Introduction to Causal Data Analysis and Modeling with Coincidence Analysis

Module 1.2

Theories of Causation

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Overview

1. Purpose and goal of a theory of causation
2. Dimensions of variance between theories of causation
3. Overview over the main theories of causation
4. Regularity theory

Why a theory of causation?

Walter goes on vacation. His neighbor agrees to water Walter's plants. However, the neighbor is unreliable and regularly forgets to tend to the plants. When Walter returns, his plants are dead. Which of the following are causes of the death of Walter's plants?

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- Big Bang

Purpose of a theory of causation

- A theory of causation determines under what conditions X and Y are causally related. In other words, they provide a **definition** of the following form

$$X \text{ causes } Y \text{ if, and only if, } \Omega. \qquad (*)$$

- **Constraint:** candidate theories of form $(*)$ must reproduce pre-theoretic causal judgements.
- **Problem:** pre-theoretic causal judgements are often ambiguous and not always consistent.

Realistic goal of a theory of causation

- A theory of causation cannot attempt to capture *all* pre-theoretic causal judgments.
- The goal must be to account for a maximally large consistent proper subset of all pre-theoretic causal judgments.
- The theoretical literature on causation, so far, has not settled on one distinguished proper subset of pre-theoretic causal judgements that every theory has to reproduce.

→ There exist **multiple theories of causation**.

Reductionism vs. non-reductionism

Is causation a fundamental concept?

- A **reductionist theory** answers "no". The notion of causation can be defined in non-causal terms.
- A **non-reductionist theory** answers "yes". The notion of causation cannot be defined in non-causal terms.

Ontology of causation

What types of entities are causes and effects?

- **Widespread intuition 1:** causes and effects are occurrences, events, states of affairs in time and space.
  - The accident is the cause of Walter's injury.
- **Widespread intuition 2:** non-occurrences/absences/omissions can also be causally effective.
  - The absence of a traffic light is a cause of the accident.

→ **'Event' theories** vs. **'fact' theories**.

→ Theories remaining **non-committal** by referring to causes and effects by means of *variables*, *factors*, or *values* of variables/factors

General vs. singular causation

- Two causal relations must be kept apart: one on type level, **general causation**, and one on token level, **singular causation**.
- The relation of general causation connects types (of events or facts), the relation of singular causation connects tokens (of events or facts).
  - "Smoking causes lung cancer" vs. "Walter's smoking causes Walter's lung cancer".
  - "Collisions with icebergs cause shipwrecks" vs. "The Titanic's collision with the iceberg causes the Titanic's shipwreck".

→ **Token-level theories** vs. **type-level theories**.

Transitivity

Is causation transitive?

> Walter goes hiking. On a steep slope he sees that a huge boulder has dislodged 50 meters above him and is rolling towards him. At the last moment, he manages to duck. The boulder just misses his head. Walter remains uninjured. The dislodging of the boulder is a cause of Walter's ducking, which in turn is a cause of his physical integrity. Is the dislodging of the boulder also a cause of Walter's physical integrity?

- **Transitive theories** vs. **intransitive theories**.

Causal realism vs. causal anti-realism

Causal realism: Not only causes and effects and their behavior patterns exist but also the causal relation itself. (e.g. Tooley 1987)

Causal anti-realism: Only causes and effects and their behavior patterns exist. (e.g. Hume 1748)

➙ **Production theories** vs. **difference-making theories**.

Determinism

Is causation deterministic? Is indeterminism in data due to noise or fundamental?

Principle of determinism: Whenever the same types of causes occur, the same types of effects occur as well (same causes, same effects).

- According to the standard interpretation of quantum mechanics our universe is fundamentally indeterministic.
- It is unclear whether fundamental indeterminism percolates up.

→ **Deterministic theories** vs. **indeterministic theories**.

What are the properties of the notion(s) of causation to be analyzed?

- Is causation reducible?
- Does causation relate events or facts?
- Is causation a type-level or token-level relation?
- Is causation transitive?
- Does the causal relation itself exist (in addition to its relata)?
- Is causation deterministic?

