A

FOL INTERACTION RULES

Table A.1: FOL rules for detecting **Divergent Causations**

From Table 4.3: $b_1 :: P(t_1 \mid do(a_1)) \geqslant 0.5$ $a_1 \subseteq a_2$ $b_2 :: P(t_2 \mid do(a_2)) \geqslant 0.5$ $t_1.deriv \neq t_2.deriv \rightarrow \Diamond$ $t_1 \leftrightharpoons t_2 \rightarrow \Box$ $b_2 :: P(t_2 \mid do(a_2)) < 0.5$ $t_1.deriv = t_2.deriv \rightarrow \Diamond$ $t_1 = t_2 \rightarrow \Box$	$(\forall norm_1, norm_2 \in Norm)(\forall ctrb_1, ctrb_2 \in Contribution)$ $\Big((norm_1.reg = norm_2.reg \wedge hasNorm(ctrb_1, norm_1)$ $\wedge\, hasNorm(ctrb_2, norm_2) \wedge norm_1.act \subseteq norm_2.act$ $\wedge\, \mathbf{ctrb_1.trans.prop = ctrb_2.trans.prop \wedge ctrb_1.causProb \geqslant 0.5}$ $\wedge\, ((\mathbf{ctrb_2.causProb \geqslant 0.5 \wedge ctrb_1.trans.deriv \neq ctrb_2.trans.deriv})$ $\vee\, (\mathbf{ctrb_2.causProb < 0.5 \wedge ctrb_1.trans.deriv = ctrb_2.trans.deriv})))$ $\rightarrow (\exists! \mathbf{int} \in \mathbf{DivergentCausations})$ $\Big(relates(int, norm_1) \wedge relates(int, norm_2)$ $\wedge\, relates(int, norm_2.act) \wedge relates(int, ctrb_1) \wedge relates(int, ctrb_2)$ $\wedge\, ((\mathbf{ctrb_1.trans = ctrb_2.trans \vee inv(ctrb_1.trans, ctrb_2.trans})$ $\rightarrow \mathbf{int.modalStr = 1})$ $\vee\, (\neg(\mathbf{ctrb_1.trans = ctrb_2.trans \vee inv(ctrb_1.trans, ctrb_2.trans}))$ $\rightarrow \mathbf{int.modalStr = 0.5}))$ $\wedge\, int.deonticStr = (\lvert norm_1.strength \rvert + \lvert norm_2.strength \rvert)/2$ $\wedge\, int.beliefStr = (ctrb_1.belief.strength + ctrb_2.belief.strength)/2$ $\wedge\, int.causationStr = ctrb_1.causProb \times ctrb_2.causProb\Big)\Big)$

Table A.2: FOL rules for detecting **Repetitions**

From Table 4.4: r_1 is positive r_2 is positive $a_1 = a_2 \rightarrow \Box$ $a_1 \subset a_2 \rightarrow \Diamond$	$(\forall \text{norm}_1, \text{norm}_2 \in \text{Norm})\Big((\text{norm}_1.\text{reg} = \text{norm}_2.\text{reg}$ $\wedge\ \mathbf{norm_1.strength \geqslant 0} \wedge \mathbf{norm_2.strength \geqslant 0} \wedge \mathbf{norm_1.act \subseteq norm_2.act})$ $\rightarrow (\exists! \mathbf{int} \in \mathbf{Repetition})\Big(\text{relates}(\text{int}, \text{norm}_1) \wedge \text{relates}(\text{int}, \text{norm}_2)$ $\wedge\ \text{relates}(\text{int}, \text{norm}_2.\text{act})$ $\wedge\ ((\mathbf{norm_1.act = norm_2.act \rightarrow int.modalStr = 1})$ $\vee\ (\mathbf{norm_1.act \subset norm_2.act \rightarrow int.modalStr = 0.5}))$ $\wedge\ \text{int.deonticStr} = (\lvert\text{norm}_1.\text{strength}\rvert + \lvert\text{norm}_2.\text{strength}\rvert)/2\Big)\Big)$
Cumulative rules	$(\forall \text{int}_A, \text{int}_B \in \text{Repetition})(\forall \text{norm}_1, \text{norm}_2, \text{norm}_3 \in \text{Norm})\Big($ $(\text{relates}(\text{int}_A, \text{norm}_1) \wedge \mathbf{relates(int_A, norm_2)} \wedge \mathbf{relates(int_B, norm_2)}$ $\wedge\ \text{relates}(\text{int}_B, \text{norm}_3) \wedge \text{norm}_1 \neq \text{norm}_3)$ $\rightarrow (\exists! \mathbf{cumInt} \in \mathbf{Repetition})(\text{partOf}(\text{int}_A, \text{cumInt}) \wedge \text{partOf}(\text{int}_B, \text{cumInt}))\Big)$ $(\forall \mathbf{cumInt_A}, \mathbf{cumInt_B}, \mathbf{int_1}, \mathbf{int_2}, \mathbf{int_3} \in \mathbf{Repetition})\Big(($ $\text{partOf}(\text{int}_1, \text{cumInt}_A) \wedge \mathbf{partOf(int_2, cumInt_A)} \wedge \mathbf{partOf(int_2, cumInt_B)}$ $\wedge\ \text{partOf}(\text{int}_3, \text{cumInt}_B) \wedge \text{int}_1 \neq \text{int}_3) \rightarrow \mathbf{cumInt_A} = \mathbf{cumInt_B}\Big)$

