Book Review Reflection

CAUSAL INFERENCE IN STATISTICS: AN ATTEMPT AT SOME REFLECTION

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It is a great pleasure and a distinct honor to be invited to read and, possibly, offer some comments to Dr. Lawrence D. Stone's review [1] of the book [2]. I like Dr. Stone's review, which is high quality, highly professional, and carefully written. Determining the causal relationships between actions and results is one of humanity's endless struggling searches. Thus, I very much welcome the books [2] and [3], the second being the one I have browsed in recent months after a suggestion from Dr. R. Streit at the Maritime Situational Awareness Workshop (MSAW 2019, Lerici, Italy) (https://www.cmre.nato.int/msaw-2019-home). The review [1] by Dr. Stone is a precious guide and invitation to read the books [2] and [3]. The background section, the various definitions of causality (including the one proposed by Professor J. Pearl), the graphical causal models, and the definition of interventions and counterfactuals are very helpful and smoothly conduct the reader to the ensuing descriptions of Dr. Stone of the four chapters of book [2].[1,2] The summary and reference list thoroughly complete the book review.

From the summary of [1], I like to quote the "take away" messages: "Modern causal inference, which has developed methods for obtaining quantitative estimates of the effect of interventions and counterfactuals, is an important and relatively new area of analysis. Every analyst should be familiar with the concepts and definitions of causal inference. Causal inference represents a significant extension of standard statistical analysis that should become an increasingly important tool for answering questions about the effectiveness of interventions and for developing artificial intelligence (AI)-like systems that can reason and make decisions. *Present AI systems don't reason at the counterfactual level*. (Italics are mine). They make decisions based only association unlike humans who can also make decisions based on counterfactual reasoning."

Actually, I had already come across the book topic in March 2017 in Singapore. I am referring to the conference "Causality–Reality" organized by Para Limes (https://www.paralimes.org/) and Nanyang Technological University, Singapore [6].[3]

Abridged from the synopsis of the conference: "We seek to manage and control our world by establishing causalities. And we try to use science to help us. However, one of the biggest challenges for science is to untangle or better understand the relationship between causality and reality. This is especially true for complexity science that deals with the real world, or with complex systems like our brains or our immune system. *Causality* is the agency or efficacy that connects one process (the cause) with another (the effect), where the first is understood to be partly responsible for the second. *Reality* is the state of things as they actually exist, rather than as they may appear or might be imagined. Once we have met this challenge, we have the key to finding ways to sustainably manage our lives, our systems, our science, our education, our laws, our healthcare and our cities in a world that is becoming more complex and interconnected than ever before. It is also key to finding new breakthroughs in the sciences that seek to understand 'the human' and its relations" [6].

It would be of interest to have a look at the presentations from the Singapore Conference. In the following, I just picked one statement which struck me from each presentation:

- Bertil Andersson, opening address (see above quoted synopsis).
- Jan W. Vasbinder, welcome remarks ("The ultimate equations in this quote constitute causality. Cataloguing and understanding emergent behavior constitute the relation to reality.") [6]
- George Rzevski, "Managing Organization Complexity: Practical Methods and Tools for Adaptation and Causality Analysis" ("Managing complexity…") [6]
- Stuart Kauffman, Beyond Physics: The Emergence and Evolution of Life ("The emergence and evolution of life is based on physics but it is beyond physics. Evolution is an historical process arising from the non-ergodicity of the universe above the level of atoms… [4] Beyond entailing law, the evolving biosphere literally constructs itself and is the most complex system we know in the universe."[5]) [6]
- De Kai, Translating Reality to Causality ("… the study of cognition…") [6]
- Michael Puett, Rethinking Notions of Causality and Reality: Indigenous Theories from China ("…causality and reality is hotly debated in both the sciences and social sciences") [6]
- James Bailey, Schooling for Life K–12 ("…replacement of K–12 curriculum grounded in network of neurons rather than lines of forces") [6]

[1] Hot topic indeed, Google provides [4].
[2] Intriguing topic, Google provides [5].
[3] Beyond Boundaries, indicating a limitless potential for exploration [6]. "Limes" in Latin is for boundary.

[4] Medaglia, J. D., Ramanathan, D. M., Venkatesan, U. M., and Hillary F. G. The challenge of non-ergodicity in network neuroscience.Available: https://www.ncbi.nlm.nih.gov/pubmed/22149675/.
[5] Kauffman, S. *At Home in the Universe: The Search for the Laws of Self-Organization and Complexity*. Oxford, UK: University Press, 2001.

