Differentially Private Federated Averaging with James-Stein Estimator

Arizona State University

Scientific Achievement

- Developed **DPStein-FedAvg**, a novel differentially private federated learning (DPFL) algorithm integrating the **James–Stein estimator (JSE)** into the popular DP-FedAvg.
- Established a **theoretical convergence analysis** for DPStein-FedAvg and its variants, including DPStein-GD and DPStein-SGD.
- Demonstrated that JSE-based shrinkage acts as an **adaptive global learning rate mechanism** under differential privacy constraints.

Significance and Impact

- Improves the utility–privacy trade-off compared to DP-FedAvg with a constant global learning rate.
- Reduces hyperparameter tuning burden, addressing a major practical limitation in DPFL deployments.
- Provides a principled statistical framework for adaptive optimization under privacy noise, bridging shrinkage estimation theory and private federated optimization.

Technical Approach

- Incorporated the JSE into the global model aggregation step of DP-FedAvg.
- Interpreted the JSE shrinkage factor as an adaptive global learning rate, dynamically adjusting to gradient variance and DP noise.
- Conducted convergence analysis and performed numerical experiments.

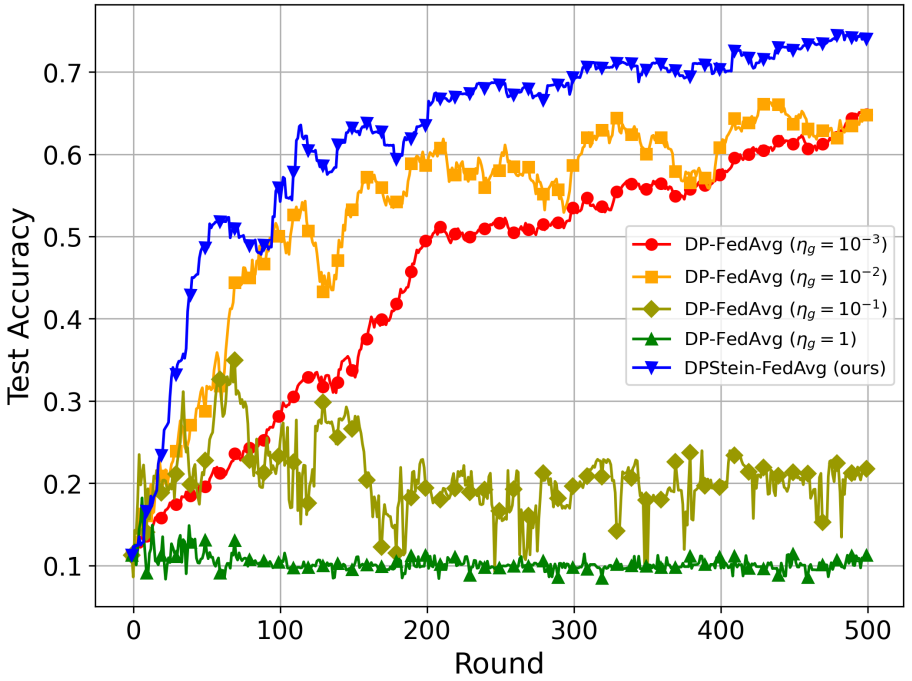

Figure. *Performance comparison between DPStein-FedAvg and DP-FedAvg with varying constant global learning rate, measured by test accuracy under privacy budget $\epsilon = 0.44$. Experiments conducted on MNIST using an MLP model.*

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