Deception in Epistemic Causal Logic

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What is deception?

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- a logic needs to express belief states of agents.

For this purpose, we use

epistemic causal logic

$=$ causal logic [Giunchiglia, et al., AIJ 2004]

$+$ belief modality

Epistemic Causal Logic: Definitions

causal rule

A causal rule is of the form:

$$\phi \Rightarrow \psi \qquad (\phi, \psi : \text{propositional formula})$$

meaning "ψ is caused if ϕ is true."
A (causal) theory is a finite set of causal rules.

model

Given a theory T and an interpretation I, define

$$T^I = \{\, \psi \mid (\phi \Rightarrow \psi) \in T \text{ for some } \phi \text{ and } I \models \phi \,\}.$$

I is a model of T if I is the unique model of T^I.
If every model of T satisfies a formula F, written $T \models F$.
If T has no model, written $T \models \bot$.

Epistemic Causal Logic: Axioms

$U^t_{ab}\phi$: an agent a utters a sentence ϕ to an agent b at time t.
$B^t_a\phi$: an agent a believes a sentence ϕ at time t

Axioms for utterance and beliefs

(axioms of utterance): $U^t_{ab}\phi \Rightarrow U^t_{ab}\phi$ and $\neg U^t_{ab}\phi \Rightarrow \neg U^t_{ab}\phi$.

(axioms of belief): $B^t_a\phi \Rightarrow B^t_a\phi$ and $\neg B^t_a\phi \Rightarrow \neg B^t_a\phi$.

$B^t_a\phi \equiv B^t_a\psi$ if $\phi \equiv \psi$.

$B^t_a(\phi \wedge \psi) \equiv B^t_a\phi \wedge B^t_a\psi$.

(axioms of inertia): $B^t_a\phi \wedge B^{t+1}_a\phi \Rightarrow B^{t+1}_a\phi$

$\neg B^t_a\phi \wedge \neg B^{t+1}_a\phi \Rightarrow \neg B^{t+1}_a\phi$.

(axiom of truth): $B^t_a\top$ for any t.

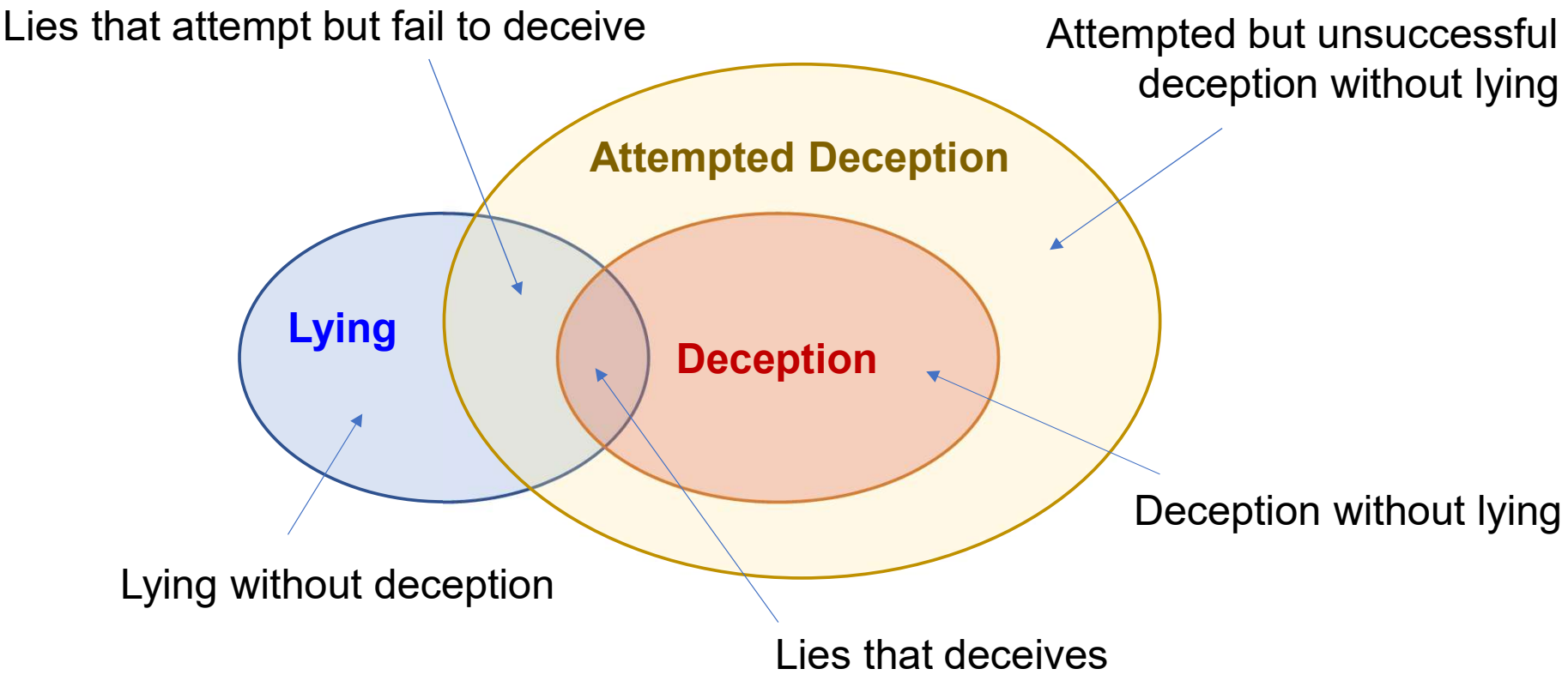
(axiom of rationality): $\neg B^t_a\bot$ for any t if a is *rational*.

