MODELING AND ANALYSIS OF CAUSAL RELATIONS

Understanding the causality behind criticality phenomena

Roman Gansch, Bosch; Tjark Koopmann, DLR

Causal relations for phenomena

- Causal theory applied to problem of understanding criticality phenomena
- Modeling of criticality phenomena with causal models
- Causality instead of correlation
- Measuring causality with metrics
- Mitigating causal influences with safety principles

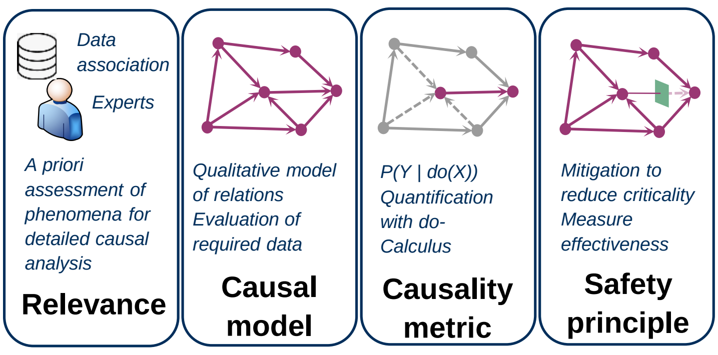

Figure 1: General workflow of understanding and mitigating a criticality phenomena. Relevant phenomena are analyzed in a causal model, their influence is measured with a metric and their impact is reduced by safety principles.

Causal models and metrics

We demonstrate the application of causality theory with an example from camera perception. As criticality phenomena the illumination and its effect on the performance is analyzed with weather as confounding effect.

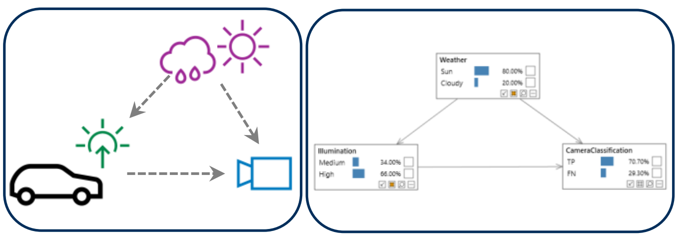

Figure 2: Example of a causal model for camera perception. Analysis is done on the *Illumination* node as exposure on the *CameraClassification* node as outcome. The *Weather* node is a confounding effect and has a strong influence the result of the evaluation.

To emphasize the importance of the causal analysis we analyze this example with exemplary data in a causal Bayesian network. The analysis shows that a correlational metric such as the conditional probability *P(Camera | Illum.)* leads to a wrong interpretation. The causal intervention metric *P(Camera | do(Illum.))* calculated with the do-calculus exposes the direct causal effect from the investigated phenomena. A strong deviation between correlation and causal metric emerges due to the confounding path via the weather node.

