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DSSGAN3D - generative model for Fast Calorimeter Shower Simulation

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Fast simulation of calorimeter showers is critical for the High-Luminosity LHC. Traditional Monte Carlo methods are computationally prohibitive for Run 4 of the LHC. We present DSSGAN3D (Directional State Space GAN), a generative adversarial network for volumetric simulations evaluated on the CaloChallenge benchmark (electron showers).
The GAN generator is conditioned on layer-wise energy fractions from a low-dimensional conditional flow matching (CFM), following the established two-stage paradigm. Our parallel CFM Transformer integrates one joint 45-dimensional ordinary differential equation, generating all fractions simultaneously.
The main GAN shower generator employs a bidirectional multi-axis Mamba backbone over the radial-longitudinal subvolume. The azimuthal coordinate lacks sequential structure and is treated as independent channels, with no cross-phi interaction in the SSM. A final lightweight PhiAttention head jointly generates all phi outputs at each position via self-attention. Conditioning via Directional Latent Routing decomposes the latent into axis-specific subvectors modulated by the energy embedding per scan direction. The generator uses full-resolution 2D spatial noise, matching the output grid directly.
DSSGAN3D achieves FPD=0.0557 with our parallel CFM model, the second-lowest among original CaloChallenge entries, surpassing all except CaloDREAM. The full pipeline runs nearly two orders of magnitude faster than other top-ranked submissions.

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