(axiom of credibility): $U^t_{ab}\phi \Rightarrow B^{t+1}_b\phi$ if b is *credulous*.

(axiom of reflection): $U^t_{ab}\phi \Rightarrow B^{t+1}_b B^t_a\phi$ if b is *reflective*.

Lying, deception and attempted deception

(Carson,T.L. "Lying and Deception: Theory and Practice", 2010)



Deception by Lying

Lying (a: speaker, b: hearer, ϕ: sentence)

$$\mathrm{LIE}_{ab}^{t}(\phi) \stackrel{def}{=} B_a^t \neg\phi \wedge U_{ab}^t \phi$$

(a lies to b if a utters a believed-false sentence ϕ to b at t)

Deception by Lying

$$\mathrm{DBL}_{ab}^{t+1}(\phi) \stackrel{def}{=} \neg\phi \wedge (\,\mathrm{LIE}_{ab}^{t}(\phi) \Rightarrow B_b^{t+1}\phi\,).$$

(a lies to b at t on a false sentence ϕ, which causes b's believing ϕ at the next time step $t+1$)

Note

- In lying, a speaker a believes ϕ but the actual falsity of ϕ is not required.
- In DBL, the actual falsity of ϕ is required.

Properties of DBL (1)

DBL does not happen if a sentence ϕ is true

$$\phi \wedge \mathrm{DBL}_{ab}^{t+1}(\phi) \models \bot$$

Lying on a false sentence succeeds to deceive if a hearer is credulous, i.e., $U_{ab}^{t}\phi \Rightarrow B_{b}^{t+1}\phi$

$$\neg\phi \wedge \mathrm{LIE}_{ab}^{t}(\phi) \models B_{b}^{t+1}\phi$$

DBL on the valid sentence always fails

$$\mathrm{DBL}_{ab}^{t+1}(\top) \models \bot$$

DBL on the contradictory sentence fails if a hearer is rational, i.e., $\neg B_{b}^{t}\bot$

$$\mathrm{LIE}_{ab}^{t}(\bot) \wedge \mathrm{DBL}_{ab}^{t+1}(\bot) \models \bot \quad \text{if } b \text{ is rational.}$$

Properties of DBL (2)

DBL fails if a rational hearer believes the contrary

$B_b^t \neg\phi \wedge \mathrm{LIE}_{ab}^t(\phi) \wedge \mathrm{DBL}_{ab}^{t+1}(\phi) \models \bot$ if b is rational.

If a rational hearer is credulous, DBL succeeds even if the hearer believes the contrary

$\neg\phi \wedge B_b^t \neg\phi \wedge \mathrm{LIE}_{ab}^t(\phi) \models B_b^{t+1}\phi$
if b is credulous and rational.

A hearer b does not believe that a speaker a is lying if b is rational, reflective (i.e., $U_{ab}^t\phi \Rightarrow B_b^{t+1}B_a^t\phi$) and believes that a is also rational.

