Briefing on Artificial Intelligence and Mathematics – Protect Pure Maths

This briefing has been prepared by the Protect Pure Maths campaign, founded with the London Mathematical Society.

The briefing highlights the inextricable link between mathematics and AI, and the need for mathematicians to be at the centre of all forms of AI governance and research. The briefing includes a number of recommendations, ranging from effective governance of AI to ensuring we have the necessary mathematical skills to harness its potential and ensure it is safe.

Overview

1. Mathematical sciences underpin and enable AI. AI relies on mathematics, whether that is driverless cars or the science of search engine ranking. Mathematical models such as rough path theory enable the production of powerful applied tools, allowing companies and individuals to identify solutions and address global challenges.

2. Mathematics also allows us to understand how to use AI, and to answer questions on it, explaining what is behind the code and the application. You cannot make sense of AI, without understanding the mathematical concepts and tools that are behind it, including linear algebra, matrix theory, and vectors.

3. As AI becomes increasingly complex and widespread in many walks of life, it is imperative that we are able to fully grasp the mathematical processes behind AI, how we use and apply them, and how we understand and see AI. Therefore mathematics must be central to the governance and development of AI.

4. Mathematics will be needed to satisfy the requirements of the Alliance for Data Science Professionals (AfDSP) which expects to accredit Data Science degree programmes in universities against Standards developed by the profession. The Government should work closely with the Alliance to encourage awareness and uptake of these standards across the AI community which will in turn reinforce the UK's ambition to be a global superpower in data science and AI, leading the world in data science innovation, education and ethics.

5. This briefing from Protect Pure Maths provides examples of how AI is underpinned by mathematics and also makes recommends on future governance.

Mathematics and AI

<u>Data</u>

6. AI makes use of data to extract results and make predictions. Real data contains numerous ethical and confidentiality issues. Even when AI is used to create synthetic data, it is based on the structures of real data. This problematic as traces of the real data can remain. With greater understanding of the mathematics behind how AI uses data, we reduce the chances of large ethical and confidentiality breaches.

7. Mathematical tools, along with greater understand of the mathematics used, can also be used to create solutions. Agent-based modelling (AGM) is a highly effective way of using mathematics for the social sciences, involving the computational modelling of systems and so creating data from the bottom up, removing the need to use real data.

8. AGM greatly extends the power of traditional search methods, allowing for a more accurate capture of data on human behaviour, as well a deeper exploration of large areas and sectors. AGM is used across multidiscipline sectors including economics, electricity markets, labour markets, collective behaviour, ecological systems, and institutional design. Without ensuring that those governing, creating, and advancing AI have an adequate understanding of the role and importance of the mathematical sciences, we risk damaging consequences in relation to people's data.

Energy

9. Energy policy is increasingly important, not only in terms of its availability and accessibility but also its link to national security.

10. As renewable energies, like wind power, are increasingly integrated into the electricity grid, there is more uncertainty as the pattern of the wind is unpredictable[1]. This will make planning and scheduling much more challenging, and it will take sophisticated mathematics to get it right.

11. A mathematical understanding of processes that have random patterns allows them to be analysed (known as stochastic) and is essential because networks, such as electricity grids, can have random patterns in predicting both power and demand.

12. Without this understanding and continual development of the mathematical processes, our ability to master and use AI will be diminished.

Technology

13. Mathematical processes can help develop AI tools that can have huge positive consequences for daily life. Mathematical signatures have been combined with machine learning to enable lightweight, fast, and accurate recognition of complex and unpredictable data streams from different sources.

14. For example, an app was developed in China which translates handwritten characters into text[2]. This combined mathematical signatures with another technology, deep convolutional neural nets. The rough paths model allows effective character recognition in real time, and significantly improved the accuracy and speed of the app. The technology was acquired and released for a wider audience in China. The handwriting interface allowing those with less digital confidence to access services and information through the Internet and now has around seventy-five million users a day.

15. Without embedding the study of mathematical sciences in the governance and development of AI, we will be unable to continue to create such technological breakthroughs.

Health

16. Rough path models have also been used to analyse Intensive Care Unit data to identify those patients most likely to develop sepsis – a rapid onset condition with potentially devastating consequences. Similarly, mathematical techniques such as Ricci flow, a technique used in investigating colorectal cancer, is a process from differential geometry that maps the prone and the supine colonic mesh surfaces to allow for accurate scanning and treatment[3].

17. Advances in topological data analysis (TDA), an emerging field of mathematics that studies shape within datasets, offer novel descriptors of spatial data that have the potential to inform histological analysis.

18. Quantifying and comparing complex spatial biological datasets is crucial for medical applications and remains an active area of research. As datasets become more complicated, the methods used to understand them must be increasingly complex and sophisticated. This includes methods such as multiparameter persistent homology and multi parameter landscapes – both mathematical tools in computational topology - which are used to quantify differences in synthetic data of immune cell infiltration as well as significant medical data such as clinical

[1] Isaac Newton Institute for Mathematical Studies, Renewable Energy and Telecommunications - Isaac Newton Institute
[2] University of Oxford, Rough Paths: gaining insights and building solutions | University of Oxford
[3] Isaac Newton Institute for Mathematical Studies, Case study (newton.ac.uk)

tumour histology data of T cells, macrophages, and hypoxia[4]. Both rough paths and persistent homology have been developed on the back of concepts developed and studied over decades in pure maths.

