May 17, 2016

1 Grammar (References)

$$\begin{array}{llr}
e ::= & x & \textit{expressions} \\
\mid & r & \\
\mid & \texttt{new}\ x \Rightarrow \overline{\sigma = e} & \\
\mid & e.m(e) & \\
\mid & e.\pi(e) & \\
\mid & l & (\textit{runtime form}) \\
 & & \\
v ::= & r & \textit{values} \\
\mid & l & \\
 & & \\
d ::= & \texttt{def}\ m(x : \tau) : \tau & \textit{unlabeled decls.} \\
 & & \\
\sigma ::= & d\ \texttt{with}\ \varepsilon & \textit{labeled decls.}
\end{array}$$

$$\begin{array}{llr}
\tau ::= & \{\bar{\sigma}\} & \textit{types} \\
\mid & \{\bar{r}\} & \\
 & & \\
\Gamma ::= & \varnothing & \textit{contexts} \\
\mid & \Gamma,\ x : \tau & \\
 & & \\
\mu ::= & \varnothing & \textit{store} \\
\mid & \mu,\ l \mapsto \{x \Rightarrow \overline{\sigma = e}\} & \\
\mid & \mu,\ l \mapsto \{x \Rightarrow \bar{r}\} &
\end{array}$$

- l-terms are memory addresses.
- The contents of μ have the form $l \mapsto \{x \Rightarrow \overline{\sigma = e}\}$, which means the memory address l points to an object with the type $\{\bar{\sigma}\}$. x is the 'this' variable.
- For an expression e, $[e_1/x_1, ..., e_n/x_n]e$ is a new expression with the structure of e, where every free occurrence of x_i is replaced with e_i.
- $\varnothing$ refers to the empty set. The empty type, consisting of zero method declarations, is denoted `Unit`.
- A configuration is a pair $\mu \mid e$.
- $\mu \mid e \longrightarrow \mu' \mid e'$ if, after one reduction step on e in heap μ, the program ends in heap μ' and ready to execute e'.
- To execute a program e is to perform reduction steps starting from the configuration $\langle \varnothing, e \rangle$.
- $\mu_1 \mid e_1 \longrightarrow_* \mu_2 \mid e_2$ if the configuration $\mu_2 \mid e_2$ can be reached from the configuration $\mu_1 \mid e_1$ by the application of one or more reduction rules.
- If $\mu_1 \mid e_1 \longrightarrow_* \mu_2 \mid v$, for some value v, then we say that $\mu_1 \mid e_1$ terminates.

2 Dynamic Semantics (References)

This first section introduces a basic dynamic semantics with no notion of a runtime effect.

$$\boxed{\mu \mid e \longrightarrow \mu \mid e}$$

$$\frac{\mu \mid e_1 \longrightarrow \mu \ ; \ e_1'}{\mu \mid e_1.m(e_2) \longrightarrow \mu' \mid e_1'.m(e_2)} \ (\text{E-MethCall1}) \qquad \frac{\mu \mid e_2 \longrightarrow \mu' \mid e_2'}{\mu \mid l.m(e_2) \longrightarrow \mu' \mid l.m(e_2')} \ (\text{E-MethCall2})$$

$$\frac{l \mapsto \{x \Rightarrow \overline{\sigma = e}\} \in \mu \quad \texttt{def m}(y : \tau_1) : \tau_2 \ \texttt{with} \ \varepsilon = e' \in \overline{\sigma = e}}{\mu \mid l.m(v) \longrightarrow \mu \mid e'[l/x, v/y]} \ (\text{E-MethCall3})$$

$$\frac{\mu \mid e_1 \longrightarrow \mu' \mid e_1'}{\mu \ ; \ e_1.\pi(e_2) \longrightarrow \mu' \ ; \ e_1'.\pi(e_2)} \ (\text{E-OperCall1}) \qquad \frac{\mu \mid e_2 \longrightarrow \mu' \mid e_2'}{\mu \mid r.\pi(e_2) \longrightarrow \mu' \mid r.\pi(e_2')} \ (\text{E-OperCall2})$$

$$\frac{r \in R \quad \pi \in \Pi}{\mu \mid r.\pi(v) \longrightarrow \mu' \mid \texttt{Unit}} \ (\text{E-OperCall3})$$

$$\frac{l \notin dom(\mu)}{\mu \mid \texttt{new x} \Rightarrow \overline{\sigma = e} \longrightarrow \mu, l \mapsto \texttt{new x} \Rightarrow \overline{\sigma = e} \mid l} \ (\text{E-New}_\sigma)$$

