Block-structured Adaptive Mesh Refinement in C++

The AMROC Framework for Parallel AMR

Short course at INPE, 30th June to 1st July 2016

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Structure of the lectures

1. Structured adaptive mesh refinement
   - Background and available SAMR software
   - The recursive SAMR algorithm
   - Overview of the AMROC software system
   - Distributed memory parallelization

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   - Shock-capturing schemes for gas dynamics
   - Higher-order discretizations
   - Magneto-hydroynamics
   - Code snippets for interfacing with AMROC

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   - Code snippets for interfacing with AMROC
3. Discussion session
   - Demo of AMROC
   - Installation on student computers
   - Running examples, etc.

Structure of the lectures - II

4. Complex hyperbolic SAMR applications
   - Consideration of non-Cartesian geometries
   - Shock-induced combustion simulation with AMROC
   - Fluid-structure interaction with the Virtual Test Facility
   - Combressible turbulence simulation

Structure of the lectures - II

4. Complex hyperbolic SAMR applications
   - Consideration of non-Cartesian geometries
   - Shock-induced combustion simulation with AMROC
   - Fluid-structure interaction with the Virtual Test Facility
   - Combressible turbulence simulation
5. Advanced topics
   - Adaptive lattice Boltzmann methods with AMROC
   - Large eddy simulation of subsonic problems
   - Using SAMR for geometric multigrid methods

Useful references I

Finite volume methods for hyperbolic problems

- LeVeque, R. J. (2002). *Finite volume methods for hyperbolic problems*. Cambridge University Press, Cambridge, New York.
- Godlewski, E. and Raviart, P.-A. (1996). *Numerical approximation of hyperbolic systems of conservation laws*. Springer Verlag, New York.
- Toro, E. F. (1999). *Riemann solvers and numerical methods for fluid dynamics*. Springer-Verlag, Berlin, Heidelberg, 2nd edition.
- Laney, C. B. (1998). *Computational gasdynamics*. Cambridge University Press, Cambridge.

Structured Adaptive Mesh Refinement

- Berger, M. and Colella, P. (1988). Local adaptive mesh refinement for shock hydrodynamics. *J. Comput. Phys.*, 82:64–84.
- Bell, J., Berger, M., Saltzman, J., and Welcome, M. (1994). Three-dimensional adaptive mesh refinement for hyperbolic conservation laws. *SIAM J. Sci. Comp.*, 15(1):127–138.
- Berger, M. and LeVeque, R. (1998). Adaptive mesh refinement using wave-propagation algorithms for hyperbolic systems. *SIAM J. Numer. Anal.*, 35(6):2298–2316.

Useful references II

- Deiterding, R. (2011). Block-structured adaptive mesh refinement - theory, implementation and application, *Series in Applied and Industrial Mathematics: Proceedings*, 34: 97–150.

Lattice-Boltzmann methods

- Succi, S. (2001). *The Lattice Boltzmann Equation for Fluid Dynamics and Beyond*. Oxford Science Publications.
- Guo, Z., Shu, C. (2013). *Lattice Boltzmann Method and Its Applications in Engineering*, World Scientific.
- Hähnel, D. (2004). *Molekulare Gasdynamik*, Springer.
- Aidun, C. K., Clausen, J. A. (2010). Lattice-Boltzmann method for complex flows. *Annu. Rev. Fluid Mech.*, 42: 439–472.

Adaptive multigrid (finite difference and finite element based in textbooks)

- Hackbusch, W. (1985). *Multi-Grid Methods and Applications*. Springer Verlag, Berlin, Heidelberg.
- Briggs, W. L., Henson, V. E., and McCormick, S. F. (2001). *A Multigrid Tutorial*. Society for Industrial and Applied Mathematics, 2nd edition.
- Trottenberg, U., Oosterlee, C., and Schüller, A. (2001). *Multigrid*. Academic Press, San Antonio.

Useful references III

- Martin, D. F. (1998). *A cell-centered adaptive projection method for the incompressible Euler equations*. PhD thesis, University of California at Berkeley.

Implementation, parallelization

- Hornung, R. D., Wissink, A. M., and Kohn, S. H. (2006). Managing complex data and geometry in parallel structured AMR applications. *Engineering with Computers*, 22:181–195.
- Rendleman, C. A., Beckner, V. E., Lijewski, M., Crutchfield, W., and Bell, J. B. (2000). Parallelization of structured, hierarchical adaptive mesh refinement algorithms. *Computing and Visualization in Science*, 3:147–157.
- Deiterding, R. (2005). Construction and application of an AMR algorithm for distributed memory computers. In Plewa, T., Linde, T., and Weirs, V. G., editors, *Adaptive Mesh Refinement - Theory and Applications*, volume 41 of *Lecture Notes in Computational Science and Engineering*, pages 361–372. Springer.

Applications (from my own work only)

- Deiterding, R. and Wood, S (2013). Parallel adaptive fluid-structure interaction simulation of explosions impacting on building structures. *Computers & Fluids*, 88: 719–729.

Useful references IV

- Deiterding, R., Radovitzky, R., Mauch, S. P., Noels, L., Cummings, J. C., and Meiron, D. I. (2006). A virtual test facility for the efficient simulation of solid materials under high energy shock-wave loading. *Engineering with Computers*, 22(3-4):325–347.
- Pantano, C., Deiterding, R., Hill, D. J., and Pullin, D. I. (2007). A low-numerical dissipation patch-based adaptive mesh refinement method for large-eddy simulation of compressible flows. *J. Comput. Phys.*, 221(1):63–87.
- Barton, P. T., Deiterding, R. and Meiron, D. I. and Pullin, D. I. (2013). Eulerian adaptive finite-difference method for high-velocity impact and penetration problems, *J. Comput. Phys.*, 240: 76–99.
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- Deiterding, R. (2009). A parallel adaptive method for simulating shock-induced combustion with detailed chemical kinetics in complex domains. *Computers & Structures*, 87:769–783.
- Ziegler, J. L., Deiterding, R. Shepherd, J. E. and Pullin, D. I. (2011). An adaptive high-order hybrid scheme for compressive, viscous flows with detailed chemistry. *J. Comput. Phys.*, 230(20): 7598–7630.

Useful references V

- Gomes, A. K. F., Domingues, M. O., Schneider, K., Mendes, O., Deiterding, R. (2015). An adaptive multiresolution method for ideal magnetohydrodynamics using divergence cleaning with parabolic-hyperbolic correction. *Applied Numerical Mathematics* 95: 199–213.
- Deiterding, R. and Wood, S. L. (2015). A dynamically adaptive lattice Boltzmann method for predicting wake phenomena in fully coupled wind engineering problems. *IV Int. Conf. on Coupled Problems in Science and Engineering* 489–500.