- ► Nick Obolensky, A Military View ("…a non-hierarchical complex adaptive system, instead of as a traditional hierarchical one, can get surprising results") [6]
- ► Ernst Pöppel, Trust as Basis for the Concept of Causality: A Biological Speculation ("…humans have the tendency to attribute only one cause when trying to understand whatever has happened or whatever is given") [6]
- ► Stefan Thurner, How Complexity Weakens Causality—Emerging Dangers—and Ways Out ("…we discuss problems that emerge from a world that is getting increasingly complex and seemingly less causal such as the gradual public acceptance of a 'post-factual era'") [6]
- ► Ilan Chabay, Behavioral Causality—Anthropocene Reality ("The UN Sustainability Development Goals (SDGs) set 17 ambitious targets for moving to sustainable futures. How are we to understand, enable, and foster collective behavior changes that can address these complex changes?") [6]
- ► Peter Edwards, Technological Myopia ("Innovation is good; disruptive innovation is better! Will explore some of the unforeseen consequences of disruptive technologies and ask why it is that we have such difficulty anticipating them.") [6]
- ► Mile Gu, Quantum Simplicity: Can quantum mechanics better isolate the causes of natural things? ("Certain observed phenomena may appear to require tracking immense amounts of information to model classically, and yet remarkable little information quantum mechanically.") [6]
- ► Sydney Brenner, Causality in Evolution ("Complexity... invisible reality") [6]
- ► Jan W. Vasbinder, closing remarks [6]

To me, the recurrent word of these talks is complexity, which resonates with Pearl's book too.

In the "Epilogue, The Art and Science of Cause and Effect," pp. 401–428 [3], very captivating to read, the pivotal role of Graphical Causal Models (GCM) in identifying causal effects is summarized.[6] The key point is the great complexity of realistic GCM. Detailed models are always difficult, maybe impossible, to achieve together with accurate initial/boundary condition data, otherwise…chaotic models come up with corresponding unpredictability.

I am acquainted with the A. L. Barabasi work (e.g., [7]), the new science of networks, a perspective which seems of interest to consider. In the most basic form, a network is a set of objects and a set of connections between pairs of objects. From a mathematical point of view, a network takes the form of a graph where the interconnected objects are represented by mathematical abstractions called vertices (or nodes), and the connections called edges. A. L. Barabasi's book introduces the science of networks to the general audience. It provides an introduction to the main models and properties of networks and their applications in many areas of real life. The subtitle of the book is also informative: "How Everything is Connected to Everything Else and What It Means for Business, Science, and Everyday Life". Thus, it is evident that network/graph theory plays a key role in modelling physical phenomena and systems. Signal processing over graphs is also becoming an attractive and powerful engineering tool. Emergent behaviors, typical of networks, arise through formation of patterns not reducible to a single agent's behavior.

A. L. Barabasi and coworkers tackled the mathematics of controllability and observability, generalizing the concepts introduced by Prof. R. E. Kalman in 1963, of somehow realistic networks [8] and [9].[7,8] The Nobel Laureate Murray Gell-Mann (who discovered the quark particle) introduced a way to measure the complexity of network by means of its plecticity [10].[9] A brief review of the methods to try to measure complexity is in chapter 10 of [11]. In the same chapter, two study cases have been described to calculate the complexity and controllability of nets of a few hundred nodes and a few thousand connections.

I see potential intersections between GCM and the above quoted theory of nets. I would argue that similar topics related to complexity, controllability, and observability (and more in general the *"ilitis"* of description of dynamic systems) should be explored and taken into account in GCM for realistic applications. Indeed in [3], p. 77, the *identifiability and the causal effect identifiability* are described. Graphical tests of *identifiability* are tackled at p. 89 and the following pages.

Another remarkable topic afforded in [2], and carefully spotted in [1], is the counterfactuality. To me this is an outstanding technical novelty introduced in the GCM.

Speaking with the neuroscientist Ph.D., C. Di Dio (coauthor of [12]), whose kind assistance is warmly acknowledged, I learned something on the neuroscience point of view of counterfactual thinking [12].[10,11] In summary, by means of the counterfactual reasoning, we exploit all our cognitive resources to evaluate which would have been the results we would have achieved if we had acted in an alternative way. This implies comparing the expected result with the one actually obtained. The process serves to modulate the behavior in order to improve it. The emotional component is also involved because the disappointment for not having obtained the desired result translates into the motivation to change. The areas involved are the orbitofrontal area where the comparison between the expected and the real takes place. This is where the signal starts in terms of error, which updates our expectations by means of connec-

[6] A public lecture delivered by Prof. J. Pearl, November 1996, as part of the UCLA Faculty Research Lectureship Program.

