Compiling from F_i^+ to JavaScript

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Syntax of F_i^+

$$
\begin{array}{lrl}
\text{Types} & A, B, C ::= & \top \mid \bot \mid \mathbb{B} \mid X \mid A \to B \mid \forall X * A.\ B \mid \{\ell : A\} \mid A \,\&\, B \\
\text{Type indices} & T ::= & \mathbb{B} \mid \overrightarrow{T} \mid T^{\forall} \mid \{\ell : T\} \mid T_1 \,\&\, T_2 \\
\text{Expressions} & e ::= & \{\} \mid b \mid x \mid \mathbf{fix}\, x : A.\ e \mid \lambda x : A.\ e : B \mid e_1\ e_2 \mid \Lambda X * A.\ e : B \mid e\ A \mid \{\ell = e\} \mid e.\ell \\
& & \mid e_1 ,, e_2 \mid e : A \\
\text{Values} & v ::= & \{\} \mid b \mid \lambda x : A.\ e : B \mid \Lambda X * A.\ e : B \mid \{\ell = v\} \mid v_1 ,, v_2
\end{array}
$$

$\boxed{|A| = T}$ *(Type translation)*

$$
|\mathbb{B}| = \mathbb{B} \qquad |X| = \mathbf{atoi}(X) \qquad |\forall X * A.\ B| = |B|^{\forall} \qquad |A \to B| = \overrightarrow{|B|} \qquad |\{\ell : A\}| = \{\ell : |A|\}
$$

$$
\frac{A_{k_1} < A_{k_2} < \cdots < A_{k_m} \qquad \neg\rceil A_k \lceil}{|A_1 \& A_2 \& \cdots \& A_n| = |A_{k_1}| \& |A_{k_2}| \& \cdots \& |A_{k_m}|}
$$

$\boxed{\rceil A \lceil}$ *(Top-like types)*

$$
\frac{}{\rceil \top \lceil}\ \textsc{TL-Top} \qquad \frac{\rceil A \lceil \quad \rceil B \lceil}{\rceil A \,\&\, B \lceil}\ \textsc{TL-And} \qquad \frac{\rceil B \lceil}{\rceil A \to B \lceil}\ \textsc{TL-Arrow} \qquad \frac{\rceil B \lceil}{\rceil \forall X * A.\ B \lceil}\ \textsc{TL-All} \qquad \frac{\rceil A \lceil}{\rceil \{\ell : A\} \lceil}\ \textsc{TL-Rcd}
$$

$\boxed{A^{\circ}}$ *(Ordinary types)*

$$
\frac{}{\top^{\circ}}\ \textsc{O-Top} \qquad \frac{}{\bot^{\circ}}\ \textsc{O-Bot} \qquad \frac{}{\mathbb{B}^{\circ}}\ \textsc{O-Base} \qquad \frac{}{X^{\circ}}\ \textsc{O-Var} \qquad \frac{B^{\circ}}{(A \to B)^{\circ}}\ \textsc{O-Arrow} \qquad \frac{B^{\circ}}{(\forall X * A.\ B)^{\circ}}\ \textsc{O-All} \qquad \frac{A^{\circ}}{\{\ell : A\}^{\circ}}\ \textsc{O-Rcd}
$$

$\boxed{\Gamma \vdash e \Leftrightarrow A \leadsto J \mid z^{\pm}}$ *(Type-directed compilation)*

$$\frac{\Gamma \vdash e \Leftrightarrow A \leadsto J \mid z^{-}}{\Gamma \vdash e \Leftrightarrow A \leadsto S_0 \mid z^{+}}\ \textsc{J-Gen}$$

$$\frac{}{\Gamma \vdash \{\} \Rightarrow \top \leadsto \varnothing \mid z^{-}}\ \textsc{J-Top}$$

$$\frac{\rceil B \lceil}{\Gamma \vdash \lambda x\!:\!A.\ e\!:\!B \Rightarrow A \to B \leadsto \varnothing \mid z^{-}}\ \textsc{J-TopAbs}$$

$$\frac{\rceil B \lceil}{\Gamma \vdash \Lambda X\!*\!A.\ e\!:\!B \Rightarrow \forall X\!*\!A.\ B \leadsto \varnothing \mid z^{-}}\ \textsc{J-TopTAbs}$$

