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Do people reason rationally about causally related events? Markov violations, weak inferences, and failures of explaining away ☆

Benjamin M. Rottman [a,*], Reid Hastie [b]

[a] Learning Research and Development Center, University of Pittsburgh, 3939 O'Hara Street, Pittsburgh, PA 15260, United States
[b] The University of Chicago Booth School of Business, 5807 South Woodlawn Ave, Chicago, IL 60637, United States

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ABSTRACT

Making judgments by relying on beliefs about the causal relationships between events is a fundamental capacity of everyday cognition. In the last decade, Causal Bayesian Networks have been proposed as a framework for modeling causal reasoning. Two experiments were conducted to provide comprehensive data sets with which to evaluate a variety of different types of judgments in comparison to the standard Bayesian networks calculations. Participants were introduced to a fictional system of three events and observed a set of learning trials that instantiated the multivariate distribution relating the three variables. We tested inferences on chains $X_1 \rightarrow Y \rightarrow X_2$, common cause structures $X_1 \leftarrow Y \rightarrow X_2$, and common effect structures $X_1 \rightarrow Y \leftarrow X_2$, on binary and numerical variables, and with high and intermediate causal strengths. We tested transitive inferences, inferences when one variable is irrelevant because it is blocked by an intervening variable (Markov Assumption), inferences from two variables to a middle variable, and inferences about the presence of one cause when the alternative cause was known to have occurred (the normative "explaining away" pattern). Compared to the normative account, in general, when the judgments should change, they change in the normative direction. However, we also discuss a few persistent violations of the standard normative model. In addition, we evaluate the relative success of 12 theoretical explanations for these deviations.

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* Corresponding author.

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1. Introduction

Causal inference is a ubiquitous aspect of every-day life. How much will Apple Computer's stock increase if it releases a new model of iPhone before the holiday season? What if Samsung also releases a new model? What are my chances of developing Sickle Cell disease given that my mother has Sickle Cell disease? Does the probability increase if her mother also had Sickle Cell disease? How much better will I perform on the exam if I study one more hour? What if that means that I will get one hour less sleep? We make hundreds of judgments every day that rely on beliefs about how two or more events are causally and probabilistically related to each other.

Some theorists have even suggested that causal cognition is fundamental to almost all everyday and expert judgments (Hagmayer & Osman, 2012; Hastie, 2016). Many well-established phenomena from the literature on judgment and decision making are directly produced or are moderated by causal reasoning, including multiple-cue judgments, the reliance on base rate information in judgments under uncertainty, hindsight and belief perseveration, conjunction fallacies, the Planning Fallacy, and many aspects of consumer judgments. Many decisions can also be best understood as choosing actions because they are expected to <u>cause</u> desired outcomes (Hagmayer & Sloman, 2009). And, there are many empirical demonstrations that category classification and category-based inferences are saturated with causal reasoning (Murphy & Medin, 1985; Rehder, 2010).

The current research focuses on judgments that people make about multiple causal events embedded in a causal structure. For example, when predicting whether one has Sickle Cell disease from knowledge of one's mother's and grandmother's status, the following causal structure can be used to guide the prediction: [*Grandmother Has Sickle Cell Disease* → *Mother Has Sickle Cell Disease* → *Child's Sickle Cell Status*]. The judgment about whether to study for another hour for a test also makes use of causal structure knowledge; studying for an extra hour causes less sleep, and both the amount of studying and the amount of sleep influence exam performance. Many of the consequential judgments people make involve events embedded in networks.

The outline for the introduction is as follows. We first introduce the basic Causal Bayesian Network model of causal judgment. We then discuss limitations of prior experiments that have tested the CBN model. Finally, we discuss prior research on three reasoning habits that will be the focus of the current research.

1.1. The simple point-estimate Causal Bayesian Network (CBN) model

In the last two decades Graphical Probabilistic Models (also called Causal Bayesian Networks; CBN) have come to dominate the modeling of probabilistic causal phenomena in science, engineering, and medicine, and they have also become the most popular model of human causal reasoning (Holyoak & Cheng, 2011; Rips, 2008; Sloman & Lagnado, 2015; Waldmann & Hagmayer, 2013). Causal Bayesian Networks are specifically designed to handle inference problems for which the events are embedded within a causal network.

CBN theory works at both a qualitative and quantitative level. Qualitatively, the structure of the network can be used to deduce certain properties. For example, when predicting X_1 on the common cause network [$X_1 \leftarrow Y \rightarrow X_2$], once the state of Y is known X_2 is completely irrelevant. Additionally, the correlation between X_1 and Y must be stronger than the correlation between X_1 and X_2. Some of the most influential studies of inferences on causal networks have focused on qualitative judgments (Park & Sloman, 2013, except Experiment 3; Rehder, 2014; Rehder & Burnett, 2005).

CBN theory also can be used to make quantitative inferences such as estimating precisely the probability of X_1 given knowledge that Y is present, summarized as $P(x_1 = 1|y = 1)$. Making these quantitative inferences requires knowledge of the parameters that define the statistical relations between each cause–effect link in the network. There are two ways that such parameters can be conveyed to participants. The first is to verbally state the probability of each effect given its direct causes, or equivalently, the 'causal strength' that each cause has on its direct effects (Fernbach, Darlow, & Sloman, 2010; Fernbach & Rehder, 2013; Krynski & Tenenbaum, 2007; Morris & Larrick, 1995). Participants then