Mathematics, the pandemic and complex systems

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Abstract:

We indirectly question the role of mathematics in the response to the COVID-19 pandemic. Firstly, we look at its importance in analysing the complexity of the systems currently facing us. Next, we look at the resulting relationship between mathematics and other disciplines, and why it is important that mathematics plays a part in scientific approaches to handle the major challenges presented by these systems.

I would like to thank the organisers Melanija Mitrović and Norbert Hounkonnou for giving me the opportunity to give this short talk.

I do not work in the field of epidemic modelling, so I will not provide precise information on models put in place in relation to COVID-19. However I have worked for a long time now on the use of graph theory to model real major networks - social networks, trading networks, real neural networks - and I have taken part in many interdisciplinary projects. Yet graph theory and the notion of a "network" are both very prevalent in scientific studies relating to COVID-19, and a multidisciplinary approach would appear increasingly important for effective handling of COVID-19. So I am going to indirectly question the role of mathematics in the response to the pandemic, firstly by briefly considering the complexity of the systems currently facing us, then the resulting relationship between mathematics and other disciplines, and why it is important that mathematics plays a role in scientific approaches to tackle the major issues created by these systems, such as social, environmental or health issues.

Mathematical models relating to the spread of an epidemic, management of statistical information on the number of infected people, vaccine research, preventive measures, economic measures... it quite quickly became apparent that we could not separate these different actions if we wanted to effectively combat the pandemic. This has resulted in what we call a "complex system", which is characterised by multi-scale dynamics, cascade effects leading to sudden quantitative and qualitative changes, and feedback loops which result in a non-linear system dynamic. These systems generally act in a manner which can be difficult to predict if we ignore the interactions between their different components. Whilst this complexity has become apparent to everyone during the current pandemic, researchers have been interested in the analysis of complex systems for decades,[1] and it is almost a cliché to say that complexity is everywhere: environmental changes, social communities, collective dynamics in biological systems, urban and transport systems, natural risks, brain function... Analysis of these complex systems was quite difficult until the mid-20th century, but our modern ability to produce a huge quantity of data on the real world's workings, combined with powerful calculations and increased storage capacity, has provided a fresh insight into understanding and processing this complexity, from both a practical and theoretical point of view. However, for many reasons this process often ignores qualitative approaches, which are common in human and social sciences, and even in experimental sciences. In my opinion, and to give just a few examples, the challenges which we must currently tackle relate to our inability to include local, traditional or indigenous knowledge in global sustainable development models, the difficulty of including clinical knowledge in bioengineering approaches, the weakness of non-economic criteria when evaluating comparative advantages on dynamic markets, or the difficulty of including knowledge on parties in environmental development models, and so on. For public or private decision makers, having access to large amounts of quantitative data can even lead to bypassing any discussion required to understand the dynamic of a complex phenomenon in progress. During a Big Data conference in Toulouse in 2015, Bernard Stiegler[2] stated: "*[…] the problem is that Big Data has an unfortunate tendency to circumvent all deliberation processes, absolutely every one [...]*". What I mean to say here is that even though rapid action is needed to better understand the world's complexity, a complexity which we help to create, there will be no Big Data miracle or life-saving scientific discipline. Believing in one or the other would even be counter-productive, as it would limit the implementation of an effective approach to analysing complexity. A lot of hope is placed on "machine learning", a concept made possible by Big Data, which is found throughout our society, particularly to guide actions, whether political, economic or even medical, in a world that is moving ever faster and is increasingly interconnected. We need to be quick to keep up, and as explained by Etienne Klein citing Francis Bacon, we need to innovate, as the idea of life-saving innovation is a common one. However no one can work quicker than a computer, which can process up to hundreds of billions of operations per second, which is why we entrust decisions to algorithms and data. Mathematics is at the heart of the action, as it often structures simulation models which will be used en masse to assess the "efficacy" of an innovation, but also a political decision[3]. For example in France, when political figures grasped the scale of the pandemic, suddenly everyone learned about epidemic mathematical models and the famous R_0. At this point, whether consciously or unconsciously, two incorrect views of mathematics could emerge. Firstly, because we could be led to believe that mathematics is able to deal easily with complexity, whereas the models we have today need thousands of examples to learn and are easily misled. My friend the economist Alan Kirman told me last year about Melanie Mitchell's thoughts on machine learning[4] "*the machine doesn't understand what "the meaning" means, and that's the problem*". Secondly, because we could be led to think that mathematics is nothing more than a

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[1] The Santa Fe Institute was founded in 1984. https://www.santafe.edu

[2] https://www.canal-u.tv/video/fmsh/les_donnees_en_shs_quelle_politique_bernard_stiegler.21150

[3] see for example https://epidemap.com/

[4] Mitchell, M. (2019). Artificial Intelligence Hits the Barrier of Meaning. Information, 10(2), 51.

more or less enhanced form of data processing. Alain Connes[5] said in an interview with France Info on 8 May 2018: "*What really surprises me is that Évariste Galois was able to understand concepts without doing the calculations. I think we are starting to confuse* "*understanding without doing*" with "*doing without understanding*"*. However the essence of humans is understanding, and this is something completely out-of-reach of artificial intelligence [...] Currently, artificial intelligence lacks common sense and above all genius*". It seems to me that we are witnessing a significant collective loss of trust in society, in ourselves.