3 Dynamic Semantics (References + Effects)

We amend the definition of configuration. A configuration is a triple $\mu \mid e \mid \varepsilon$, where ε represents the accumulated set of effects (i.e. pairs from $R \times \Pi$) from the program execution so far. A program e has the effect (r, π) if $\varnothing \mid e \mid \varnothing \ \longrightarrow_* \ \mu \mid e' \mid \varepsilon$, where $(r, \pi) \in \varepsilon$.

$$\boxed{\mu \mid e \mid \varepsilon \longrightarrow \mu \mid e \mid \varepsilon}$$

$$\frac{\mu \mid e_1 \mid \varepsilon \longrightarrow \mu \mid e_1' \mid \varepsilon'}{\mu \mid e_1.m(e_2) \mid \varepsilon \longrightarrow \mu' \mid e_1'.m(e_2) \mid \varepsilon'} \ (\text{E-MethCall1}) \qquad \frac{\mu \mid e_2 \mid \varepsilon \longrightarrow \mu' \mid e_2' \mid \varepsilon'}{\mu \mid l.m(e_2) \mid \varepsilon \longrightarrow \mu' \mid l.m(e_2') \mid \varepsilon'} \ (\text{E-MethCall2})$$

$$\frac{l \mapsto \{x \Rightarrow \overline{\sigma = e}\} \in \mu \quad \texttt{def m}(y : \tau_1) : \tau_2 \ \texttt{with} \ \varepsilon_2 = e' \in \overline{\sigma = e}}{\mu \mid l.m(v) \mid \varepsilon \longrightarrow \mu \mid e'[l/x, v/y] \mid \varepsilon} \ (\text{E-MethCall3})$$

$$\frac{\mu \mid e_1 \mid \varepsilon \longrightarrow \mu' \mid e_1' \mid \varepsilon'}{\mu \mid e_1.\pi(e_2) \mid \varepsilon \longrightarrow \mu' \mid e_1'.\pi(e_2) \mid \varepsilon'} \ (\text{E-OperCall1}) \qquad \frac{\mu \mid e_2 \mid \varepsilon \longrightarrow \mu' \mid e_2' \mid \varepsilon'}{\mu \mid r.\pi(e_2) \mid \varepsilon \longrightarrow \mu' \mid r.\pi(e_2') \mid \varepsilon'} \ (\text{E-OperCall2})$$

$$\frac{r \in R \quad \pi \in \Pi}{\mu \mid r.\pi(v) \mid \varepsilon \longrightarrow \mu' \mid \texttt{Unit} \mid \varepsilon \cup \{(r, m)\}} \ (\text{E-OperCall3})$$

$$\frac{l \notin dom(\mu)}{\mu \mid \texttt{new x} \Rightarrow \overline{\sigma = e} \mid \varepsilon \longrightarrow \mu, l \mapsto \texttt{new x} \Rightarrow \overline{\sigma = e} \mid l \mid \varepsilon} \ (\text{E-New}_\sigma)$$

4 Dynamic Semantics (No References)

This section gives a dynamic semantics with no references or effects. There are no configurations; reduction is applied to expressions.

