React-tRace Core

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Syntax:

$$\begin{aligned}
\text{Value } v &::= x \mid \mathsf{true} \mid \mathsf{false} \mid n \mid s \mid \lambda x : \tau.e \mid \mathcal{C} \mid \mathsf{text}\ v \mid \mathsf{tag}(v, \overline{v}, \overline{v}) \\
&\quad \mid \mathsf{attr}(v, v) \mid \mathsf{onClick}\ v \\
\text{Expression } e &::= \mathsf{return}\ v \mid \mathsf{let}\ x = e\ \mathsf{in}\ e \mid v\ v \mid v \oplus v \mid \mathsf{if}\ v\ \mathsf{then}\ e\ \mathsf{else}\ e \\
\text{Top-level expr } \hat{e} &::= e \mid \mathsf{let}\ (x, x_{\mathsf{set}}) = \mathsf{useState}^{\ell}(v)\ \mathsf{in}\ \hat{e} \mid \mathsf{let}\ x = e\ \mathsf{in}\ \hat{e} \\
\text{Program } P &::= e \mid \mathsf{let}\ x = e\ \mathsf{in}\ P \mid \mathsf{let}\ \mathcal{C}(x : \tau) = \hat{e}\ \mathsf{in}\ P \\
\text{Type } \tau &::= \mathbf{1} \mid \mathsf{bool} \mid \mathsf{int} \mid \tau \xrightarrow{E} \tau \mid \mathsf{view} \mid \mathsf{component}\ \tau \mid \mathsf{setter}\ \tau \mid \mathsf{attr} \\
\text{Effect } E &::= \epsilon \mid \mathsf{Mut}
\end{aligned}$$

Internal representations:

$$\begin{aligned}
\text{Component declarations } \Delta &::= [\overline{\mathcal{C} \mapsto \tau}] \\
\text{Phase } \phi &::= \mathsf{Init} \mid \mathsf{Succ} \\
\text{Tree } t &::= \mathsf{lit}\ v \mid \mathsf{node}(id, v, \overline{v}, \overline{t}) \mid p \\
\text{Realized component} \pi &::= \{\mathsf{spec} : \langle \mathcal{C}, v \rangle, \mathsf{st} : [\overline{\ell \mapsto v}], \mathsf{child} : t\} \\
\text{Tree memory } m &::= [\overline{p \mapsto \pi}] \\
\text{Component definitions } \mathcal{D} &::= [\overline{\mathcal{C} \mapsto x.\hat{e}}] \\
\text{Mode } \mu &::= \mathsf{start}(P) \mid \mathsf{idle} \mid \mathsf{rerender}(m)
\end{aligned}$$

Effect unification:

$$E_1 \circ E_2 = \begin{cases} \epsilon & E_1 = E_2 = \epsilon \\ \mathsf{Mut} & \text{otherwise} \end{cases}$$

All typing judgments are relative to a fixed Δ, which can be determined prior to typechecking by iterating through all components in the program and noting their arguments' type annotations.

Value typing: $\Gamma \vdash_\Delta v : \tau$

$$\frac{x : \tau \in \Gamma}{\Gamma \vdash_\Delta x : \tau}\ \textsc{TVal-Var} \qquad \frac{}{\Gamma \vdash_\Delta () : \mathbf{1}}\ \textsc{TVal-Unit}$$

$$\frac{}{\Gamma \vdash_\Delta \mathsf{true} : \mathsf{bool}}\ \textsc{TVal-True} \qquad \frac{}{\Gamma \vdash_\Delta \mathsf{false} : \mathsf{bool}}\ \textsc{TVal-False}$$

$$\frac{}{\Gamma \vdash_\Delta n : \mathsf{int}}\ \textsc{TVal-Int} \qquad \frac{}{\Gamma \vdash_\Delta s : \mathsf{string}}\ \textsc{TVal-Str}$$

$$\frac{\Gamma, x : \tau_1 \vdash_\Delta e : \tau_2 \mid E}{\Gamma \vdash_\Delta \lambda x : \tau_1 . e : \tau_1 \xrightarrow{E} \tau_2}\ \textsc{TVal-Lam} \qquad \frac{\mathcal{C} : \mathsf{component}\ \tau \in \Delta}{\Gamma \vdash_\Delta \mathcal{C} : \mathsf{component}\ \tau}\ \textsc{TVal-Comp}$$