[7] "Identify the set of driver nodes with time-dependent control that can guide the system's entire dynamics in a complex directed network." [8]

[8] "A system is called observable if the system's complete internal state can be reconstructed from its outputs." [9]

[9] Simply speaking, it is related to the connectivity of the graph. It is expressed via the "betweeness centrality" of nodes.

[10] Università Cattolica del Sacro Cuore, Milan (I), Member of the Research Unit on Theory of Mind, Department of Psychology.

[11] Additional scientific literature, such as [13] and [14], have been suggested by Ph.D. M. Boccia, kindly acknowledged, University of Rome (I), Sapienza, Department of Psychology.

tions with subcortical (amygdala) and with cortical (frontal). The anterior cingulate cortex and hippocampus play also a key role for modulating behavior. These results extend the possible role of a *mirror-neuron like mechanism* beyond basic emotions. A gambling task and functional-Magnetic-Resonance-Imaging (fMRI) were used to test this hypothesis using *regret*, the negative cognitively-based emotion arising from a counterfactual comparison between the outcome of chosen and discarded options, whereby the discarded option would have produced higher benefits to the individual [12], [15].

The discovering of mirror-neurons effect is one of the most exciting events in neuroscience [16]. Mirror-neurons are related to empathy, imitation, the chameleon effect, and probably language (sing, calls, etc.) development. Researchers in cognitive neuroscience and cognitive psychology consider that this system provides the physiological mechanism for the *perception-action* cycle. The mirror-neurons may be important for understanding the actions and intentions of other people, and for learning new skills by imitation. It is also suggested that mirror-neuron systems may simulate observed actions, and thus contribute to theory of mind skills. It is felt that mirror neurons are the neural basis of the human capacity to feel empathy, and namely to resonate with another's emotional states. Thanks to the visual/audio-motor coupling mediated by the mirror system, some processes, such as understanding others' motor goals and intentions, are faster compared to systems based on mere cognitive, inferential processes. In the 1980s and 1990s, Prof. Giacomo Rizzolatti (coauthor of [12]) was working with G. Di Pellegrino, L. Fadiga, L. Fogassi, and V. Gallese at the University of Parma, Italy, and discovered this phenomenon [17], [18].

This said, I am unable to suggest how this neuroscience view of counterfactual thinking can be embedded in the math of GCM. Counterfactual thinking depends on an integrated network of systems for affective processing, mental simulation, and cognitive control to guide adaptive behavior [13]. This could be the avenue for future research. Teaming with neuroscientists and psychologists would be—in my opinion—most welcome.

Probabilistic counterfactual and probability of causation are powerfully developed in [3] and properly mentioned in [1] from [2]. This could raise the question as to whether probability may continue to be the way to measure randomness, which is the physical phenomenon. Researchers and engineers are exploring—among others—belief functions and imprecise probability theory [19], [20]. I refrain to dwell on this debated topic. I just wish to mention two remarkable books [21] and [22] by N. Taleb. [21] considers the extreme impact of rare and unpredictable outlier events, called the Black Swan theory. [22] introduces the concept of antifragility, which is beyond resilience or robustness. Quoted from N. Taleb: "Antifragility makes us understand fragility better… Anything that has more upside than downside from random events is antifragile; the reverse is fragile." Examples that could be classified as antifragile are: stochastic tinkering, simulated annealing, and stochastic resonance [23], [24]. Many others are presented in the Taleb book. The subtitle of the Taleb book is: "How to live in a world we don't understand." Quoting Taleb's main subject matter: "decision under opacity", that is, a map and a protocol on how we would live in a world we don't understand.

This struggling question appears to resonate also in the close of "Epilogue" of [3]. "But the really challenging problems are still ahead: we still do not have a causal understanding of poverty and cancer and intolerance, and only the accumulation of data and the insight of great minds will eventually lead to such understanding. The data is all over the place, the insight is yours, and now an abacus is at your disposal, too. I hope the combination amplifies each of these components."

Prof. J. Pearl's sense of hope is indeed very welcome.

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