Explicit and Implicit Coupling Strategies for Overset Grids

Jörg Brunswig, Manuel Manzke, Thomas Rung

Fluiddynamik und Schiffstheorie
TUHH

Outline

- FreSCo+
- Grid Coupling
  - Interpolation Schemes
  - Implementation
  - Mass Conservation
- Examples
  - Lid-driven Cavity Flow
  - Cylinder in a Channel
  - Oscillating Cylinder
- Conclusion / Outlook

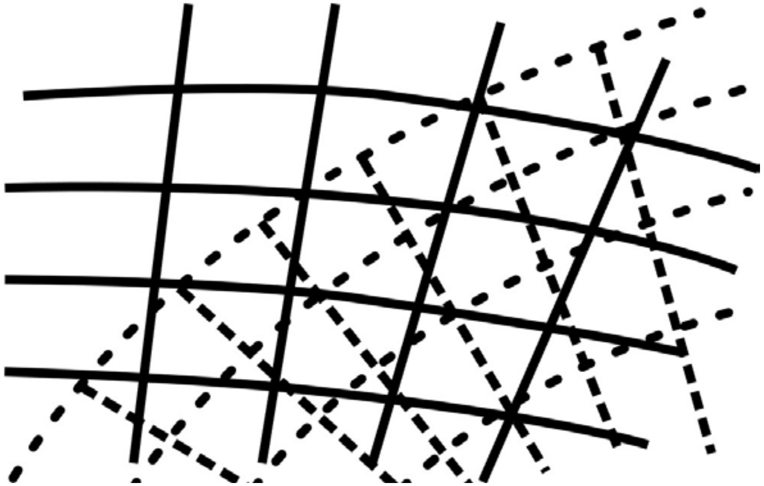
FreSCo$^+$

- Spin-off of FreSCo (TUHH, HSVA, MARIN)
- Segregated Algorithm
- 2nd Order (Space/Time)
- Pressure Correction: SIMPLE
- Unstructured Grids
- Various Turbulence Models
- Interface Capturing Methode (VoF) for two-phase flows
- Parallel Environment: MPI
- Load Balancing using ParMetis

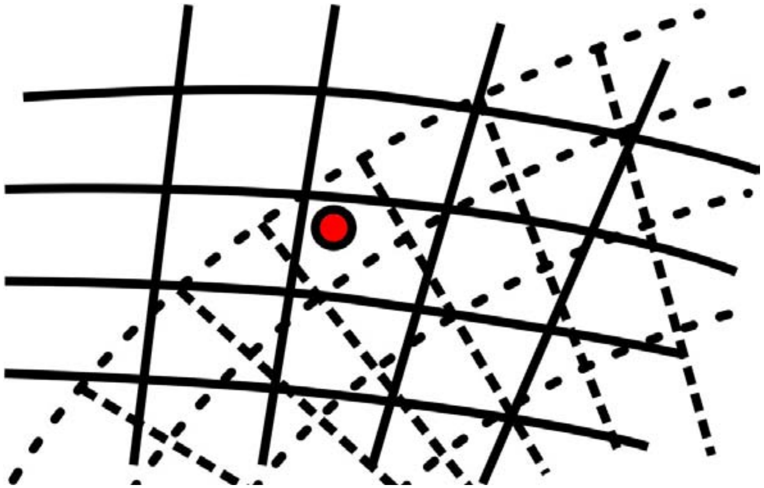
Grid Coupling

- All grids organized in single equation system
- Grid coupling by interpolation schemes:
  - Cell Center
  - Cell Center + Gradient Correction
  - Simplex Mesh (bilinear / trilinear interpolation)
  - Inverse Distance
- Coupling can be implicit or explicit