$$\frac{\Gamma \vdash_\Delta v : \tau \qquad \tau \in \{\mathsf{bool}, \mathsf{int}, \mathsf{string}\}}{\Gamma \vdash_\Delta \mathsf{text}\ v : \mathsf{view}}\ \textsc{TVal-Text}$$

$$\frac{\Gamma \vdash_\Delta v : \mathsf{string} \qquad (\forall i)\ \Gamma \vdash_\Delta v_i : \mathsf{attr} \qquad (\forall j)\ \Gamma \vdash_\Delta v_j : \mathsf{view}}{\Gamma \vdash_\Delta \mathsf{tag}(v, \overline{v_i}, \overline{v_j}) : \mathsf{view}}\ \textsc{TVal-Tag}$$

$$\frac{\Gamma \vdash_\Delta v_k : \mathsf{string} \qquad \Gamma \vdash_\Delta v_v : \mathsf{string}}{\Gamma \vdash_\Delta \mathsf{attr}(v_k, v_v) : \mathsf{attr}}\ \textsc{TVal-Attr}$$

$$\frac{\Gamma \vdash_\Delta v : \mathbf{1} \xrightarrow{E} \mathbf{1}}{\Gamma \vdash_\Delta \mathsf{onClick}\ v : \mathsf{attr}}\ \textsc{TVal-OnClick}$$

Base expression typing: $\Gamma \vdash_\Delta e : x \mid E$

$$\frac{\Gamma \vdash_\Delta v : \tau}{\Gamma \vdash_\Delta \mathsf{return}\ v : \tau \mid \epsilon}\ \textsc{TExp-Ret}$$

$$\frac{\Gamma \vdash_\Delta e_1 : \tau_1 \mid E_1 \qquad \Gamma, x : \tau_1 \vdash_\Delta e_2 : \tau_2 \mid E_2}{\Gamma \vdash_\Delta \mathsf{let}\ x = e_1\ \mathsf{in}\ e_2 : \tau_2 \mid E_1 \circ E_2}\ \textsc{TExp-Let}$$

$$\frac{\Gamma \vdash_\Delta v_1 : \tau_1 \xrightarrow{E} \tau_2 \qquad \Gamma \vdash_\Delta v_2 : \tau_1}{\Gamma \vdash_\Delta v_1\ v_2 : \tau_2 \mid E}\ \textsc{TExp-AppFun}$$

$$\frac{\Gamma \vdash_\Delta v_1 : \mathsf{component}\ \tau \qquad \Gamma \vdash_\Delta v_2 : \tau}{\Gamma \vdash_\Delta v_1\ v_2 : \mathsf{view} \mid \epsilon}\ \textsc{TExp-AppComp}$$

$$\frac{\Gamma \vdash_\Delta v_1 : \mathsf{setter}\ \tau \qquad \Gamma \vdash_\Delta v_2 : \tau}{\Gamma \vdash_\Delta v_1\ v_2 : \mathbf{1} \mid \mathsf{Mut}}\ \textsc{TExp-AppSet}$$

$$\frac{\Gamma \vdash_\Delta v_1 : \mathsf{int} \qquad \Gamma \vdash_\Delta v_2 : \mathsf{int} \qquad \oplus : \mathbb{Z} \times \mathbb{Z} \to \mathbb{Z}}{\Gamma \vdash_\Delta v_1 \oplus v_2 : \mathsf{int}}\ \textsc{TExp-Bop}$$

$$\frac{\Gamma \vdash_\Delta v : \mathsf{bool} \qquad \Gamma \vdash_\Delta e_1 : \tau \mid E_1 \qquad \Gamma \vdash_\Delta e_2 : \tau \mid E_2}{\Gamma \vdash_\Delta \mathsf{if}\ v\ \mathsf{then}\ e_1\ \mathsf{else}\ e_2 : \tau \mid E_1 \circ E_2}\ \textsc{TExp-If}$$

Top-level expression typing: $\Gamma \Vdash_\Delta \hat{e} : \tau$

$$\frac{\Gamma \vdash_\Delta e : \tau \mid \epsilon}{\Gamma \Vdash_\Delta \hat{e} : \tau}\ \textsc{That-Lift} \qquad \frac{\Gamma \vdash_\Delta e : \tau_1 \mid \epsilon \qquad \Gamma, x : \tau_1 \Vdash_\Delta \hat{e} : \tau_2}{\Gamma \Vdash_\Delta \mathsf{let}\ x = e\ \mathsf{in}\ \hat{e} : \tau_2}\ \textsc{That-Let}$$

$$\frac{\Gamma \vdash_\Delta v : \tau_1 \qquad \Gamma, x : \tau_1, x_{\mathsf{set}} : \tau_1 \xrightarrow{\mathsf{Set}} \mathbf{1} \Vdash_\Delta \hat{e} : \tau_2}{\Gamma \Vdash_\Delta \mathsf{let}\ (x, x_{\mathsf{set}}) = \mathsf{useState}^\ell(v)\ \mathsf{in}\ \hat{e} : \tau_2}\ \textsc{That-State}$$