$$\frac{\Gamma \vdash e \Rightarrow A \qquad \rceil A \lceil}{\Gamma \vdash \{\ell = e\} \Rightarrow \{\ell : A\} \leadsto \varnothing \mid z^{-}}\ \textsc{J-TopRcd}$$

$$\frac{T = |\mathbb{B}|}{\Gamma \vdash b \Rightarrow \mathbb{B} \leadsto S_1 \mid z^{-}}\ \textsc{J-Base}$$

$$\frac{x : A \in \Gamma}{\Gamma \vdash x \Rightarrow A \leadsto S_2 \mid z^{-}}\ \textsc{J-Var}$$

$$\frac{x : A \in \Gamma}{\Gamma \vdash x \Rightarrow A \leadsto S_3 \mid z^{+}}\ \textsc{J-VarGen}$$

$$\frac{\Gamma, x : A \vdash e \Leftarrow A \leadsto J \mid z^{-}}{\Gamma \vdash \mathbf{fix}\, x\!:\!A.\ e \Rightarrow A \leadsto S_4 \mid z^{-}}\ \textsc{J-Fix}$$

$$\frac{T = \overrightarrow{|B|} \qquad \Gamma, x : A \vdash e \Leftarrow B \leadsto J \mid y^{+}}{\Gamma \vdash \lambda x\!:\!A.\ e\!:\!B \Rightarrow A \to B \leadsto S_5 \mid z^{-}}\ \textsc{J-Abs}$$

$$\frac{\Gamma \vdash e_1 \Rightarrow A \leadsto J_1 \mid x^{+} \qquad A \rhd B \to C \qquad \Gamma \vdash e_2 \Leftarrow B \leadsto J_2 \mid y^{+} \qquad x : A \bullet y_0 \leadsto J_3 \mid z}{\Gamma \vdash e_1\, e_2 \Rightarrow C \leadsto S_6 \mid z^{-}}\ \textsc{J-App}$$

$$\frac{T = |B|^{\forall} \qquad \Gamma, X * A \vdash e \Leftarrow B \leadsto J \mid y^{+}}{\Gamma \vdash \Lambda X\!*\!A.\ e\!:\!B \Rightarrow \forall X\!*\!A.\ B \leadsto S_7 \mid z^{-}}\ \textsc{J-TAbs}$$

$$\frac{\Gamma \vdash e \Rightarrow B \leadsto J_1 \mid y^{+} \qquad B \rhd \forall X\!*\!C_1.\ C_2 \qquad \Gamma \vdash A * C_1 \qquad Ts = \mathbf{itoa}\,|A| \qquad y : B \bullet Ts \leadsto J_2 \mid z}{\Gamma \vdash e\, A \Rightarrow C_2[X \mapsto A] \leadsto J_1; J_2 \mid z^{-}}\ \textsc{J-TApp}$$

$$\frac{T = \{\ell : |A|\} \qquad \Gamma \vdash e \Rightarrow A \leadsto J \mid y^{+}}{\Gamma \vdash \{\ell = e\} \Rightarrow \{\ell : A\} \leadsto S_8 \mid z^{-}}\ \textsc{J-Rcd}$$

$$\frac{\Gamma \vdash e \Rightarrow A \leadsto J_1 \mid y^{+} \qquad A \rhd \{\ell : B\} \qquad y : A \bullet \ell \leadsto J_2 \mid z}{\Gamma \vdash e.\ell \Rightarrow B \leadsto J_1; J_2 \mid z^{-}}\ \textsc{J-Proj}$$

$$\frac{\Gamma \vdash e_1 \Rightarrow A \leadsto J_1 \mid z^{-} \qquad \Gamma \vdash e_2 \Rightarrow B \leadsto J_2 \mid z^{-} \qquad \Gamma \vdash A * B}{\Gamma \vdash e_1 \,,,\, e_2 \Rightarrow A \,\&\, B \leadsto J_1; J_2 \mid z^{-}}\ \textsc{J-Merge}$$

$$\frac{\Gamma \vdash e \Leftarrow A \leadsto J \mid z^{-}}{\Gamma \vdash e : A \Rightarrow A \leadsto J \mid z^{-}}\ \textsc{J-Anno}$$

$$\frac{\Gamma \vdash e \Leftarrow A \leadsto J \mid z^{+}}{\Gamma \vdash e : A \Rightarrow A \leadsto J \mid z^{+}}\ \textsc{J-AnnoGen}$$

