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An integrative paradigm for building causal knowledge

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Abstract

A core aspiration of the ecological sciences is to determine how systems work, which implies the challenge of developing a causal understanding. Causal inference has long been approached from a statistical perspective, which can be limited and restrictive for a variety of reasons. Ecologists and other natural scientists have historically pursued mechanistic knowledge as an alternative approach to causal understanding, though without explicit reference to the requirements of causal statistics. In this paper, I describe the premises of an expanded paradigm for causal studies, the Integrative Causal Investigation Paradigm, that subsumes causal statistics and mechanistic investigation into a multi-evidence approach. This paradigm is distinct from the one articulated by causal statistics in that it (1) focuses its attention on the long-term goal of building causal knowledge across multiple studies and (2) recognizes the essential role of mechanistic investigations in establishing a causal understanding. The Integrative Paradigm, consequentially, proposes that there are multiple methodological routes to building causal knowledge and thus represents a pluralistic perspective. This paper begins by describing the crux of the problem faced by causal statistics. To understand this problem, it should be recognized that the word *causal* has multiple meanings and a variety of evidential standards. An expanded vocabulary is developed so as to reduce ambiguities and clarify critical issues. I further show by example that there is an important ingredient typically omitted from consideration in causal statistics, which is the known information related to the mechanisms underlying relationships being evaluated. To address this issue, I describe a procedure, Causal Knowledge Analysis, that involves an evaluation and compilation of existing evidence indicative of causal content and the features of mechanisms. Causal Knowledge Analysis is applied to three example situations to illustrate the process and its potential for contributing to the development of causal knowledge. The implications of adopting the proposed paradigm and associated procedures are discussed and include the potential for advancing ecology, the potential for clarifying causal methodology, and the potential for contributing to predictive forecasting.

An author biosketch is provided in Appendix S1.

explicit reference to causal criteria. Causal Knowledge Analysis is particularly relevant for forecasting because of the potential for a deeper understanding of the mechanistic elements controlling predictability of phenomena. The prospects for successful prediction are heavily influenced by the nature of the mechanisms involved. Predictive ecologists have begun to discuss more thoroughly the issue of transportability (Yates et al., 2018). As this paper suggests, invariant mechanisms, including constraints, provide fertile bases for research to support forecasting. This paper seeks to encourage a more systematic accounting of evidence in support of documenting established causal knowledge. This documentation can serve multiple purposes, including as an aid to causal statistical analyses but also as an advent to understanding the predictability of various phenomena and the needed information to enhance prediction.

ON PARADIGMS, EPISTEMIC SYSTEMS, EXCEPTIONS, AND THE ROLE OF EXAMPLES

This paper refers to integrative causal investigation as a *paradigm*, which implies certain things. The use of this term is meant to conform to Kuhn's (2012) treatment of the subject and equates to a general worldview. The Integrative Paradigm as a distinct concept proposes the general worldview that causal understanding can be arrived at from statistical and mechanistic investigations. Aside from generality, another property of scientific paradigms described by Kuhn is the expectation that the concept will promote further evolution and refinement and is not an immutable prescription, which can of course be replaced by a slightly different prescription. Certainly, the general idea is ancient though it has taken the work of philosophers to remind us of the role of mechanisms in causal understanding. Causal Knowledge Analysis as presented has more of the properties of a prescribed list of criteria (e.g., Table 1 and Box 3) which should not be referred to as a paradigm.

Philosophical discussions of causality are importantly influenced by counter-examples. A motivation for emphasizing that the Integrative Paradigm is a pluralistic system is that it attempts to avoid dogmatism. The possibility that functional causal knowledge can be constructed without mechanistic understanding is certainly an accepted possibility within the Integrative Paradigm. As the capabilities of causal search methods and artificial intelligence develop, it is entirely possible that sufficient empirical search may lead to a level of prediction that goes beyond that possible by mechanistic explanation. The question remains as to whether such capabilities will enable diagnostic evaluations and novel interventions, but at this point such possibilities cannot be ruled out. What we can be sure of is that a variety of methods will ultimately contribute to our progress in developing a causal understanding of ecological systems.

This paper represents a bare beginning towards advancing causal inquiry. One potential outcome is for closer attention to be paid to the enterprise of building causal knowledge and understanding. Future development might focus on analysis of a wide range of specific examples. General commonalities may be identified while new types of evidence and interpretations are likely to arise as more examples are evaluated.

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CONFLICT OF INTEREST STATEMENT

The author declares no conflicts of interest.

DATA AVAILABILITY STATEMENT

Data from Broussard (2024) were used for Figure 5 and these data are available in figshare at https://doi.org/10.6084/m9.figshare.25999003.v1.

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