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Practical guidance for developing causal network topology

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Abstract: Causal networks are signed digraphs, a graphical model to capture cause-and-effect relationships in a rigorous and logically consistent way. The network topology describes the physical and logical relationship of nodes in a network, the schematic arrangement of links and nodes, or some hybrid combination thereof. Once the topology of such a network is established, it opens the door for a wide range of powerful analysis and visualisation, such as causal inference and Bayesian network analysis.

This paper focuses on practical guidance in the development of network topology, both as a mental system model and as precursor for a Bayesian network. The development of network topology is a translation, an abstraction of mental, conceptual models into a strict logical framework of cause-and-effect relationships. This framework allows to test the internal logical consistency of a signed digraph with experts. In our experience, networks tend to get complex and, especially for multi-disciplinary subject matters, no single expert has expertise over the entire scope of the network. They necessarily focus on subdomains within their expertise. This often leads to convoluted causal pathways with counterintuitive relationships between starting and end nodes. Testing of the internal logic can be done by (1) listing all the causal links between starting nodes and end nodes and (2) propagating signs of relationships between nodes along causal pathways to determine the sign of the causal pathway. In the context of environmental impact assessment, this can be augmented by (3) propagating categorical, qualitative assessment of likelihood, consequence and mitigation options for each link.

While no single expert has expertise over the entire network, they can readily identify relationships that do not make sense, based on the result of the analysis above. Such counterintuitive results can include (1) unexpected links between starting and end nodes (or unexpected lack thereof), (2) starting nodes modelled to lead to an increase in an end node, while the opposite is expected (or vice versa) or (3) causal pathways with a likelihood/consequence/mitigation score much different than expected. Exposing these allows a targeted examination of the topology to identify which nodes are causing counterintuitive logical causal pathways. We found that the main reasons for counterintuitive pathways are (1) ambiguity in naming and defining nodes, (2) uncritical linking of nodes and (3) overly long causal pathways, i.e. pathways linking many nodes.

We developed several strategies to resolve counterintuitive causal pathways and refine the causal network topology in the context of causal networks for environmental impact assessment. Refining the definition and description of nodes is most important. It requires a critical assessment of what is included in the node and what is explicitly excluded. It often helped to replace value-laden node names (e.g. habitat degradation) with more neutral terms (e.g. habitat integrity) to avoid double negatives (a decrease in habitat degradation is a positive result in environmental impact assessment). We also developed logical rules to help in splitting nodes or combining nodes. This generally results in causal pathway that are better defined and more tractable. Within the context of environmental impact assessment, the development of causal network topology benefited greatly from a strict framework with node categories. We adopted a framework with five node types; driver, activity, stressor, process and endpoint, and imposed the rule that each causal pathway should have one of each node type, but no more (i.e. no links from stressor to stressor). While this occasionally leads to less intuitive descriptions, it imposed a structure on the network that made it much more accessible and tractable and therefore better suited for communication.

The development of causal networks is an iterative process. The guidance and advice we developed as part of this research greatly helps in engagement with experts and results in more robust causal networks, providing a sound basis for further analysis.

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