

## 9.5 Conclusions

This chapter has explicated and analyzed the interplay between the necessary and sufficient components of causation. Using counterfactual interpretations that rest on structural model semantics, we demonstrated how simple techniques of computing probabilities of counterfactuals can be used in computing probabilities of causes, deciding questions of identification, uncovering conditions under which probabilities of causes can be estimated from statistical data, and devising tests for assumptions that are routinely made (often unwittingly) by analysts and investigators.

On the practical side, we have offered several useful tools (partly summarized in Table 9.3) for epidemiologists and health scientists. This chapter formulates and calls attention to subtle assumptions that must be ascertained before statistical measures such as excess risk ratio can be used to represent causal quantities such as attributable risk or probability of causes (Theorem 9.2.14). It shows how data from both experimental and nonexperimental studies can be combined to yield information that neither study alone can reveal (Theorem 9.2.15 and Section 9.3.4). Finally, it provides tests for the commonly made assumption of “no prevention” and for the often asked question of whether a clinical study is representative of its target population (equation (9.32)).

On the conceptual side, we have seen that both the probability of necessity (PN) and probability of sufficiency (PS) play a role in our understanding of causation and that each component has its logic and computational rules. Although the counterfactual concept of necessary cause (i.e., that an outcome would not have occurred “but for” the action) is predominant in legal settings [Robertson, 1997] (Robertson 1997) and in ordinary discourse, the sufficiency component of causation has a definite influence on causal thoughts.

The importance of the sufficiency component can be uncovered in examples where the necessary component is either dormant or ensured. Why do we consider striking a match to be a more adequate explanation (of a fire) than the presence of oxygen? Recasting the question in the language of PN and PS, we note that, since both explanations are necessary for the fire, each will command a PN of unity. (In fact, the PN is actually higher for the oxygen if we allow for alternative ways

of igniting a spark). Thus, it must be the sufficiency component that endows the match with greater explanatory power than the oxygen. If the probabilities associated with striking a match and the presence of oxygen are denoted  $p_m$  and  $p_o$ , respectively, then the PS measures associated with these explanations evaluate to  $PS(\text{match}) = p_o$  and  $PS(\text{oxygen}) = p_m$ , clearly favoring the match when  $p_o \gg p_m$ . Thus, a robot instructed to explain why a fire broke out has no choice but to consider both PN and PS in its deliberations.

Should PS enter legal considerations in criminal and tort law? I believe that it should—as does I.J. Good (1993)—because attention to sufficiency implies attention to the consequences of one’s action. The person who lighted the match ought to have anticipated the presence of oxygen, whereas the person who supplied—or who could (but failed) remove—the oxygen is not generally expected to have anticipated match-striking ceremonies.

However, what weight should the law assign to the necessary versus the sufficient component of causation? This question obviously lies beyond the scope of our investigation, and it is not at all clear who would be qualified to tackle the issue or whether our legal system would be prepared to implement the recommendation. I am hopeful, however, that whoever undertakes to consider such questions will find the analysis in this chapter to be of some use. The next chapter combines aspects of necessity and sufficiency in explicating a more refined notion: “actual cause.”

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