Scaling Analysis of a Hierarchical Parallelization of Large Inverse Multiple-Scattering Solutions

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Inverse-Scattering Problems
- Transmitter
- Reconstructed Object
- Receiver
- Reconstruction Window

Multiple-scattering reconstructions does not make any fundamental approximation.

Multilevel Fast Multipole Algorithm (MLFMA) Schematic

Original Object
- Imaged
- with High Contrast
- Single-scattering Reconstruction
- Multiple-scattering Reconstruction

Original Object Imaged
- with Limited View
- Single-scattering Reconstruction
- Multiple-scattering Reconstruction

MLFMA Provides fast solutions of forward-scattering problems with O(N) computational complexity.

Distorted-Born Approximation
- Scattering Equation: \( \phi = \phi_b + G_b \phi \)
- Variational Equation: \( \delta \phi = G_b \delta \phi + \delta G_b \phi \)

Higher-order Variations (neglected)

Hierarchical Parallelization

Vehicle: MPI
- Parallelizing MLFMA (Simultaneously with illuminations)

Strong Scaling
- Parallelizing illuminations is almost perfectly efficient due to the independent nature of forward solutions.

Conclusions
- A hierarchical parallelization strategy to improve the scalability of inverse multiple-scattering solutions is proposed.
- An inverse problem involving a large Shepp-Logan phantom is solved on up to 1,024 CPU nodes of the Blue Waters supercomputer in order to demonstrate the strong-scaling efficiency of the proposed parallelization scheme.

Future Plans
- GPU nodes will be employed for massively-parallel solutions (done & submitted: 4k GPUs. Approx. 4x speedup over CPUs).
- Real-life problems will be solved with real measurement data. Not trivial because of noise, calibration, etc.

Nonlinear Optimization
- There is not a single way to do this, however, we found nonlinear conjugate-gradient method is efficient for this algorithm.

• Gradient-Descent: \( -\nabla \Phi = -F^T b \)
• Conjugate-Gradient
  - CG
  - SD
• Newton-Type Methods
  - \( \mu^2 I + F^T F \delta \Phi = \nabla \Phi \)
  - \( P \): Functional Derivative Operator

Hierarchical Parallelization
- Column Rank: 6
- row Rank: 5
- Out Scaling
- Up Scaling
- MLFMA
- MPI_Comm_split( MPI_Comm comm, int color, int key, MPI_COMM newcomm)

Large Reconstruction
- Iteration 1
- Iteration 2
- Iteration 10
- Iteration 20
- Iteration 50
- Reference

MLFMA scaling is not perfect due to the MPI communications in each matrix-vector multiplication.

See More Results & Animations:

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