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Information as a tool to model causal complexity

The mechanistic causal process account, such as that offered by Salmon (1998) and Dowe (2000), offers a distinctive account of causation but one faced with a number of criticisms. Two problems are germane to this paper: it has difficulties picking out the right "grain size" with respect to size scale and organization; and it offers no way to understand why counterfactuals, especially interventionist counterfactuals (Woodward 2003), are ubiquitous and efficient in conveying information about causal relationships. As Williamson (2011) has pointed out, this mechanistic causal process approach is too low-level; it lacks the means to preclude downward causal drainage to the microphysical. I also note how the mechanistic causal process account fails with respect to three key characteristics of causation identified by Woodward (2010): stability of a causal relationship under changes to conditions; proportionality of changes in causes to changes in effects; and specificity of causal and effect, such that there are reasonably comparable numbers of potential causes and potential effects.

The spirit of Salmon's account, however, involves higher-level causal relata as genuinely causal, even if the details don't provide the means to ensure it. Further, his rejection of counterfactuals was motivated by a resistance to the modal realism of Lewis and others, and an emphasis on the actuality and productive character of causation. With additional conceptual tools, and a sense of the term 'counterfactual' that is firmly grounded in the actual world, we can utilize the mechanistic causal processes in a manner consistent with Salmon's general aim, but in a way that provides for a quite detailed mathematical modeling of complex causal structures, including arbitrarily high-level causal relata. While Salmon considered an information-theoretic approach to causation, the field of information theory has developed considerably since his writing, and has a number of tools that can be used to bring together the mechanistic causal process and interventionist counterfactual theories.

The goal of this paper is to demonstrate how causal relata and relationships can be represented in ways that render them amenable to the application of mathematical tools from information theory. It takes some philosophical preparation of the material, as it were, in order to apply these tools. I will not be developing the ways in which these tools can then be applied, but focusing on the preparatory aspects to show how the mechanistic causal process in conjunction with the interventionist counterfactual approach yield a target for information-theoretic treatment.

I introduce the notion of counterfactual robustness, first by using microstates and macrostates of a box of gas, and then generalizing to any counterfactually robust higher level causal relata. In an energetically isolated box of gas, there are many microstates of the gas that are equivalent with respect to a macrostate like being at a given temperature. The macrostate is a particular volume in phase space, such that all of the points representing microstates within the volume are of the same macrostate. It does not matter which point in that volume is occupied by the system, so long as it is some point in that volume. Further, this is not merely an epistemological point about knowing which point it occupies. The claim is stronger: the causal profile of the macrostate is genuinely indifferent to which of the relevant microstates are actualized. The macro state is thus counterfactually robust, in that a number of details about the microstate that actually occurred could have varied without changing the causal relationships into which the macro-level relatum entered.

This generalizes nicely to any causal relata that are counterfactually robust: the overwhelming majority of causal relata would have remained the same (considered in terms of their causal profile) had certain details of their microstate been different. The microstates, in the generalized version, are given by the precise details of the nexus of causal processes and interactions. Such counterfactually robust causal relata are thus not identical to their actual microinstantiations, but instead to those instantiations plus a counterfactual robustness zone, defining the boundary of what could have been different about the microstate such that the higher-level causal relata was not altered. The boundaries of this zone are given by the counterfactuals associated with the causal relata in question: the boundary in phase space is drawn by considering the relevant counterfactuals as ways to delineate what changes have or fail to have an outcome for the causal relata in question.

This means that causal relata can be represented as volumes in phase space, where 1) the phase space is defined in terms of degrees of freedoms of nodes in the nexus comprised of causal processes and interactions, and 2) the boundaries of the volumes are defined in terms of counterfactuals outlining the causal relationships or relata of interest. The final step is straightforward: those volumes can be partitioned in different ways, with a probability distribution put over the partition, so that we can evaluate information-theoretic relationships between different volumes in a shared phase space. Volumes with high mutual information, for instance, will reflect a high degree of connection in the causal nexus between the higher-level relata; high entropy between two volumes reflects a low degree of causal connectedness.

This approach allows us to address the shortcomings with Salmon's original view, by providing a precise way to determine the right "grain size" for maximizing stability, proportionality, and specificity (Woodward 2010) in representing complex, multi-level causal systems. The volumes representing causal relata can be partitioned in a variety of ways, with coarser or finer grain. We have discovered a proportional causal relationship in such a system when we find a partition size for causal relata that maximizes the mutual information between them, thus justifying that grain size as the 'right' one to use. Given a non-arbitrary choice of the level at which to characterize causal relata, we can then give very precise answers as to the stability of the causal relationship in question, across changes in background conditions as well as changes in level, and we can assess the specificity of our causal relata in terms of the value of the mutual information thus achieved, compared with other ways of drawing volume boundaries.

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