A Hierarchical Challenge: AMR

10/16/2018
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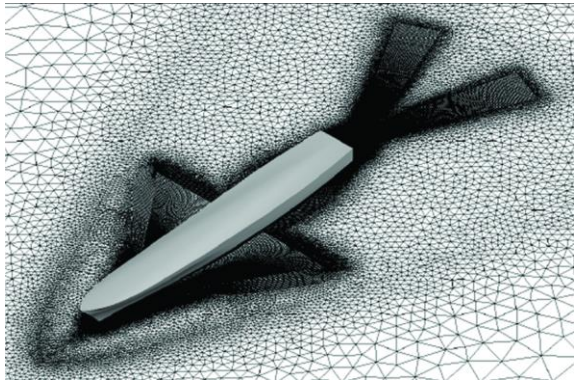
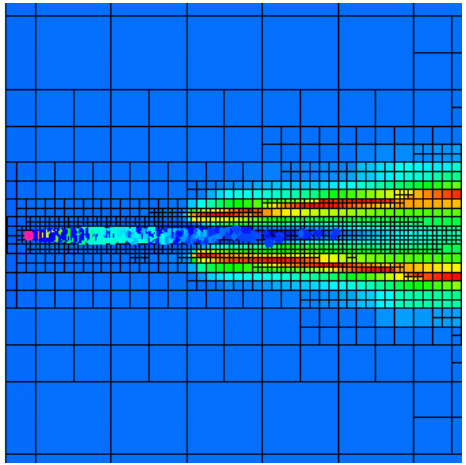
Adaptive Mesh Refinement

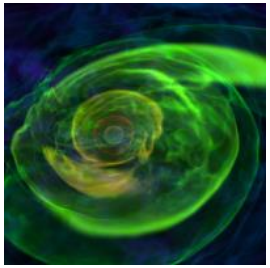
- Computational science is becoming more expensive
  - More detailed science
  - Bigger machines -> more data
- Only model what matters
  - Unstructured meshes
  - Structured but hierarchical meshes

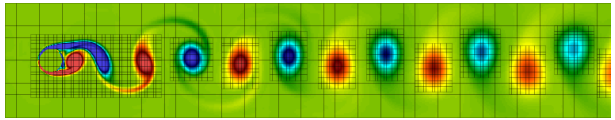


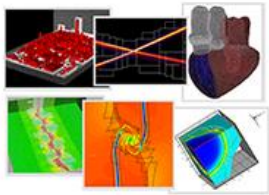


AMR Software

- AMReX (formerly BoxLib)
  - https://fastmath-scidac.llnl.gov/software/amrex.html
- Chombo
  - https://commons.lbl.gov/display/chombo/Chombo+-+Software+for+Adaptive+Solutions+of+Partial+Differential+Equations
- SAMRAI
  - https://computation.llnl.gov/projects/samrai
- Combustion, Astrophysics, Fluid Flows