Table A.3: FOL rules for detecting **Alternatives**

From Table 4.4: $\mathtt{r}_1$ is positive $\mathtt{ctr}_1$ is positive $\mathtt{r}_2$ is positive $\mathtt{ctr}_1$ is positive $a_1 \not\supset a_2$ t_1.deriv $=$ t_2.deriv $t_1 = t_2$ $\wedge a_1 \not\subseteq a_2 \rightarrow \Box$ $t_1 \neq t_2$ $\vee a_1 \subset a_2 \rightarrow \Diamond$	$(\forall \text{norm}_1, \text{norm}_2 \in \text{Norm})(\forall \text{ctrb}_1, \text{ctrb}_2 \in \text{Contribution})\Big($ $(\text{norm}_1.\text{reg} = \text{norm}_2.\text{reg} \wedge \text{hasNorm}(\text{ctrb}_1, \text{norm}_1)$ $\wedge\, \text{hasNorm}(\text{ctrb}_2, \text{norm}_2)$ $\wedge\, \mathbf{norm_1.strength} \geqslant \mathbf{0} \wedge \mathbf{ctrb_1.value} \geqslant \mathbf{0}$ $\wedge\, \mathbf{norm_2.strength} \geqslant \mathbf{0} \wedge \mathbf{ctrb_2.value} \geqslant \mathbf{0}$ $\wedge\, \mathbf{norm_1.act} \not\supseteq \mathbf{norm_2.act}$ $\wedge\, \mathbf{ctrb_1.trans.prop} = \mathbf{ctrb_2.trans.prop}$ $\wedge\, \mathbf{ctrb_1.trans.deriv} = \mathbf{ctrb_2.trans.deriv}$ $\wedge\, \text{ctrb}_1.\text{causProb} > 0 \wedge \text{ctrb}_2.\text{causProb} > 0)$ $\rightarrow (\exists! \mathbf{int} \in \mathbf{Alternative})\Big(\text{relates}(\text{int}, \text{norm}_1) \wedge \text{relates}(\text{int}, \text{norm}_2)$ $\wedge\, \text{relates}(\text{int}, \text{norm}_1.\text{act}) \wedge \text{relates}(\text{int}, \text{norm}_2.\text{act})$ $\wedge\, \text{relates}(\text{int}, \text{ctrb}_1) \wedge \text{relates}(\text{int}, \text{ctrb}_2)$ $\wedge\, (((\mathbf{ctrb_1.trans} = \mathbf{ctrb_2.trans} \wedge \mathbf{norm_1.act} \not\subseteq \mathbf{norm_2.act})$ $\quad \rightarrow \mathbf{int.modalStr} = \mathbf{1})$ $\vee\, ((\mathbf{ctrb_1.trans} \neq \mathbf{ctrb_2.trans} \vee \mathbf{norm_1.act} \subset \mathbf{norm_2.act})$ $\quad \rightarrow \mathbf{int.modalStr} = \mathbf{0.5}))$ $\wedge\, \text{int.deonticStr} = (\lvert \text{norm}_1.\text{strength} \rvert + \lvert \text{norm}_2.\text{strength} \rvert)/2$ $\wedge\, \text{int.beliefStr} = (\text{ctrb}_1.\text{belief.strength} + \text{ctrb}_2.\text{belief.strength})/2$ $\wedge\, \text{int.causationStr} = \text{ctrb}_1.\text{causProb} \times \text{ctrb}_2.\text{causProb}\Big)\Big)$
Cumulative rules	$(\forall \text{int}_A, \text{int}_B \in \text{Alternative})(\forall \text{norm}_1, \text{norm}_2, \text{norm}_3 \in \text{Norm})\Big($ $(\text{relates}(\text{int}_A, \text{norm}_1) \wedge \mathbf{relates}(\mathbf{int_A}, \mathbf{norm_2}) \wedge \mathbf{relates}(\mathbf{int_B}, \mathbf{norm_2})$ $\wedge\, \text{relates}(\text{int}_B, \text{norm}_3) \wedge \text{norm}_1 \neq \text{norm}_3)$ $\rightarrow (\exists! \mathbf{cumInt} \in \mathbf{Alternative})($ $\quad \text{partOf}(\text{int}_A, \text{cumInt}) \wedge \text{partOf}(\text{int}_B, \text{cumInt}))\Big)$ $(\forall \mathbf{cumInt_A}, \mathbf{cumInt_B}, \mathbf{int_1}, \mathbf{int_2}, \mathbf{int_3} \in \mathbf{Alternative})\Big(($ $\text{partOf}(\text{int}_1, \text{cumInt}_A) \wedge \mathbf{partOf}(\mathbf{int_2}, \mathbf{cumInt_A}) \wedge \mathbf{partOf}(\mathbf{int_2}, \mathbf{cumInt_B})$ $\wedge\, \text{partOf}(\text{int}_3, \text{cumInt}_B) \wedge \text{int}_1 \neq \text{int}_3) \rightarrow \mathbf{cumInt_A} = \mathbf{cumInt_B}\Big)$