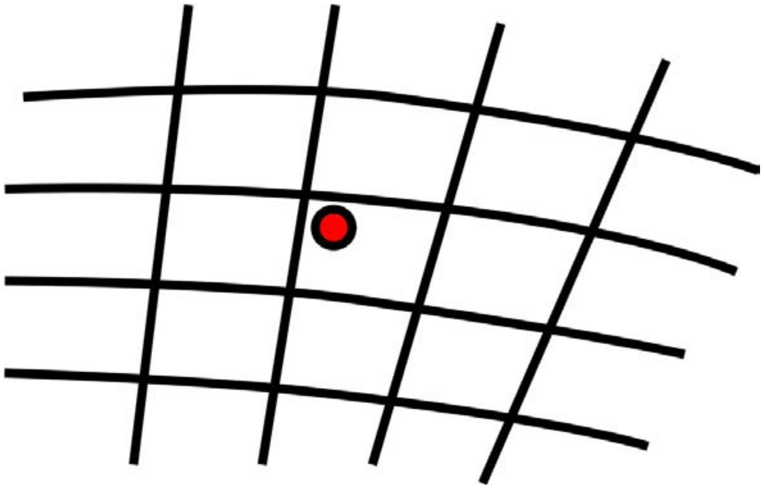
Grid Coupling: Interpolation Equation



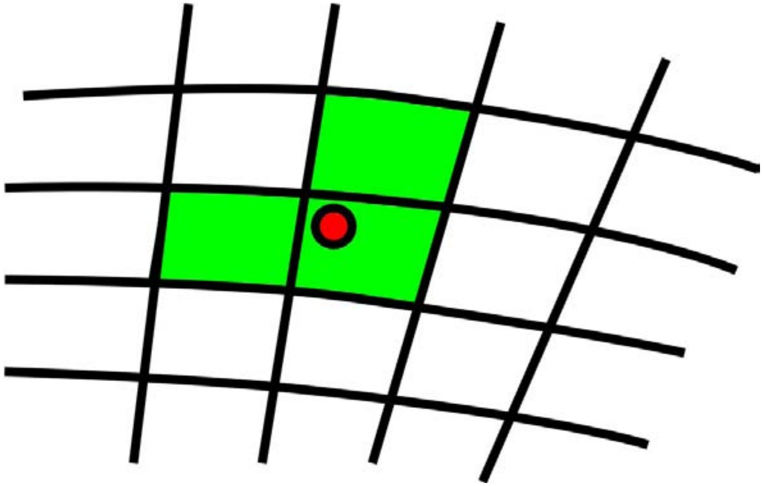
Grid Coupling: Interpolation Equation



Grid Coupling: Interpolation Equation

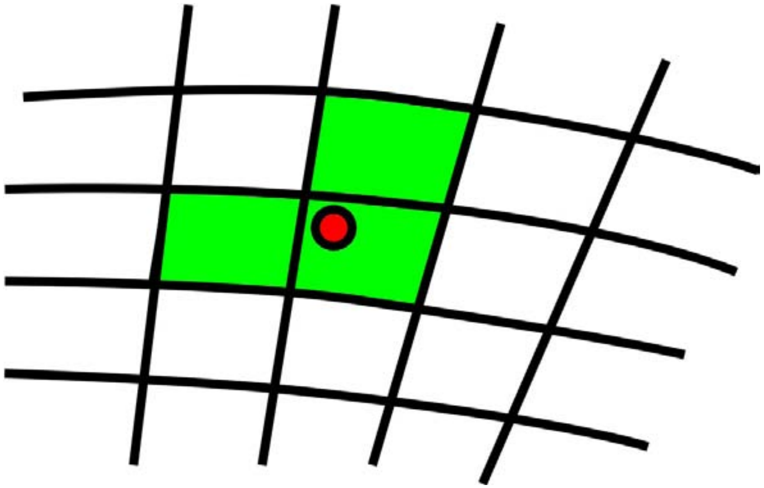


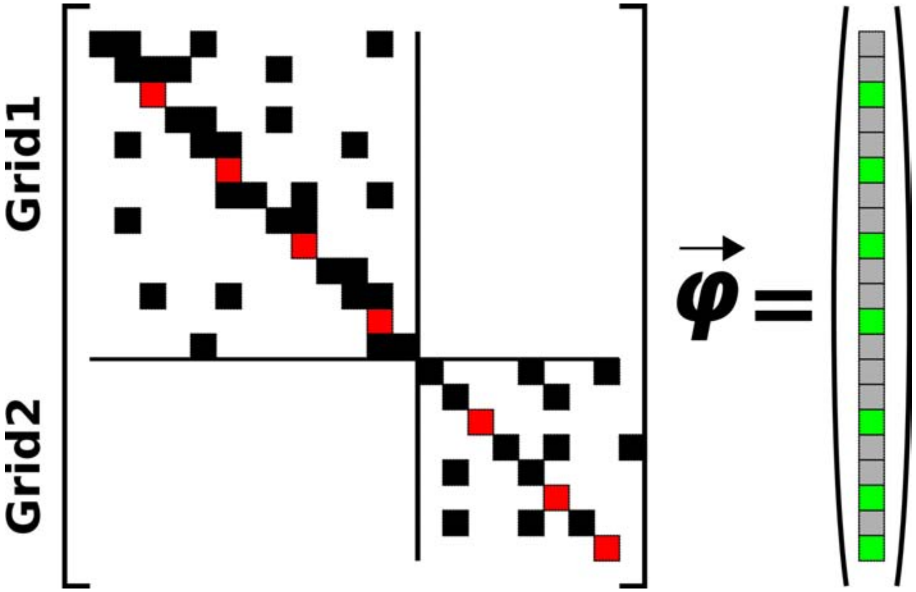
Grid Coupling: Interpolation Equation



$$\phi^{target} = C + \sum_{i=1}^{n} a_i \phi_i^{donor}$$

Grid Coupling: Interpolation Equation

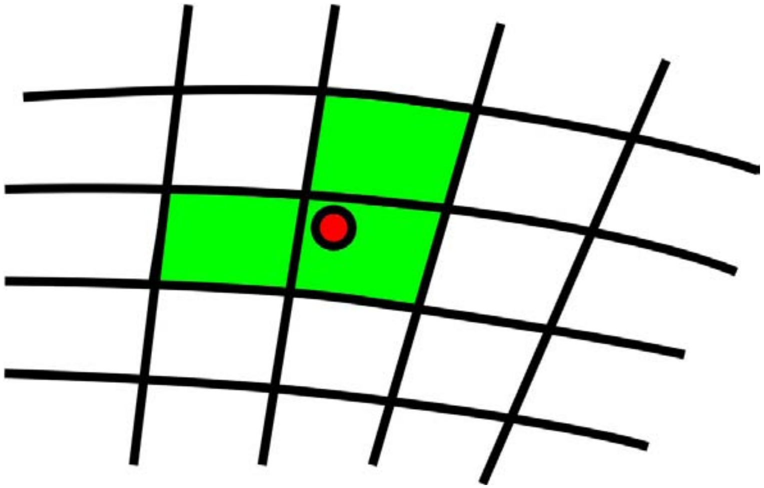


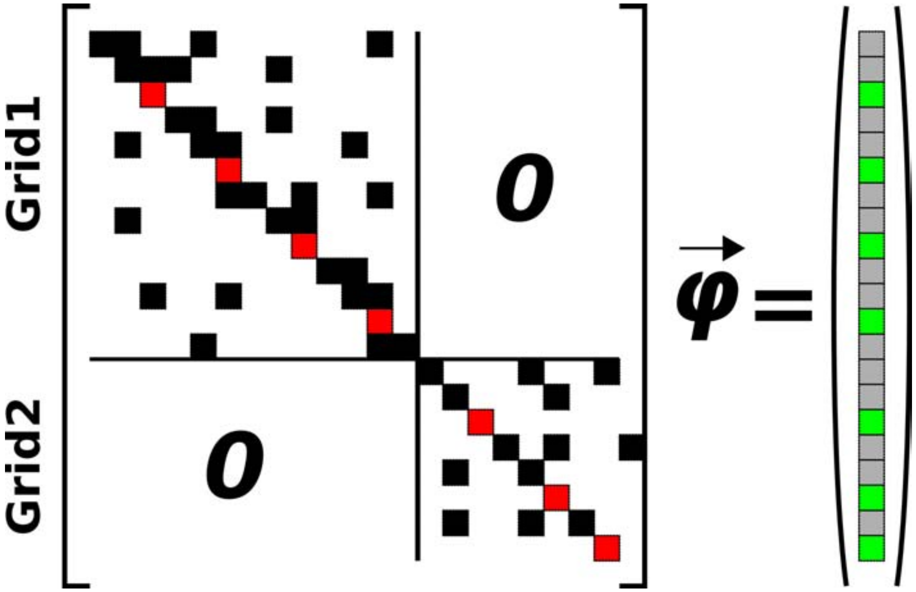


$$\phi^{target} = C + \sum_{i=1}^{n} a_i \phi_i^{donor}$$

Main Diagonal **Right Hand Side**

Grid Coupling: Interpolation Equation

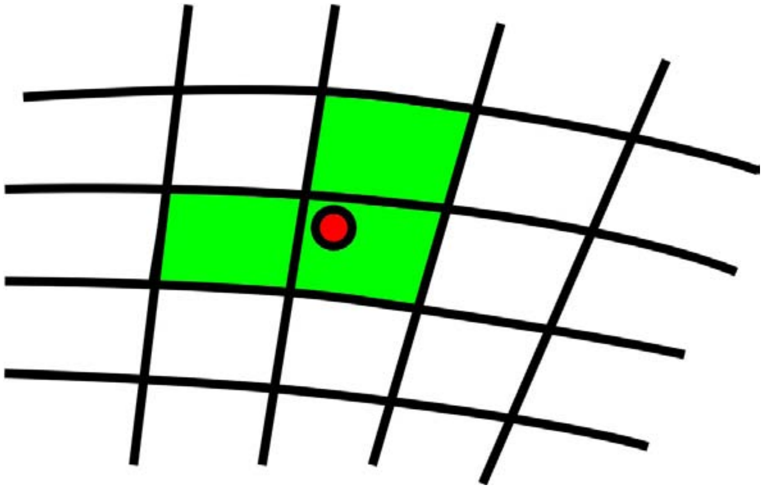


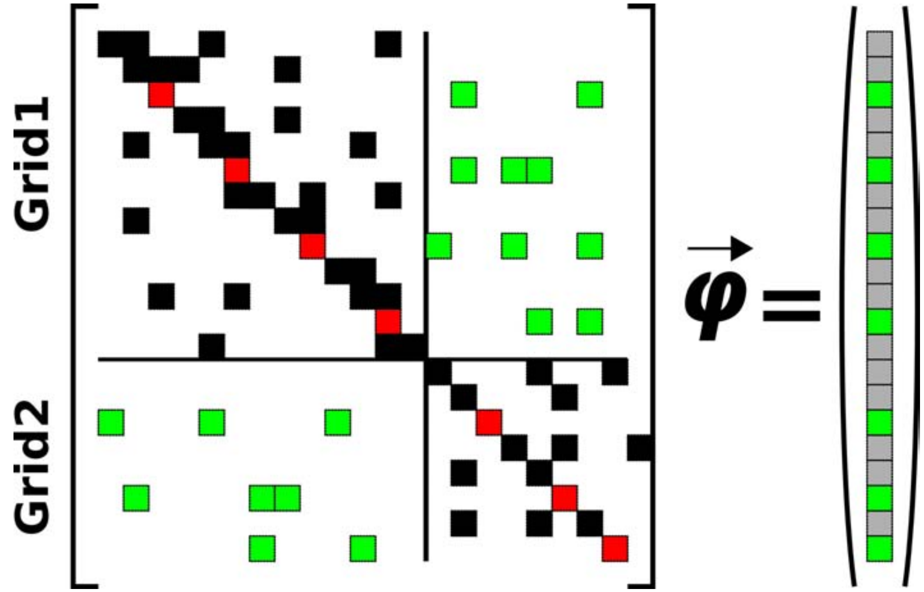


$$\phi^{target} = C + \sum_{i=1}^{n} a_i \phi_i^{donor}$$

Explicit Coupling

Main Diagonal **Right Hand Side**





$$\phi^{target} - \sum_{i=1}^{n} a_i \phi_i^{donor} = C$$

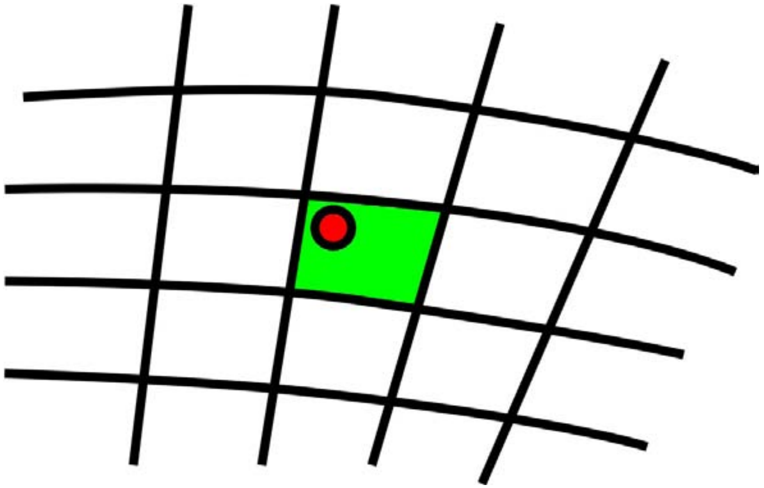
Implicit Coupling

Main Diagonal

Right Hand Side

Off-Diagonal Elements

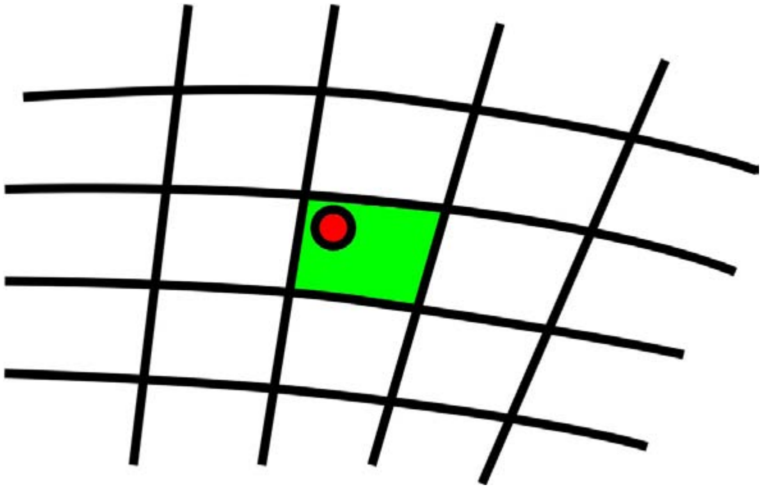
Grid Coupling: Cell Center



$$\phi^{target} - \sum_{i=1}^{n} a_i \phi_i^{donor} = C$$

$n = 1$ $\quad\quad\quad\quad$ $C = 0$

Grid Coupling: Cell Center

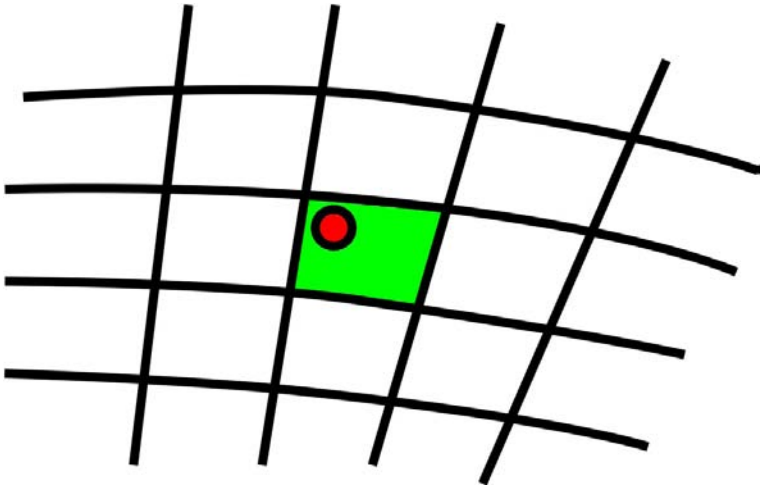


- Very simple scheme
- Fully implicit interpolation possible
- Result is bounded
- Not very accurate

$$\phi^{target} - \sum_{i=1}^{n} a_i \phi_i^{donor} = C$$

$$n = 1 \qquad C = 0$$

Grid Coupling: Cell Center + Gradient Correction

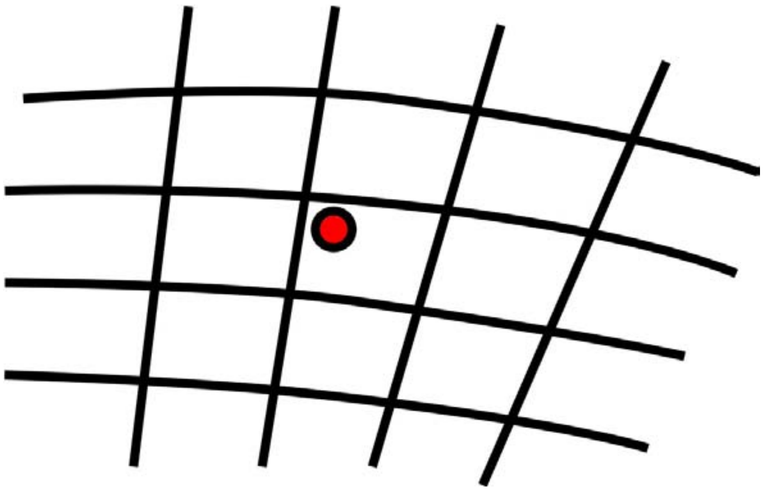


- Very simple scheme
- Explicit part always present
- Result is not bounded
- Gradients required
- Improved accuracy

$$\phi^{target} - \sum_{i=1}^{n} a_i \phi_i^{donor} = C$$

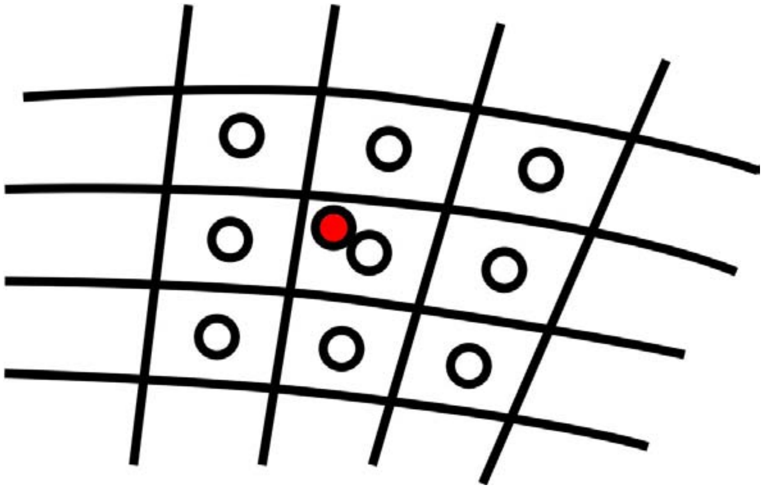
$$n = 1 \qquad C = \mathbf{grad}(\phi^{donor}) \cdot (\vec{x}^{target} - \vec{x}^{donor})$$

Grid Coupling: Simplex Mesh



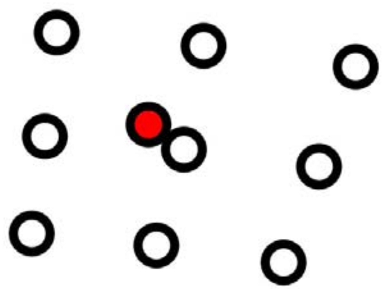
$$\phi^{target} - \sum_{i=1}^{n} a_i \phi_i^{donor} = C$$