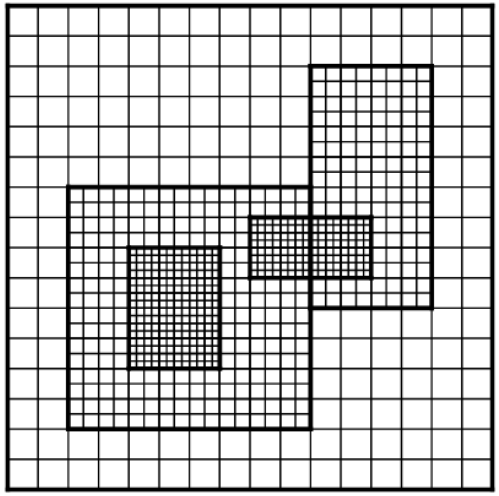


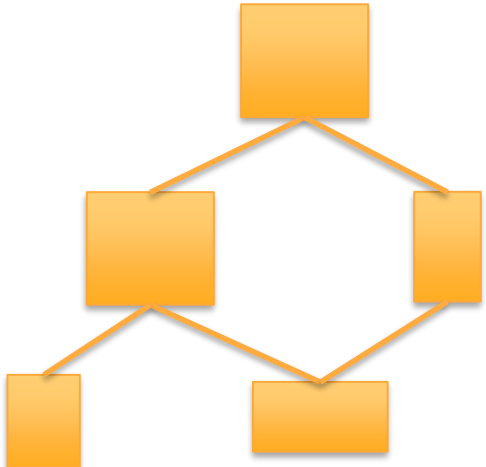




How does AMR Work

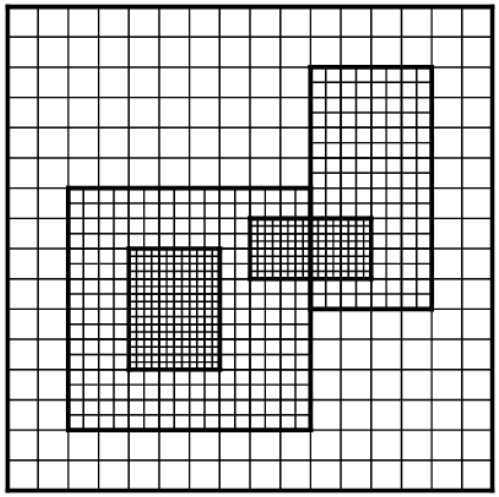
- Start with a regular mesh at level 0
- Add refinements when needed to track “interesting” behavior
    - Usually shock/flame wavefronts
- Recursively refine (up to ~7-8 levels)
- Refinements do not have to properly nest
- Lower levels need more memory

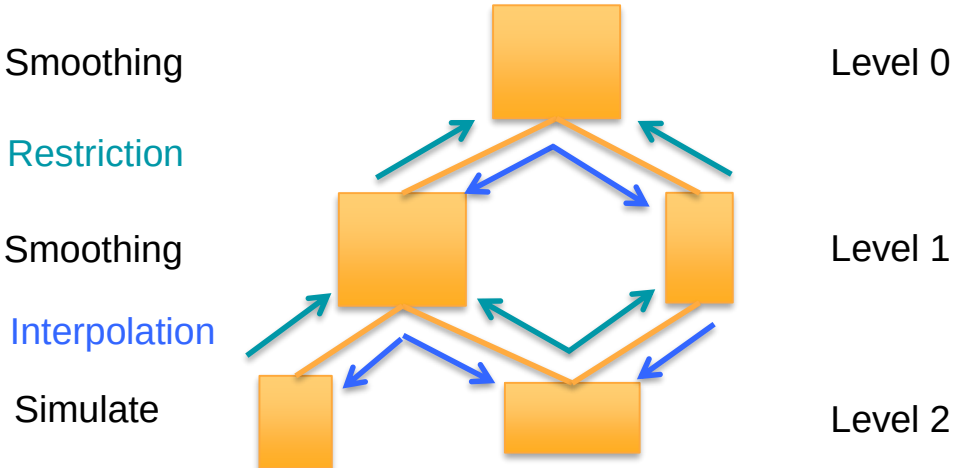




AMR Operations

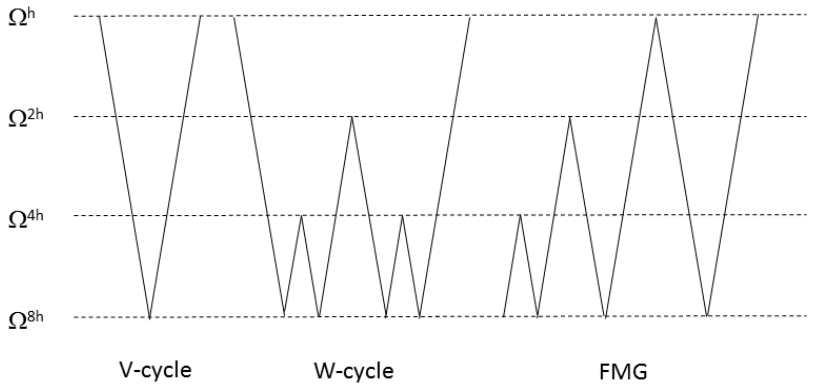
- Simulation
  - Mostly on the lower levels
  - Sometimes on intermediate levels too
- Restriction/Projection
  - Nasty boundary conditions
- Smoothing
- Interpolation/Prolongation
  - More nasty boundary conditions