Table A.4: FOL rules for detecting **Repairable** Interactions

From Tables 4.5,4.6: r_1 is positive $ctr_1 \geqslant 0$ $ctr_2 < 0$ $a_1 \not\subseteq a_2$ $a_1 \not\supseteq a_2$ $t_1 \leftrightharpoons t_2 \rightarrow \Box$ $t_1.\text{deriv} \neq t_2.\text{deriv} \rightarrow \Diamond$	$(\forall \text{norm}_1, \text{norm}_2 \in \text{Norm})(\forall \text{ctrb}_1, \text{ctrb}_2 \in \text{Contribution})\Big($ $(\text{norm}_1.\text{reg} = \text{norm}_2.\text{reg} \wedge \text{hasNorm}(\text{ctrb}_1, \text{norm}_1)$ $\wedge \text{hasNorm}(\text{ctrb}_2, \text{norm}_2) \wedge \mathbf{norm_1.strength} \geqslant \mathbf{0}$ $\wedge \mathbf{ctrb_1.value} \geqslant \mathbf{0} \wedge \mathbf{ctrb_2.value} < \mathbf{0}$ $\wedge\ \mathbf{norm_1.act} \not\subseteq \mathbf{norm_2.act} \wedge \mathbf{norm_1.act} \not\supseteq \mathbf{norm_2.act}$ $\wedge\ \text{ctrb}_1.\text{trans.prop} = \text{ctrb}_2.\text{trans.prop}$ $\wedge\ \text{ctrb}_1.\text{trans.deriv} \neq \text{ctrb}_2.\text{trans.deriv}$ $\wedge\ \text{ctrb}_1.\text{causProb} > 0 \wedge \text{ctrb}_2.\text{causProb} > 0)$ $\rightarrow (\exists! \text{int} \in \text{Repairable})\Big(\text{relates}(\text{int}, \text{norm}_1) \wedge \text{relates}(\text{int}, \text{norm}_2)$ $\wedge\ \text{relates}(\text{int}, \text{ctrb}_1) \wedge \text{relates}(\text{int}, \text{ctrb}_2)$ $\wedge\ (\ \mathbf{inv}(\mathbf{ctrb_1.trans}, \mathbf{ctrb_2.trans}) \rightarrow \mathbf{int.modalStr} = \mathbf{1})$ $\vee\ (\neg(\mathbf{inv}(\mathbf{ctrb_1.trans}, \mathbf{ctrb_2.trans})) \rightarrow \mathbf{int.modalStr} = \mathbf{0.5}))$ $\wedge\ \text{int.deonticStr} = (\lvert\text{norm}_1.\text{strength}\rvert + \lvert\text{norm}_2.\text{strength}\rvert)/2$ $\wedge\ \text{int.beliefStr} = (\text{ctrb}_1.\text{belief.strength} + \text{ctrb}_2.\text{belief.strength})/2$ $\wedge\ \text{int.causationStr} = \text{ctrb}_1.\text{causProb} \times \text{ctrb}_2.\text{causProb}\Big)\Big)$
Cumulative rules	$(\forall \text{int}_A, \text{int}_B \in \text{Repairable})(\forall \text{norm}_1, \text{norm}_2, \text{norm}_3 \in \text{Norm})\Big(\Big($ $\text{relates}(\text{int}_A, \text{norm}_1) \wedge \mathbf{relates}(\mathbf{int_A}, \mathbf{norm_2}) \wedge \mathbf{relates}(\mathbf{int_B}, \mathbf{norm_2})$ $\wedge\ \text{relates}(\text{int}_B, \text{norm}_3) \wedge \text{norm}_1 \neq \text{norm}_3$ $\wedge\ (\exists \text{ctrb} \in \text{Contribution})(\text{hasNorm}(\text{ctrb}, \text{norm}_2) \wedge \text{ctrb.value} < 0$ $\wedge\ \text{relates}(\text{int}_A, \text{ctrb}) \wedge \text{relates}(\text{int}_B, \text{ctrb})))$ $\rightarrow (\exists! \mathbf{cumInt} \in \mathbf{Repairable})($ $\text{partOf}(\text{int}_A, \text{cumInt}) \wedge \text{partOf}(\text{int}_B, \text{cumInt}))\Big)$ $(\forall \mathbf{cumInt_A}, \mathbf{cumInt_B}, \mathbf{int_1}, \mathbf{int_2}, \mathbf{int_3} \in \mathbf{Repairable})\Big(\Big($ $\text{partOf}(\text{int}_1, \text{cumInt}_A) \wedge \mathbf{partOf}(\mathbf{int_2}, \mathbf{cumInt_A}) \wedge \mathbf{partOf}(\mathbf{int_2}, \mathbf{cumInt_B})$ $\wedge\ \text{partOf}(\text{int}_3, \text{cumInt}_B) \wedge \text{int}_1 \neq \text{int}_3) \rightarrow \mathbf{cumInt_A} = \mathbf{cumInt_B}\Big)$