Grid Coupling: Simplex Mesh



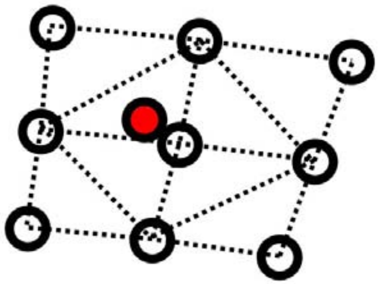
$$\phi^{target} - \sum_{i=1}^{n} a_i \phi_i^{donor} = C$$

Grid Coupling: Simplex Mesh



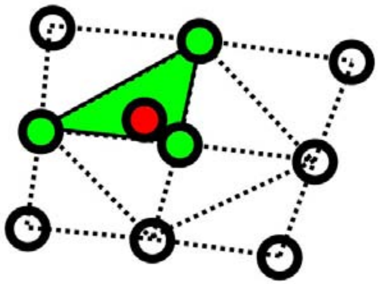
$$\phi^{target} - \sum_{i=1}^{n} a_i \phi_i^{donor} = C$$

Grid Coupling: Simplex Mesh



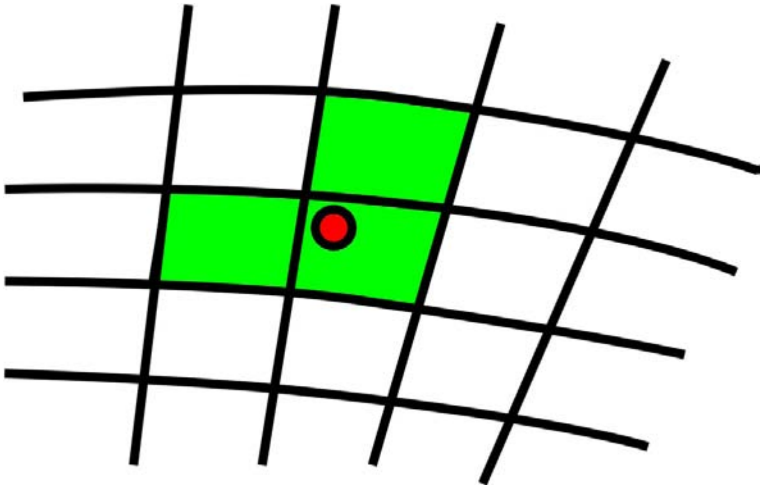
$$\phi^{target} - \sum_{i=1}^{n} a_i \phi_i^{donor} = C$$

Grid Coupling: Simplex Mesh



$$\phi^{target} - \sum_{i=1}^{n} a_i \phi_i^{donor} = C$$

Grid Coupling: Simplex Mesh

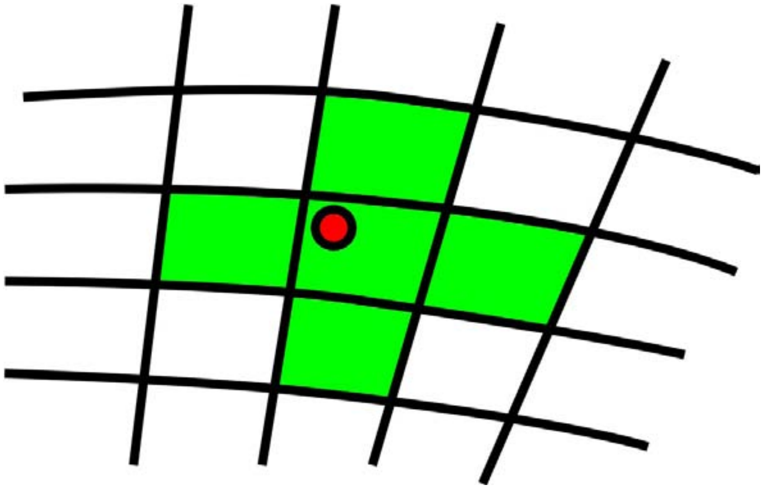


- Overhead for simplex mesh construction
- Algorithmic difficulties for 'real life' meshes (e.g. bound. layers)
- Fully implicit interpolation possible
- Result is bounded
- Improved accuracy

$$\phi^{target} - \sum_{i=1}^{n} a_i \phi_i^{donor} = C$$

2D: $n = 3$ **3D:** $n = 4$ $C = 0$

Grid Coupling: Inverse Distance



- Simple scheme
- Fully implicit interpolation possible
- Result is bounded
- Weighting function contains free parameter

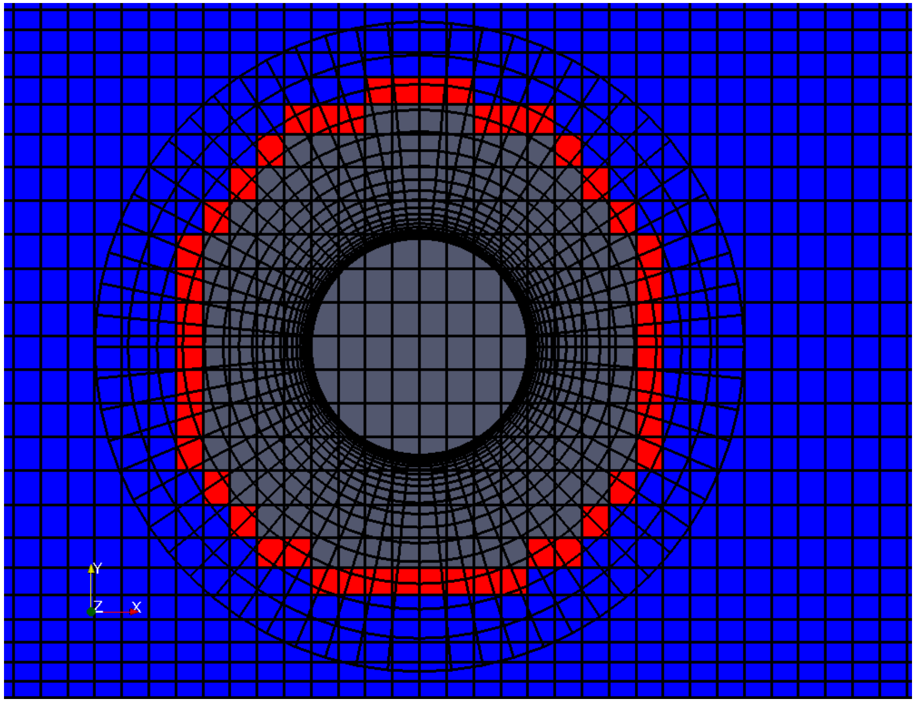
Not very accurate

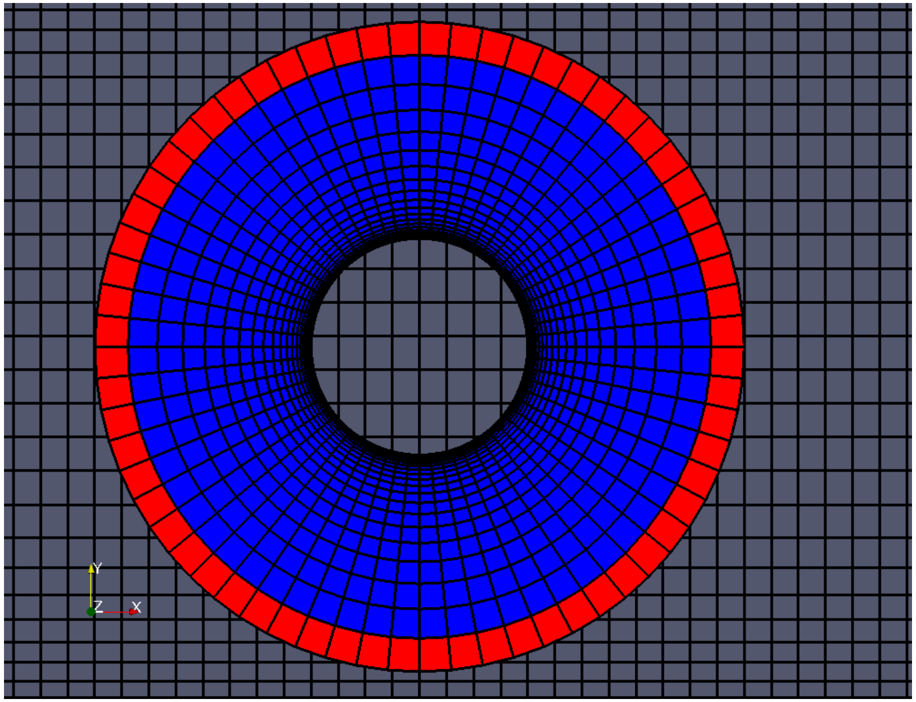
$$\phi^{target} - \sum_{i=1}^{n} a_i \phi_i^{donor} = C$$

$$n = n_{neighbours} + 1 \qquad C = 0$$

Grid Coupling: Mass Conservation

Background Mesh | **Foreground Mesh**

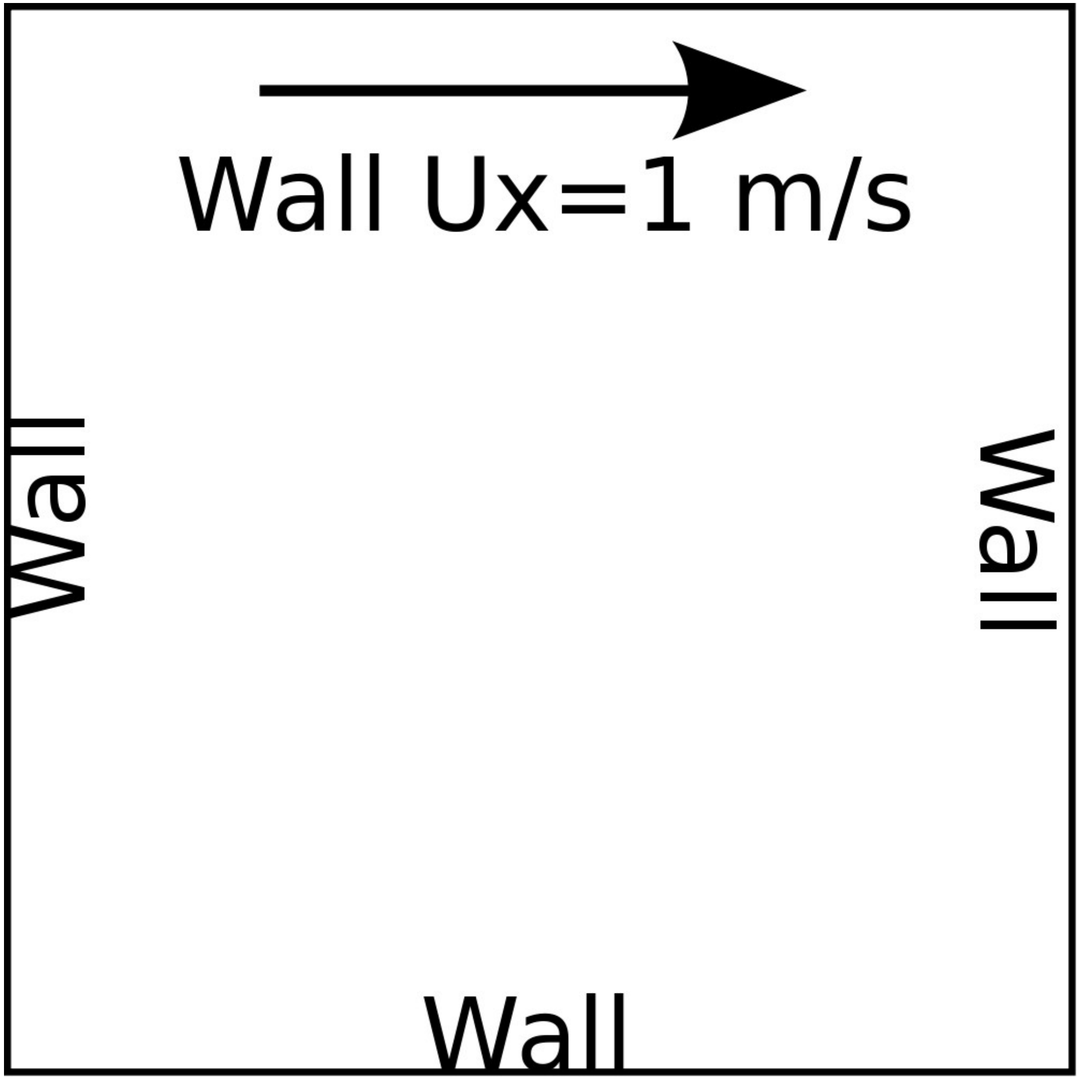




Mass flow through faces between solved cells (blue) and interpolated cells (red) must sum up to zero!