$$\frac{\Gamma \vdash e \Rightarrow A \leadsto J_1 \mid x^{+} \qquad x : A <: y : B \leadsto J_2}{\Gamma \vdash e \Leftarrow B \leadsto J_1; J_2 \mid y^{-}}\ \textsc{J-Sub}$$

$$\frac{\Gamma \vdash e \Rightarrow A \leadsto J \mid z^{-}}{\Gamma \vdash e \Leftarrow A \leadsto J \mid z^{-}}\ \textsc{J-SubEq}$$

$$\frac{\Gamma \vdash e \Rightarrow A \leadsto J \mid z^{+}}{\Gamma \vdash e \Leftarrow A \leadsto J \mid z^{+}}\ \textsc{J-SubEqGen}$$

```
/* S0 */
var z = {};  J;

/* S1 */
z[T] = b;

/* S2 */
Object.assign(z, x.get);

/* S3 */
var z = x.get;

/* S4 */
var x = { get: z };
J;
```

```
/* S5 */
z[T] = x => {
  J;  return y;
};

/* S6 */
J1;
var y0 = {
  get get() {
    J2;
    Object.defineProperty(
      this, "get",
      {value: y}
    );  return y;
  }
};  J3;
```

```
/* S7 */
z[T] = X => {
  J;  return y;
};

/* S8 */
z[T] = {
  get get() {
    J;
    Object.defineProperty(
      this, "get",
      {value: y}
    );  return y;
  }
};
```

$\boxed{x : A \bullet \mathit{arg} \rightsquigarrow J \mid z}$ *(Distributive application)*

A-Top
$$\frac{\rceil A \lceil}{x : A \bullet \mathit{arg} \rightsquigarrow \varnothing \mid z}$$

A-Arrow
$$\frac{T = \overrightarrow{|B|}}{x : A \to B \bullet y \rightsquigarrow S_9 \mid z}$$

A-All
$$\frac{T = |B|^{\forall}}{x : \forall X * A.\ B \bullet Ts \rightsquigarrow S_9' \mid z}$$

A-Rcd
$$\frac{T = \{\ell : |A|\}}{x : \{\ell : A\} \bullet \ell \rightsquigarrow S_9'' \mid z}$$

A-And
$$\frac{x : A \bullet \mathit{arg} \rightsquigarrow J_1 \mid z \qquad x : B \bullet \mathit{arg} \rightsquigarrow J_2 \mid z}{x : A \,\&\, B \bullet \mathit{arg} \rightsquigarrow J_1; J_2 \mid z}$$

```
/* S9 */
Object.assign(z, x[T](y));

/* S9' */
Object.assign(z, x[T](Ts));

/* S9'' */
Object.assign(z, x[T].get);
```

$\boxed{x : A <: y : B \rightsquigarrow J}$ *(Coercive subtyping)*

S-Top
$$\frac{B^\circ \qquad \rceil B \lceil}{x : A <: y : B \rightsquigarrow \varnothing}$$

S-Base
$$\frac{T = |\mathbb{B}|}{x : \mathbb{B} <: y : \mathbb{B} \rightsquigarrow S_{10}}$$

S-Var
$$\frac{}{x : X <: y : X \rightsquigarrow S'_{10}}$$

S-Arrow
$$\frac{\begin{array}{c} T_1 = |\overrightarrow{A_2}| \\ T_2 = |\overrightarrow{B_2}| \qquad {B_2}^\circ \\ x_1 : B_1 <: y_1 : A_1 \rightsquigarrow J_1 \\ x_2 : A_2 <: y_2 : B_2 \rightsquigarrow J_2 \end{array}}{x : A_1 \to A_2 <: y : B_1 \to B_2 \rightsquigarrow S_{11}}$$

S-All
$$\frac{\begin{array}{c} T_1 = |A_2|^\forall \qquad T_2 = |B_2|^\forall \\ {B_2}^\circ \qquad B_1 <: A_1 \\ x_0 : A_2 <: y_0 : B_2 \rightsquigarrow J \end{array}}{x : \forall X * A_1.\ A_2 <: y : \forall X * B_1.\ B_2 \rightsquigarrow S_{12}}$$

S-Rcd
$$\frac{\begin{array}{c} T_1 = \{\ell : |A|\} \\ T_2 = \{\ell : |B|\} \\ B^\circ \qquad x_0 : A <: y_0 : B \rightsquigarrow J \end{array}}{x : \{\ell : A\} <: y : \{\ell : B\} \rightsquigarrow S_{13}}$$