Table A.5: FOL rules for detecting **Side-Effect** Interactions

From Table 4.6: r_1 is positive $ctr_1 > 0$ r_2 is positive $ctr_2 \leqslant 0$ $a_1 \not\subseteq a_2$ $a_1 \not\supseteq a_2$ $t_1 \leftrightharpoons t_2 \rightarrow \Box$ $t_1.\text{deriv} \neq t_2.\text{deriv} \rightarrow \Diamond$	$(\forall \text{norm}_1, \text{norm}_2 \in \text{Norm})(\forall \text{ctrb}_1, \text{ctrb}_2 \in \text{Contribution})\Big($ $\big(\text{norm}_1.\text{reg} = \text{norm}_2.\text{reg} \wedge \text{hasNorm}(\text{ctrb}_1, \text{norm}_1)$ $\wedge\ \text{hasNorm}(\text{ctrb}_2, \text{norm}_2)$ $\wedge\ \mathbf{norm_1.strength \geqslant 0 \wedge ctrb_1.value > 0}$ $\wedge\ \mathbf{norm_2.strength \geqslant 0 \wedge ctrb_2.value \leqslant 0}$ $\wedge\ \mathbf{norm_1.act \not\subseteq norm_2.act \wedge norm_1.act \not\supseteq norm_2.act}$ $\wedge\ \text{ctrb}_1.\text{trans.prop} = \text{ctrb}_2.\text{trans.prop}$ $\wedge\ \text{ctrb}_1.\text{trans.deriv} \neq \text{ctrb}_2.\text{trans.deriv}$ $\wedge\ \text{ctrb}_1.\text{causProb} > 0 \wedge \text{ctrb}_2.\text{causProb} > 0\big)$ $\rightarrow (\exists! \mathbf{int} \in \mathbf{SideEffect})\Big(\text{relates}(\text{int}, \text{norm}_1) \wedge \text{relates}(\text{int}, \text{norm}_2)$ $\wedge\ \text{relates}(\text{int}, \text{ctrb}_1) \wedge \text{relates}(\text{int}, \text{ctrb}_2)$ $\wedge\ (\ \mathbf{inv}(\mathbf{ctrb_1.trans}, \mathbf{ctrb_2.trans}) \rightarrow \mathbf{int.modalStr = 1})$ $\vee\ (\neg(\mathbf{inv}(\mathbf{ctrb_1.trans}, \mathbf{ctrb_2.trans})) \rightarrow \mathbf{int.modalStr = 0.5}))$ $\wedge\ \text{int.deonticStr} = (\lvert\text{norm}_1.\text{strength}\rvert + \lvert\text{norm}_2.\text{strength}\rvert)/2$ $\wedge\ \text{int.beliefStr} = (\text{ctrb}_1.\text{belief.strength} + \text{ctrb}_2.\text{belief.strength})/2$ $\wedge\ \text{int.causationStr} = \text{ctrb}_1.\text{causProb} \times \text{ctrb}_2.\text{causProb}\Big)\Big)$
Cumulative rules	$(\forall \text{int}_A, \text{int}_B \in \text{SideEffect})(\forall \text{norm}_1, \text{norm}_2, \text{norm}_3 \in \text{Norm})\Big(($ $\text{relates}(\text{int}_A, \text{norm}_1) \wedge \mathbf{relates}(\mathbf{int_A}, \mathbf{norm_2}) \wedge \mathbf{relates}(\mathbf{int_B}, \mathbf{norm_2})$ $\wedge\ \text{relates}(\text{int}_B, \text{norm}_3) \wedge \text{norm}_1 \neq \text{norm}_3$ $\wedge\ (\exists \text{ctrb} \in \text{Contribution})(\text{hasNorm}(\text{ctrb}, \text{norm}_2) \wedge \text{ctrb.value} < 0$ $\wedge\ \text{relates}(\text{int}_A, \text{ctrb}) \wedge \text{relates}(\text{int}_B, \text{ctrb})))$ $\rightarrow (\exists! \mathbf{cumInt} \in \mathbf{SideEffect})($ $\text{partOf}(\text{int}_A, \text{cumInt}) \wedge \text{partOf}(\text{int}_B, \text{cumInt}))\Big)$ $(\forall \mathbf{cumInt_A}, \mathbf{cumInt_B}, \mathbf{int_1}, \mathbf{int_2}, \mathbf{int_3} \in \mathbf{SideEffect})\Big(($ $\text{partOf}(\text{int}_1, \text{cumInt}_A) \wedge \mathbf{partOf}(\mathbf{int_2}, \mathbf{cumInt_A}) \wedge \mathbf{partOf}(\mathbf{int_2}, \mathbf{cumInt_B})$ $\wedge\ \text{partOf}(\text{int}_3, \text{cumInt}_B) \wedge \text{int}_1 \neq \text{int}_3) \rightarrow \mathbf{cumInt_A = cumInt_B}\Big)$

Table A.6: FOL rules for detecting **Compliance**

From Table 4.6: r_1 is positive ctr_1 is negative ctr_2 is negative $t_1 = t_2 \rightarrow \Box$ $t_1.deriv = t_2.deriv \rightarrow \Diamond$	$(\forall norm_1, norm_2 \in Norm)(\forall ctrb_1, ctrb_2 \in Contribution)\Big($ $(norm_1.reg = norm_2.reg \land hasNorm(ctrb_1, norm_1)$ $\land hasNorm(ctrb_2, norm_2) \land \mathbf{norm_1.strength \geqslant 0}$ $\land \mathbf{ctrb_1.value < 0} \land \mathbf{ctrb_2.value < 0}$ $\land ctrb_1.trans.prop = ctrb_2.trans.prop$ $\land ctrb_1.trans.deriv = ctrb_2.trans.deriv$ $\land ctrb_1.causProb > 0 \land ctrb_2.causProb > 0)$ $\rightarrow (\exists! \mathbf{int} \in \mathbf{Compliance})\Big(relates(int, norm_1) \land relates(int, norm_2)$ $\land relates(int, ctrb_1) \land relates(int, ctrb_2)$ $\land (\mathbf{v_1.trans = ctrb_2.trans \rightarrow int.modalStr = 1})$ $\lor (\neg(\mathbf{ctrb_1.trans = ctrb_2.trans}) \rightarrow \mathbf{int.modalStr = 0.5}))$ $\land int.deonticStr = (\lvert norm_1.strength\rvert + \lvert norm_2.strength\rvert)/2$ $\land int.beliefStr = (ctrb_1.belief.strength + ctrb_2.belief.strength)/2$ $\land int.causationStr = ctrb_1.causProb \times ctrb_2.causProb\Big)\Big)$
Cumulative rules	$(\forall int_A, int_B \in Compliance)\Big(\Big((\forall norm_1, norm_2, norm_3 \in Norm)($ $relates(int_A, norm_1) \land \mathbf{relates(int_A, norm_2)} \land \mathbf{relates(int_B, norm_2)}$ $\land relates(int_B, norm_3) \land norm_1 \neq norm_3 \land norm_2.strength \geqslant 0$ $\land (\exists ctrb \in Contribution)(hasNorm(ctrb, norm_2)$ $\land relates(int_A, ctrb) \land relates(int_B, ctrb)))$ $\rightarrow (\exists! \mathbf{cumInt} \in \mathbf{Compliance})($ $partOf(int_A, cumInt) \land partOf(int_B, cumInt))\Big)$ $(\forall \mathbf{cumInt_A, cumInt_B, int_1, int_2, int_3 \in Compliance})\Big(($ $partOf(int_1, cumInt_A) \land \mathbf{partOf(int_2, cumInt_A)} \land \mathbf{partOf(int_2, cumInt_B)}$ $\land partOf(int_3, cumInt_B) \land int_1 \neq int_3) \rightarrow \mathbf{cumInt_A = cumInt_B}\Big)$

