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Commentary

Using CUDA to Speed-up IceCube's Photon Propagation Code

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DESCRIPTION

The IceCube neutrino observatory is the world's leading instrument for detecting neutrinos with energy greater than 1 TeV and an important component of the global multi-messenger astrophysics effort. IceCube is made up of 5160 Digital Optical Modules (DOMs) that are buried deep under glacial ice at the geographic South Pole. Individual photons and their arrival time can be detected with O(ns) accuracy by the DOMs. The primary array has already been detailed; deep core is a dense and tiny sub-detector that extends sensitivity to 10 GeV; and ice top is a surface air shower array that examines O(PeV) cosmic rays.

IceCube is a multidisciplinary experiment that addresses astrophysics, dark matter research, cosmic rays, particle physics, and geophysical sciences. IceCube is always on and achieves over 99 percent uptime while being responsive to the entire sky. The discovery of an all-sky astrophysical neutrino flux and the identification of a neutrino from Blazar TXS 0506+056 that prompted follow-up studies from a slew of other telescopes and observatories are among the highlights of IceCube's scientific results.

Secondary particles (muons and hadronic or electromagnetic cascades) are produced when neutrinos interact with the ice around or inside IceCube, as well as cosmic ray interactions in the atmosphere above IceCube. As they move through the highly clear ice, these secondary particles create Cherenkov light (blue as viewed by humans). Cherenkov photons detected by DOMs can be utilised to reconstruct the parent neutrino or cosmic ray air shower's direction, kind, and energy.

Because of the optical complexity of the ice in the Antarctic glacier, modelling the transmission of these Cherenkov photons has proved difficult. Over the last decade, IceCube's simulation has evolved to incorporate a strong method for simulating “direct” photon propagation utilizing GPUs. This simulation module is up to 200 times faster than a CPU-based implementation and, more importantly, can account for some ice properties, such as a shift in ice properties along the height of the glacier and varying ice properties as a function of polar angle, that are critical for performing precision measurements but would be extremely difficult to implement with a table-based simulation that parameterizes the ice properties in finite volume bins.

Gen2 and the icecube upgrade

The IceCube collaboration has begun a series of detector upgrades. IceCube Upgrade is the first phase of the detector upgrade, and it focuses on detector calibration, neutrino oscillation studies, and R&D for new detection modules with larger light gathering areas. Following phases, known as IceCube-Gen2, will focus on high-energy neutrinos (>10 TeV), including optical and radio detection. As a result, science output will rise, and the demand for Monte Carlo simulation and data processing will rise.

Propagation of photons

The simple mathematical nature of photons, their common algorithm, their capacity to propagate photons independently, and the possibility of employing single-precision floating point mathematics allow for huge parallelization using either a large number of CPU cores or GPUs.

The following sections make up the algorithm. Cherenkov-emitting particle (e.g., tracks with a charge) or calibration light source trajectories are divided into stages. Each step represents a region with Cherenkov emission parameters that are close to uniform, i.e., constant particle velocity v/c within safe ranges. The average number of Cherenkov photons to be released is then calculated using the step length and velocity. This average is then utilized to create an integer number of photons from the step by sampling from a Poisson distribution.

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