S-AndL
$$\frac{C^\circ \qquad x : A <: y : C \rightsquigarrow J}{x : A \,\&\, B <: y : C \rightsquigarrow J}$$

S-AndR
$$\frac{C^\circ \qquad x : B <: y : C \rightsquigarrow J}{x : A \,\&\, B <: y : C \rightsquigarrow J}$$

S-Split
$$\frac{\begin{array}{c} B_1 \lhd B \rhd B_2 \\ x : A <: y_1 : B_1 \rightsquigarrow J_1 \\ x : A <: y_2 : B_2 \rightsquigarrow J_2 \\ y_1 : B_1 \rhd z : B \lhd y_2 : B_2 \rightsquigarrow J_3 \end{array}}{x : A <: z : B \rightsquigarrow S_{14}}$$

```
/* S10 */
y[T] = x[T];

/* S10' */
for (var T of X) {
  y[T] = x[T];
}


/* S12 */
y[T2] = X => {
  var x0 = x[T1](X);
  var y0 = {};  J;
  return y2;
};
```

```
/* S11 */
y[T2] = p => {
  var x2 = x[T1]({
    get get() {
      var x1 = p.get;
      var y1 = {};  J1;
      Object.defineProperty(
        this, "get",
        {value: y1}
      );  return y1;
    }
  });
  var y2 = {};  J2;
  return y2;
};
```

```
/* S13 */
y[T2] = {
  get get() {
    var x0 = x[T1].get;
    var y0 = {};  J;
    Object.defineProperty(
      this, "get",
      {value: y0}
    );  return y0;
  }
}

/* S14 */
var y1 = {};  J1;
var y2 = {};  J2;
J3;
```

$$\boxed{x : A \ \triangleright\ z : C \ \triangleleft\ y : B \ \rightsquigarrow\ J}$$

(Coercive merging)

$$\text{M-And}\quad \frac{}{x : A \ \triangleright\ z : A \,\&\, B \ \triangleleft\ y : B \ \rightsquigarrow\ S_{15}}$$

$$\text{M-Arrow}\quad \frac{T = |\overrightarrow{B}| \qquad T_1 = |\overrightarrow{B_1}| \qquad T_2 = |\overrightarrow{B_2}| \qquad y_1 : B_1 \ \triangleright\ y : B \ \triangleleft\ y_2 : B_2 \ \rightsquigarrow\ J}{x_1 : A \to B_1 \ \triangleright\ z : A \to B \ \triangleleft\ x_2 : A \to B_2 \ \rightsquigarrow\ S_{16}}$$

$$\text{M-All}\quad \frac{T = |B|^{\forall} \qquad T_1 = |B_1|^{\forall} \qquad T_2 = |B_2|^{\forall} \qquad y_1 : B_1 \ \triangleright\ y : B \ \triangleleft\ y_2 : B_2 \ \rightsquigarrow\ J}{x_1 : \forall X * A.\ B_1 \ \triangleright\ z : \forall X * A.\ B \ \triangleleft\ x_2 : \forall X * A.\ B_2 \ \rightsquigarrow\ S_{17}}$$

$$\text{M-Rcd}\quad \frac{T = \{\ell : |A|\} \qquad T_1 = \{\ell : |A_1|\} \qquad T_2 = \{\ell : |A_2|\} \qquad y_1 : A_1 \ \triangleright\ y : A \ \triangleleft\ y_2 : A_2 \ \rightsquigarrow\ J}{x_1 : \{\ell : A_1\} \ \triangleright\ z : \{\ell : A\} \ \triangleleft\ x_2 : \{\ell : A_2\} \ \rightsquigarrow\ S_{18}}$$

```
/* S15 */
Object.assign(z, x, y);

/* S16 */
z[T] = p => {
  var y1 = x1[T1](p);
  var y2 = x2[T2](p);
  var y = {};  J;
  return y;
};
```

```
/* S17 */
z[T] = X => {
  var y1 = x1[T1](X);
  var y2 = x2[T2](X);
  var y = {};  J;
  return y;
};
```

```
/* S18 */
z[T] = {
  get get() {
    var y1 = x1[T1].get;
    var y2 = x2[T2].get;
    var y = {};  J;
    Object.defineProperty(
      this, "get",
      {value: y}
    );  return y;
  }
};
```