A Comprehensive Review of Federated Learning: Privacy, Multimodality, and Robustness in Heterogeneous Environments

Adarsh R Menon
Department of Computer Science and Engineering (AIML) PES University, Bengaluru, Karnataka, India

Aarav Adarsh
Department of Computer Science and Engineering (AIML) PES University, Bengaluru, Karnataka, India

Chetana Srinivas
Department of Computer Science and Engineering (AIML) PES University, Bengaluru, Karnataka, India

Aditya Venkatesh
Department of Computer Science and Engineering (AIML) PES University, Bengaluru, Karnataka, India

A Haveesh Kumar
Department of Computer Science and Engineering (AIML) PES University, Bengaluru, Karnataka, India

Abstract:

Federated Learning (FL) enables collaborative model training while preserving data privacy by keeping raw data locally on client devices . Despite its advantages, prac-tical FL deployments face major challenges due to statistical heterogeneity, multimodal data distributions, missing modalities, and the trade–off between privacy, utility and efficiency. Existing methods typically address these challenges in isolation, resulting in performance degradation, excessive overhead, or weakened privacy guarantees. This paper presents a comprehensive review of recent advances in federated learning through a pillar-based analysis. A technical taxonomy is introduced to categorize aggregation strategies, privacy mechanisms, and modality han-dling approaches. Key research gaps are identified, highlighting the absence of unified frameworks that simultaneously address heterogeneity, multimodality, and strong privacy. Finally, future research directions toward practical and trustworthy federated learning systems are discussed.

Keywords:

Federated learning, privacy preservation, multi-modal learning, non-IID data, homomorphic encryption, differ-ential privacy.