CONVOLUTIONAL NEURAL NETWORKS DEMYSTIFIED:
A MATCHED FILTERING APPROACH TO FULLY INTERPRETABLE CNNs

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Abstract: Convolutional Neural Networks Demystified: A Matched Filtering Approach to Fully Interpretable CNNs

Deep Neural Networks (DNN) and especially Convolutional Neural Networks (CNN) have revolutionized the way we approach the analysis of large quantities of data. However, the largely ad-hoc fashion of their development, albeit one reason for their rapid success, has also brought to light the intrinsic limitations of CNNs - in particular those related to their black box nature. In addition, the ability to 'explain' both the way such systems behave and the results they produce is increasingly becoming an imperative in many practical applications. Therefore, it would be particularly useful to establish physically meaningful mechanisms underpinning the operation of CNNs, thus helping to resolve the issue of interpretability of the processing steps and explain their input-output relationship. To this end, we revisit the operation of CNNs from first principles and show that their very backbone – the convolution operation – represents a matched filter which examines the input for the presence of characteristic patterns in data. Our treatment is mainly based on temporal signals, naturally generated by physical sensors, which admit rigorous analysis through systems science. This serves as a vehicle for a unifying account on the overall functionality of CNNs, whereby both the convolution-activation-pooling chain and learning strategies are shown to admit a compact and elegant interpretation under the umbrella of matched filtering. In addition to helping reveal the physical principles underpinning CNNs and providing an intuitive understanding of their operation, the treatment of CNNs from a matched filtering perspective is also shown to offer a platform to support further developments in this area. Finally, a matched filtering approach to the interpretation of CNNs for images and graph CNNs (GCNN) is provided, and is supported by examples.

Biography: Danilo P. Mandic is a professor in signal processing with Imperial College London, UK, and has been working in the areas of machine intelligence, statistical signal processing, big data, learning on graphs, and bioengineering. He is a Fellow of the IEEE and a current President of the International Neural Networks Society (INNS). Dr Mandic is a Director of the Financial Machine Intelligence Lab at Imperial, and has more than 500 publications in international journals and conferences. He has published two research monographs on neural networks, entitled "Recurrent Neural Networks for Prediction", Wiley 2001, and "Complex Valued Nonlinear Adaptive Filters: Noncircularity, Widely Linear and Neural models", Wiley 2009 (both first books in their respective areas), and has co-edited books on Data Fusion (Springer 2008) and Neuro- and Bio-Informatics (Springer 2012). He has also co-authored a two-volume research monograph on tensor networks for Big Data, entitled "Tensor Networks for Dimensionality Reduction and Large Scale Optimization" (Now Publishers, 2016 and 2017), and more recently a research monograph on Data Analytics on Graphs (Now Publishers, 2021). Dr Mandic is a 2019 recipient of the Dennis Gabor Award for "Outstanding Achievements in Neural Engineering", given by the International

Neural Networks Society. He was a 2018 winner of the Best Paper Award in IEEE Signal Processing Magazine for his article on tensor decompositions for signal processing applications, and a 2021 winner of the Outstanding Paper Award in the International Conference on Acoustics, Speech and Signal Processing (ICASSP) series of conferences. Dr Mandic was a Technical Chair of the ICASSP 2019 conference, and has served as a Senior or Associate Editor for IEEE Signal Processing Magazine (2022-present, and 2011-2017), IEEE Transactions on Neural Networks and Learning Systems (2008-2013), IEEE Transactions on Signal Processing (2007-2010), and IEEE Transacions on Signal and Information Processing over Networks (2014-2018). He was appointed by the World University Service (WUS) as a Visiting Lecturer within the Brain Gain Program (BGP), in 2015. Dr Mandic is a 2014 recipient of President Award for Excellence in Postgraduate Supervision at Imperial College and holds six patents. Prof Mandic is a current President of the International Neural Networks Society (INNS) and Distinguished Lecturer of IEEE Computational Intelligence Society and IEEE Signal Processing Society.