→ Theories of causation take these conceptual decisions and render unclear pre-theoretic intuitions precise and transparent.

Regularity theory (Hume, Mill, Mackie)

Definition ①

A is a cause of *B* iff *A* is part of a redundancy-free set of conditions $A*X$ that, *ceteris paribus*, is regularly followed by *B*.

① reduces causation to regularities between factors taking values

① type-level

① allows for causation by absence/omission.

① deterministic

① non-transitive

① anti-realist, difference-making

① constitutes the conceptual fundament of CNA

Counterfactual theory (Lewis)

Definition ②

In a situation $\mathcal{S}$ in which events A and B occur, A is a cause of B iff it holds that had A not occurred in $\mathcal{S}$, B would not have occurred in $\mathcal{S}$ either.

- ② reduces causation to counterfactual dependencies between events
- ② token-level
- ② does not allow for causation by absence/omission
- ② deterministic
- ② transitive
- ② anti-realist, difference-making
- ② constitutes the conceptual fundament of the Potential Outcomes Framework (Rubin, Morgan, Winship)

Probabilistic theory (Reichenbach, Suppes)

Definition ③

A is a cause of B iff $\mathrm{P}(B|A) > \mathrm{P}(B)$ and there does not exist a further factor C such that $\mathrm{P}(B|A{*}C) = \mathrm{P}(B|C)$.

- ③ reduces causation to probabilistic dependencies between variables/factors
- ③ type-level
- ③ allows for causation by absence/omission.
- ③ non-deterministic
- ③ non-transitive
- ③ anti-realist, difference-making
- ③ constitutes the conceptual fundament Bayesian network methods (Pearl, Spirtes, Glymour, Scheines)

Interventionist theory (Woodward)

Definition ④

A is a cause of *B* iff there exists a possible intervention *I* on *A* that is accompanied by a change in *B*, when everything else is held fixed by interventions.

- ④ non-reductive
- ④ type-level
- ④ allows for causation by absence/omission
- ④ does not presuppose determinism
- ④ non-transitive
- ④ anti-realist, difference-making
- ④ constitutes the conceptual fundament of interventionist methods (Woodward, Pearl).

Mechanistic theory (Glennan)

Definition ⑤

An event A is a cause of an event B iff there is a mechanism connecting A and B.

- ⑤ non-reductive
- ⑤ token-level
- ⑤ does not allow for causation by absence/omission.
- ⑤ does not presuppose determinism
- ⑤ non-committal with respect to transitivity
- ⑤ realist, production
- ⑤ constitutes the fundament of Process Tracing (Beach, Pedersen)

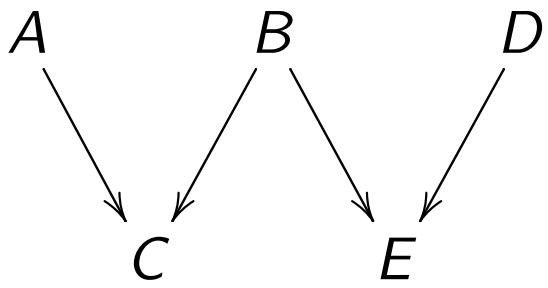
Summary

- There exist different theories of causation, each of which captures different aspects of causation and reproduces different pre-theoretic causal intuitions.
- There does *not exist a catch-all theory* of causation.
- All available theories have their advantages and disadvantages. They are more or less suitable for given research purposes.
- The theory that is most suitable for the goals pursued by CNA (and CCMs) is the **regularity theory** because it is custom-built to account for conjunctivity and disjunctivity.

Regularity theory

- Tradition goes back David Hume (1748) John Stuart Mill (1843).
- The best known modern regularity theory is the so-called **INUS theory** due to John Leslie Mackie, *The Cement of the Universe*, (1974).
- The aim of the INUS theory is to define causation in terms of Boolean operations of **sufficiency** and **necessity**.