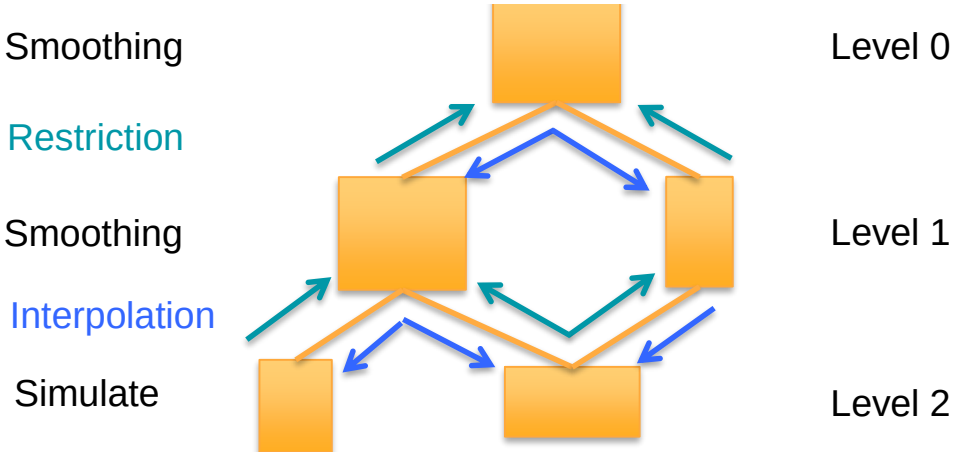




Hierarchical Solvers for Hierarchical Levels

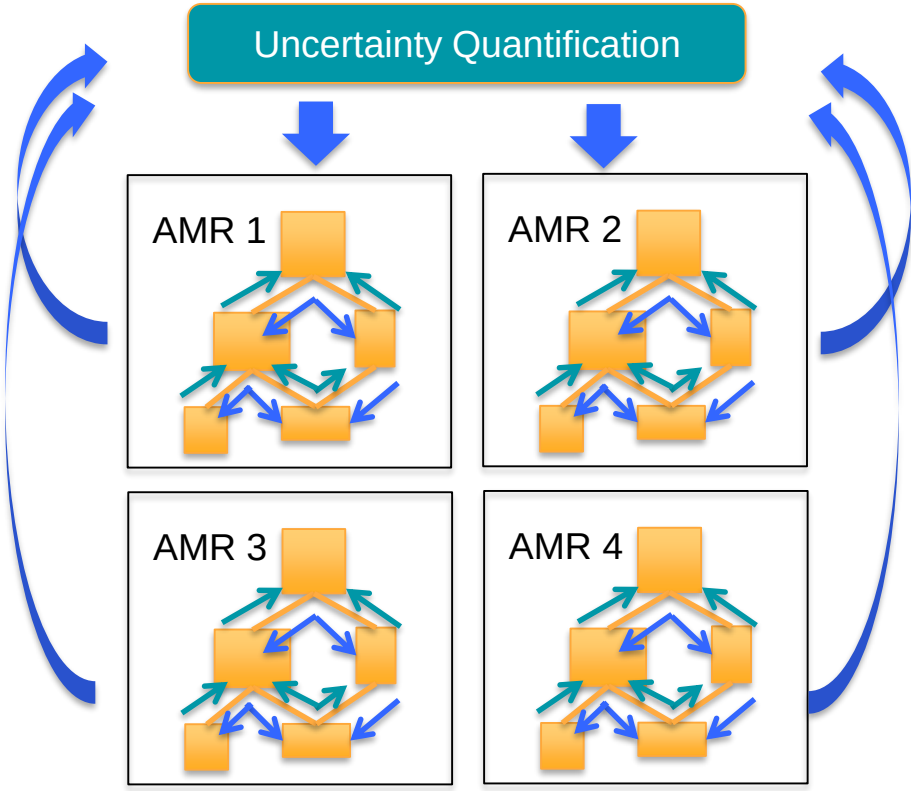
- Smoothing is multi-grid on AMR
  - Sparse in parent levels
- Pattern of smoothing depends on simulation and data
  - Cycle patterns change based on convergence rate
- Can often be doing multiple smoothing steps in parallel for different physical quantities
- Use libraries like HYPRE/Trilinos





