$$
\begin{array}{rcll}
\text{values } v & ::= & x & \text{variable} \\
 & | & () & \text{unit} \\
 & | & n & \text{integer} \\
 & | & \texttt{Left}\ v \ \ | \ \texttt{Right}\ v & \text{sum constructors} \\
 & | & (v_1, v_2) & \text{pair} \\
 & | & \texttt{fun}\ x \mapsto c & \text{function} \\
 & | & \texttt{handler}\ (\texttt{ret}\ x \mapsto c_r ; h) & \text{handler} \\
 & & & \\
\text{computations } c & ::= & \texttt{ret}\ v & \text{returned value} \\
 & | & \texttt{match}\ v\ \texttt{with}\ (x, y) \mapsto c & \text{product match} \\
 & | & \texttt{match}\ v\ \texttt{with}\ \texttt{Left}\ x \mapsto c_1 \mid \texttt{Right}\ x \mapsto c_2 & \text{sum match} \\
 & | & v_1\ v_2 & \text{application} \\
 & | & op(v;\ y.c) & \text{operation call} \\
 & | & \texttt{let rec}\ f\ \ x = c_1\ \texttt{in}\ c_2 & \text{recursive function} \\
 & | & \texttt{do}\ x \leftarrow c_1\ \texttt{in}\ c_2 & \text{sequencing} \\
 & | & \texttt{with}\ v\ \texttt{handle}\ c & \text{handling} \\
 & & & \\
\text{operation clauses } h & ::= & \emptyset \mid h \cup \{op(x;\ k) \mapsto c_{op}\} &
\end{array}
$$

Figure 1: *EEFF* Term Syntax

$$\frac{}{\texttt{match}\ (v_1, v_2)\ \texttt{with}\ (x, y) \mapsto c\ \rightsquigarrow\ c[x \mapsto v_1, y \mapsto v_2]}$$

$$\frac{}{\texttt{match Left}\ v\ \texttt{with Left}\ x \mapsto c_l \mid \texttt{Right}\ x \mapsto c_r\ \rightsquigarrow\ c_l[x \mapsto v]}$$

$$\frac{}{\texttt{match Right}\ v\ \texttt{with Left}\ x \mapsto c_l \mid \texttt{Right}\ x \mapsto c_r\ \rightsquigarrow\ c_r[x \mapsto v]}$$

$$\frac{}{(\texttt{fun}\ x \mapsto c)\ v\ \rightsquigarrow\ c[x \mapsto v]} \qquad \frac{c_1\ \rightsquigarrow\ c_1'}{\texttt{do}\ x \leftarrow c_1\ \texttt{in}\ c_2\ \rightsquigarrow\ \texttt{do}\ x \leftarrow c_1'\ \texttt{in}\ c_2}$$

$$\frac{}{\texttt{do}\ x \leftarrow \texttt{ret}\ v\ \texttt{in}\ c\ \rightsquigarrow\ c[x \mapsto v]}$$

$$\frac{}{\texttt{do}\ x \leftarrow op(v;\ y.c_1)\ \texttt{in}\ c_2\ \rightsquigarrow\ op(v;\ y.\texttt{do}\ x \leftarrow c_1\ \texttt{in}\ c_2)}$$

$$\frac{c\ \rightsquigarrow\ c'}{\texttt{with}\ v\ \texttt{handle}\ c\ \rightsquigarrow\ \texttt{with}\ v\ \texttt{handle}\ c'}$$

$$\frac{}{\texttt{with}\ (\texttt{handler}\ (\texttt{ret}\ x \mapsto c_r; h))\ \texttt{handle}\ (\texttt{ret}\ v)\ \rightsquigarrow\ c_r[x \mapsto v]}$$

$$\frac{H = (\texttt{handler}\ (\texttt{ret}\ x \mapsto c_r; h)) \qquad (op(x;\ k) \mapsto c_{op}) \in h}{\texttt{with}\ H\ \texttt{handle}\ (op(v;\ y.c))\ \rightsquigarrow\ c_{op}[x \mapsto v, k \mapsto (\texttt{fun}\ y \mapsto \texttt{with}\ H\ \texttt{handle}\ c)]}$$

Figure 2: *EEFF* Operational Semantics

$$
\begin{array}{rcll}
\text{(value) type } A, B & ::= & \texttt{unit} & \text{unit type} \\
& \mid & \texttt{int} & \text{int type} \\
& \mid & \texttt{empty} & \text{empty type} \\
& \mid & A + B & \text{sum type} \\
& \mid & A \times B & \text{product type} \\
& \mid & A \to \underline{C} & \text{function type} \\
& \mid & \underline{C} \Rightarrow \underline{D} & \text{handler type} \\
\\
\text{computation type } \underline{C}, \underline{D} & ::= & A ! \Sigma / \mathcal{E} & \\
\\
\text{signature } \Sigma & ::= & \emptyset \mid \Sigma \cup \{ op : A \to B \} & \\
\\
\text{value context } \Gamma & ::= & \varepsilon \mid \Gamma, x : A & \\
\\
\text{template context } \mathtt{Z} & ::= & \varepsilon \mid \mathtt{Z}, z : A \to * & \\
\\
\text{template } T & ::= & z\ v & \text{applied variable} \\
& \mid & \texttt{match}\ v\ \texttt{with}\ (x, y) \mapsto T & \text{product match} \\
& \mid & \texttt{match}\ v\ \texttt{with}\ \texttt{Left}\ x \mapsto T_1 \mid \texttt{Right}\ x \mapsto T_2 & \text{sum match} \\
& \mid & op(v;\ y.T) & \text{operation call} \\
\\
\text{(effect) theory } \mathcal{E} & ::= & \emptyset \mid \mathcal{E} \cup \{ \Gamma ; \mathtt{Z} \vdash T_1 \sim T_2 \} &
\end{array}
$$

