Mauro Sanchirico's MS defense is scheduled on Friday 12/10/2021, 2-4 PM.

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Villanova University

ECE DEPARTMENT
MS Thesis Defense

Topic: The Analytically Modified Integral Transform Expansion Applied to Neural Networks and Other Nonlinear Systems

Speaker: Mauro J. Sanchirico III

Date: 12/3/2021

Time/Place: 10:00 AM – 12:00 PM Virtual (Zoom)

Advisor: Dr. C. Nataraj, Dr. Xun Jiao

Committee Members: Dr. C. Nataraj (VU), Dr. Xun Jiao (VU), Mr. Sean O'Rourke (LM)

Contact Info: ECE Department ☎ (610) 519-4970

Abstract:
This thesis presents a novel polynomial expansion facilitating detailed and exact analysis of a broad class of nonlinear functions. The primary motivation is to formulate a polynomial expansion for application to nonlinear activation functions employed in neural networks. In the study of neural networks, polynomial expansions have been applied to address well-known difficulties in the verifiable, explainable, and secure deployment thereof. Existing approaches span classical Taylor and Chebyshev methods, asymptotics, and many numerical approaches. While these individually have useful properties such as exact error formulas, monic form, adjustable domain, and robustness to undefined derivatives, there are no approaches that provide a consistent method yielding an expansion with all these properties.

To address this gap, an analytically modified integral transform expansion (AMITE) is developed. AMITE is a novel expansion via integral transforms modified using a derived criterion for convergence. The AMITE technique is applied to a broad class of functions, including the rectified linear unit (ReLU), the hyperbolic secant, the hyperbolic secant squared, and the hyperbolic tangent. Compared with existing state of the art expansion techniques, AMITE is the first that can provide six previously mutually exclusive desired properties such as exact coefficient and error formulas while remaining robust to undefined derivatives. The utility of the expansion is demonstrated through a main case study in MLP equivalence testing where a blackbox network under test is stimulated and a replicated multivariate polynomial form is efficiently extracted from the response to enable comparison (conformance testing) against the original network.

General utility is then further demonstrated through case studies in nonlinear waves and nonlinear circuits. First, a problem involving waves traveling in shallow water is solved where the mean height of a shallow water wave with an uncertain wavenumber is derived. Further, two problems relating to characterization of biased and unbiased nonlinear amplifiers are solved in terms of several families of novel integer sequences which are derived and tabulated for the first time. We conclude that AMITE presents a new dimension of expansion methods that are suitable for precise analysis of nonlinearities arising in a wide variety of nonlinear circuits and systems, and specifically has noteworthy utility in opening new directions and opportunities for the theoretical analysis and testing of neural networks.