Recommendations

Governance

19. To effectively govern the use of AI, an understanding of the role of the mathematical sciences is critical. The mathematical sciences must therefore be central to governance of AI, to ensure that algorithms are unbiased, data is protected, and decision making is clear and transparent.

20. As AI develops, training data needs to be updated regularly. Algorithms that work well on one machine, might work differently on others (to do with the power of the computer and its architecture). Therefore, any ongoing maintenance and development of AI must also include the mathematical sciences to ensure any continued troubleshooting, transparency and protection.

21. To ensure we can continue to make new discoveries and support the development of AI, we must commit to fostering an ongoing flow of talented mathematicians from diverse backgrounds. This is consistent with many government directives, and vital if we are to continue to contribute to social and technical advances in the century ahead. Without this commitment, we will not be able to provide the next generation of skilled mathematicians to ensure strong economic growth, better jobs, and new discoveries.

22. The mathematical sciences are at the very foundations of data science and AI. This is the reason why mathematics will be needed to satisfy the requirements of the Alliance for Data Science Professionals (AfDSP) which expects to accredit Data Science degree programmes in universities against Standards developed by the profession. Comprised of leading professional bodies in the computer science, mathematics and statistics, and supported by the Alan Turing Institute and the National Physical Laboratory (NPL), degree accreditation will be an Alliance-led activity, drawing on representatives and expertise from the learned society partners. This work accompanies the professional competency frameworks for data science professionals launched by the Alliance in July 2022 and already being used by a wide spectrum of employers to recognise and maintain professional standards of practice in the field. The Government should work closely with the Alliance to encourage awareness and uptake of these standards across the AI community which will in turn reinforce the UK's ambition to be a global superpower in data science and AI, leading the world in data science innovation, education and ethics.

23. Any body or institution set up to oversee the governance of AI must therefore include and involve mathematicians. This should include those mathematical institutions that have significant expertise in AI governance issues – such as the Ada Lovelace Institute and the Alan Turing Institute. This will ensure that AI is more transparent and explainable to the public, as set out in the evidence submitted to the Department for Business, Energy and Industrial Strategy by the Department for Digital, Culture, Media and Sport on AI.

24. To ensure appropriate transparency and understanding of AI, it is critical to support the development and enhancement of the mathematical skills that underpin AI. For example, this could form part of the Government's intention to ensure 16-18 year olds continue to study mathematics. The Government should draw on the work of the Maths Futures Programme of the Royal Society and utilise it to understand what maths is needed in future and by whom, so that education can be adjusted.

25. Government should also formulate a Strategy for Maths to strengthen the UK's world leadership in the mathematical sciences and to equip the UK to compete in a global economy increasingly influenced by data, complex systems and AI.

[4] Katherine Benjamin, Aneesha Bhandari, Zhouchun Shang, Yanan Xing, Yanru An, Nannan Zhang, Yong Hou, Ulrike Tillmann, Katherine R. Bullb, and Heather A. Harrington, 2022, 2212.06505.pdf (arxiv.org)

Skills and research

26. Without emerging fields of mathematics such as those highlighted in this briefing, the UK will not remain at the forefront of AI development.

27. AI cannot exist without the mathematical sciences and the mathematical sciences must be adequately funded to ensure we have the talent pipeline with the necessary skills and understanding to continue to advance and progress AI tools.

28. We must support and fully fund the pipeline of future mathematicians and those working in AI operations.

29. Nationally, this means that access to mathematics courses at Higher Education institutes across the country must be maintained and adequately funded. Universities face ever greater financial pressure from high inflation and a real terms decline in the value of the maximum domestic tuition fee. Due to the pandemic, admission data has been skewed for the last 2-3 years, and the situation is being compounded by not enough funding being allocated, including the remaining £176m of the £300m in additional funding promised by the Government in 2020. This is depriving departments of vital funding whether through PhD studentships or research grants. While larger mathematics departments at Russell Group universities continue to thrive and grow, but this is leading to the mathematical sciences becoming an almost exclusively high-tariff degree with far fewer lower-tariff, non-traditional options available for those who wish to continue to study beyond A level.

30. Furthermore, we must avoid systematic biases that may result from a lack of diversity. A well-known example of such biases is that of facial recognition technology.[5]

31. The recent 'Science and Technology Framework' noted the need to establish a competitive advantage through attracting international talent. There are challenges to recruit and retain top-quality academic and teaching staff in high demand areas such as AI and computational statistics. This could be alleviated by lower visa costs to attract world-leading mathematicians, as well as supporting additional investment in PhD placements to ensure a sustainable pipeline.

[5]The Alan Turing Institute, 2020, 'Understanding bias in facial recognition technology'