Table A.7: FOL rules for detecting **Safety** due to Negation of Causation

From Table 4.7: r_1 is positive r_2 is positive ctr_1 is negative $freq_1 \leqslant 0.25$ $freq_2 \geqslant 0.5$ ctr_2 is negative $t_1 = t_2 \rightarrow \square$ $t_1.\text{deriv} = t_2.\text{deriv} \rightarrow \lozenge$ ctr_2 is positive $t_1 \leftrightharpoons t_2 \rightarrow \square$ $t_1.\text{deriv} \neq t_2.\text{deriv} \rightarrow \lozenge$	$(\forall \mathbf{norm_1}, \mathbf{norm_2} \in \mathbf{Norm})(\forall \mathbf{ctrb_1}, \mathbf{ctrb_2} \in \mathbf{Contribution})\Big($ $\big(\text{norm}_1.\text{reg} = \text{norm}_2.\text{reg} \wedge \text{hasNorm}(\text{ctrb}_1, \text{norm}_1)$ $\wedge\, \text{hasNorm}(\text{ctrb}_2, \text{norm}_2) \wedge \mathbf{norm_1.strength} \geqslant \mathbf{0}$ $\wedge\, \mathbf{ctrb_1.value} < \mathbf{0} \wedge \mathbf{norm_2.strength} \geqslant \mathbf{0}$ $\wedge\, \text{ctrb}_1.\text{trans.prop} = \text{ctrb}_2.\text{trans.prop}$ $\wedge\, ((\mathbf{ctrb_2.value} < \mathbf{0} \wedge \mathbf{ctrb_1.trans.deriv} = \mathbf{ctrb_2.trans.deriv})$ $\vee\, (\mathbf{ctrb_2.value} \geqslant \mathbf{0} \wedge \mathbf{ctrb_1.trans.deriv} \neq \mathbf{ctrb_2.trans.deriv}))$ $\wedge\, \mathbf{ctrb_1.causProb} \leqslant \mathbf{0.25} \wedge \mathbf{ctrb_2.causProb} \geqslant \mathbf{0.5}\big)$ $\rightarrow (\exists! \mathbf{int} \in \mathbf{Safety})\Big(\text{relates}(\text{int}, \text{norm}_1) \wedge \text{relates}(\text{int}, \text{norm}_2)$ $\wedge\, \text{relates}(\text{int}, \text{ctrb}_1) \wedge \text{relates}(\text{int}, \text{ctrb}_2)$ $\wedge\, (\,(\mathbf{ctrb_1.trans} = \mathbf{ctrb_2.trans} \vee \mathbf{inv}(\mathbf{ctrb_1.trans}, \mathbf{ctrb_2.trans})$ $\rightarrow \mathbf{int.modalStr} = \mathbf{1})$ $\vee\, (\neg(\mathbf{ctrb_1.trans} = \mathbf{ctrb_2.trans} \vee \mathbf{inv}(\mathbf{ctrb_1.trans}, \mathbf{ctrb_2.trans}))$ $\rightarrow \mathbf{int.modalStr} = \mathbf{0.5}))$ $\wedge\, \text{int.deonticStr} = (\lvert \text{norm}_1.\text{strength} \rvert + \lvert \text{norm}_2.\text{strength} \rvert)/2$ $\wedge\, \text{int.beliefStr} = (\text{ctrb}_1.\text{belief.strength} + \text{ctrb}_2.\text{belief.strength})/2$ $\wedge\, \text{int.causationStr} = (\mathbf{1} - \text{ctrb}_1.\text{causProb}) \times \text{v}_2.\text{causProb}\Big)\Big)$
Cumulative rules	$(\forall \mathbf{int_A}, \mathbf{int_B} \in \mathbf{Safety})\Big(\big(\forall \mathbf{norm_1}, \mathbf{norm_2}, \mathbf{norm_3} \in \mathbf{Norm})($ $\text{relates}(\text{int}_A, \text{norm}_1) \wedge \mathbf{relates}(\mathbf{int_A}, \mathbf{norm_2}) \wedge \mathbf{relates}(\mathbf{int_B}, \mathbf{norm_2})$ $\wedge\, \text{relates}(\text{int}_B, \text{norm}_3) \wedge \text{norm}_1 \neq \text{norm}_3 \wedge \text{norm}_2.\text{strength} \geqslant 0$ $\wedge\, (\exists \mathbf{ctrb} \in \mathbf{Contribution})(\text{hasNorm}(\text{ctrb}, \text{norm}_2) \wedge \text{ctrb.value} \leqslant 0$ $\wedge\, \text{ctrb.causProb} \leqslant 0.25 \wedge \text{relates}(\text{int}_A, \text{ctrb}) \wedge \text{relates}(\text{int}_B, \text{ctrb})))$ $\rightarrow (\exists! \mathbf{cumInt} \in \mathbf{Safety})\big(\text{partOf}(\text{int}_A, \text{cumInt}) \wedge \text{partOf}(\text{int}_B, \text{cumInt})\big)\Big)$ $(\forall \mathbf{cumInt_A}, \mathbf{cumInt_B}, \mathbf{int_1}, \mathbf{int_2}, \mathbf{int_3} \in \mathbf{Safety})\Big(\big($ $\text{partOf}(\text{int}_1, \text{cumInt}_A) \wedge \mathbf{partOf}(\mathbf{int_2}, \mathbf{cumInt_A}) \wedge \mathbf{partOf}(\mathbf{int_2}, \mathbf{cumInt_B})$ $\wedge\, \text{partOf}(\text{int}_3, \text{cumInt}_B) \wedge \text{int}_1 \neq \text{int}_3\big) \rightarrow \mathbf{cumInt_A} = \mathbf{cumInt_B}\Big)$

