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Transfer learning for efficient emulator training in relativistic heavy-ion collisions

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Bayesian inference is a key tool in relativistic heavy-ion collision studies, enabling probabilistic constraints on model parameters through computational simulations and model-to-data comparison. The information obtained through these simulations, however, is limited to discrete parameter-space points (typically a few hundred to a few thousand design points).

To overcome this bottleneck, the field relies on emulators: surrogate models trained on simulation data. Current approaches use Gaussian Processes (GP) to interpolate simulations, but generating sufficient training data remains expensive. We propose a transfer learning strategy that reduces computational costs by reusing knowledge from simplified simulations.

In relativistic heavy-ion models, approximately 80% of CPU time is spent simulating hadronic transport, where resonance decays (fast to compute) dominate over collisions (slow to compute). By training emulators on a hybrid dataset—combining sparse full simulations (with collisions and decays) and abundant cheap simulations (decays only)—we achieve comparable precision to traditional methods while significantly reducing CPU time. This approach enables more efficient Bayesian analyses without sacrificing accuracy, broadening the scope of feasible studies in heavy-ion phenomenology.

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