

# Execution Semantics of Pattern/Scope Combinations

Pattern/scope combinations	QRE semantics and verdict procedure
always P after Q	$\text{EoE} \mid (\text{Q P}^* (\neg[P] \mid \text{EoE}))$ <hr/> <p>A diagram showing a 'match' node branching into two paths. The top path is labeled <math>\neg[P] = \text{null}</math> and leads to a circle containing the symbol <math>\top</math>. The bottom path is labeled <math>\neg[P] \neq \text{null}</math> and leads to a circle containing the symbol <math>\perp</math>.</p>
always P after Q until R	$\text{EoE} \mid (\text{Q P}^* (\neg[P] \mid \text{R} \mid \text{EoE}))$ <hr/> <p>A diagram showing a 'match' node branching into two paths. The top path is labeled <math>\text{EoE} = \text{null}</math> and leads to a circle. From this circle, two paths emerge: one labeled <math>\neg[P] \neq \text{null}</math> leading to a circle with <math>\perp</math>, and another labeled <math>\neg[P] = \text{null}</math> leading to a circle with <math>?</math>. The bottom path from the 'match' node is labeled <math>\text{EoE} \neq \text{null}</math> and leads to a circle with <math>\top</math>.</p>
always P before Q	$\text{EoE} \mid \text{Q} \mid \neg[P]$ <hr/> <p>A diagram showing a 'match' node branching into two paths. The top path is labeled <math>\neg[P] = \text{null}</math> and leads to a circle containing the symbol <math>\top</math>. The bottom path is labeled <math>\neg[P] \neq \text{null}</math> and leads to a circle containing the symbol <math>\perp</math>.</p>
always P between Q and R	$\text{EoE} \mid (\text{Q P}^* \neg[P] \text{P}^* (\text{R} \mid \text{EoE}))$ <hr/> <p>A diagram showing a 'match' node branching into two paths. The top path is labeled <math>\text{EoE} = \text{null}</math> and leads to a circle. From this circle, two paths emerge: one labeled <math>\neg[P] \neq \text{null}</math> leading to a circle with <math>\perp</math>, and another labeled <math>\neg[P] = \text{null}</math> leading to a circle with <math>?</math>. The bottom path from the 'match' node is labeled <math>\text{EoE} \neq \text{null}</math> and leads to a circle with <math>\top</math>.</p>
always P globally	$\text{EoE} \mid \neg[P]$ <hr/> <p>A diagram showing a 'match' node branching into two paths. The top path is labeled <math>\neg[P] = \text{null}</math> and leads to a circle containing the symbol <math>\top</math>. The bottom path is labeled <math>\neg[P] \neq \text{null}</math> and leads to a circle containing the symbol <math>\perp</math>.</p>

Table 1: Semantics of Universality patterns as QREs and verdict procedures.

Pattern/scope combinations	QRE semantics and verdict procedure
exists [2,3] P after Q	$\text{EoE} \mid (\underline{Q} (\neg[P]^* P' (\neg[P]^* \underline{P} (\neg[P]^* \underline{P} (\neg[P]^* P' \mid \text{EoE}) \mid \text{EoE}) \mid \text{EoE}) \mid \text{EoE}))$ <hr/>
exists [2,3] P after Q until R	$\underline{\text{EoE}} \mid (\underline{Q} (\neg[P]^* P' (\neg[P]^* \underline{P} (\neg[P]^* \underline{P} (\neg[P]^* P' \mid R \mid \underline{\text{EoE}}) \mid R \mid \underline{\text{EoE}}) \mid R \mid \underline{\text{EoE}}) \mid R \mid \underline{\text{EoE}}) \mid R \mid \underline{\text{EoE}}))$ <hr/>
exists [2,3] P before Q	$\neg[P]^* P' (\neg[P]^* \underline{P} (\neg[P]^* \underline{P} (\neg[P]^* P' \mid Q \mid \text{EoE}) \mid Q \mid \text{EoE}) \mid Q \mid \text{EoE}))$ <hr/>
exists [2,3] P between Q and R	$\underline{\text{EoE}} \mid Q \neg[P,R]^* (\underline{P} \neg[P,R]^*)^* (R \mid \underline{\text{EoE}})$ <hr/>
exists [2,3] P globally	$\neg[P]^* P' (\neg[P]^* \underline{P} (\neg[P]^* \underline{P} (\neg[P]^* P' \mid \text{EoE}) \mid \text{EoE}) \mid \text{EoE})) \mid \text{EoE}$ <hr/>

Table 2: Semantics of Existence patterns as QREs and verdict procedures.

