Fast Sphere Intersection Tests for Shooting-Bouncing Ray Tracing: Space Partitioning and Ray Path Voxelization

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This paper addresses performance issues of Shooting-Bouncing Ray (SBR) tracing when using observation sphere-based sampling to compute the field distribution. While much previous work has explored the application of ray-tracing techniques to computational electromagnetics (CEM), these asymptotic techniques have not shared the popularity of full-wave approaches such as Finite Element Method (FEM) or Method of Moments (MoM). Meager adoption of ray-tracing techniques has been due primarily to high computational costs and poor accuracy for many problems. While researchers are once more beginning to take interest in asymptotic techniques such as SBR for large CEM problems due to the burgeoning availability of computing resources, there seems to be opportunities for a lot more work to be done toward improving the computational scaling of SBR for large problems.

We first discuss the observation sphere approach to sampling in the SBR technique and its associated accuracy improvements. We demonstrate the necessity of the observation sphere technique to conserve transmitted power in the given SBR implementation, and present the costly computations required for accurate ray segment-sphere intersection tests when sphere sizes are dynamic.

We then examine the SBR technique with an emphasis on performance, giving an overview of the associated algorithms and their implementations on modern computing hardware. We highlight the bottlenecks in the approach, focusing notably on the challenge presented by the observation sphere approach and its poor scaling with field sample point count, m, and ray count, n. With modern applications such as communication node optimization and 5G modeling requiring dense volumetric field data, an effective SBR technique will need to scale effectively with this crucial parameter.

We finally demonstrate a reduction in the asymptotic computational complexity of the sphere intersection test from $O(nm)$ to $O(n \log m)$ and further reduction of the scaling coefficient of the fast algorithm with respect to the conventional implementation. To achieve this complexity reduction, we present a novel algorithm relying on space partitioning and ray-path voxelization. We demonstrate that the developed algorithm produces, a priori, the indices of space partition cells that must be checked for a given ray path, preventing costly ray-cell intersection checks that, although trivial for small scenes, are prohibitively costly in the large scenes for which SBR is seeing renewed interest.