The problem to be solved



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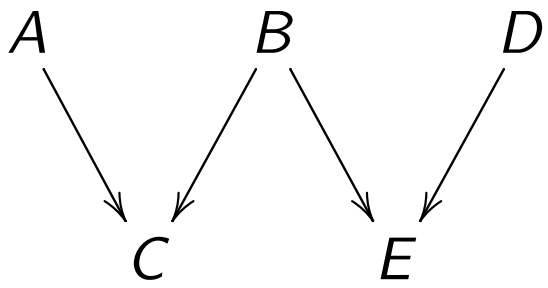

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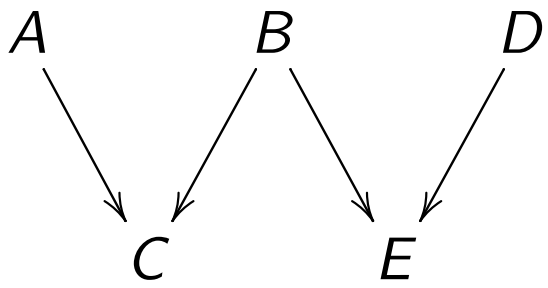

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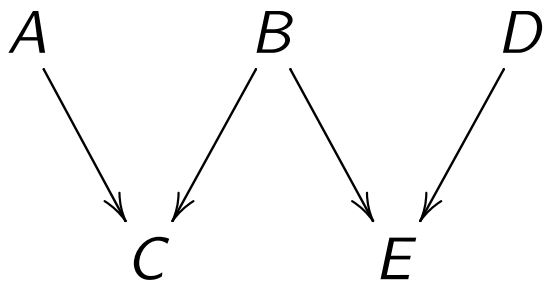

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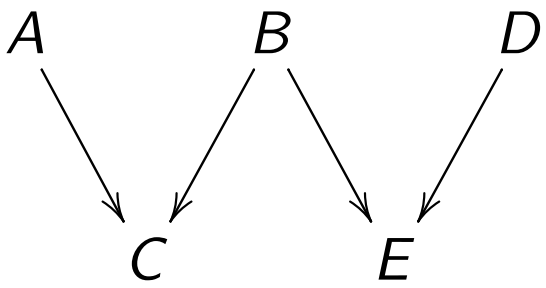

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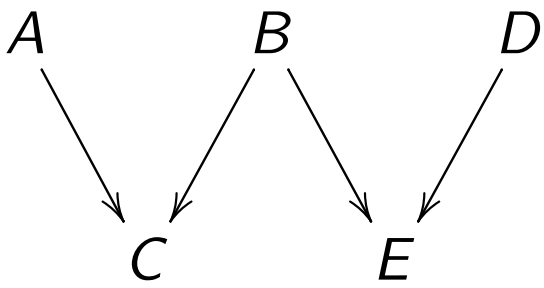

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but some do: $B + D \leftrightarrow E$ (2)

$\rightarrow$ Question: Which ones?

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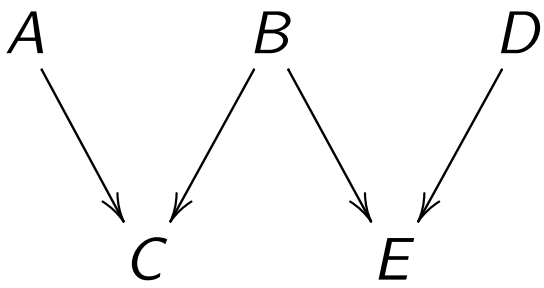

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but some do: $B + D \leftrightarrow E$ (2)

$\rightarrow$ Question: Which ones? Answer: the **redundancy-free ones**.

INUS theory of causation (Mackie)

INUS-condition

An INUS-condition of an effect B is an **i**nsufficient but **n**on-redundant part of an **u**nnecessary but **s**ufficient condition of B.

INUS causation

A is a cause of B if, and only if, A is at least an INUS-condition of B.

