A summary view of causal models

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This is to summarize what I think are the key points relative to causal modelling and to identify research areas.

The debate on causation

The debate on causation is made difficult by the lack of scientific consensus on the meaning of both scientific explanations and causation. Let's start with physics. In a nutshell, physics as a scientific theory consists in finding general laws of nature and explain contingent facts through logical deduction. That is, physics explains by stating general laws and make deductions from general laws. For instance, the heat equation is a law of nature. If we want to model the diffusion of temperature in a piece of metal, we solve the heat equation with numerical methods.

Formalized by Carl Hempel and Paul Oppenheim, this principle is called Deductive-Nomological (DN) principle. Research in physics has two objectives: finding more general laws and finding new deductions that describe specific empirical contexts. This notion of scientific explanations works even if we reject reductionism, and we believe that science is hierarchical. At each level in the hierarchy, we have laws of nature and deduction of specific facts.

Explanation by generalization and deduction is not causal, at least not in the sense that causation means that a change of a variable X produces a change of a variable Y and the reverse action is impossible. This, however, is not the only definition of causation. The critical point is that we can solve the debate whether physics is causal or not only if we have a clear notion of causation. In the absence of a clear definition of causation the debate is purely terminological.

In addition, when we study complex systems, we might study systems whose behavior has not been axiomatized, and perhaps cannot be axiomatized. There are also sciences, such as psychology, which cannot be formulated with the DN principle. In these sciences, it might be difficult separating explanation from causation. For example, we might say that emission of CO_2 causes the earth temperature to increase. Statements like this are causal statements. Does it mean that science is causal?

I would say no, because we are studying systems, artefacts with an internal structure which is responsible for causation. Psychology raises additional problems because the concepts of psychology are difficult to define. We might state that frustration causes aggressivity. Statements like this one are causal statements but how do we define frustration?

Therefore, we can conclude that axiomatic science such as physics is not causal but tends to explain with generalization-deduction. However, specific systems might exhibit a causal behavior due to their internal structure. There are sciences whose objective is to study specific systems. These systems might be causal, and the relative sciences might be causal.

Causal systems and causal models

Causal systems are ubiquitous. Every system where a part of the system controls another part is a causal system. Causal systems might be operated by humans or by other systems. If causal systems are based on physical laws, their description depends on the structure of the system. Formulating in general the structure of causal systems might be very difficult or even impossible.

In the last three decades scientists and philosophers have studied systems that are not based on well-established theories. These systems are described by a set of random variables whose probability distribution is known or, at least, it can be estimated. Knowing the probability distribution implies that we know correlations between variables. The research question is whether it is possible to delve deeper and to find causal relationships between variables. A few examples will clarify.

Perhaps the most typical examples come from the medical field. Consider a large population of individuals who experience different symptoms and exhibit medical tests. The problem is to formulate diagnoses, that is, to associate diseases to symptoms. Human medical doctors formulate diagnoses based on their experience, diagnostic rules, and causal reasoning. We want to use causal AI to formulate diagnoses automatically to support medical doctors. The empirical data is a set of correlations symptom/tests-disease but we want to arrive at a deeper understanding of the cause of disease.

Or consider a population of people with a specific disease who receive different treatments. We want to understand what treatments are the most effective. We have empirical correlations between treatments and disease but we want to arrive at a deeper understanding of the relationship between treatment and disease.

Finally consider firms described by a number of variables. Management intervenes on some variables to improve results, either operational or financial results. For example, management might invest in R&D to innovate products and improve sales and profitability. We have historical data on correlations between changes of the descriptive variables. Correlations are not sufficient to suggest strategies of intervention. We want to understand the causal links between variables.

Examples can be multiplied. One might immediately object that causation is a more serious affair that manipulating correlations. One expects that the causal relationship between symptoms and disease depends on the structure and functioning of the human body plus the biochemical relationships between all the substances produced in the body. We could make the same considerations about relationships between treatment and disease and also between variables describing a firm.

Given the true complexities of causal relationships, what contributions we expect to obtain from causal models? The answer is based on two points.

First observe that there is no firm theory of diseases and of treatment and there is no firm theory of the inner working of a firm. The dynamics of some diseases are well known but in many cases the dynamics is uncertain. And the association treatment-disease is far from being deterministic. Same considerations for the behavior of a firm.

Second, we assume that causal relationships are hierarchical. We start with simplified causal relationships and then adding variables we can delve deeper into causal relationships.

Therefore, we assume that discovering causal relationships will unveil a level of causality that depends on the variables that we are using. Adding variables, we can reach a more detailed level of causality. Causal models proposed in the literature, Bayesian networks and SCMs, are simple models that represent only a direct causality without feedback loops

Discovering causal models

Methodologies and algorithms that discover causal relationships of models such as SCMs are based on making specific hypotheses on the probability distribution of variables that allow to determine the structure of conditional independence. The structure of conditional independence breaks down the global causal relationships into separate independent mechanisms. If we accept the hierarchical nature of causality, causal mechanisms in turn can be resolved into a structure of sub-mechanism.

Ultimately, the structure of causal mechanisms discovered by algorithms such as TETRAD should be coherent with more refined causal relationships implied by chemical or biological relationships or by the inner working of a firm's process.

Practical and theoretical contributions

From the above considerations it should be clear that the causal relationships discovered by algorithms such as TETRAD are not necessarily good representations of a causal structure if the choice of variables is not adequate.

Therefore, the first practical research contribution is defining methodologies to help finding the optimal descriptive framework. In the case of firm, we should leverage the experience of managers. Somehow the causal model should be in agreement management experience. If there are disagreements one should try understanding why the discovery process does not correspond to intuition.

Second, it should be understood that causal models are discovered and should live within a larger non causal model. This is obvious for technological models. A car braking system is a causal system that live inside a bigger system which is only partially causal. Some theoretical effort is needed to understand how a causal model might interact with a global model, for instance a VAR model in economics.

Third, causal models must evolve. We have established the point that the evolution of causal models is akin to paradigm changes in physics. In fact, evolution of causal models involves both the discovery of new structural equations and of new descriptive frameworks. Embedding causal models into an evolutionary framework is probably a big theoretical effort.

In summary, causal models can be helpful but they must be in agreement with the entire body of knowledge about the system they represent. The assumption of the hierarchical nature of causal systems is critical. Causal systems must e embedded in a general non-causal model and must evolve.