

$cd ::= \text{class } C \text{ extends } D \{ \overline{fd}; kd \overline{md} \}$	class
$fd ::= t \ C \ f$	field
$kd ::= q \ C \ (\ t \ C \ g, t \ C \ f \) \{ \text{super}(g); \text{this.f} = f; \};$	constructor
$md ::= t \ C \ m \ (\ t \ C \ \text{this}, t \ C \ x \) \{ t \ C \ y \ s; \text{return } z \}$	instance method
$e ::= x \mid x.f$	expression
$s ::= x = e \mid x.f = y \mid x = y.m(z) \mid \text{super}(g) \mid x = \text{new } t() \mid s; s$	statement
$t ::= k \ q$	qualifier type
$k ::= \text{initiazlized} \mid \text{underinitialized} \mid \text{unknowninitialized}$	initializatioin qualifier
$q ::= \text{readonly} \mid \text{polyimmutable} \mid \text{mutable} \mid \text{immutable}$	immutability qualifier

Each class has only one constructor. But it doesn't affect the generality.

Type Hierarchy

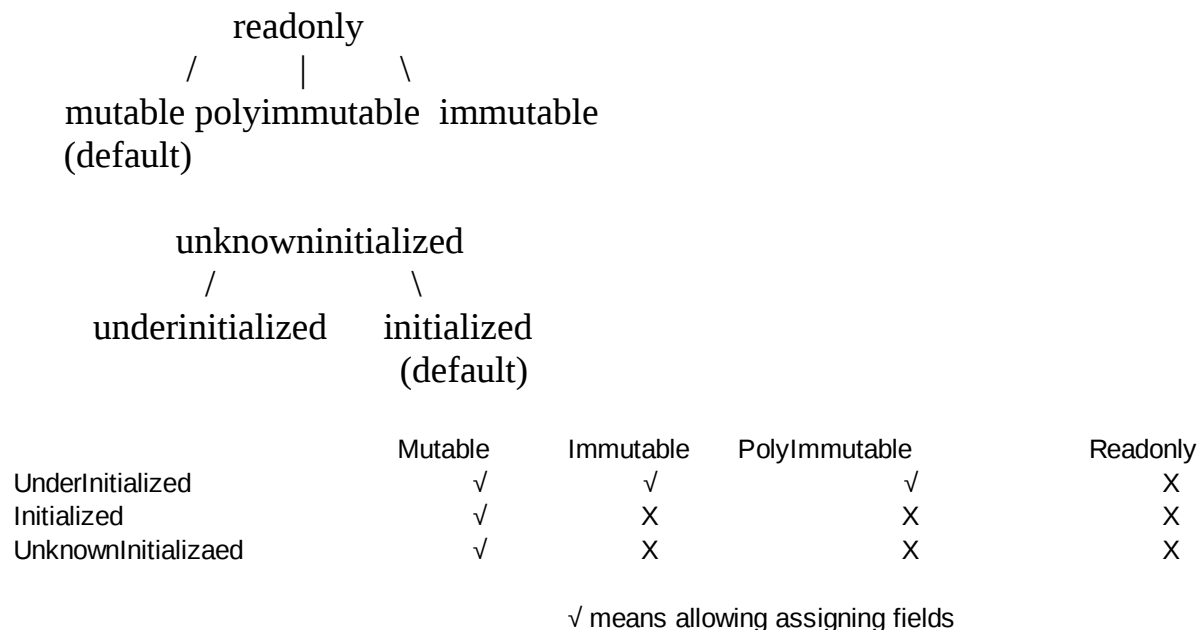


Figure 1 Combination of qulifiers. Two qualifier hierarchies are orthogonal. If an object is under initialization, its immutability guarantee is not satisfied. So even immutable and polyimmutable objects can also be modified when under initialization. We don't have readonly objects, so there is no need to initialize readonly objects. Therefore, readonly doesn't have such exception when under initialization.

Subtype relations:

$$k_1 \ q_1 <: k_2 \ q_2 \iff k_1 <: k_2 \wedge q_1 <: q_2$$

Helper Functions

$$\frac{q \text{ C } f}{\text{fType}(f) = q} \quad \text{No initialization modifier on field declarations}$$

cBody(c) returns constructor body of c.
mBody(m) returns method body of m.

Viewpoint Adaptation Rules

$$\begin{aligned} _ \triangleright \text{mutable} &= \text{mutable} \\ _ \triangleright \text{readonly} &= \text{readonly} \\ _ \triangleright \text{immutable} &= \text{immutable} \\ q \triangleright \text{polyimmutable} &= q \end{aligned}$$

Special Rules

- Forbid mutable and readonly on fields
- Forbid readonly constructor return type
- In constructor, $q_{\text{this}} = q_{\text{ret}}$
- Does not allow initialization modifier on fields and constructor return types

Typing Rules

$$\frac{x \in \Gamma}{\Gamma \vdash x : \Gamma(x)} \quad (\text{T-VAR})$$

$$\Gamma(x) = k_x q_x \quad \text{fType}(f) = q_f \quad q = q_x \triangleright q_f$$

$$k = \begin{cases} \text{initialized} & \text{if } k_x = \text{initialized} \\ \text{unknowninitialized} & \text{otherwise} \end{cases}$$