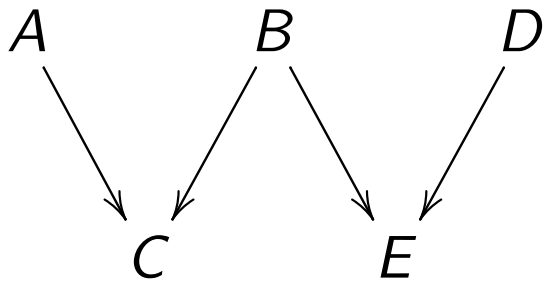
Example (match striking):

$$S{*}O{*}w \ + \ C{*}O \ + \ F{*}O \ + \ \ldots \ + \ X{*}y{*}Z \ \leftrightarrow \ B \qquad (1)$$

- Every sufficient condition on the left-hand side of (1) is redundancy-free.

➙ "Singing a song" (I) does not count as cause of B, despite $S{*}O{*}w{*}I \ \rightarrow \ B$.

Machester factory hooters problem



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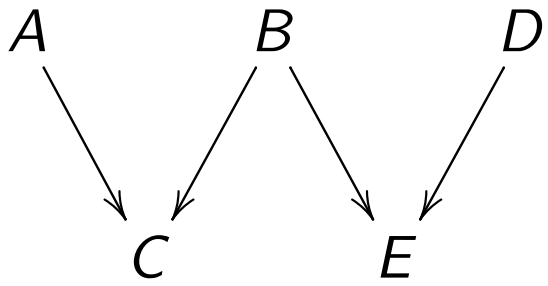

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$$B \rightarrow E$$

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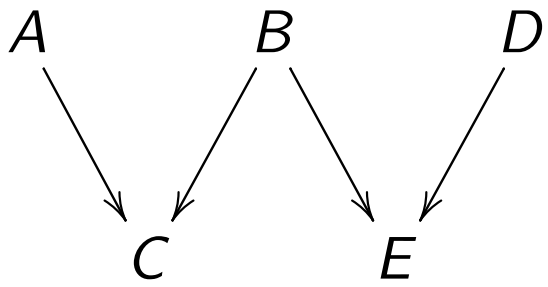

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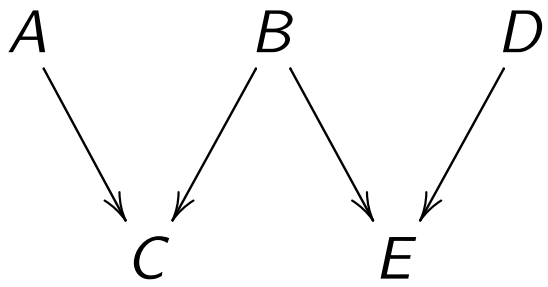

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What are the INUS-conditions of E?

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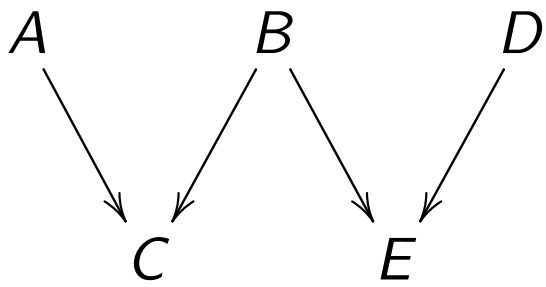
Solving the MFH problem



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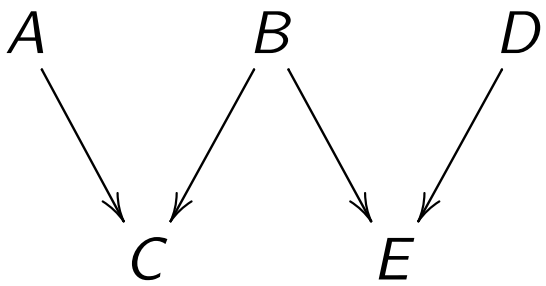
Solving the MFH problem