Pattern/scope combinations	QRE semantics and verdict procedure
never P after Q	$\text{EoE} \mid (Q \text{ .*? } (\underline{P} \mid \text{EoE}))$ <hr/> <p>A diagram showing a 'match' node branching into two paths. The top path is labeled 'P = null' and leads to a 'T' (True) node. The bottom path is labeled 'P ≠ null' and leads to a '⊥' (False) node.</p>
never P after Q until R	$\underline{\text{EoE}} \mid (Q \text{ .*? } (\underline{P} \mid R \mid \underline{\text{EoE}}))$ <hr/> <p>A diagram showing a 'match' node branching into two paths. The top path is labeled 'EoE = null' and leads to a circular node. From this circular node, two paths emerge: one labeled 'P ≠ null' leading to a '⊥' node, and another labeled 'P = null' leading to a '?' node. The bottom path from 'match' is labeled 'EoE ≠ null' and leads to a 'T' node.</p>
never P before Q	$\text{EoE} \mid Q \mid \underline{P}$ <hr/> <p>A diagram showing a 'match' node branching into two paths. The top path is labeled 'P = null' and leads to a 'T' node. The bottom path is labeled 'P ≠ null' and leads to a '⊥' node.</p>
never P between Q and R	$\underline{\text{EoE}} \mid (Q \neg [P]^* (\underline{P} \neg [P]^*)? (R \mid \underline{\text{EoE}}))$ <hr/> <p>A diagram showing a 'match' node branching into two paths. The top path is labeled 'EoE = null' and leads to a circular node. From this circular node, two paths emerge: one labeled 'P ≠ null' leading to a '⊥' node, and another labeled 'P = null' leading to a '?' node. The bottom path from 'match' is labeled 'EoE ≠ null' and leads to a 'T' node.</p>
never P globally	$\text{EoE} \mid \underline{P}$ <hr/> <p>A diagram showing a 'match' node branching into two paths. The top path is labeled 'P = null' and leads to a 'T' node. The bottom path is labeled 'P ≠ null' and leads to a '⊥' node.</p>

Table 3: Semantics of Absence patterns as QREs and verdict procedures.

Pattern/scope combinations	QRE semantics and verdict procedure
S precedes P after Q	$\text{EoE} \mid Q \text{ . } * ? \text{ (EoE} \mid S \mid \underline{P})$ <hr/> <p>A flowchart starting with a 'match' node. Two arrows branch out: one labeled 'P = null' pointing to a 'T' (True) node, and another labeled 'P ≠ null' pointing to a '⊥' (False) node.</p>
S precedes P after Q until R	$\underline{\text{EoE}} \mid Q \text{ . } * ? \text{ (}\underline{\text{EoE}} \mid R \mid S \mid \underline{P}\text{)}$ <hr/> <p>A flowchart starting with a 'match' node. Two arrows branch out: one labeled 'EoE = null' pointing to a circular node, and another labeled 'EoE ≠ null' pointing to a 'T' (True) node. From the circular node, two arrows branch out: one labeled 'P ≠ null' pointing to a '⊥' (False) node, and another labeled 'P = null' pointing to a '?' (Unknown) node.</p>
S precedes P before Q	$\text{EoE} \mid Q \mid S \mid \underline{P}$ <hr/> <p>A flowchart starting with a 'match' node. Two arrows branch out: one labeled 'P = null' pointing to a 'T' (True) node, and another labeled 'P ≠ null' pointing to a '⊥' (False) node.</p>
S precedes P between Q and R	$\underline{\text{EoE}} \mid Q \neg [P, R, S]^* (S \neg [R]^* \mid \underline{P} \neg [R]^*) ? \text{ (}\underline{\text{EoE}} \mid R\text{)}$ <hr/> <p>A flowchart starting with a 'match' node. Two arrows branch out: one labeled 'EoE = null' pointing to a circular node, and another labeled 'EoE ≠ null' pointing to a 'T' (True) node. From the circular node, two arrows branch out: one labeled 'P ≠ null' pointing to a '⊥' (False) node, and another labeled 'P = null' pointing to a '?' (Unknown) node.</p>
S precedes P globally	$\text{EoE} \mid S \mid \underline{P}$ <hr/> <p>A flowchart starting with a 'match' node. Two arrows branch out: one labeled 'P = null' pointing to a 'T' (True) node, and another labeled 'P ≠ null' pointing to a '⊥' (False) node.</p>