More Hierarchy: Uncertainty Quantification

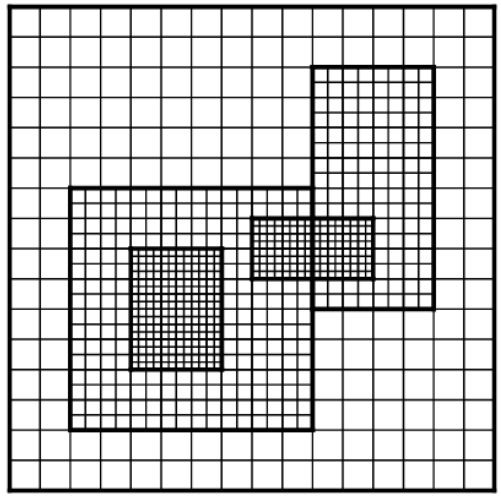
- Discover “sensitivities” to input parameters in simulation
- Play simulation forward with small perturbations
- Sometimes play simulation backwards too (very data intensive)
- Approximate tolerances

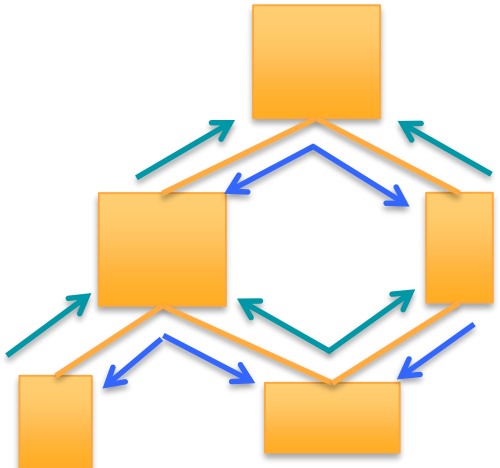


Kinds of Hierarchy

- Hierarchy of Data
  - Multiple levels of simulation data
- Hierarchy of Computation
  - Computations of levels are nested
- Hierarchy of Software
  - UQ -> AMR -> MG

- Hierarchy of Data != Computation
- Haven’t discussed memory hierarchy





Hierarchy of Data

- Memory pressure is the biggest problem here
- When re-gridding have to repartition to support memory distribution
- Consider locality with as well as across levels when repartitioning
- Need for multiple dynamically-created logical partitions of data

Hierarchy of Compute

- Computations are specified hierarchically
- MG cycles create sub computations
- Each computation can be recursively divided for multiple processing elements
- Unmated hierarchy of data can pose challenges for functional computations
- Tree of tasks to match machine
- Flat top-level task for handling levels

Hierarchy of Software

- These software packages are huge!
- Will NOT be completely re-written
- Will NOT provide interoperability with each other (sometimes not even with themselves)
- Implicit parallelism discovery
- Extract parallelism and hierarchy across abstraction boundaries

Conclusion

- Many kinds of hierarchy in AMR
- Hierarchy is dynamic
  - Must be dealt with at runtime
- Kinds of hierarchy do not match
  - Makes software composition challenging
- AMR is HARD ☺