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Accurate Small Scale Dynamics in COLA.

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Ongoing galaxy surveys map the Universe's large-scale structure with unprecedented fidelity across immense cosmological volumes. Cosmological inference at the field level demands thousands of N-body simulations. To fully exploit Stage-IV data, simulators must therefore produce fast, high-precision realisations spanning vast cosmological volumes and reaching deep into the non-linear regime. The COmoving Lagrangian Acceleration (COLA) algorithm accelerates large-scale cosmological simulations by decoupling the temporal evolution of large and small scales: large scales are evolved analytically using Lagrangian Perturbation Theory (LPT), while small scales are integrated numerically. Contrary to a common misconception, COLA does not inherently sacrifice small-scale accuracy for speed: the LPT change of frame of reference can be done with any force calculation technique. I show that accurate small-scale dynamics can be obtained at a tractable computational cost by employing Particle–Particle–Particle–Mesh (P3M) force evaluations within an LPT frame of reference, achieving the precision of tree-based codes down to scales of just a few particle lengths. This result is a significant advance towards fully harnessing the cosmological potential of Stage-IV galaxy surveys.

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