Program judgment: $\Gamma \vdash_\Delta P$

$$\frac{\Gamma \vdash_\Delta e : \tau \mid \epsilon \qquad \Gamma, x : \tau \vdash_\Delta P}{\Gamma \vdash_\Delta \mathsf{let}\ x = e\ \mathsf{in}\ P}\ \textsc{TProg-Let}$$

$$\frac{\Gamma, x : \tau \Vdash_\Delta \hat{e} : \mathsf{view} \qquad \Gamma \vdash_\Delta P}{\Gamma \vdash_\Delta \mathsf{let}\ \mathcal{C}(x : \tau) = \hat{e}\ \mathsf{in}\ P}\ \textsc{TProg-Comp}$$

$$\frac{\Gamma \vdash_\Delta e : \mathsf{view} \mid \epsilon}{\Gamma \vdash_\Delta \mathsf{run}\ e}\ \textsc{TProg-Run}$$

Throughout the semantics, we use the notation $m' = m \mid x = v$ to concisely denote nested map/record updates. The above should be read as "m' equals m with field x set to v". For instance, $m' = m \mid m[p].st[\ell] = v$ updates the state field of m at path p and location ℓ to value v and names the result m'.

Pure expression semantics: $m\,;\, e \mapsto e'\,;\, m'$

$$\frac{m\,;\, e_1 \mapsto e_1'\,;\, m'}{m\,;\, \mathsf{let}\ x = e_1\ \mathsf{in}\ e_2 \mapsto \mathsf{let}\ x = e_1'\ \mathsf{in}\ e_2\,;\, m'}\ \textsc{E-LetPure}$$

$$\begin{aligned}
m\,;\, \mathsf{let}\ x = \mathsf{return}\ v\ \mathsf{in}\ e &\mapsto e[v/x]\,;\, m && \textsc{E-Ret}\\
m\,;\, (\lambda x.e)v &\mapsto e[v/x]\,;\, m && \textsc{E-AppFun}\\
m\,;\, \mathcal{C}\ v &\mapsto \langle \mathcal{C}, v\rangle\,;\, m && \textsc{E-AppComp}\\
m\,;\, \mathsf{set}@_p^{\ell}\ v &\mapsto ()\,;\, m' && \textsc{E-AppSet}\\
&\quad (m' = m \mid m[p].st[\ell] = v)\\
m\,;\, n_1 \oplus n_2 &\mapsto \mathsf{return}\ [\![n_1 \oplus n_2]\!]\,;\, m && \textsc{E-Bop}\\
m\,;\, \mathsf{if\ true\ then}\ e_1\ \mathsf{else}\ e_2 &\mapsto e_1\,;\, m && \textsc{E-IfTrue}\\
m\,;\, \mathsf{if\ false\ then}\ e_1\ \mathsf{else}\ e_2 &\mapsto e_2\,;\, m && \textsc{E-IfFalse}
\end{aligned}$$

Top-level expression semantics: $m\,;\, \hat{e} \mapsto_p^{\phi} \hat{e}'\,;\, m'$

$$\frac{m\,;\, e \mapsto e'\,;\, m'}{m\,;\, e \mapsto_p^{\phi} e'\,;\, m'}\ \textsc{E-Lift}$$

$$\frac{m\,;\, e \mapsto e'\,;\, m'}{m\,;\, \mathsf{let}\ x = e\ \mathsf{in}\ \hat{e} \mapsto_p^{\phi} \mathsf{let}\ x = e'\ \mathsf{in}\ \hat{e}\,;\, m'}\ \textsc{E-LetTop}$$