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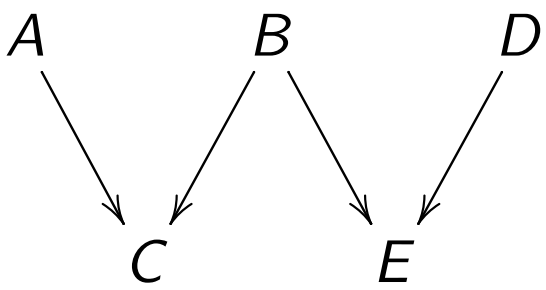
Solving the remaining problem of the INUS theory



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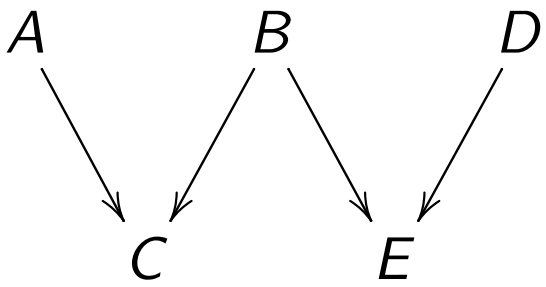
Solving the remaining problem of the INUS theory



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B	factory hooters go off at 5PM
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	A	B	C	D	E
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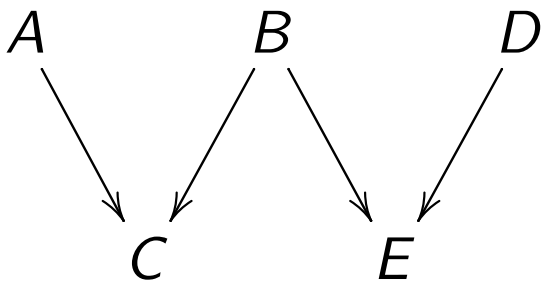
c_7	0	0	0	1	1
c_8	0	0	0	0	0

$$a{*}C + B + D \leftrightarrow E$$

it holds: $a{*}C \rightarrow B$ but not $B \rightarrow a{*}C$

Solving the remaining problem of the INUS theory



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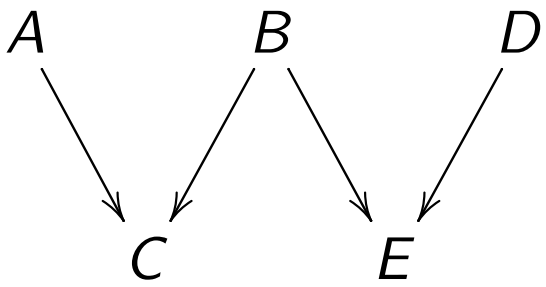
$$a{*}C + B + D \leftrightarrow E$$

it holds: $a{*}C \rightarrow B$ but not $B \rightarrow a{*}C$

it holds: $E \rightarrow B + D$ but neither $E \rightarrow a{*}C + B$ nor $E \rightarrow a{*}C + D$

Solving the remaining problem of the INUS theory



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$$\cancel{a^*C} + B + D \leftrightarrow E$$

it holds: $a^*C \rightarrow B$ but not $B \rightarrow a^*C$

it holds: $E \rightarrow B + D$ but neither $E \rightarrow a^*C + B$ nor $E \rightarrow a^*C + D$

$a^*C + B + D$ is not redundancy-free!

Rigorous redundancy elimination

- The INUS theory only eliminates redundancies from sufficient but not from necessary conditions.
- But causes are difference-makers; causal structures do not feature redundancies.
- Only sufficient and necessary conditions without any redundancies whatsoever are **difference-makers** and, hence, causally interpretable.

→ ***M***INUS-theory of causation.

Minimal sufficiency/necessity

Minimal sufficiency

A^*X is minimally sufficient for B iff A^*X is sufficient for B, and A^*X does not contain a sufficient proper part.

Minimal necessity

$A + X$ is minimally necessary for B iff $A + X$ is necessary for B, and $A + X$ does not contain a necessary proper part.

