Parallel-in-Time Computation for Maxwell's Equations

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Over the past decades, computational electromagnetics (CEM) has led to many simulation-driven scientific discoveries. These electromagnetic (EM) simulations are enabled by fast and rigorous numerical solutions of Maxwell's Equations as well as rapid advances in high-performance computing (HPC) systems. Meanwhile, the growing sophistication in real-world applications and the increasing demand on the simulation fidelity have driven the need for advanced mathematics and algorithms. The greater levels of fidelity lead directly to the requirement of very large multi-scale EM computations in both space and time.

One potential solution is the development of extreme-scale, ultra-parallel algorithms on the emerging exascale HPC platforms. Regarding to the time-scale and space-scale challenges, the former is unlikely to benefit directly from the next generation massively parallel architectures. Current time-dependent CEM solvers are typically parallel only in space. The sequential-in-time nature of the solvers can achieve good parallel scaling when the number of spatial mesh points per core is large. But the parallel efficiency quickly deteriorates even saturates if spatial parallelism has been fully exploited. Therefore, a futuristic question arises that if it is possible to parallelize the time dimension for Maxwell's Equations.

The objective of this work is to investigate high-resolution, high-performance algorithms to address the space-scale and time-scale challenges in high fidelity EM analysis. Technical ingredients include: (i) a parallel space-time domain decomposition method to fully utilize the exascale concurrency, (ii) optimized Schwarz transmission conditions for quasi-optimal convergence, and (iii) an effective coarse-graining approach via hierarchical skeletonization for multi-scale computation. It is envisioned that the simulation capability and modeling fidelity of developed solvers will scale with the exponential growth in computing power.