$\mathrm{LIE}_{ab}^t(\phi) \wedge B_b^{t+1}(\mathrm{LIE}_{ab}^t(\phi)) \models \bot$ if b is rational, reflective, and believes that a speaker a is rational.

Deception without Lying

Deception by Bluffing

$$\mathrm{DBB}^{t+1}_{ab}(\phi) \stackrel{def}{=} \neg\phi \wedge (\,\mathrm{BLUF}^{t}_{ab}(\phi) \Rightarrow B^{t+1}_{b}\phi\,)$$

where $\mathrm{BLUF}^{t}_{ab}(\phi) \stackrel{def}{=} \neg B^{t}_{a}\phi \wedge \neg B^{t}_{a}\neg\phi \wedge U^{t}_{ab}\phi$

Deception by Truthful Telling

$$\mathrm{DBT}^{t+1}_{ab}(\phi) \stackrel{def}{=} \neg\phi \wedge (\,\mathrm{TRT}^{t}_{ab}(\phi) \Rightarrow B^{t+1}_{b}\phi\,)$$

where $\mathrm{TRT}^{t}_{ab}(\phi) \stackrel{def}{=} B^{t}_{a}\phi \wedge U^{t}_{ab}\phi$

Deception by Omission (or withholding information)

$$\mathrm{DBO}^{t+1}_{ab}(\phi) \stackrel{def}{=} \phi \wedge (\,\mathrm{WI}^{t}_{ab}(\phi) \Rightarrow \neg B^{t+1}_{b}\phi\,)$$

where $\mathrm{WI}^{t}_{ab}(\phi) \stackrel{def}{=} B^{t}_{a}\phi \wedge \neg U^{t}_{ab}\phi$

Intentional Deception

Intentional DBL and DBB

- $\text{I-DBL}_{ab}^{t+1}(\phi) \stackrel{def}{=} \neg\phi \wedge (\,\text{LIE}_{ab}^{t}(\phi) \wedge B_a^t B_b^{t+1}\phi \Rightarrow B_b^{t+1}\phi\,)$
- $\text{I-DBB}_{ab}^{t+1}(\phi) \stackrel{def}{=} \neg\phi \wedge (\,\text{BLUF}_{ab}^{t}(\phi) \wedge B_a^t B_b^{t+1}\phi \Rightarrow B_b^{t+1}\phi\,)$

By $B_a^t B_b^{t+1}\phi$, a speaker a believes that a hearer b will believe the false sentence ϕ in the next time step.

Intentional Deception

Intentional DBL and DBB

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- $\text{I-DBB}_{ab}^{t+1}(\phi) \stackrel{def}{=} \neg\phi \wedge (\,\text{BLUF}_{ab}^{t}(\phi) \wedge B_a^t B_b^{t+1}\phi \Rightarrow B_b^{t+1}\phi\,)$

Intentional DBT

$$\text{I-DBT}_{ab}^{t+1}(\phi,\psi) \stackrel{def}{=} \neg\psi \wedge (\,\text{TRT}_{ab}^{t}(\phi) \wedge B_a^t(B_b^{t+1}\phi \supset B_b^{t+1}\psi) \wedge B_a^t\neg\psi \Rightarrow B_b^{t+1}\psi\,)$$

A speaker a truthfully tells ϕ while a believes that a hearer b's believing ϕ leads to b's believing another false sentence ψ in the next time step.

Intentional Deception

Intentional DBL and DBB

- $\text{I-DBL}_{ab}^{t+1}(\phi) \stackrel{def}{=} \neg\phi \wedge (\,\text{LIE}_{ab}^{t}(\phi) \wedge B_a^t B_b^{t+1}\phi \Rightarrow B_b^{t+1}\phi\,)$
- $\text{I-DBB}_{ab}^{t+1}(\phi) \stackrel{def}{=} \neg\phi \wedge (\,\text{BLUF}_{ab}^{t}(\phi) \wedge B_a^t B_b^{t+1}\phi \Rightarrow B_b^{t+1}\phi\,)$

Intentional DBT

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Intentional DBO

$$\text{I-DBO}_{ab}^{t+1}(\phi) \stackrel{def}{=} \phi \wedge (\,\text{WI}_{ab}^{t}(\phi) \wedge B_a^t\neg B_b^t\phi \Rightarrow \neg B_b^{t+1}\phi\,)$$

A speaker a withholds ϕ while believing b's ignorance of ϕ, which causes b's disbelieving ϕ (or prevents b from believing ϕ) in the next time step.

