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A Systematic Review on the Role of Differential Equations in Advancing Continuous and Dynamic Machine Learning Models

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Abstract: *Machine learning has rapidly evolved from static data-driven models to systems capable of learning complex dynamic behavior in real time. Differential equations serve as a fundamental mathematical tool for describing continuous change across various natural and engineered processes. This paper provides a systematic review of differential equation-based approaches that enhance both theoretical understanding and practical efficiency in machine learning. The study highlights the role of ordinary differential equations in neural network optimization and introduces the concept of neural ODEs for continuous-depth architectures. Applications of stochastic differential equations in uncertainty modeling, reinforcement learning, and generative AI are also explored. Additionally, the paper examines the use of partial differential equations in physics-informed learning and computer vision tasks. By synthesizing recent research contributions, this review emphasizes how differential equation integration strengthens generalization, improves stability, and supports dynamic decision-making within intelligent systems. Potential future advancements and research gaps are identified to promote further innovation in continuous machine learning frameworks.*

Keywords: Differential Equations, Neural ODEs, Machine Learning, Optimization Methods, Dynamic Systems, Stochastic Modeling, Physics-Informed Learning, Partial Differential Equations.