Special Issue on Machine Learning, Data Science, and Artificial Intelligence in Plasma Research

THIS Special Issue of the IEEE TRANSACTIONS ON PLASMA SCIENCE (TPS) follows the first American Physical Society Division of Plasma Physics (APS-DPP) mini-conference on Machine Learning, Data Science, and Artificial Intelligence in Plasma Research held during the 60th APS-DPP Meeting in Portland, OR, USA (November 5–9, 2018). It contains selected highlights from not only the mini-conference but also the broader plasma physics community. Although data science has a long and rich history in plasma physics, dating back at least three decades, it is experiencing a renaissance, thanks in large part to the advances outside of plasma physics. Novel algorithms, hardware, and analytic techniques (buoyed by the open source software ecosystem) have led plasma scientists to explore ways in which the data revolution could accelerate and inform scientific discovery. Emerging data-driven methods could have a transformative effect across the full spectrum of plasma research. For fusion energy research, some areas of opportunities [item 1) in the Appendix] include using machine learning (ML) or data methods for scientific discoveries, augmented instrumentation, accelerated model development and simulations, data-informed intelligent controls of the experiment, and data-enhanced predictions. The DPP mini-conference and the articles herein represent only a tiny cross section of contemporary research on data-driven plasma science. The 3rd International Conference on Data-Driven Plasma Science (ICDDPS-3) will be held in Okinawa, Japan, in April 2020 [item 2) in the Appendix], with expected presentations on fusion plasmas and low-temperature plasmas and beyond. Furthermore, Plasma Science is not unique in its exploration of Scientific Machine Learning: the Second Workshop on Machine Learning and the Physical Sciences (NeurIPS 2019, Vancouver, BC, Canada, December 2019) and it illustrates a trend in cross disciplinary collaboration with contributions from plasma research.

This is only one example of a concerted effort from people with different scientific backgrounds and goals to share data-driven ideas and results with an emphasis on plasma research. Fresh and seasoned plasma researchers alike are attracted to adopt data-driven methods because of both their potential for new results and the growing challenges associated with information extraction from large data sets that come with better instrumentation for experiments or more powerful simulation tools available for theory and simulations. The explosive growth of the data will continue, mirroring Moore's law for transistor growth. It is likely that the use of ML and other data methods for plasma research may soon no longer be a matter of taste but rather become a practice of necessity. Can data-driven methods finally provide some answers or solutions to the long-standing questions due to the complexity and rich manifestation of plasmas, such as disruption avoidance in tokamaks, practical fusion energy, or plasma turbulence? We wish that this Special Issue could contribute to the growth and be at least a witness for such a transition and growth.

Currently, many data methods including ones presented in this Special Issue can find their origins outside plasma research. Open code repositories, such Github and the public webpages from individual research groups, are combined with open platforms, such as Python, making data-driven methods highly accessible. Meanwhile, the power of data methods, such as deep learning, presents a mystery of "black-box magic" even to the leading experts in this highly disciplinary research field. Taking advantages of the continuous growth of the computing hardware and novel computing architectures, further development of algorithms, neural networks, and data visualization tools may need to be combined with knowledge about plasmas, making physics-constrained or physics-informed ML and data method a frontier of research.

Nine papers are included in this Special Issue across a variety of experimental, theoretical, and computational plasma physics. On the experimental front, using data and ML for magnetic fusion and inertial confinement fusion is emphasized. One additional article on low-temperature plasmas is also included. This does not preclude the fact that the interests of both thermonuclear fusion and nonfusion plasma communities are high. New results are reported on feeding experiment measurements, such as bolometer, magnetic field, and visible light for data mining and information that is not directly measurable (disruption prediction, implosion yields, and fast ion physics, to name a few). Data methods themselves, such as convolution neural networks, deep learning, transfer learning, sparse Gaussian processes, Bayesian methods, and uncertainty quantification, are integral aspects of the results presented.

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APPENDIX
RELATED WORKS

1) *Advancing Fusion With Machine Learning Research Needs Workshop*. Accessed: Sep. 15, 2019. [Online]. Available: https://science.osti.gov/-/media/fes/pdf/workshop-reports/FES_ASCR_Machine_Learning_Report.pdf?la=en&hash=27C6DA2A9A92F884DC618FCB928A89F4C39BD764
2) *ICDDPS-3*. Accessed: Dec. 12, 2019. [Online]. Available: http://www.ppl.eng.osaka-u.ac.jp/ICDDPS3/

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