Simulating Optical Photons in HEP experiments on GPUs

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Abstract:
We describe a hybrid computing application to significantly speed up the optical photon generation and transport in Geant4 detector simulations using graphical processing units (GPUs).

In this letter we propose to create a hybrid computing application to significantly speed up the optical photon generation and transport in Geant4 detector simulations using graphical processing units (GPUs).
Optical photons are copiously produced when charged particles pass through a scintillation material. Taking liquid Argon based TPC's (LAr TPC) as an example, a few 10000s of vacuum-ultraviolet (VUV) photons are produced per MeV of energy loss [1]. As the simulation time for tracking optical photons is linearly proportional to the size of detector volume, it can be prohibitively expensive to trace all optical photons in a neutrino experiment with a large fiduciary detector volume. For this reason, photon responses in LAr-based detector simulation rely on look-up tables often even for small test-beam detectors. This solution still involves the time-consuming process of the lookup table preparation and suffers from a poor fidelity compared to the full simulation. Also, the tables grow with the detector size and the number of optical readout channels. This can reach a point where the memory requirements become so large that they do not allow jobs to run at the current computing facilities where there are strict limits on the size of the memory and CPU time used by a job.
Owing to recent advances of parallel computing architectures, modern high-performance computing (HPC) facilities equipped with many CPU cores with deeper vector pipelines (SIMD) or massively many cores (GPU) can enormously accelerate the capacity of computation for arithmetically intensive applications. For LAr-based neutrino experiments such as the Deep Underground Neutrino Experiment (DUNE)[2], it is pertinent to utilize such facilities.

In order to enable large scale studies of optical processes in such experiments, we propose to implement a general application using Geant4 for simulating particles induced by neutrino interactions or cosmic rays inside LAr TPC based detectors. The application will allow to easily configure physics processes, geometry and detector configuration during run-time and therefore making it a convenient tool to optimize detector designs and perform detector R&D.
We will replace processing of optical photons on the CPU with processing them on the GPU, while modeling of physics and particle transport for all other particles will remain to be processed on the CPU.
Optical processing will be done with Opticks, which is a package developed for reactor-based neutrino experiments (Daya Bay and JUNO). Opticks [3] implements the Geant4 optical physics processes on the GPU and uses NVIDIA OptiX to parallelize the tracing of optical photons. We shall modify the current Opticks approach by adopting a task-based model, currently under development for Geant4 [4] where all the information needed to generate the optical photons for GPU processing will be collected at each Geant4 step during the tracking loop, until an optimal number of populated photons for the given GPU hardware is reached and then their generation and propagation on the device are carried out concurrently, while other tasks are processed on the CPU (host), avoiding potential memory limit problem on the GPU.

The computing performance will be evaluated and profiled, comparing the performance of the above applications using GPUs with the one where the optical photons are processed on the CPU.

Running relevant e.g. neutrino simulation applications with different detector designs on GPU-like co processors concurrently would completely eliminate the need for look up tables, as the full generation and ray tracing of optical photons could be done efficiently event by event.
The application, which we plan to enhance as needed, could become a common tool to address optical photon simulation needs of current and future experiments.
In future steps one could adapt the application to use newer versions of OptiX and investigate the use of language portability tools to make it possible to run the application on other vendor GPUs. We also plan to investigate how existing physics models and geometry libraries compatible with GPUs, developed in an earlier detector simulation R&D work [5,6,7] could be utilized.

References:

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