$$
\begin{array}{rcll}
e & ::= & x & \textit{expressions} \\
 & | & e.m(e) & \\
 & | & e.\pi(e) & \\
 & | & v & \\
\\
v & ::= & r & \textit{values} \\
 & | & \texttt{new}\ x \Rightarrow \overline{\sigma = e} & \\
\\
d & ::= & \texttt{def}\ m(x : \tau) : \tau & \textit{unlabeled decls.} \\
\\
\sigma & ::= & d\ \texttt{with}\ \varepsilon & \textit{labeled decls.}
\end{array}
\qquad
\begin{array}{rcll}
\tau & ::= & \{\bar{\sigma}\} & \textit{types} \\
 & | & \{\bar{r}\} & \\
\\
\Gamma & ::= & \varnothing & \textit{contexts} \\
 & | & \Gamma,\ x : \tau &
\end{array}
$$

$\boxed{e \longrightarrow e}$

$$\frac{e_1 \longrightarrow e_1'}{e_1.m(e_2) \longrightarrow e_1'.m(e_2)}\ (\textsc{E-MethCall1}) \qquad \frac{v_1 = \texttt{new}\ x \Rightarrow \overline{\sigma = e} \quad e_2 \longrightarrow e_2'}{v_1.m(e_2) \longrightarrow v_1.m(e_2')}\ (\textsc{E-MethCall2})$$

$$\frac{v_1 = \texttt{new}\ x \Rightarrow \overline{\sigma = e} \quad \texttt{def m}(y : \tau_1) : \tau_2\ \texttt{with}\ \varepsilon = e' \in \overline{\sigma = e}}{v_1.m(v_2) \longrightarrow [v_1/x, v_2/y]e'}\ (\textsc{E-MethCall3})$$

$$\frac{e_1 \longrightarrow e_1'}{e_1.\pi(e_2) \longrightarrow e_1'.\pi(e_2)}\ (\textsc{E-OperCall1}) \qquad \frac{e_2 \longrightarrow e_2'}{r.\pi(e_2) \longrightarrow r.\pi(e_2')}\ (\textsc{E-OperCall2})$$

$$\frac{r \in R \quad \pi \in \Pi}{r.\pi(v) \longrightarrow \texttt{Unit}}\ (\textsc{E-OperCall3})$$

5 Dynamic Semantics (Effects + No References)

$\boxed{e \mid \varepsilon \longrightarrow e \mid \varepsilon}$

$$\frac{e_1 \mid \varepsilon \longrightarrow e_1' \mid \varepsilon'}{e_1.m(e_2) \mid \varepsilon \longrightarrow e_1'.m(e_2) \mid \varepsilon'}\ (\textsc{E-MethCall1}) \qquad \frac{v_1 = \texttt{new}\ x \Rightarrow \overline{\sigma = e} \quad e_2 \mid \varepsilon \longrightarrow e_2' \mid \varepsilon'}{v_1.m(e_2) \mid \varepsilon \longrightarrow v_1.m(e_2') \mid \varepsilon'}\ (\textsc{E-MethCall2})$$

$$\frac{v_1 = \texttt{new}\ x \Rightarrow \overline{\sigma = e} \quad \texttt{def m}(y : \tau_1) : \tau_2\ \texttt{with}\ \varepsilon = e' \in \overline{\sigma = e}}{v_1.m(v_2) \mid \varepsilon \longrightarrow [v_1/x, v_2/y]e' \mid \varepsilon}\ (\textsc{E-MethCall3})$$

$$\frac{e_1 \mid \varepsilon \longrightarrow e_1' \mid \varepsilon'}{e_1.\pi(e_2) \mid \varepsilon \longrightarrow e_1'.\pi(e_2) \mid \varepsilon'}\ (\textsc{E-OperCall1}) \qquad \frac{e_2 \mid \varepsilon \longrightarrow e_2' \mid \varepsilon'}{r.\pi(e_2) \mid \varepsilon \longrightarrow r.\pi(e_2') \mid \varepsilon'}\ (\textsc{E-OperCall2})$$

$$\frac{r \in R \quad \pi \in \Pi}{r.\pi(v) \mid \varepsilon \longrightarrow \texttt{Unit} \mid \varepsilon \cup \{(r, \pi)\}}\ (\textsc{E-OperCall3})$$