MINUS-formulas

atomic MINUS-formula

A minimally necessary disjunction of minimally sufficient conjunctions for B is an atomic *MINUS-formula* of B. (Beirlaen et al. 2018)

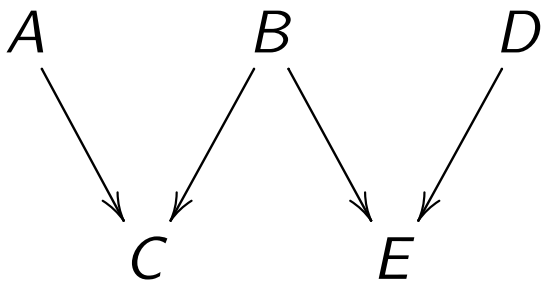
Example: $A{*}X_1 \ + C{*}X_2 \ \leftrightarrow B$

complex MINUS-formula

A complex MINUS-formula of outcomes $Y_1, \ldots, Y_n$ is a conjunction $(\Psi_1 \leftrightarrow Y_1){*} \ldots {*}(\Psi_n \leftrightarrow Y_n)$ of atomic MINUS-formulas that is itself redundancy-free, meaning it does not contain a logically equivalent proper part.

Example: $(A{*}X_1 \ + C{*}X_2 \ \leftrightarrow B){*}(B{*}X_3 \ + D{*}X_4 \ \leftrightarrow E)$

Factor set relativity



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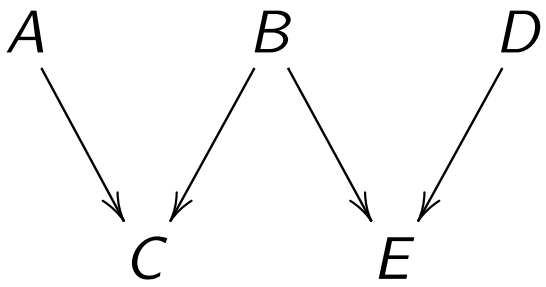
$$B + D \leftrightarrow E$$

Factor set relativity



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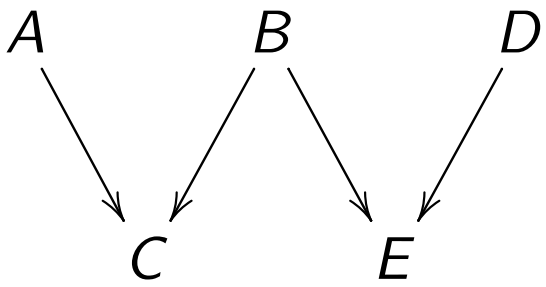
c_8	0	0	0	0

$$a{*}C + D + Z \leftrightarrow E$$

Factor set relativity



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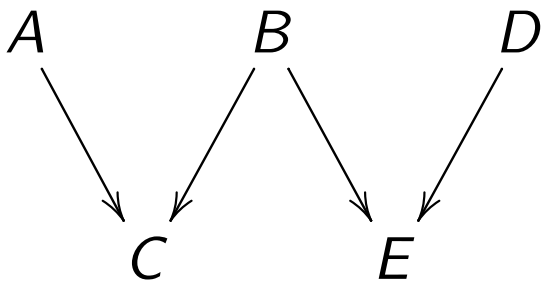
$$\cancel{a{*}C + D} + B \leftrightarrow E$$

Factor set relativity



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$$\cancel{a{*}C + D} + B \leftrightarrow E$$

- Factors that are contained in MINUS-formulas can only be causally interpreted if they remain part of a MINUS-formula across all factor set expansions, i.e. if they are **permanent parts** of a MINUS-formula.

MINUS theory of causation

MINUS theory of causation (Graßhoff/May 2001; Baumgartner/Falk 2019)

A is a cause of *B* iff *A* is contained in a MINUS-formula of *B* and remains part of a MINUS-formula for *B* across all expansions of analyzed factor sets.

- MINUS-formulas identify those sufficient and necessary conditions that are causally interpretable.
- Only Boolean dependency structures that are rigorously freed of redundant elements are difference-making structures and, thus, reflect causation.

→ A procedure of configurational data analysis that wants to uncover causation must infer minimally necessary disjunctions of minimally sufficient conditions, i.e. MINUS-formulas, from configurational data.

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