Physics-Informed Machine Learning

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Abstract – In this talk, I will review recent progress in integrating physics principles into machine learning techniques. This work will highlight current capabilities and limitations, discussing a range of applications for physics-informed learning in both forward and inverse problem settings. Physics-informed learning algorithms incorporate both observational (data-driven) and theoretical (physics-based) biases. These algorithms leverage the efficiency of machine learning to provide fast solutions while also ensuring they are accurate and consistent with the laws of nature. I will first focus on Physics-Informed Neural Networks (PINNs) and their emerging improvements, discussing how they solve particular differential equations. Compared to classical differential equation solvers, PINNs produce meshless solutions: they learn in the continuous domain and act as intelligent interpolators. I will then cover Physics-Informed Neural Operators (PINOs), which generalize PINNs into operators that solve entire families of PDEs, parameterized by coefficients or boundary conditions. I will discuss specific applications of PINNs and PINOs in multimedia signal processing, spanning contexts from astrophysics and material characterization to medical imaging. I will conclude with a discussion of current challenges and promising directions for future research in this rapidly evolving field.

Biosketch – Aggelos K. Katsaggelos received the Diploma degree in electrical and mechanical engineering from the Aristotle University of Thessaloniki in Greece, in 1979, and the M.S. and Ph.D. degrees in electrical engineering from the Georgia Institute of Technology in 1981 and 1985, respectively. In 1985, he joined the Department of Electrical Engineering and Computer Science at Northwestern University, where he is currently a professor in ECE with courtesy appointments in CS and Radiology, holder of the Joseph Cummings Chair. He has been working in the multimedia signal processing and machine learning areas, and he has supervised 83 Ph.Ds. so far. He co-authored five books, one of which is Machine Learning Refined (Cambridge University Press, 1st edition 2016, 2nd edition 2020). Prof. Katsaggelos has served the IEEE and other Professional Societies in many capacities; he was, for example, Editor-in-Chief of the IEEE Signal Processing Magazine, a member of the Board of Governors of the IEEE Signal Processing Society, and a member of the Publication Board of the IEEE PROCEEDINGS. Among his various awards, he is the recipient of the IEEE Third Millennium Medal (2000), the IEEE SPS Leo L. Beranek Meritorious Service Award (2001), the IEEE SPS Claude Shannon–Harry Nyquist Technical Achievement Award (2010), an IEEE SPS Best Paper Award (2001), an IEEE ICME Paper Award (2006), IEEE ICIP Paper Awards (2007 and 2024), an ISPA Best Paper Award (2009), a EUSIPCO Paper Award (2013), and the Spanish Society of Statistics and Operational Research-Fundación BBVA Award for the Best Applied Contribution in Statistics (2023). He was a Distinguished Lecturer of the IEEE Signal Processing Society (2007–2008) and he is a Life Fellow of the IEEE (2022) and Fellow of IEEE (1998), SPIE (2009), EUSIPCO (2017), and OSA (2018).