Figure 3: *EEFF* Type Syntax

$$\frac{\Gamma \vdash v \Mapsfrom A}{\Gamma \vdash (v : A) \Mapsto A} \qquad \frac{\Gamma \vdash v \Mapsto A' \qquad A = A'}{\Gamma \vdash v \Mapsfrom A} \qquad \frac{(x : A) \in \Gamma}{\Gamma \vdash x \Mapsto A}$$

$$\frac{}{\Gamma \vdash () \Mapsto \texttt{unit}} \qquad \frac{}{\Gamma \vdash n \Mapsto \texttt{int}} \qquad \frac{\Gamma \vdash v \Mapsfrom A}{\Gamma \vdash \texttt{Left}\ v \Mapsfrom A + B}$$

$$\frac{\Gamma \vdash v \Mapsfrom B}{\Gamma \vdash \texttt{Right}\ v \Mapsfrom A + B} \qquad \frac{\Gamma \vdash v_1 \Mapsfrom A \qquad \Gamma \vdash v_2 \Mapsfrom B}{\Gamma \vdash (v_1, v_2) \Mapsfrom A \times B}$$

$$\frac{\Gamma \vdash v_1 \Mapsto A \qquad \Gamma \vdash v_2 \Mapsto B}{\Gamma \vdash (v_1, v_2) \Mapsto A \times B} \qquad \frac{\Gamma, x : A \vdash c \Mapsfrom \underline{C}}{\Gamma \vdash \texttt{fun}\ x \mapsto c \Mapsfrom A \to \underline{C}}$$

$$\frac{\Gamma, x : A \vdash c_r \Mapsfrom \underline{D} \qquad \Gamma \vdash h : \Sigma \Rightarrow \underline{D}\ \textsf{respects}\ \mathcal{E}}{\Gamma \vdash \texttt{handler}\ (\texttt{ret}\ x \mapsto c_r; h) \Mapsfrom A!\Sigma/\mathcal{E} \Rightarrow \underline{D}} \qquad \frac{}{\Gamma \vdash \emptyset \Mapsfrom \emptyset \Rightarrow \underline{D}}$$

$$\frac{\Gamma \vdash h \Mapsfrom \Sigma \Rightarrow \underline{D} \qquad \Gamma, x : A_{op}, k : B_{op} \to \underline{D} \vdash c_{op} \Mapsfrom \underline{D} \qquad op \notin \Sigma}{\Gamma \vdash h \cup \{op(x;\ k) \mapsto c_{op}\} \Mapsfrom (\Sigma \cup \{op : A_{op} \to B_{op}\}) \Rightarrow \underline{D}}$$

$$\frac{\Gamma \vdash c \Mapsfrom \underline{C}'}{\Gamma \vdash (c : \underline{C}') \Mapsto \underline{C}} \qquad \frac{\Gamma \vdash c \Mapsto \underline{C}' \qquad \underline{C} = \underline{C}'}{\Gamma \vdash c \Mapsfrom \underline{C}}$$

$$\frac{\Gamma \vdash v \Mapsto A + B \qquad \Gamma, x : A \vdash c_l \Mapsfrom \underline{C} \qquad \Gamma, x : B \vdash c_r \Mapsfrom \underline{C}}{\Gamma \vdash \texttt{match}\ v\ \texttt{with Left}\ x \mapsto c_l \mid \texttt{Right}\ x \mapsto c_r \Mapsfrom \underline{C}}$$

$$\frac{\Gamma \vdash v \Mapsto A \times B \qquad \Gamma, x : A, y : B \vdash c \Mapsto \underline{C}}{\Gamma \vdash \texttt{match}\ v\ \texttt{with}\ (x, y) \mapsto c \Mapsto \underline{C}} \qquad \frac{\Gamma \vdash v_1 \Mapsto A \to \underline{C} \qquad \Gamma \vdash v_2 \Mapsfrom A}{\Gamma \vdash v_1\ v_2 \Mapsto \underline{C}}$$

$$\frac{\Gamma \vdash v \Mapsto A}{\Gamma \vdash \texttt{ret}\ v \Mapsto A!\emptyset/\emptyset}$$

$$\frac{(op : A_{op} \to B_{op}) \in \Sigma \qquad \Gamma \vdash v \Mapsfrom A_{op} \qquad \Gamma, y : B_{op} \vdash c \Mapsfrom A!\Sigma/\mathcal{E}}{\Gamma \vdash op(v;\ y.c) \Mapsfrom A!\Sigma/\mathcal{E}}$$

$$\frac{\Gamma \vdash c_1 \Mapsto A!\Sigma/\mathcal{E} \qquad \Gamma, x : A \vdash c_2 \Mapsfrom B!\Sigma/\mathcal{E}}{\Gamma \vdash \texttt{do}\ x \leftarrow c_1\ \texttt{in}\ c_2 \Mapsfrom B!\Sigma/\mathcal{E}} \qquad \frac{\Gamma \vdash v \Mapsto \underline{C} \Rightarrow \underline{D} \qquad \Gamma \vdash c \Mapsfrom \underline{C}}{\Gamma \vdash \texttt{with}\ v\ \texttt{handle}\ c \Mapsto \underline{D}}$$

Figure 4: *EEFF* Type System