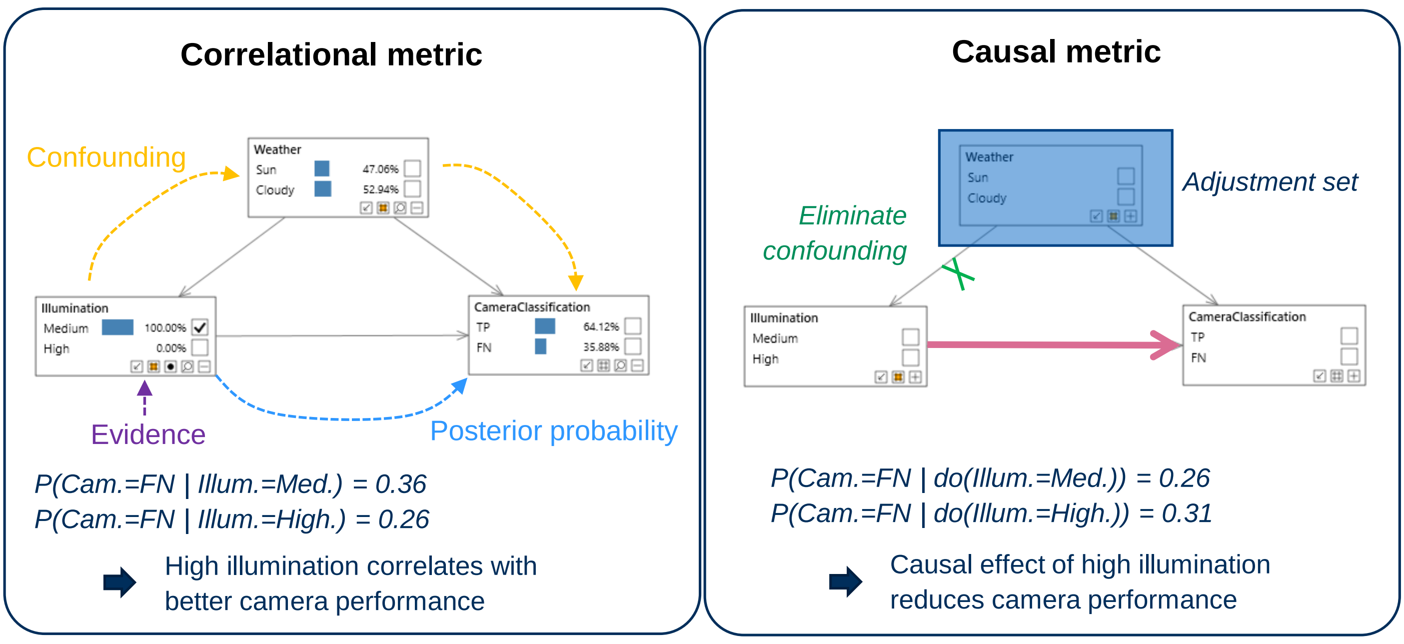

Figure 3: Difference between a correlational and causal analysis on the camera perception example.

www.vvm-projekt.de Twitter @vvm-project LinkedIn VVM Project

Projektpartner

A project developed by the VDA Leitinitiative autonomous and connected driving

Supported by: Federal Ministry for Economic Affairs and Climate Action on the basis of a decision by the German Bundestag

VERIFICATION
VALIDATION
METHODS

PROJECT of the PEGASUS FAMILY

Modeling of Causal Relations

- Causality cannot be inferred from data
  → Requires modeling of assumptions
- Vertices must be random variables
- Low dimensional outcome spaces are preferred
- Edges encode assumptions about causal connections
- CP is represented as binary variable
- Modeling of CR is enhanced inside an iteration cycle

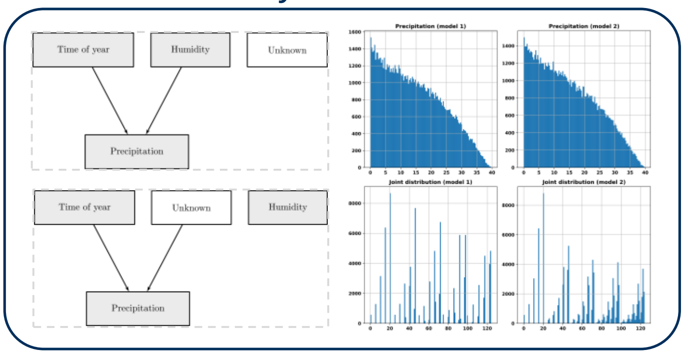

Figure 4: Comparison of the assumed causalities (model 1, upper) with the fabricated reality (model 2, lower). Compared variables are marked in light grey.

Assessment of model quality

We use two causality indicator functions in said iteration cycle. For a criticality metric $\varphi: S \to [0,1]$ and a variable X with outcome in $\{CP, \neg CP\}$, the explanation of the measured criticality due to the criticality phenomenon is given as

$$\sigma = 1 - \frac{E(\varphi | do(X = \neg CP))}{E(\varphi)}.$$

The Explanation of the emergence of CP is defined as the Kullback-Leibler divergence of the joint distributions of X together with relevant predecessors compared to the distribution of the same variables in comparison data.

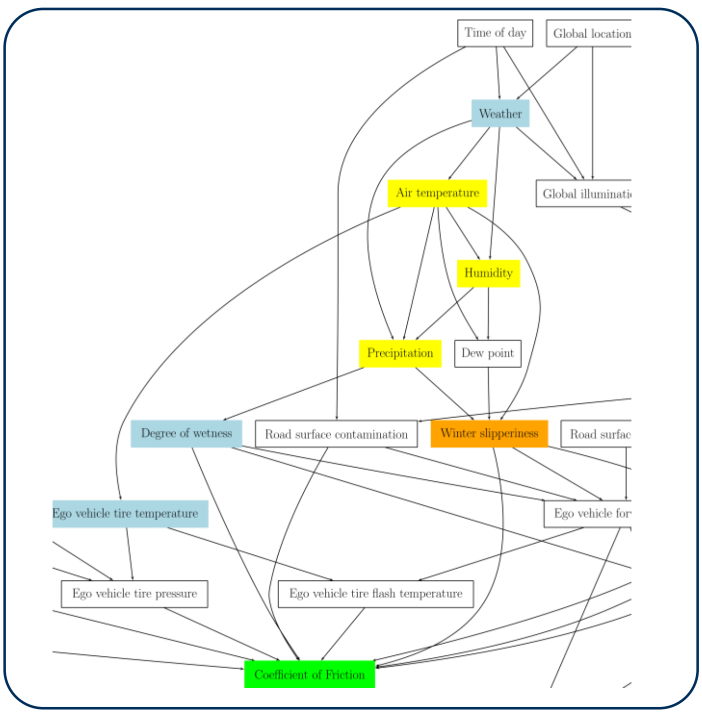

Figure 5: Minimal adjustment sets (marked in yellow and light blue) for the causal effect of winter slipperiness onto the coefficient of friction.