Apply bulk correction if necessary.

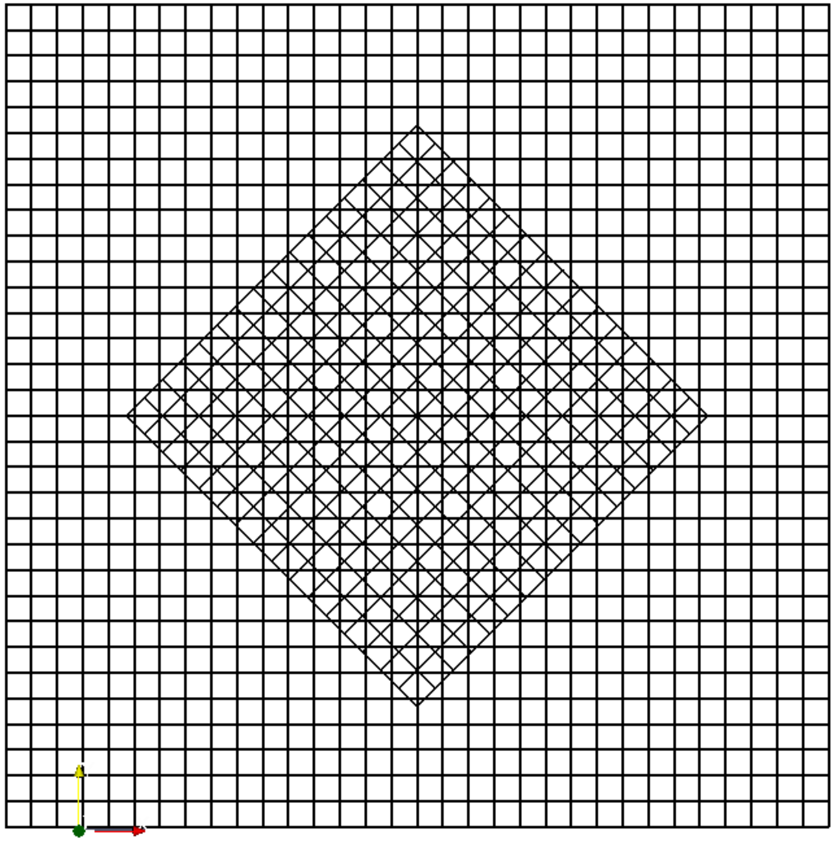
Examples: Lid-Driven Cavity Flow, Setup



L=1m

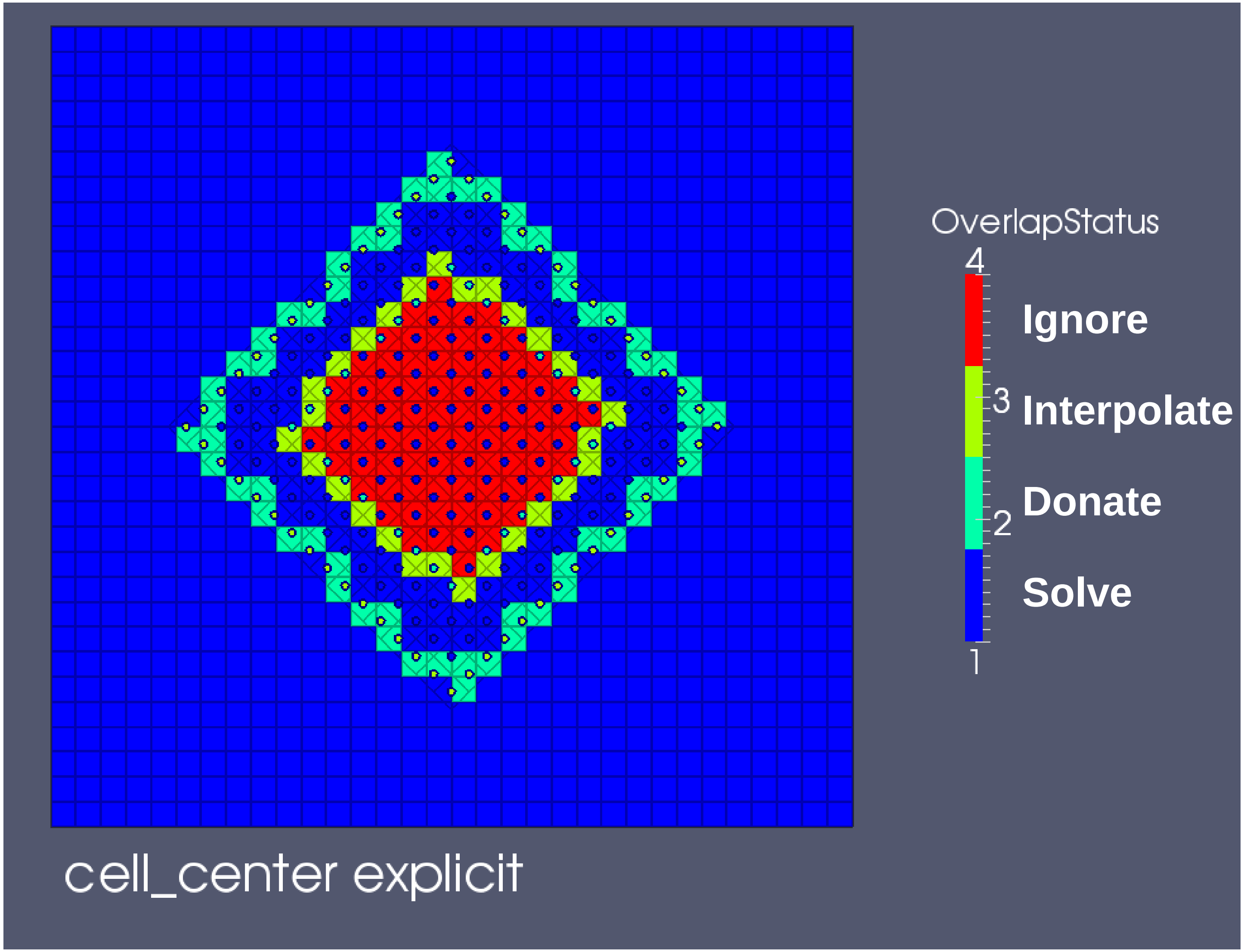
Re=100

Examples: Lid-Driven Cavity Flow, Grid

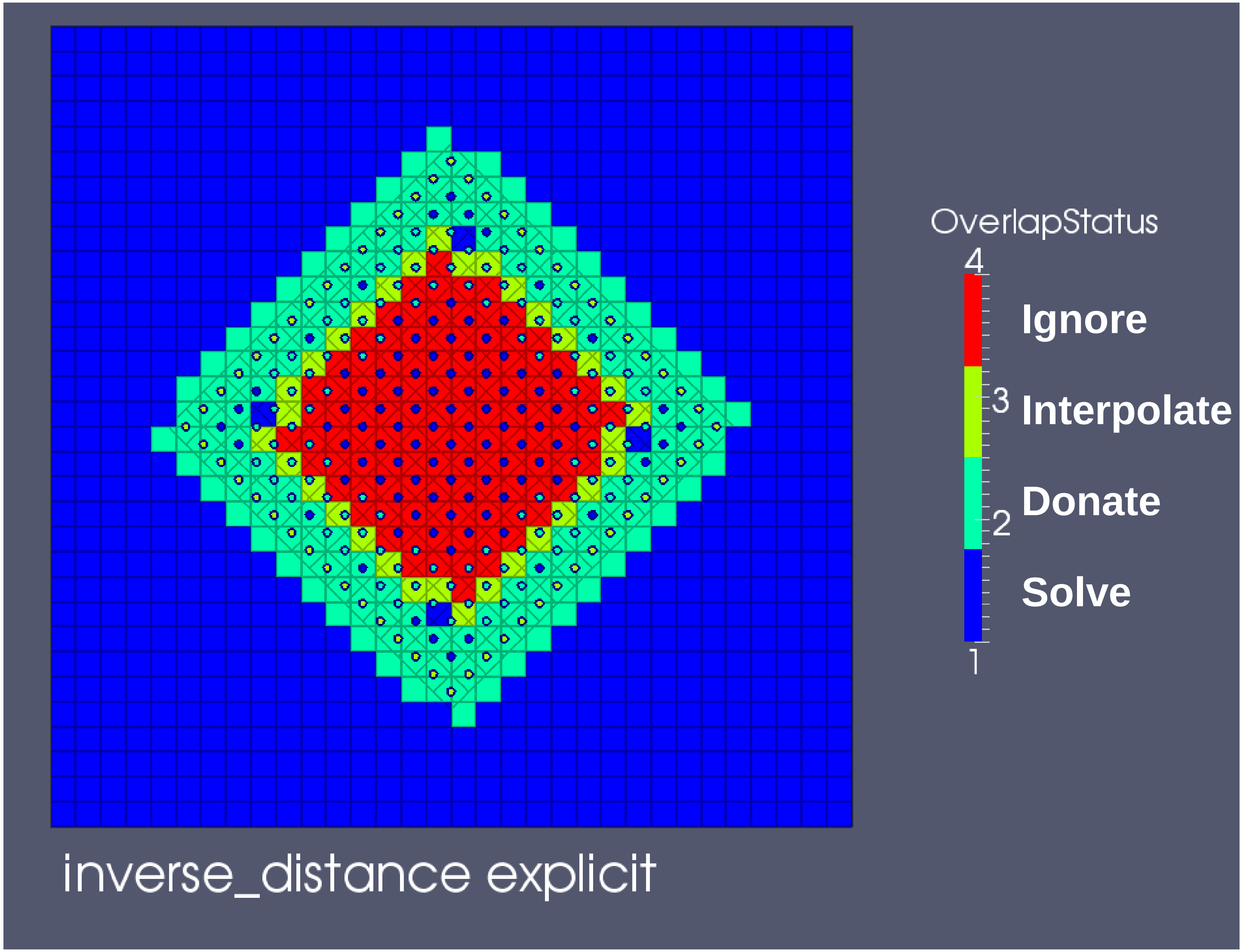


Background: 32x32 Cells