B

ALGORITHMS FOR COMPOSING TERM-BASED QUERY

Algorithm 4 describes the function *composeAction* that has two inputs: a conclusion c (for which a query is being composed) and a list `altList`. The output is a string containing the descriptions provided to the action in a certain conclusion c. Since the identifiable conclusion is about only one action (atomic or composed), this function simply returns the result of the *compose* function for the action.

Algorithm 4 : *composeAction* - Algorithm for composing the descriptions provided to the action in a conclusion

```
input  : a conclusion c
         a list altList of relations used for alternative
         descriptions
output : query Q for descriptions of the action regarded by c
begin
  | a ← action related to conclusion c via hasCauseEventType
  | return compose(a,altList)
```

Algorithm 5 describes the function *compose* that has as output a string containing the descriptions provided to an event type e and/or its sub-events concatenated as conjunction according to LC1. It is designed to be generic for event types, although in this stage of the work we consider only composition of actions. It has two inputs: an event type e and a list `altList`.

Algorithm 5 : *compose* - Algorithm for composing the descriptions when the event type considering its parts (LC1)

input : an event type e
a list $\mathfrak{altList}$ of relations used for alternative descriptions
output : query Q for event type e and its parts

```
begin
    Q ← composeDescriptions(e, altList)
    for e′ partOf e do          /* LC1:‘AND’ for composed event */
        /* recursive call for e′                  */
        Q′ ← compose(e′, altList)
        if Q′ ≠ ∅ then
            if Q ≠ ∅ then
                Q ← Q + ‘ AND ’
            Q ← Q + Q′
    return Q
```