Example on the left: $\rho = 0.43$, where $\rho = 0$ would indicate equality. Camera classification example: $\sigma = 0.1$. $\sigma = 0$ indicates no explanation, while $\sigma = 1$ indicates perfect explanation. Since ρ is a purely associational quantity it should only be understood as a necessary condition for correct causality.

Tool support for modeling & analysis

For analysis we rely on the graph description language DOT. It offers broad compatibility with graph visualization tools (e.g. Graphviz), easy integration into common IDEs (e.g. Eclipse, VS Code) and support in analysis tools for causal graphs (e.g. pgmpy, DoWhy).

Paper in preparation:
Koopmann et al.,
„Causal Models in the Criticality Analysis for Automated Vehicles"

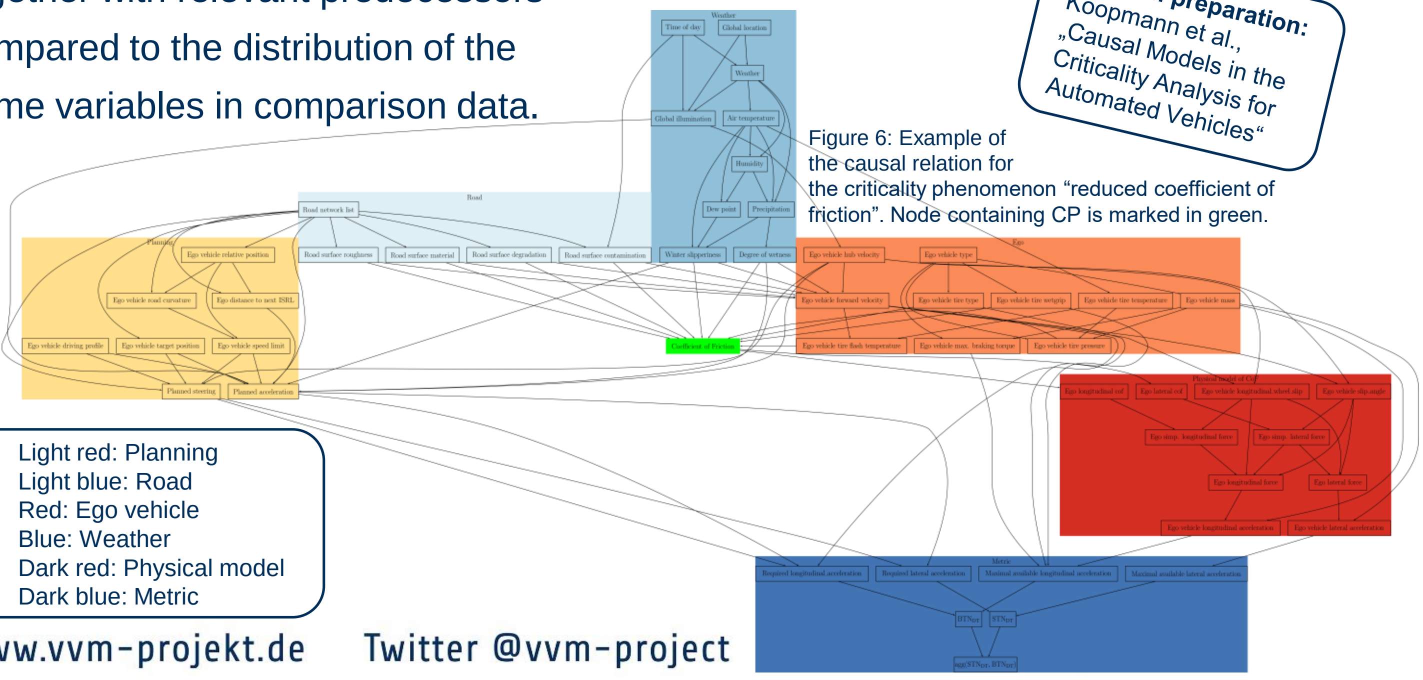

Figure 6: Example of the causal relation for the criticality phenomenon "reduced coefficient of friction". Node containing CP is marked in green.

- Light red: Planning
- Light blue: Road
- Red: Ego vehicle
- Blue: Weather
- Dark red: Physical model
- Dark blue: Metric

www.vvm-projekt.de   Twitter @vvm-project

Projektpartner

A project developed by the VDA Leitinitiative autonomous and connected driving

Supported by: Federal Ministry for Economic Affairs and Climate Action on the basis of a decision by the German Bundestag