Foreground: 16x16 Cells

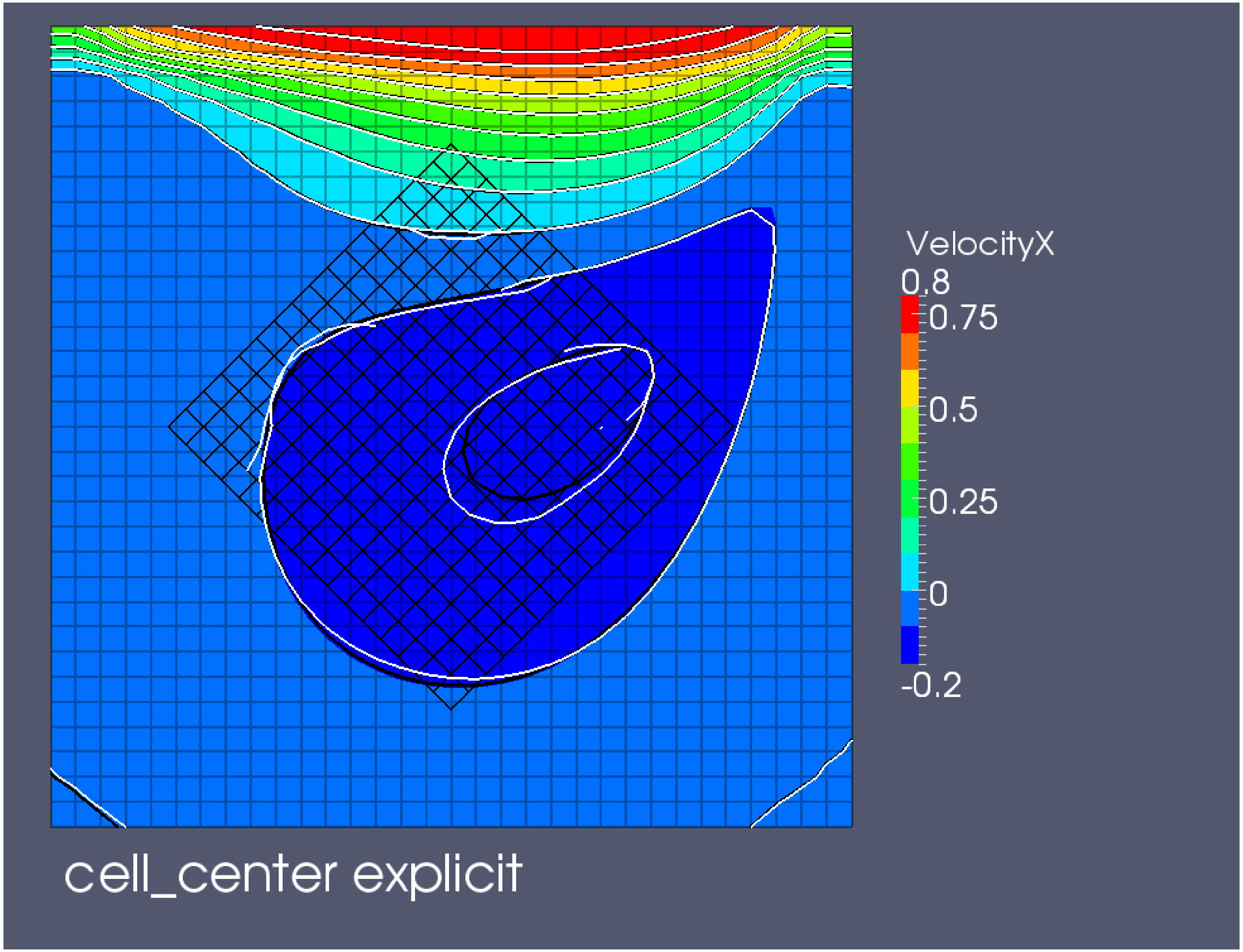
Examples: Lid-Driven Cavity Flow, Cell Status



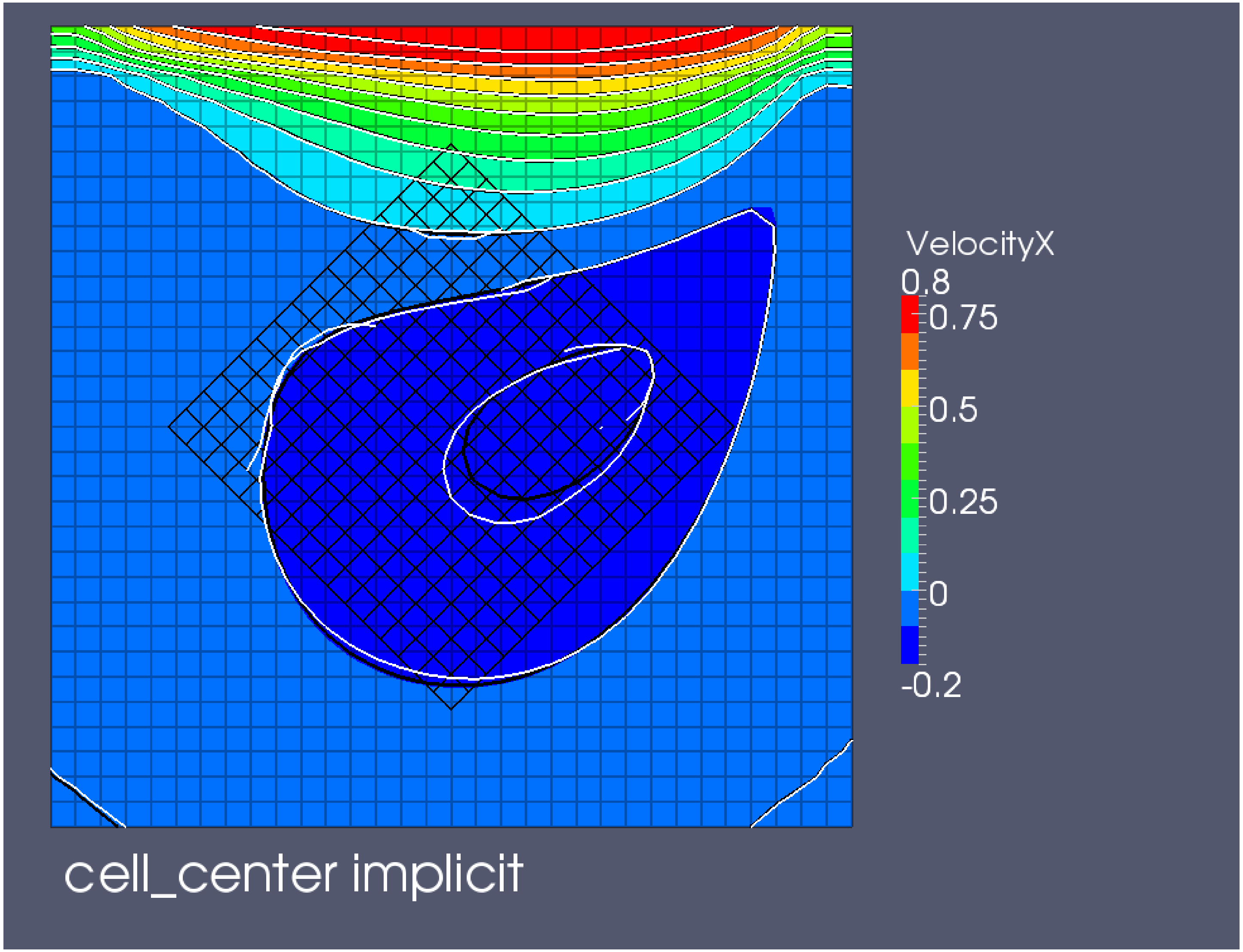
Examples: Lid-Driven Cavity Flow, Cell Status



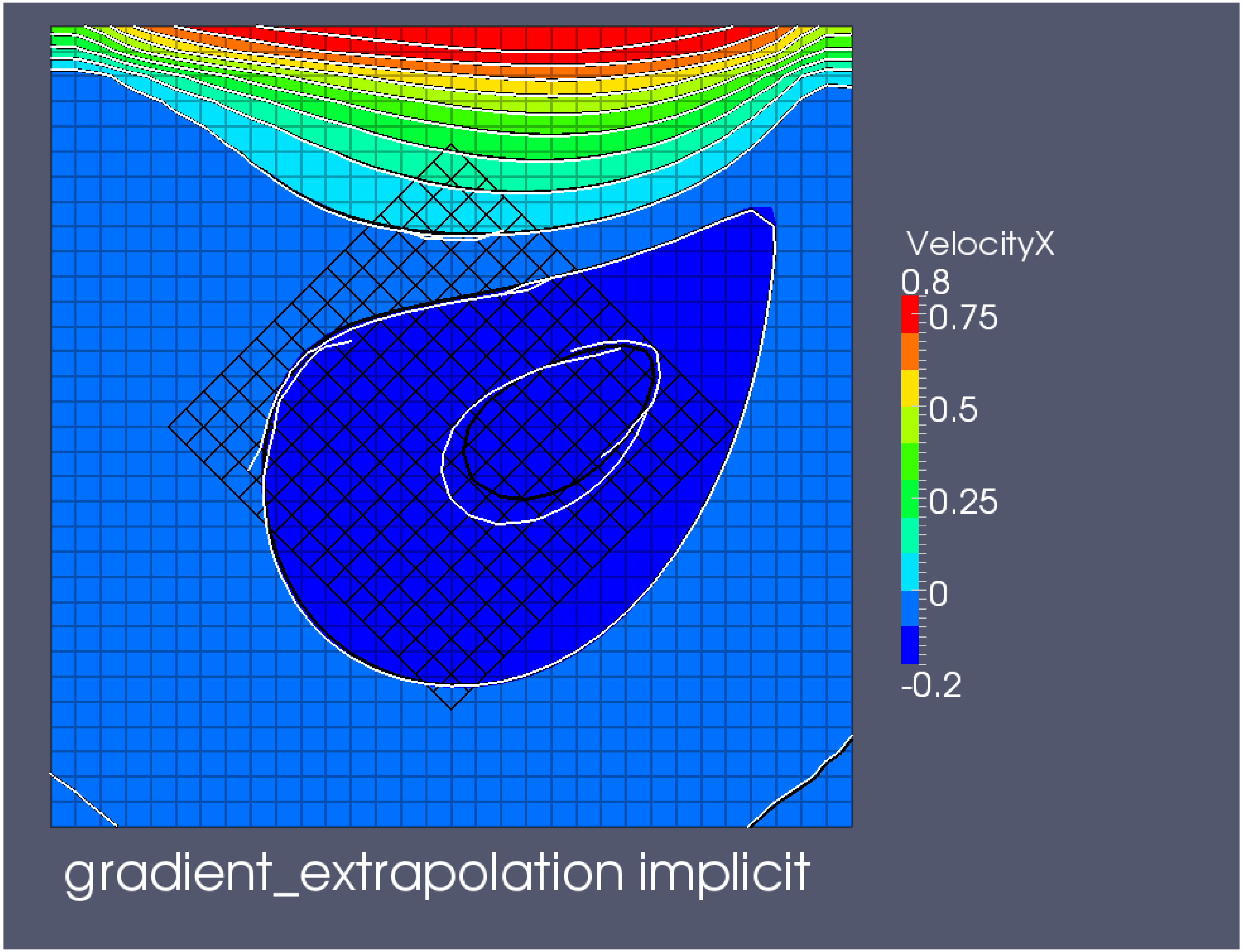
Examples: Lid-Driven Cavity Flow, Horizontal Velocity