$$\begin{aligned}
m\,;\, \mathsf{let}\ x = \mathsf{return}\ v\ \mathsf{in}\ \hat{e} &\mapsto_p^{\phi} \hat{e}[v/x]\,;\, m && \textsc{E-RetTop}\\
m\,;\, \mathsf{let}\ (x, x_{\mathsf{set}}) = \mathsf{useState}^{\ell}(v)\ \mathsf{in}\ \hat{e} &\mapsto_p^{\mathsf{Init}} \hat{e}[v/x, \mathsf{set}@_p^{\ell}/x_{\mathsf{set}}]\,;\, m' && \textsc{E-StInit}\\
&\quad (m' = m \mid m[p].\mathsf{st}[\ell] = v)\\
m\,;\, \mathsf{let}\ (x, x_{\mathsf{set}}) = \mathsf{useState}^{\ell}(v)\ \mathsf{in}\ \hat{e} &\mapsto_p^{\mathsf{Succ}} \hat{e}[v'/x, \mathsf{set}@_p^{\ell}/x_{\mathsf{set}}]\,;\, m && \textsc{E-StSucc}\\
&\quad (v' = m[p].\mathsf{st}[\ell])
\end{aligned}$$

Program expression semantics: $m\,;\,\mathcal{D}\,;\,P \Mapsto P'\,;\,\mathcal{D}'\,;\,m'$

$$\frac{m\,;\,e \mapsto e'\,;\,m'}{m\,;\,\mathcal{D}\,;\,\mathsf{run}\ e \Mapsto \mathsf{run}\ e'\,;\,\mathcal{D}\,;\,m'}\ \textsc{E-Run}$$

$$\frac{m\,;\,e \mapsto e'\,;\,m'}{m\,;\,\mathcal{D}\,;\,\mathsf{let}\ x = e\ \mathsf{in}\ P \Mapsto \mathsf{let}\ x = e'\ \mathsf{in}\ P\,;\,\mathcal{D}\,;\,m'}\ \textsc{E-LetProg}$$

$$m\,;\,\mathcal{D}\,;\,\mathsf{let}\ x = \mathsf{return}\ v\ \mathsf{in}\ P \Mapsto P[v/x]\,;\,\mathcal{D}\,;\,m \qquad \textsc{E-RetProg}$$

$$m\,;\,\mathcal{D}\,;\,\mathsf{let}\ \mathcal{C}(x) = \hat{e}\ \mathsf{in}\ P \Mapsto P\,;\,\mathcal{D}[\mathcal{C} \mapsto x.\hat{e}]\,;\,m \qquad \textsc{E-CompDef}$$

Node initialization: $\mathcal{D}\,;\,m \vdash \mathsf{init}(v) = \langle t, m' \rangle$

$$\frac{}{\mathcal{D}\,;\,m \vdash \mathsf{init}(\mathsf{text}\ v) = \langle \mathsf{lit}\ v, m \rangle}\ \textsc{Init-Lit}$$

$$\frac{id\ \mathsf{fresh} \qquad (\forall j)\ \mathcal{D}\,;\,m_j \vdash \mathsf{init}(v_j) = \langle t_j, m_{j+1} \rangle}{\mathcal{D}\,;\,m_0 \vdash \mathsf{init}(\mathsf{tag}(v, \overline{v_i}, \overline{v_j}_{j=0}^{n-1})) = \langle \mathsf{node}(id, v, \overline{v_i}, \overline{t_j}), m_n \rangle}\ \textsc{Init-Node}$$

$$\frac{\begin{array}{c} m_0 \vdash p\ \mathsf{fresh} \qquad \mathcal{D}[\mathcal{C}] = x.\hat{e} \\ m_0[p \mapsto \{\mathsf{spec} : \langle \mathcal{C}, v \rangle, \mathsf{st} : \emptyset, \mathsf{child} : \emptyset\}]\,;\,\hat{e}[v/x] \overset{*}{\mapsto}{}^{\mathsf{Init}}_{p}\ \mathsf{return}\ v'\,;\,m_1 \\ \mathcal{D}\,;\,m_1 \vdash \mathsf{init}(v') = \langle t, m_2 \rangle \end{array}}{\mathcal{D}\,;\,m_0 \vdash \mathsf{init}(\langle \mathcal{C}, v \rangle) = \langle p, m_2 \mid m_2[p].\mathsf{child} = t \rangle}\ \textsc{Init-Comp}$$

