(0 –) Control Flow Analysis

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1 0-CFA

$$
\begin{aligned}
\text{Addr} &\equiv \text{(left abstract)} \\
\text{Val} &\equiv \langle \textbf{const} \rangle \mid \langle \textbf{ref}\ \text{Addr} \rangle \mid \langle \textbf{cl}\ \text{Var}, \text{Env}, \text{Var}, e \rangle \\
\Gamma \in \text{Env} &\equiv \text{Var} \to \text{Addr} \\
\sigma \in \text{Store} &\equiv \text{Addr} \to \mathcal{P}(\text{Value} \cup \text{Kont}) \\
\kappa \in \text{Kont} &\equiv \langle \textbf{halt} \rangle \mid \langle \textbf{frame}\ \text{Env}, \text{Var}, e, \text{Addr} \rangle
\end{aligned}
$$

1.1 computation

Let $\sigma' = \sigma \sqcup [l' \mapsto \{\langle \textbf{frame}\ \Gamma, y, e', l \rangle\}]$ where $l' = \mathit{new}_k(y, \sigma)$.

- $\langle \Gamma, \sigma, (\lambda x.e), y, e', l \rangle \longmapsto \langle \sigma', \{v\}, l' \rangle$
  - $v = \langle \textbf{cl}\ y, \Gamma, x, e \rangle$
- $\langle \Gamma, \sigma, (v_1\ v_2), y, e', l \rangle \longmapsto \langle \Gamma'', \sigma'', e'', l' \rangle$
  - $\langle \textbf{cl}\ \eta, \Gamma', x', e'' \rangle \in \gamma(\Gamma, \sigma, v_1)$
  - $l'' = \mathit{new}(x', \sigma)$
  - $\Gamma'' = \Gamma'[x' := l'']$
  - $\sigma'' = \sigma' \sqcup [l'' \mapsto \gamma(\Gamma, \sigma, v_2)]$
- $\langle \Gamma, \sigma, (\texttt{ref}\ v), y, e', l \rangle \longmapsto \langle \sigma'', \{\langle \textbf{ref}\ l'' \rangle\}, l' \rangle$
  - $l'' = \mathit{new}(\sigma)$
  - $\sigma'' = \sigma' \sqcup [l'' \mapsto \gamma(\Gamma, \sigma, v)]$
- $\langle \Gamma, \sigma, (\texttt{!}\, v), y, e', l \rangle \longmapsto \langle \sigma', \bigcup \sigma(\mathit{ls}), l' \rangle$
  - $\mathit{ls} = \{ l \mid \langle \textbf{ref}\ l \rangle \in \gamma(\Gamma, \sigma, v) \}$
- $\langle \Gamma, \sigma, (v_1\ \texttt{:=}\ v_2), y, e', l \rangle \longmapsto \langle \sigma'', \{\langle \textbf{const} \rangle\}, l' \rangle$
  - $\mathit{ls} = \{ l \mid \langle \textbf{ref}\ l \rangle \in \gamma(\Gamma, \sigma, v_1) \}$
  - $\sigma'' = \sigma' \sqcup \bigsqcup_{l \in \mathit{ls}} [l \mapsto \gamma(\Gamma, \sigma, v_2)]$

1.2 expressions

- $\langle \Gamma, \sigma, v, l \rangle \longmapsto \langle \sigma, \gamma(\Gamma, \sigma, v), l \rangle$
- $\langle \Gamma, \sigma, (\texttt{let}\ x = v\ \texttt{in}\ e), l \rangle \longmapsto \langle \sigma', \gamma(\Gamma, \sigma, v), l' \rangle$
  - $l' = \mathit{new}_k(x, \sigma)$
  - $\sigma' = \sigma \sqcup [l' \mapsto \langle \textbf{frame}\ \Gamma, x, e, l \rangle]$.
- $\langle \Gamma, \sigma, (\texttt{let}\ x = f\ \texttt{in}\ e), l \rangle \longmapsto \langle \Gamma, \sigma, f, x, e, l \rangle$
- $\langle \Gamma, \sigma, (\texttt{if}\ v\ \texttt{then}\ e_1\ \texttt{else}\ e_2), l \rangle \longmapsto \langle \Gamma, \sigma, e, l \rangle$
  - $e \in \{e_1, e_2\}$

1.3 values

- $\langle \sigma, \mathit{vs}, l \rangle \mapsto \langle \Gamma', \sigma', e, l' \rangle$
  - $\langle \textbf{frame}\ \Gamma, x, e, l' \rangle \in \sigma(l)$
  - $l'' = \mathit{new}(x, \sigma)$
  - $\Gamma' = \Gamma[x := l'']$
  - $\sigma' = \sigma \sqcup [l'' \mapsto \mathit{vs}]$

The function $\gamma : \text{Env} \times \text{Store} \times v \to \mathcal{P}(\text{Val})$ is defined by

- $\gamma(\Gamma, \sigma, x) = \sigma(\Gamma(x))$
- $\gamma(\Gamma, \sigma, \_) = \{\langle \textbf{const} \rangle\}$