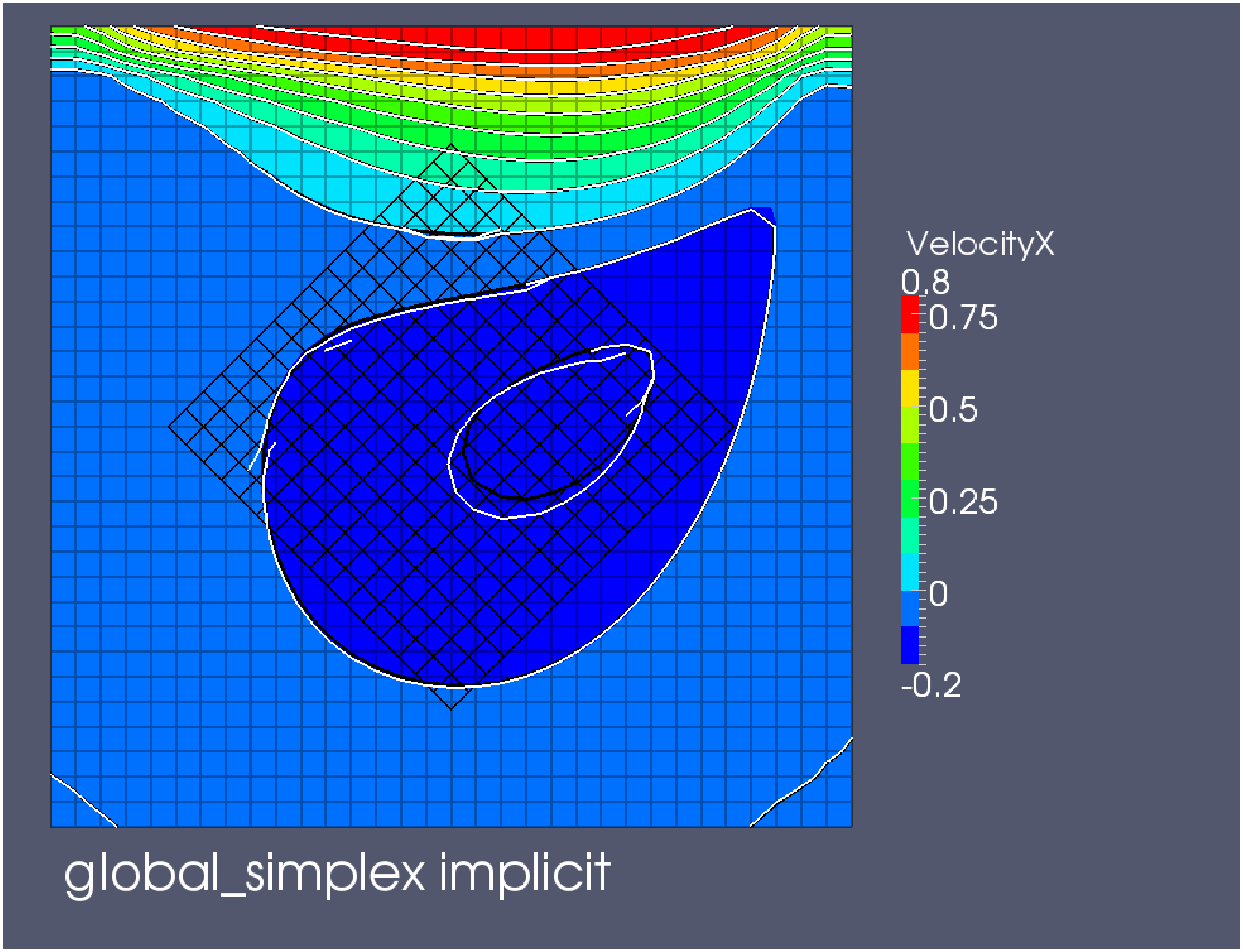
Examples: Lid-Driven Cavity Flow, Horizontal Velocity



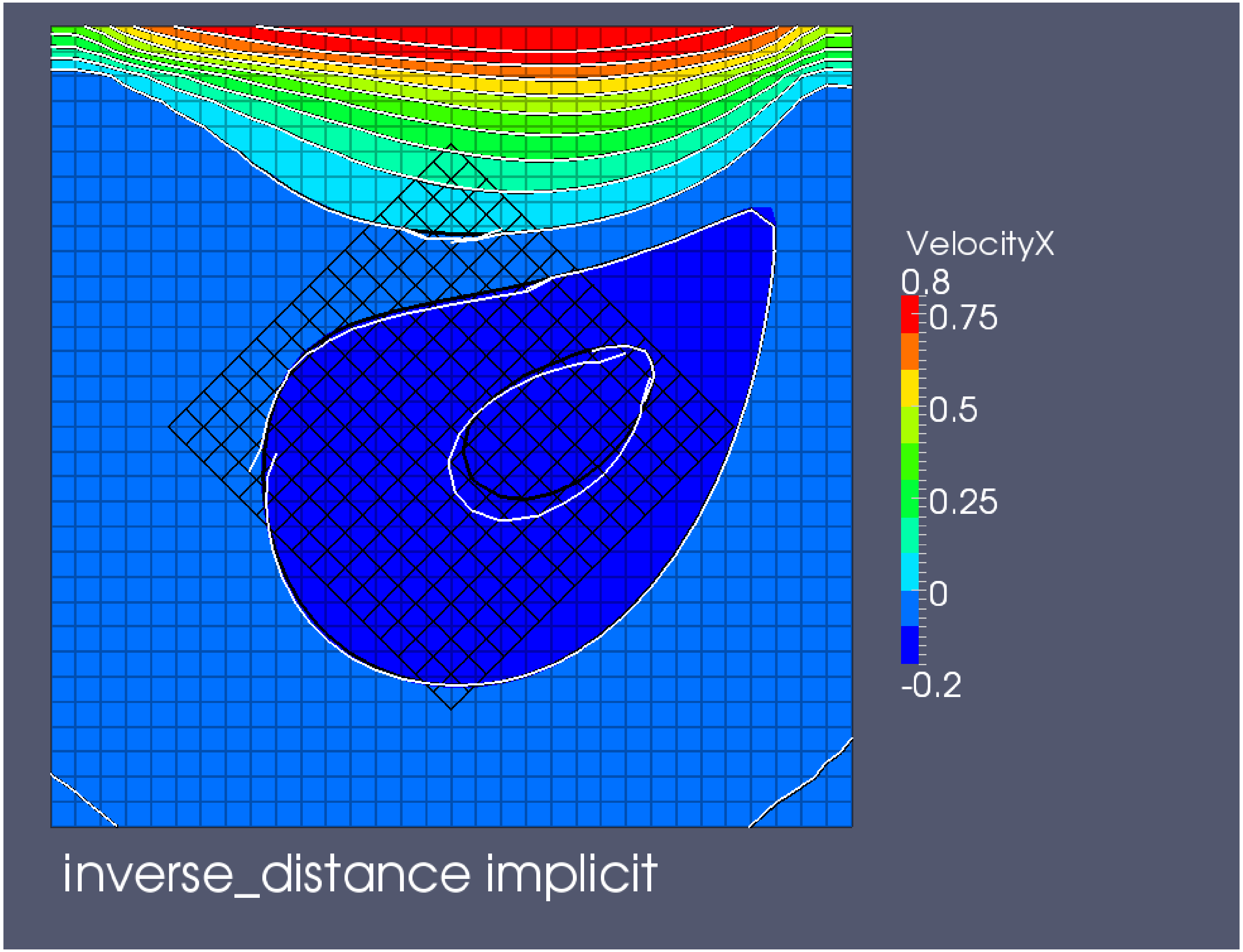
Examples: Lid-Driven Cavity Flow, Horizontal Velocity



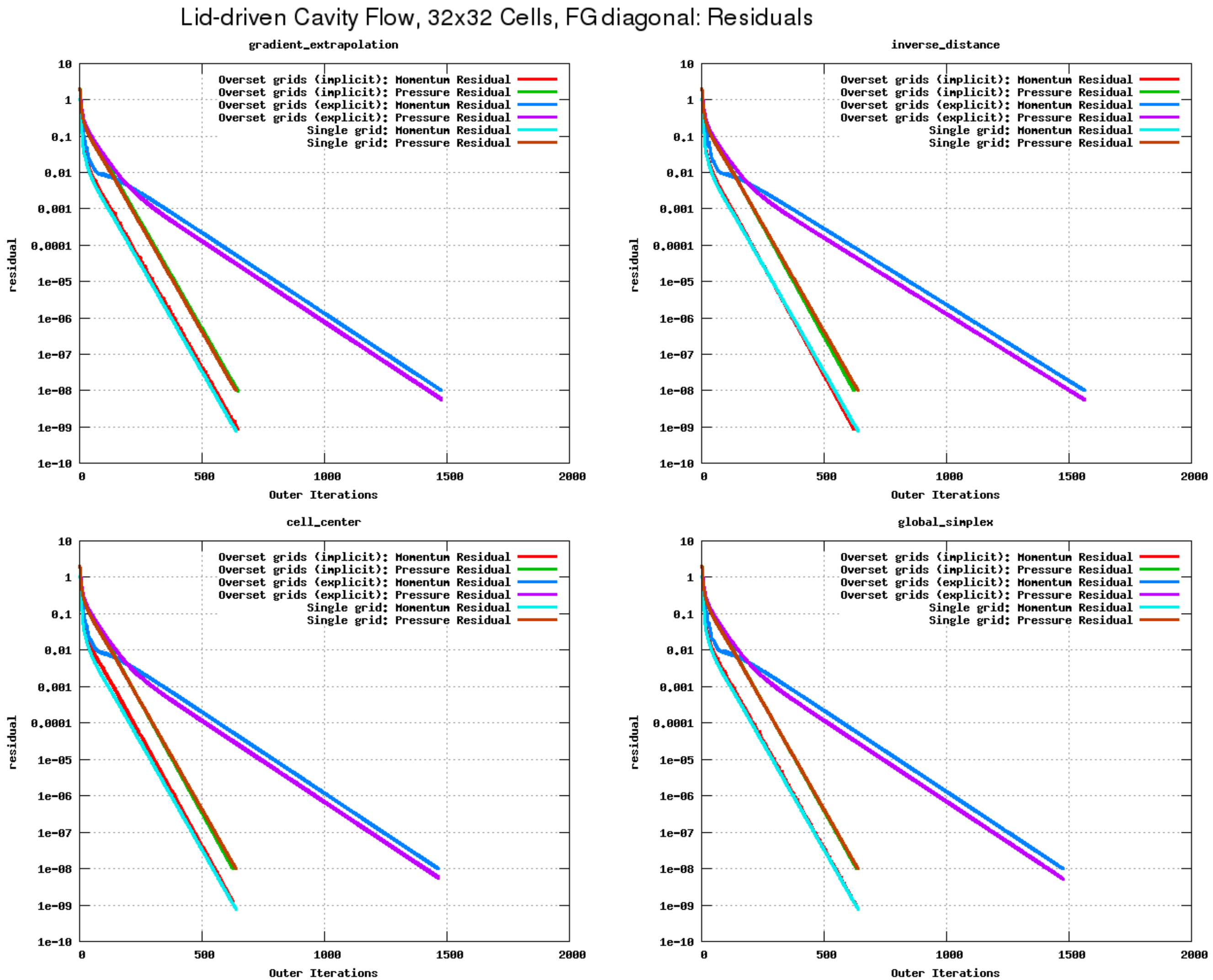
Examples: Lid-Driven Cavity Flow, Horizontal Velocity



