ \text{T\_New}$$

$$\frac{\begin{array}{c}\Gamma, \Phi, \Omega \vdash e : T@(r'_1, .., r'_k) \\ \Gamma, \Phi, \Omega \vdash e : T@(r_1, .., r_n) \\ \forall_i . \exists_j . r'_i \leq r_j \in \mathbf{P}\end{array}}{\Gamma, \Phi, \Omega \vdash \mathbf{upregion}\,(e_1, r1, .., rn) : T@(r_1, .., r_n)}\ \text{T\_UpRgn}$$

$$\frac{\Gamma, \Phi, \Omega \vdash e : T@(r'_1, .., r'_k)}{\Gamma, \Phi, \Omega \vdash \mathbf{downregion}\,(e, r1, .., rn) : T@(r_1, .., r_n)}\ \text{T\_DnRgn}$$

$$\frac{}{\Gamma, \Phi, \Omega \vdash \mathbf{newcolor}\ r : T@r}\ \text{T\_NewColor}$$

$$\frac{\begin{array}{c}\Gamma, \Phi, \Omega \vdash e_1 : \mathbf{coloring}\,(r) \\ \Gamma, \Phi, \Omega \vdash e_2 : T@r \\ \Gamma, \Phi, \Omega \vdash e_3 : \mathbf{int}\end{array}}{\Gamma, \Phi, \Omega \vdash \mathbf{color}\,(e_1, e_2, e_3) : \mathbf{coloring}\,(r)}\ \text{T\_Color}$$

$$\frac{\begin{array}{l}\Gamma, \Phi, \Omega \vdash e_1 : \mathbf{coloring}\,(r_p) \\ (\Omega' = \Omega) \wedge \left((\bigwedge_i . r_i \leq r_p) \wedge \left(\bigwedge_j . r_i * r_j\right)\right) \\ \Gamma, \Phi, \Omega' \vdash e_2 : T \\ (\{r_1, .., r_k\} \cap regions\_of(\Gamma, T)) = \varnothing\end{array}}{\Gamma, \Phi, \Omega \vdash \mathbf{partition}\ r_p\ \mathbf{using}\ e_1\ \mathbf{as}\ r_1, .., r_k \in e_2 : T}\ \text{T\_Partition}$$

$$\frac{\begin{array}{l}\texttt{<<no parses (char 4): T1 =*** EX r1',..,rk'.T2 where O1 >>} \\ \texttt{<<no parses (char 3): O1[***r1/r1',..,rk/rk'] SUB O' >>} \\ \Gamma, \Phi, \Omega \vdash e_1 : \mathbf{int} \\ (\{r_1, .., r_k\} \cap regions\_of(\Gamma, T)) = \varnothing\end{array}}{\Gamma, \Phi, \Omega \vdash \mathbf{pack}\ e_1\ \mathbf{as}\ T_1[r_1, .., r_k] : T_1}\ \text{T\_Pack}$$

$$\frac{\begin{array}{l}\texttt{T1 = exists r1',..,rk'.T2 where O} \\ \Gamma, \Phi, \Omega \vdash e_1 : T_1 \\ \texttt{<<no parses (char 4): G' =*** G[T2[r1/r1',..,rk/rk'] >>} \\ \texttt{<<no parses (char 17): O' = (O UNION O1[***r1/r1',..,rk/rk']) >>} \\ \Gamma', \Phi, \Omega' \vdash e_2 : T_3 \\ (\{r_1, .., r_k\} \cap regions\_of(\Gamma, T1, T_2)) = \varnothing\end{array}}{\Gamma, \Phi, \Omega \vdash \mathbf{unpack}\ e_1\ \mathbf{as}\ id : T_1[r_1, .., r_k] \in e_2 : T_3}\ \text{T\_UnPack}$$

$$\frac{\begin{array}{l}\texttt{<<no parses (char 26): \{(e1:T1),.., (en:Tn)\},P',Q***' -> T >>} \\ \texttt{<<no parses (char 16): G,P,O |- e1 : T[***r1/r1',..,rk/rk'] >>} \\ \Phi'[r_1/r'_1, .., r_k/r'_k] \subseteq \Phi'\end{array}}{\Gamma, \Phi, \Omega \vdash id[r_1, .., r_k](e_1, .., e_n) : T}\ \text{T\_Call}$$

$$\frac{\texttt{for 1 <= i <= p, Subset O1[r1/r1',..,rk/rk'] O\_star}}{\texttt{<<no parses (char 43): G,P,O |- function id[r,..,rk](e1,..,en) : T*** >>}}\ \text{T\_Program}$$

```
Definition rules:         9 good    4 bad
Definition rule clauses: 40 good    7 bad
```