(T-FLD)

$$\Gamma \vdash x.f : k q$$

Figure 2 Expression typing

$$\Gamma \vdash e = t_e \quad t_e <: \Gamma(x)$$

(T-VARASS)

$$\Gamma \vdash x = e$$

$$\Gamma(x) = k_x q_x \quad \Gamma(y) = k_y q_y \quad \text{typeof}(f) = q_f$$

$$q_x = \text{mutable}$$

$$\forall (k_x = \text{underinitialized} \wedge q_x = \text{immutable}) // \text{Didn't restrict } x = \text{"this"}$$

$$\forall (k_x = \text{underinitialized} \wedge q_x = \text{polyimmutable}) // \text{Didn't restrict } x = \text{"this"}$$

$$q_y <: q_x \triangleright q_f$$

$$k_x = \text{underinitialized} \vee k_y = \text{initialized}$$

(T-FLDASS)

$$\Gamma \vdash x.f = y$$

$$\Gamma(x) = k_x q_x \quad \Gamma(y) = k_y q_y \quad \Gamma(\bar{z}) = \bar{k}_z \bar{q}_z \quad \text{typeof}(m) = k_{\text{this}} q_{\text{this}}, \bar{k}_p \bar{q}_p \rightarrow k_{\text{ret}} q_{\text{ret}}$$

$$k_y <: k_{\text{this}} \quad \bar{k}_z <: \bar{k}_p \quad k_{\text{ret}} <: k_x$$

$$q_y <: q_x \triangleright q_{\text{this}} \quad \bar{q}_z <: q_x \triangleright \bar{q}_p \quad q_x \triangleright q_{\text{ret}} <: q_x$$

(T-CALL)

$$\Gamma \vdash x = y.m(\bar{z})$$

$$c \text{ in } C \quad C <: D \quad \text{typeof}(D) = \bar{k}_{p-D} \bar{q}_{p-D} \rightarrow q_{\text{ret-D}} \quad \text{typeof}(C) = \bar{\bar{}} \rightarrow q_{\text{ret-C}}$$

$$\Gamma(z) = k_z q_z \quad q_{\text{ret-C}} <: q_{\text{ret-C}} \triangleright q_{\text{ret-D}} \quad \bar{q}_z <: q_{\text{ret-C}} \triangleright \bar{q}_{p-D} \quad \bar{k}_z <: \bar{k}_{p-D}$$

(T-SUPER)

$$\Gamma \vdash \text{super}(\bar{z}) \text{ in } c$$

$$\begin{array}{l}
\Gamma(\underline{x}) = \underline{k}_x \ \underline{q}_x \quad \Gamma(\bar{y}) = \bar{k}_y \ \bar{q}_y \quad \text{typeof}(C) = \bar{k}_p \ \bar{q}_p \rightarrow q_{\text{ret}} \\
q_y <: q \triangleright q_p \quad q <: q \triangleright q_{\text{ret}} \quad q = \text{mutable} \vee q = \text{immutable} \\
k_y <: k_p \\
q <: q_x \quad k <: k_x \quad k = \begin{cases} \text{initialized} & \text{if } \bar{k}_p = \text{initialized} \\ \text{underinitialized} & \text{otherwise} \end{cases}
\end{array}$$

$$\Gamma \vdash x = \text{new } q \ C(\bar{y})$$

(T-NEW)

$$\Gamma \vdash s_1 \quad \Gamma \vdash s_2$$

$$\Gamma \vdash s_1; s_2$$

(T-SEQ)

Figure 3 Statement typing

Well-formdness Rules

$$\vdash_{\text{object } _} \text{is OK}$$

(WF-CONS-OBJECT)

$$c\text{Body}(c) = \text{super}(g); s \quad \text{typeof}(c) = \bar{k}_p \ \bar{q}_p \rightarrow q_{\text{ret}}$$

$$\Gamma = (\text{this} : \text{underinitialized } q_{\text{ret}}, \ \bar{p} : \bar{k}_p \ \bar{q}_p, \ y : \bar{k}_{\text{local}} \ \bar{q}_{\text{local}}) \quad \Gamma \vdash \text{super}(\bar{y}) \text{ in } c \quad \Gamma \vdash s$$

$$\vdash c \text{ is OK}$$

(WF-CONS)

Note: $\vdash c$ reads “constructor c is well-formed”.

$$m\text{Body}(m) = s; \text{return } z \quad \text{typeof}(m) = k_{\text{this}} \ q_{\text{this}}, \ \bar{k}_p \ \bar{q}_p \rightarrow t_{\text{ret}}$$

$$\Gamma = (\text{this} : k_{\text{this}} \ q_{\text{this}}, \ \bar{p} : \bar{k}_p \ \bar{q}_p, \ y : \bar{k}_{\text{local}} \ \bar{q}_{\text{local}}) \quad \Gamma \vdash s \quad \Gamma(z) <: t_{\text{ret}}$$

$$\vdash m \text{ is OK}$$

(WF-METH)

Figure 4 Well-formdness typing