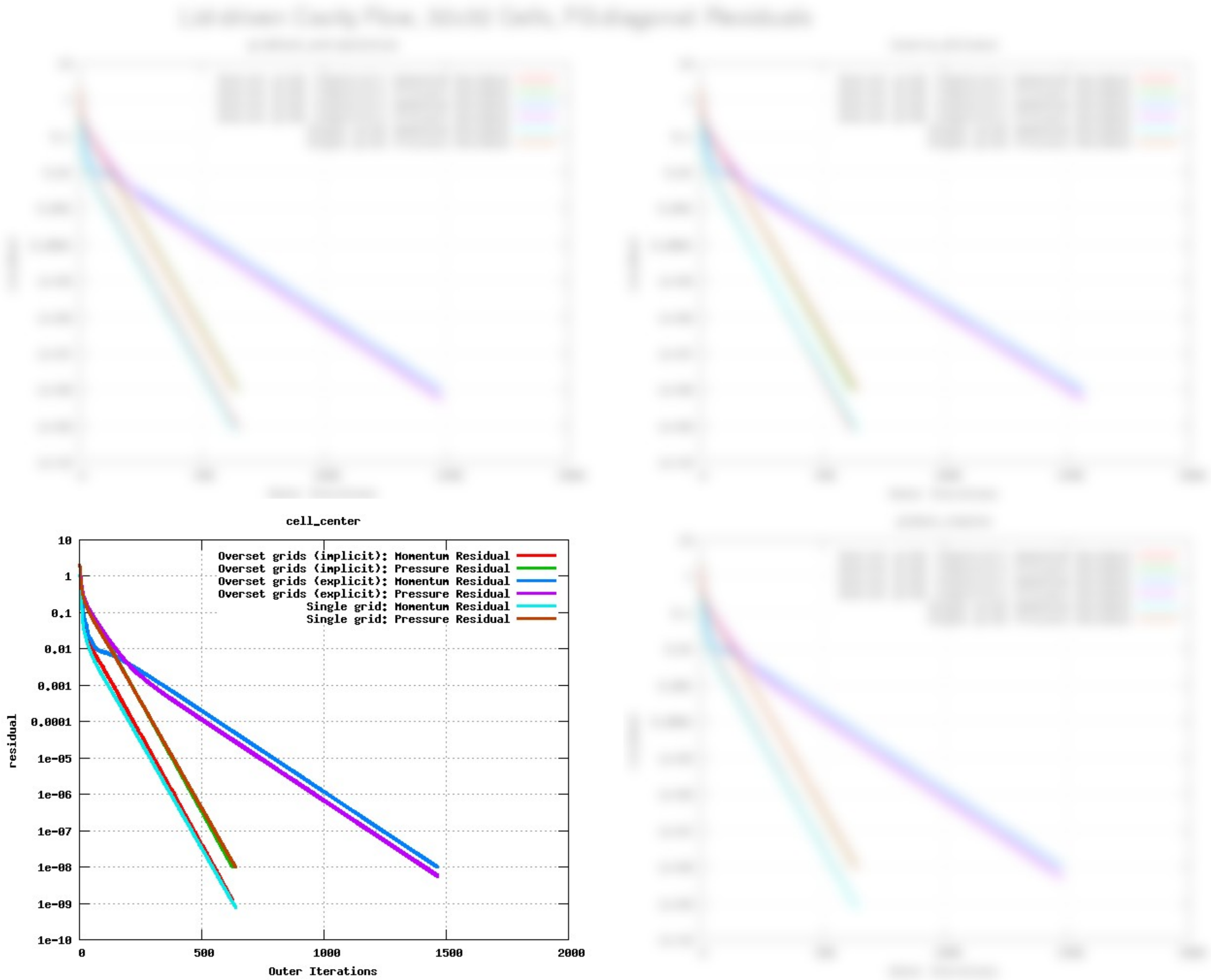
Examples: Lid-Driven Cavity Flow, Horizontal Velocity



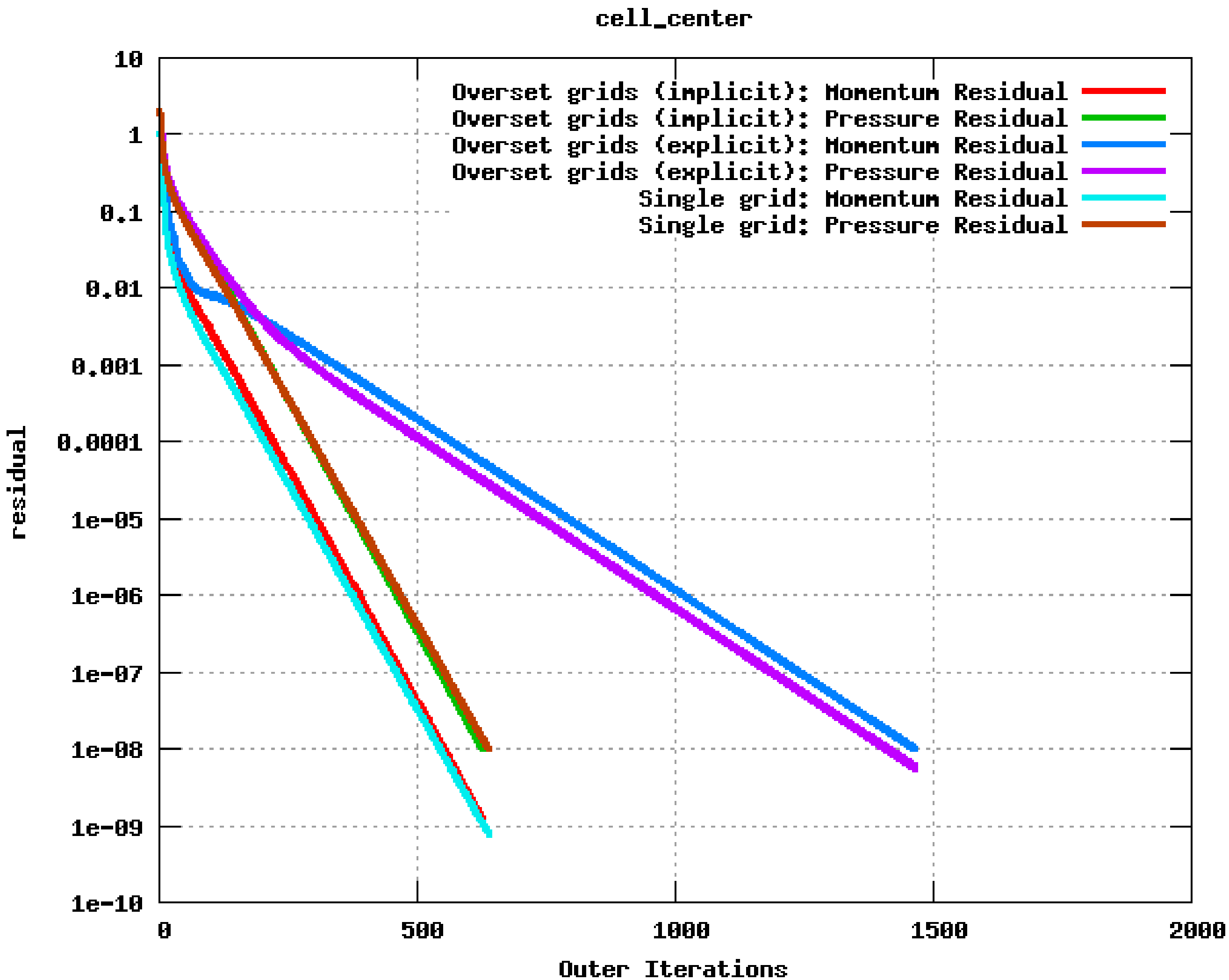
Examples: Lid-Driven Cavity Flow, Convergence



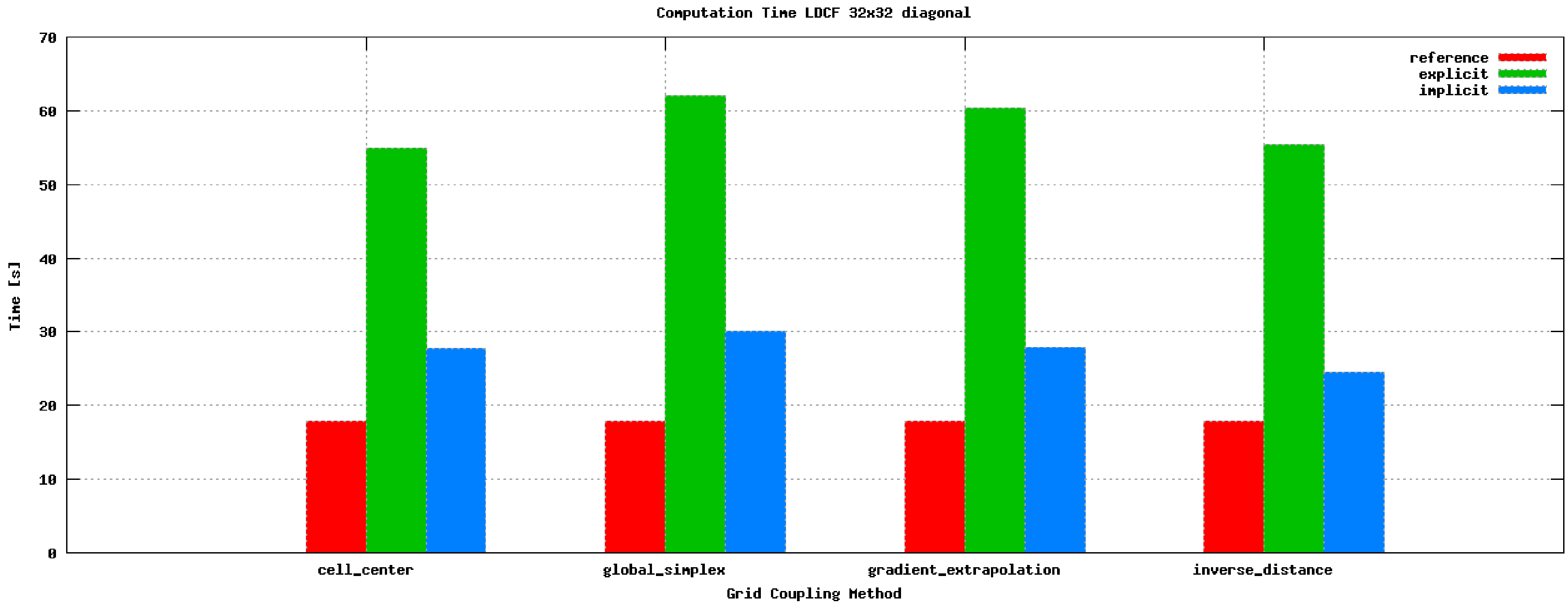
Examples: Lid-Driven Cavity Flow, Convergence



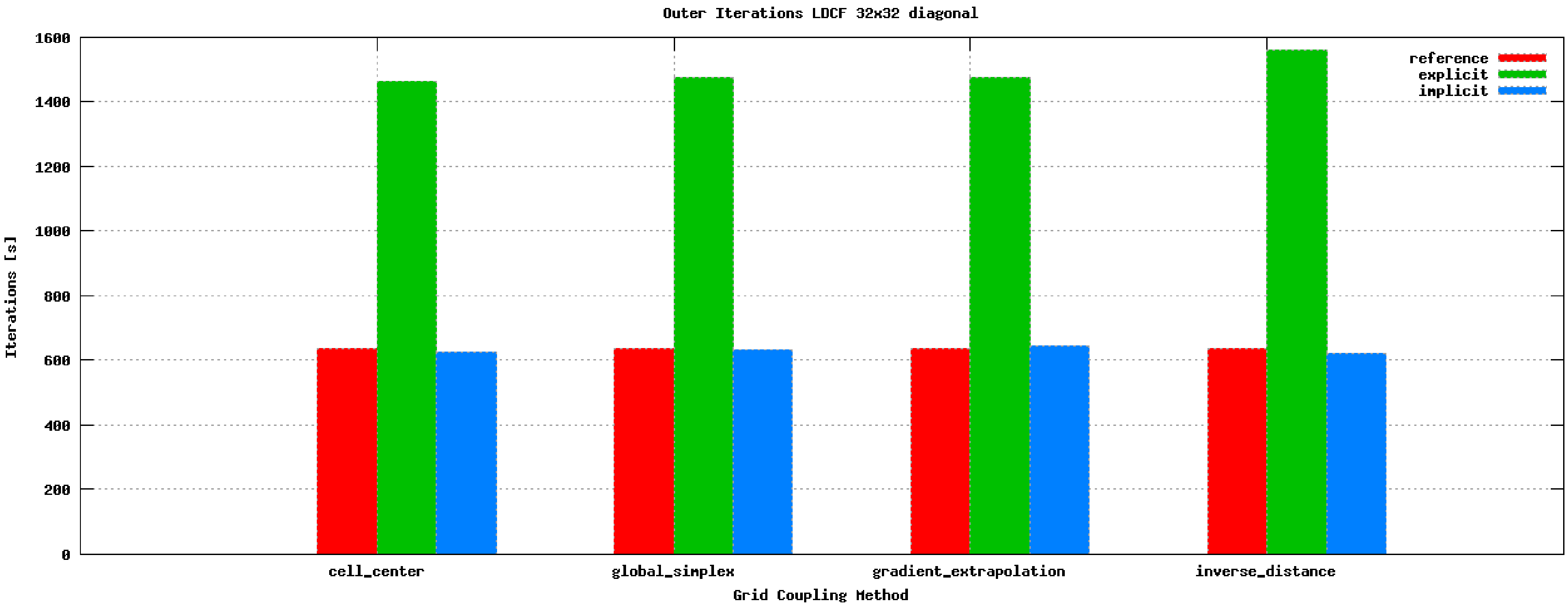
Examples: Lid-Driven Cavity Flow, Convergence



