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GQLink: an implementation of Quantized State System (QSS) methods in Geant4

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Simulation in high energy physics (HEP) requires the numerical solution of ordinary differential equations (ODE) to determine the trajectories of charged particles in a magnetic field when particles move throughout detector volumes. Each crossing of a volume interrupts the underlying numerical method that solves the equations of motion, triggering iterative algorithms to estimate the intersection point within a given accuracy. The computational cost of this procedure can grow significantly depending on the application at hand. Quantized State System (QSS) is a novel family of asynchronous discrete-event driven numerical methods exhibiting attractive features for this type of problems. QSS offers native dense output (sequences of polynomial segments updated only by accuracy-driven events) and lightweight detection and handling of volume crossings. In previous works we verified the potential of QSS to offer speedups in HEP simulations, in particular in scenarios with heavy volume crossing activity. Yet, our studies were limited to compare two standalone simulation toolkits: Geant4 (with its default Runge-Kutta method) and QSS Solver (with optimized implementations of QSS methods). A salient limitation of this approach is that physics processes were turned off for comparability purposes, restricting the comparisons to simple setups conceived as baselines. In this work we present a proof-of-concept integration of QSS within Geant4, unleashing the capability to evaluate performance in realistic HEP applications. We developed a Geant4 to QSS Link (GQLink), which is an interface for co-simulation that orchestrates robustly and transparently the interaction between QSS Solver and aspects such as geometry definition and physics processes that are kept under the control of Geant4. Results of GQLink for a simple case study to prove the correctness of the method and for a realistic HEP application using the CMS detector will be discussed along with their computing performance.

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