(Naïve) re-render: $\mathcal{D}\,;\,m_{\mathsf{old}} \vdash \mathsf{check}(m_{\mathsf{new}}, t) = m$

$$\frac{}{\mathcal{D}\,;\,m_{\mathsf{old}} \vdash \mathsf{check}(m_{\mathsf{new}}, \mathsf{lit}\ v) = m_{\mathsf{new}}}\ \textsc{Check-Lit}$$

$$\frac{(0 \le j < n) \quad \mathcal{D}\,;\,m_{\mathsf{old}} \vdash \mathsf{check}(m_j, t_j) = \langle t'_j, m_{j+1} \rangle}{\mathcal{D}\,;\,m_{\mathsf{old}} \vdash \mathsf{check}(m_0, \mathsf{node}(id, v, \overline{v_i}, \overline{t_j})) = m_n}\ \textsc{Check-Node}$$

$$\frac{\begin{array}{c} m_{\mathsf{old}}[p].\mathsf{st} = m_{\mathsf{new}}[p].\mathsf{st} \\ \mathcal{D}\,;\,m_{\mathsf{old}} \vdash \mathsf{check}(m_{\mathsf{new}}, m_{\mathsf{old}}[p].child) = m \end{array}}{\mathcal{D}\,;\,m_{\mathsf{old}} \vdash \mathsf{check}(m_{\mathsf{new}}, p) = m}\ \textsc{Check-PathConst}$$

$$\frac{\begin{array}{c} m_{\mathsf{old}}[p].\mathsf{st} \neq m_{\mathsf{new}}[p].\mathsf{st} \qquad m'[p].\mathsf{spec} = \langle \mathcal{C}, v \rangle \qquad \mathcal{D}[\mathcal{C}] = x.\hat{e} \\ m_{\mathsf{new}}\,;\,\hat{e}[v/x] \overset{*}{\mapsto}{}^{\mathsf{Succ}}_{p}\ \mathsf{return}\ v'\,;\,m \\ \mathcal{D}\,;\,m \vdash \mathsf{init}(v') = \langle t, m' \rangle \end{array}}{\mathcal{D}\,;\,m_{\mathsf{old}} \vdash \mathsf{check}(m_{\mathsf{new}}, p) = \langle p, m' \mid m[p].\mathsf{child} = t \rangle}\ \textsc{Check-PathDiff}$$

Event loop semantics: $\langle \mathcal{D}, m, t, \mu \rangle \hookrightarrow \langle \mathcal{D}', m', t, \mu' \rangle$

$$\frac{\cdot\,;\,\cdot\,;\,P \mapsto^* \mathsf{run}(\mathsf{return}\ v)\,;\,\mathcal{D}\,;\,m \qquad \mathcal{D}\,;\,m \vdash \mathsf{init}(v) = \langle t, m' \rangle}{\langle \cdot, \cdot, \cdot, \mathsf{start}(P) \rangle \hookrightarrow \langle \mathcal{D}, m', t, \mathsf{idle} \rangle}\ \textsc{Loop-Start}$$

$$\frac{\begin{array}{c}\exists\ id \qquad m \vdash \mathsf{handlers}(t, id) = \overline{v_i} \\ (0 \le i < n) \quad m_i\,;\,v_i\ ()\mapsto^*\ \mathsf{return}\ ()\,;\,m_{i+1}\end{array}}{\langle \mathcal{D}, m_0, t, \mathsf{idle} \rangle \hookrightarrow \langle \mathcal{D}, m, t, \mathsf{rerender}(m_n) \rangle}\ \textsc{Loop-Event}$$

$$\frac{D\,;\,m_{\mathsf{old}} \vdash \mathsf{check}(m_{\mathsf{new}}, t) = m}{\langle \mathcal{D}, m_{\mathsf{old}}, t, \mathsf{rerender}(m_{\mathsf{new}}) \rangle \hookrightarrow \langle \mathcal{D}, m, t, \mathsf{idle} \rangle}\ \textsc{Loop-Rerender}$$

Handler search: $m \vdash \mathsf{handlers}(t, id) = \overline{v}$

$$\frac{}{m \vdash \mathsf{handlers}(\mathsf{lit}\ v, id) = \{\}}\ \textsc{Handlers-Lit}$$

$$\frac{m \vdash \mathsf{handlers}(m[p].\mathsf{child}, id) = \overline{v}}{m \vdash \mathsf{handlers}(p, id) = \overline{v}}\ \textsc{Handlers-Comp}$$

$$\frac{}{m \vdash \mathsf{handlers}(\mathsf{node}(id, v, \overline{v_i}, \overline{v_j}), id) = \{v_h \mid \mathsf{onClick}\ v_h \in \overline{v_i}\}}\ \textsc{Handlers-Tgt}$$

$$\frac{id \neq id' \qquad (\forall j)\ m \vdash \mathsf{handlers}(v_j, id) = h_j}{m \vdash \mathsf{handlers}(\mathsf{node}(id', v, \overline{v_i}, \overline{v_j}), id) = \bigcup_{\forall j} h_j}\ \textsc{Handlers-Node}$$