Table 4: Semantics of Precedence patterns as QREs and verdict procedures.

Pattern/scope combinations	QRE semantics and verdict procedure
S respondsTo P after Q	$\text{EoE} \mid Q \neg[P]^* (\underline{P} \neg[S]^* \underline{S} \neg[P]^*)^* (\underline{P} \neg[S]^*)? \text{EoE}$ <hr/> <p>A diagram showing a 'match' node branching into two paths. The top path is labeled <math> P  =  S </math> and leads to a circle containing 'T'. The bottom path is labeled <math> P  \neq  S </math> and leads to a circle containing '⊥'.</p>
S respondsTo P after Q until R	$\underline{\text{EoE}} \mid Q \neg[P, R]^* (\underline{P} \neg[R, S]^* \underline{S} \neg[P, R]^*)^* (\underline{P} \neg[R, S]^*)? (R \mid \underline{\text{EoE}})$ <hr/> <p>A diagram showing a 'match' node branching into two paths. The top path is labeled <math> P  =  S </math> and leads to a circle. From this circle, two paths emerge: one labeled <math>\text{EoE} \neq \text{null}</math> leading to a circle containing 'T', and another labeled <math>\text{EoE} = \text{null}</math> leading to a circle containing '?'. The bottom path from 'match' is labeled <math> P  \neq  S </math> and leads to a circle containing '⊥'.</p>
S respondsTo P before Q	$\text{EoE} \mid Q \mid (\underline{P} \neg[S]^* \underline{S} \neg[P]^*)^* (\underline{P} \neg[S]^*)? (\text{EoE} \mid Q)$ <hr/> <p>A diagram showing a 'match' node branching into two paths. The top path is labeled <math> P  =  S </math> and leads to a circle containing 'T'. The bottom path is labeled <math> P  \neq  S </math> and leads to a circle containing '⊥'.</p>
S respondsTo P between Q and R	$\underline{\text{EoE}} \mid Q \neg[P, R]^* (\underline{P} \neg[R, S]^* \underline{S} \neg[P, R]^*)^* (\underline{P} \neg[R, S]^*)? (R \mid \underline{\text{EoE}})$ <hr/> <p>A diagram showing a 'match' node branching into two paths. The top path is labeled <math>\text{EoE} = \text{null}</math> and leads to a circle. From this circle, two paths emerge: one labeled <math> P  \neq  S </math> leading to a circle containing '⊥', and another labeled <math> P  =  S </math> leading to a circle containing '?'. The bottom path from 'match' is labeled <math>\text{EoE} \neq \text{null}</math> and leads to a circle containing 'T'.</p>
S respondsTo P globally	$(\underline{P} \neg[S]^* \underline{S} \neg[P]^*)^* (\underline{P} \neg[S]^*)? \text{EoE}$ <hr/> <p>A diagram showing a 'match' node branching into two paths. The top path is labeled <math> P  =  S </math> and leads to a circle containing 'T'. The bottom path is labeled <math> P  \neq  S </math> and leads to a circle containing '⊥'.</p>

Table 5: Semantics of Response patterns as QREs and verdict procedures.