
CoRe Essay 3

Causality

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Abstract

Causality, a profound force shaping our world, has intrigued scholars for centuries. This paper delves into the intricate realm of causality and its distinctiveness from mere covariation or association, highlighting the fundamental challenges of distinguishing between correlation and causation. This paper also examines the interplay of causality and time as a central theme, with a focus on causality's role in reconstructing past events and predicting future outcomes. Building a computational model for causal reasoning involves meticulous data collection, causal discovery through constraint-based and score-based algorithms, and the construction of causal graphs.

1 Introduction

Causality, the enigmatic force that defines the way events and phenomena unfold in our world, has long captivated the imagination of scholars and thinkers. Understanding causality goes beyond merely recognizing associations in time and space. It delves into the core fabric of reality, elucidating the intricate tapestry of relationships among variables.

Causal modeling, an interdisciplinary field, finds its roots in the statistical revolution of the 1920s [4]. At its core, a causal model is a powerful tool that allows us to make predictions about the behavior of complex systems. It not only forecasts how variables interact but also provides insights into counterfactual claims about the system's behavior. Furthermore, it empowers us to predict the effects of interventions, shedding light on how changing one variable might influence others. Causal models also reveal the probabilistic dependence or independence of the variables within the system, offering a structured way to dissect complex relationships.

2 Causality is different from covariation/association

Covariation or association pertains to the statistical observation that when one variable changes, another variable also changes. This relationship is quantified through correlation, which measures the strength and direction of the association between two variables. In an association, there is no presumption of a cause-and-effect relationship. It simply means that as one variable varies, the other tends to vary as well. However, this covariation may not necessarily imply a direct or indirect causal link.

Causation, on the other hand, goes beyond mere association. Causation asserts that changes in one variable directly bring about changes in another, indicating a cause-and-effect relationship between the variables. In a causal relationship, not only are the two variables correlated, but there is also a mechanism or link by which one variable influences the other. Establishing causation is a more stringent requirement in scientific research because it demands evidence of a causal pathway.

The distinction between correlation and causation is fundamental in research, and it is exemplified by two significant challenges: [1]

The Third Variable Problem: This problem arises when a third variable, known as a confounder, influences both of the variables that appear correlated. The confounder can create the illusion of a causal relationship between the two variables when, in fact, there is none. For example, in the case of the correlation between ice cream sales and violent crime rates, hot temperatures can be the confounding variable that affects both variables separately. Failure to account for such third variables can introduce bias into research and lead to incorrect causal inferences.

The Directionality Problem: This problem occurs when two variables are correlated, and there may indeed be a causal relationship between them, but it is difficult to determine the direction of causation. In other words, it's unclear which variable is causing changes in the other, or if there might be a bidirectional causal relationship. For instance, the correlation between vitamin D levels and depression doesn't reveal whether low vitamin D causes depression, if depression leads to reduced vitamin D intake, or if there is a complex interplay between the two.

In summary, correlation reflects a statistical association between variables, while causation implies a direct cause-and-effect relationship. Recognizing the distinction between these concepts and addressing challenges such as the third variable problem and the directionality problem is crucial for conducting rigorous and valid scientific research. Researchers must exercise caution in drawing causal conclusions, especially when dealing with observational data, and consider alternative explanations for observed associations.

3 Causal perception is special

Perception has long been a central topic in the realm of cognitive psychology, encompassing various sensory modalities such as vision, audition, and touch. While it is widely acknowledged that perception serves as the foundational basis for cognitive processes, there is an ongoing debate [6, 8] surrounding the delineation between perception and cognition. This debate has particularly gained prominence in the context of causal perception, wherein individuals discern the relationships between events in their environment.

The traditional view in psychology has often drawn a clear distinction between perception and cognition, with sensory perception considered a relatively bottom-up process. However, recent research has raised questions about this dichotomy, suggesting that certain perceptual processes, such as color perception, may be influenced by cognitive factors, thus blurring the lines between sensory and cognitive aspects. It is within this context that the examination of causal perception's unique characteristics becomes paramount.

While some argue that causal perception shares commonalities with sensory perception, empirical evidence [3, 2] suggests that it is more closely associated with higher-level cognitive functions. Causal perception involves the extraction and interpretation of causal relationships from sensory information. This process is inherently more complex than straightforward sensory perception and requires the integration of contextual and temporal information, involving cognitive functions such as memory, reasoning, and inference. The speed and flexibility with which individuals can make causal inferences suggest that cognitive processes are closely interwoven with the perception of causality.

4 The role of time in causality

Causality and temporality are fundamental concepts that have captivated the realms of philosophy, physics, statistics, computer science, and other academic disciplines. The interconnection of causality and time has been a subject of profound interest and debate, with implications extending to various practical fields.

One of the central themes in the literature is the capacity of causality to facilitate the reconstruction of past events. The ability to infer causality relationships between events that have already transpired provides insights into the historical sequence of events. This aspect of causality is closely tied to time, as the temporal order of cause and effect is intrinsic to this process. We explore the methodologies and implications of using causality to reconstruct the past in various academic and practical contexts.

Another salient facet of the literature is the role of causality in predicting future events through counterfactual reasoning. Causality, by identifying relationships between variables and events, enables the formulation of hypothetical scenarios or "what-if" questions. By manipulating causal factors,

the future can be predicted, and alternative outcomes explored. This predictive aspect of causality relies heavily on the understanding of how time plays a role in the causal relationships, especially the requirement that the cause precedes the effect in time.

The literature [5] underscores the critical importance of time's duration and direction in causality. While time itself is often regarded as unidirectional in our subjective experience, the time-reversibility of physical laws introduces complexities into the equation. Some physical laws exhibit temporal symmetry, implying that causality can operate in both temporal directions, while others are asymmetrical and valid in only one direction. The paper examines how these varying conceptions of time in causality impact our understanding of the relationship between cause and effect.

5 Causal modeling

The ability to discern causal relations and structures from observational data is a complex yet essential endeavor, as it empowers us to go beyond the mere observation of correlations and toward a deeper understanding of the mechanisms governing various phenomena. Building a computational model for capturing causal relations and structures offers a means to unlock this understanding, with significant implications for decision-making, policy formulation, and scientific discovery.

The foundation of any computational model for capturing causality lies in the data [7]. The process begins with the collection of observational data, which serves as the raw material for identifying causal relationships. Data collection should be carried out meticulously, taking into account the characteristics of the dataset, such as the data type (cross-sectional, time-series, or longitudinal), the quality of the data, and the potential presence of confounding variables. The selection of an appropriate dataset is critical to ensure the success of the causal modeling process.

Causal discovery involves the identification of causal relationships among variables within the dataset. This step typically entails two broad approaches: constraint-based and score-based algorithms. Constraint-based algorithms employ statistical tests to establish conditional independence relationships, ultimately forming a causal graph that represents the causal structure. Score-based algorithms, on the other hand, assign scores to candidate causal graphs based on various criteria, such as the Bayesian Information Criterion. The choice between these approaches depends on the complexity of the dataset and the computational resources available.

6 Conclusion

Causal inference is a powerful tool for understanding the relationships between variables and making informed decisions. However, researchers must be aware of the challenges and limitations associated with causal inference and employ appropriate methods and strategies to address them. Rigorous research design, data analysis, and interpretation are essential to draw valid causal conclusions and contribute to the advancement of knowledge in various fields.

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