To understand a crisis like the current COVID-19 pandemic, the approach using the methods and tools of complex systems is an integrated way to tackle questions, which we cannot avoid and which does not bypass disciplines. Rooted in disciplines but breaking free from disciplinary confinement, it is used to understand interactions between the different dimensions in play. Like any interdisciplinary approach, which is new for us 20th or 21st century researchers, it is a revolution in thinking and knowledge which is built over time, and the urgency of situations which we have and will have to face should not lead us to think that we can reduce time spent on scientific research to the bare minimum. Science is a universe of controversy where methods, results and models must be discussed at length to be robust. Mathematics is no exception, and we know that the mathematical models used now are backed by tens of years of research. What is the strength of mathematics in this context, and its position?

The power of mathematics largely stems from its generic nature, which is necessary to navigate the various concepts. Accustomed to reasoning with abstract objects, the mathematician has unique skills, providing a multidisciplinary group with the ability to understand interactions between logical reasoning and concepts. The mathematicians are also able to ignore any a priori approach, as they know that by changing hypotheses, a false result can become true. There are no taboos in mathematics; no one will prevent you from assuming that certain hypotheses are true and exploring what this means. But other sciences need to develop in silos, based on more or less implicit assumptions or observations, which cannot be broken; the efficiency is remarkable, but switching to other hypotheses is rarely considered. This is not about valuing mathematics above other sciences, which are more empirical or rooted in the world's realities, but pointing out the differences. For example, contradictions are forbidden in mathematical reasoning, whilst there are plenty in our society, and contradictory debate is the core methodology of human and social sciences. In a real world which wants to understand and control its evolution, where we are asked to predict increasingly far into the future, the universal nature of mathematics can obscure our vision. At this stage of reasoning, we could discuss the applicability of mathematics or knowing if the world is mathematical. From Galileo to Einstein and Kant, these questions have been discussed since ancient times, and I am not qualified to discuss such philosophical matters. However, it seems that we can admit that mathematics is neither an experimental science nor an observational science, and that the effectiveness of mathematics as a "tool to control complexity" or a "language of the world's imagination"[6] is not self-evident. As underlined by Jean-Michel Salanskis "all notions used to describe reality and its changes are included and affected by the chosen mathematical framework". A model is always built on hypotheses and with a choice of variables or distributions of possible variables

[5] 1982 Fields Medal, 2001 Crafoord Prize, 2004 CNRS Gold Medal.

[6] Salanskis, Jean-Michel. "Appliquer les mathématiques", *Rue Descartes*, vol. 74, no. 2, 2012, pp. 4-19.

which are not random, must be discussed, and are generally simplifications of reality. It is not enough to program formal models and supply them with "Big Data" to get a representation of the world in 10, 50 or 100 years. We really need to see a model as a piece of a puzzle that we put together as a group, each with different knowledge and skills. We can even quote George E.P. Box: "all models are wrong, but some are useful".

However I am convinced that mathematics must be involved, with other disciplines, in systems to study and understand complex phenomena which make up the world today, and in which it is already involved (development of social networks, growth of financial bubbles, etc.). To do so, it has an additional challenge to overcome: overcoming its language, which is technical but necessary. This is required for an interdisciplinary exchange to take place, particularly with less formalised sciences but which also have their own concepts, methods and tools. The mathematician probably needs to take a risk and aim to explain the representations that they have in mind in "simple" terms, share the fact that they make sense, in the mathematical world, and that they can also make sense in an interdisciplinary process to create innovations to understand and improve the world in which we live. With mutual listening and consideration, discourse is possible. All that said, we still need mathematics to be well received, and I worry when, during a meeting in 2017 on AI organised by Facebook Paris, Yann LeCun, Facebook's Chief AI Scientist, says the following when talking about the fact that we do not really know how deep learning algorithms work: "*[...] it's not a major problem. It's very satisfying to have an explanation, and it reassures humans if an artificial intelligence system has an explanation. But ultimately what we want is good reliability*". Was he simply being provocative? In a world witnessing AI developing at breakneck speeds, it is likely that it will be used widely to deal with major social, environmental or health challenges, like the current pandemic. Can we accept that the tools used are not understood by humans? Can we fight effectively against a pandemic if we simply know what is going to happen, but do not understand why? Do these few sentences, which completely go against the comments made previously by Alain Connes, completely deny mathematics' involvement in the implementation of these AI tools? Does this not deny the importance of mathematical theory?

To conclude, I would say that mathematics does not have a choice and must be included in the major socio-environmental and health challenges which we are facing. It must be included, because it contributes additional skills to other scientific fields, and in the field of AI which is itself involved, the responsibility of understanding why certain systems "work" relies on it. Over time, I am convinced that "doing without understanding" can only be a victim of its excessive ambition if it wants to interfere in all decision-making processes. Only systems which the human is able to understand and therefore control would survive long-term. Mathematics must also be involved because it otherwise risks being exploited by those who "use" it without understanding it, and potentially used to back up crucial decisions. It must be involved, without the illusion of offering absolute truth. As noted by Jacques Austruy[7] in the 1960s, a period when the craze for structuralism encouraged combinatorial and topological formalisations of the world, "[...] whilst mathematics is a precise language, it is not as neutral a language as mathematicians sometimes believe".

[7] Austruy, J. (1961). Methodes mathematiques et sciences de l'homme. *Revue économique, 12*(3), 414-439.