Adaptive Atmospheric Modeling on Unstructured Grids - Generic Techniques

Abstract
Efficient unstructured grid adaptive modeling requires for advanced programming and numerical techniques. In this presentation we demonstrate several such generic techniques applied to simple example applications in atmospheric and ocean modeling. Efficient grid generation is achieved by triangular bisection, optimized data locality can be realized by space-filling curve ordering, and data management is stream lined by a gather-scatter paradigm.

We apply these numerical schemes to a semi-Lagrangian cell integrated mass conserving advection scheme, and to a finite-element wave propagation application in tsunami ocean modeling.

Triangular refinement
- Bisection of marked edge.
- Applicable in 2D (triangles) and 3D (tetrahedra), see fig. 1.
- Generic refinement tree: binary tree data structure.
- Linearization of tree structure by space-filling curves (see below).

Data Management
- Gather-scatter paradigm (see fig. 2).
- Object oriented, tree structured data for mesh management.
- Vector structured data for numerical computations.
- Locality preservation via space-filling curves (see below).
- Low overhead (<1%) for gather and scatter operations.

Implementation/Software
- Fortran 90 library with module interface.
- Modular software package, simple API.
- Open source (after registration) with documentation.
- Web page for ticketing, Wiki, etc.: http://www.amatos.info
- User feedback is welcome!

Space-filling Curves (SFC)
- Computation of SFC indices “on the fly” in combination with refinement strategy (see above).
- Zero overhead for SFC computation and reordering.
- SFC indexing: bit manipulations based on refinement level, orientation, mother index (fig. 6).
- Domain partitioning for parallelization: optimal load balancing, near optimal edge cut (fig. 7).
- Matrix structure optimization by reordering unknowns (comparision of different algorithms in fig. 8).
- Cache optimization due to neighborhood preservation property of SFC (fig. 9).

Prototype Tsunami Model
- Based on shallow water equations:
  \[ \frac{\partial h}{\partial t} + \nabla \cdot (h + h^2) = 0 \]
  \[ \frac{\partial v}{\partial t} + v \cdot \nabla v + f_e \times v - g \nabla h + F \]
- Finite element discretization with P1-P1NC elements (fig. 12).
- Radiation/Reflection boundary conditions.
- Second order leap-frog time stepping.
- Refinement control by Gradient Refinement/Remeshing in each time-step (fig. 13).

Summary and Acknowledgements
Efficient data structures and strategies for 2D and 3D adaptive mesh refinement were introduced. These techniques are readily combined with advanced methods for atmospheric and ocean modeling.

Thanks to F. Klaschka, L. Mørkøw, S. Danilov, D. Sein, O. Kunst, M. Käser, J. Zimmermann.

Literature