Types

TFb

$$e ::= \cdots \mid \text{Let } x:\tau = e \text{ In } e \mid \text{Function } x:\tau \to e$$

$$\tau ::= \text{Bool} \mid \text{Int} \mid \tau \to \tau$$

$$\Gamma ::= \{x:\tau, \ldots\}$$

$$\boxed{\Gamma \vdash e : \tau}$$

What are the TFb type rules for
Not e   and   If e_1 Then e_2 Else e_3

$$\frac{\Gamma \vdash e : \text{Bool}}{\Gamma \vdash \text{Not } e : \text{Bool}}$$

$$\frac{\Gamma \vdash e_1 : \text{Bool} \quad \Gamma \vdash e_2 : \tau \quad \Gamma \vdash e_3 : \tau}{\Gamma \vdash \text{If } e_1 \text{ Then } e_2 \text{ Else } e_3 : \tau}$$

If True Then 0 Else False

If $\frac{e \Rightarrow v}{\text{produce } v.}$ then running e should produce v.

If $\emptyset \vdash e : \tau$ and
    $e \Rightarrow v$ then
        $v : \tau$. $(v \in \tau)$

TFb is normalizing (if there is no Let Rec).

Normalizing: $\forall e. \exists v. e \Rightarrow v$

$\qquad\qquad \tau_1 = \tau_1 \to \tau_2 \quad \cdots \to \tau_2 \to \tau_2$

(Function a: $(\tau_2 \to \tau_2) \to a$ a) (Function a: $\to a$ a)

$\qquad$ (Function f: $(\text{Int} \to \text{Int}) \to \text{Function } x : \text{Int} \to f\ (f\ x)$))

$$0 \quad 0 \not\Rightarrow$$
$$\emptyset \vdash 0 \quad 0 : X$$

$$\frac{\cdots}{\Gamma \vdash \text{Let Rec } f\ x : \tau = e_1 \text{ In } e_2 : \tau'}$$

$$\dfrac{\dfrac{\emptyset \vdash 1:Int \quad \emptyset \vdash 2:Int}{\emptyset \vdash 1=2:Bool} \qquad \overline{\emptyset \vdash False:Bool}}{\emptyset \vdash 1=2 \ Or \ False : Bool}$$

Or $\quad \dfrac{\Gamma \vdash e_1:Bool \quad \Gamma \vdash e_2:Bool}{\Gamma \vdash e_1 \ Or \ e_2 : Bool}$

False $\quad \dfrac{}{\Gamma \vdash False:Bool}$

= $\quad \dfrac{\Gamma \vdash e_1:Int \quad \Gamma \vdash e_2:Int}{\Gamma \vdash e_1 = e_2 : Bool}$

Int $\quad \dfrac{}{\Gamma \vdash \mathbb{Z}:Int}$

TFbR

$$e ::= \cdots \mid \{l = e, \ldots\} \mid e.l$$
$$v ::= \cdots \mid \{l = v, \ldots\}$$
$$\tau ::= \cdots \mid \{l : \tau, \ldots\}$$

Do not write $\Rightarrow$ in a type rule.

$$\boxed{\{a = 5, b = True\}} : \boxed{\{a : Int, b : Bool\}}$$

$$\frac{\Gamma \vdash e_1 : \tau_1 \qquad \cdots \qquad \Gamma \vdash e_n : \tau_n}{\Gamma \vdash \{l_1 = e_1, \ldots, l_n = e_n\} : \{l_1 : \tau_1, \ldots, l_n : \tau_n\}}$$

$$\frac{\Gamma \vdash e : \{l_1 : \tau_1, \ldots, l_n : \tau_n\} \qquad l = l_k}{\Gamma \vdash e.l : \tau_k}$$

$$e : \{a : Int, b : Bool\}$$

TFbS $\langle S, e \rangle \implies \langle S, v \rangle$
                                              └─ heap only exists at runtime
             $\Gamma \vdash e : \tau$

$e ::= \cdots \mid Ref \ e \mid e := e \mid !e$

$v ::= \cdots \mid c$

$c ::=$ (infinite set of cell names)

$\tau ::= \cdots \mid Ref \ \tau$

$$\frac{\Gamma \vdash e : \tau}{\Gamma \vdash Ref \ e : Ref \ \tau} \qquad \frac{\Gamma \vdash e_1 : Ref \ \tau \quad \Gamma \vdash e_2 : \tau}{\Gamma \vdash e_1 := e_2 : \tau} \qquad \frac{\Gamma \vdash e : Ref \ \tau}{\Gamma \vdash !e : \tau}$$

"checked exceptions" $Int \xrightarrow{\# Foo \ Bool} Bool$

"unchecked exceptions" $Int \longrightarrow Bool$