Indirect Deception

- $\text{IN-DBL}_{ac}(\phi) \stackrel{def}{=} \text{(I-)DBL}_{ab}^{t+1}(\phi) \wedge \text{DBT}_{bc}^{t+2}(\phi)$
  (a's lying on ϕ results in b's believing a false sentence ϕ, and then b's truthful telling on ϕ results in c's believing ϕ)
- $\text{IN-DBB}_{ac}(\phi) \stackrel{def}{=} \text{(I-)DBB}_{ab}^{t+1}(\phi) \wedge \text{DBT}_{bc}^{t+2}(\phi)$
- $\text{IN-DBT}_{ac}(\phi) \stackrel{def}{=} \text{DBT}_{ab}^{t+1}(\phi) \wedge \text{DBT}_{bc}^{t+2}(\phi)$
- $\text{IN-DBO}_{ac}(\phi) \stackrel{def}{=} \text{(I-)DBO}_{ab}^{t+1}(\phi) \wedge \neg U_{bc}^{t+1}\phi \Rightarrow \neg B_{c}^{t+2}\phi$
  (a's withholding ϕ results in b's disbelieving a true sentence ϕ. Then b does not inform c of ϕ, which results in c's disbelieving ϕ)
- $\text{IN-I-DBT}_{ac}(\phi, \psi) \stackrel{def}{=} \text{I-DBT}_{ab}^{t+1}(\phi, \psi) \wedge \text{DBT}_{bc}^{t+2}(\psi)$

Self-Deception

Self-deception by lying produces contradictory belief

$$\mathrm{LIE}^t_{aa}(\phi) \wedge \text{(I-)}\mathrm{DBL}^{t+1}_{aa}(\phi) \models B^{t+1}_a \bot$$

$B^t_a \neg\phi$ in $\mathrm{LIE}^t_{aa}(\phi)$ implies $B^{t+1}_a \neg\phi$ by the axioms of inertia. $\mathrm{DBL}^{t+1}_{aa}(\phi)$ implies $B^{t+1}_a \phi$. Then, $B^{t+1}_a \neg\phi \wedge B^{t+1}_a \phi \equiv B^{t+1}_a \bot$

If a rational agent is credulous, self-DBL does not involve contradictory belief

$$\mathrm{LIE}^t_{aa}(\phi) \wedge \text{(I-)}\mathrm{DBL}^{t+1}_{aa}(\phi) \not\models B^{t+1}_a \bot$$

if a is credulous and rational

A credulous agent revises its belief from $B^t_a \neg\phi$ to $B^{t+1}_a \phi$. $B^{t+1}_a \phi$ implies $\neg B^{t+1}_a \neg\phi$ by the axiom of rationality. Then the axioms of inertia do not produce $B^{t+1}_a \neg\phi$ from $B^t_a \neg\phi$.

Self-Deception

Self-deception by bluffing does not produce contradictory belief

$$\mathrm{BLUF}^{t}_{aa}(\phi) \wedge \text{(I-)}\mathrm{DBB}^{t+1}_{aa}(\phi) \models \neg B^{t}_{a}\phi \wedge B^{t+1}_{a}\phi$$

Self-deception by omission does not produce contradictory belief

$$\mathrm{WI}^{t}_{aa}(\phi) \wedge \text{(I-)}\mathrm{DBO}^{t+1}_{aa}(\phi) \models B^{t}_{a}\phi \wedge \neg B^{t+1}_{a}\phi$$

(a person, who believes something true but does not refer to it, will *forget* it.)

Self-deception by truthful-telling does not contradict while inconsistency arises if accompanied by intention

- $\mathrm{TRT}^{t}_{aa}(\phi) \wedge \mathrm{DBT}^{t+1}_{aa}(\phi) \not\models B^{t+1}_{a}\bot$
- $\mathrm{TRT}^{t}_{aa}(\phi) \wedge \text{I-}\mathrm{DBT}^{t+1}_{aa}(\phi, \psi) \models B^{t+1}_{a}\bot$

Summary

- Different types of deception are formulated using epistemic causal logic.
- From the computational perspective, a causal theory handled in this study is translated into a logic program under the answer set semantics.
- The current framework is extended to handle more complicated cases by taking *a theory of mind* into consideration.