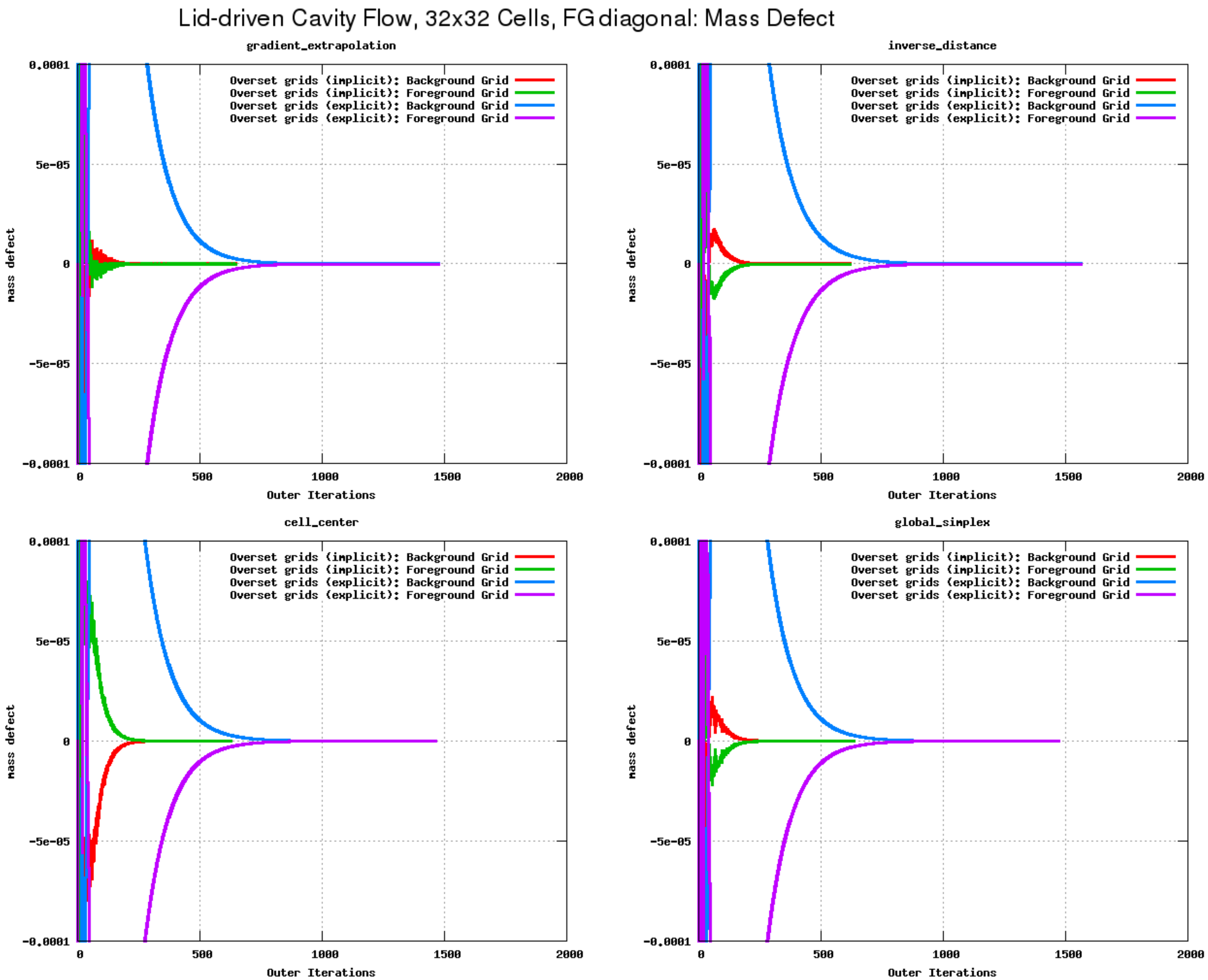
Examples: Lid-Driven Cavity Flow, Performance



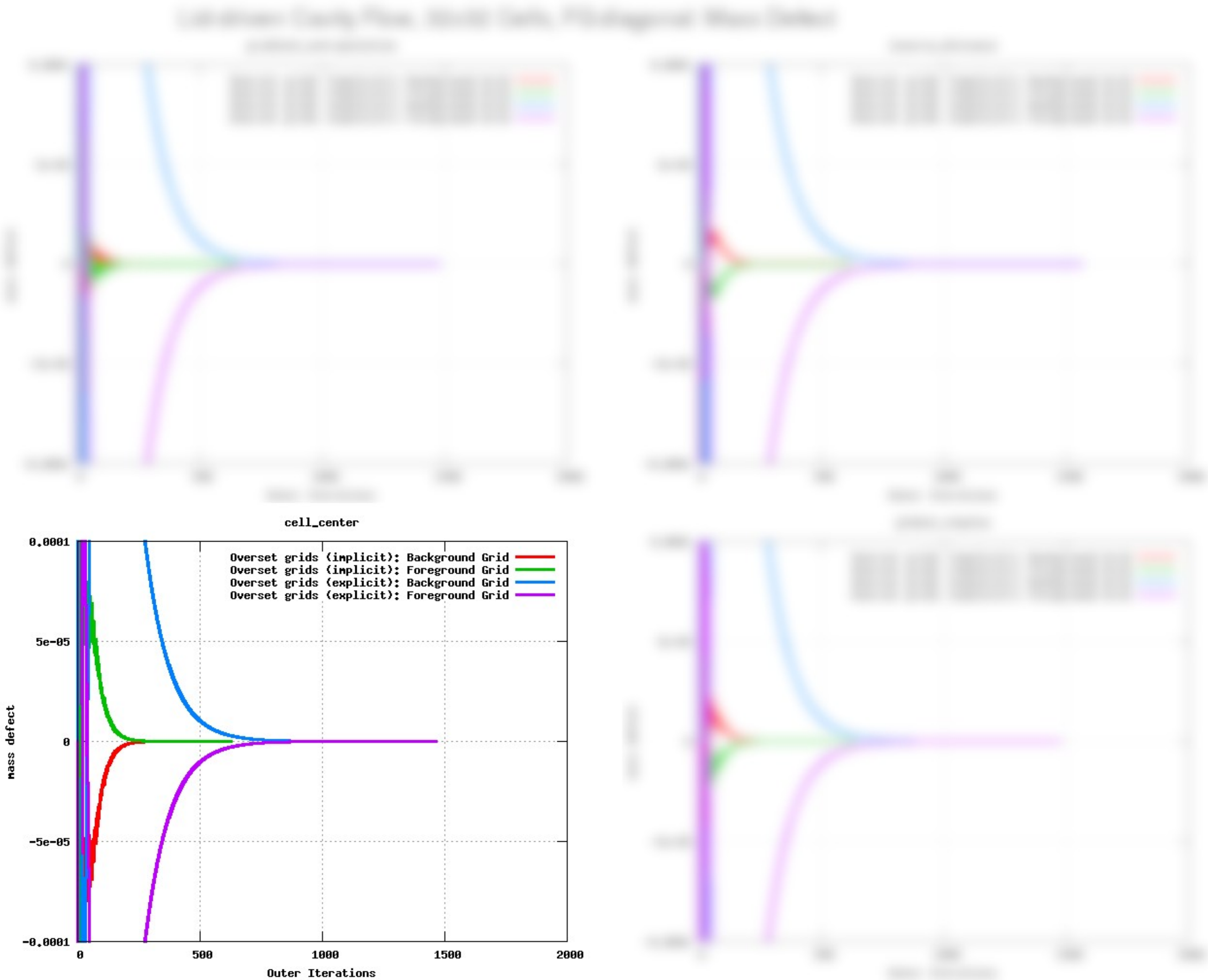
Examples: Lid-Driven Cavity Flow, Performance



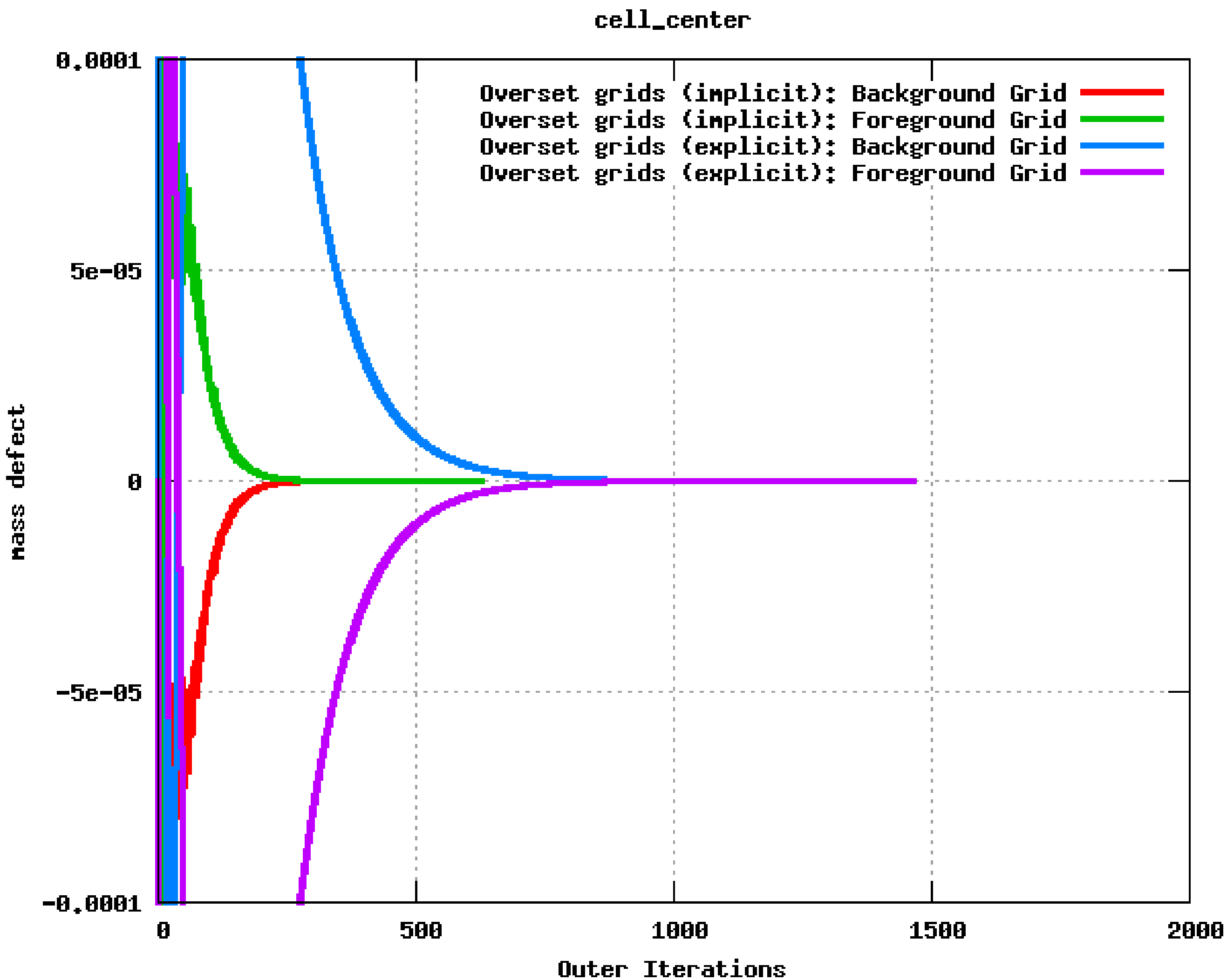
Examples: Lid-Driven Cavity Flow, Mass Conservation



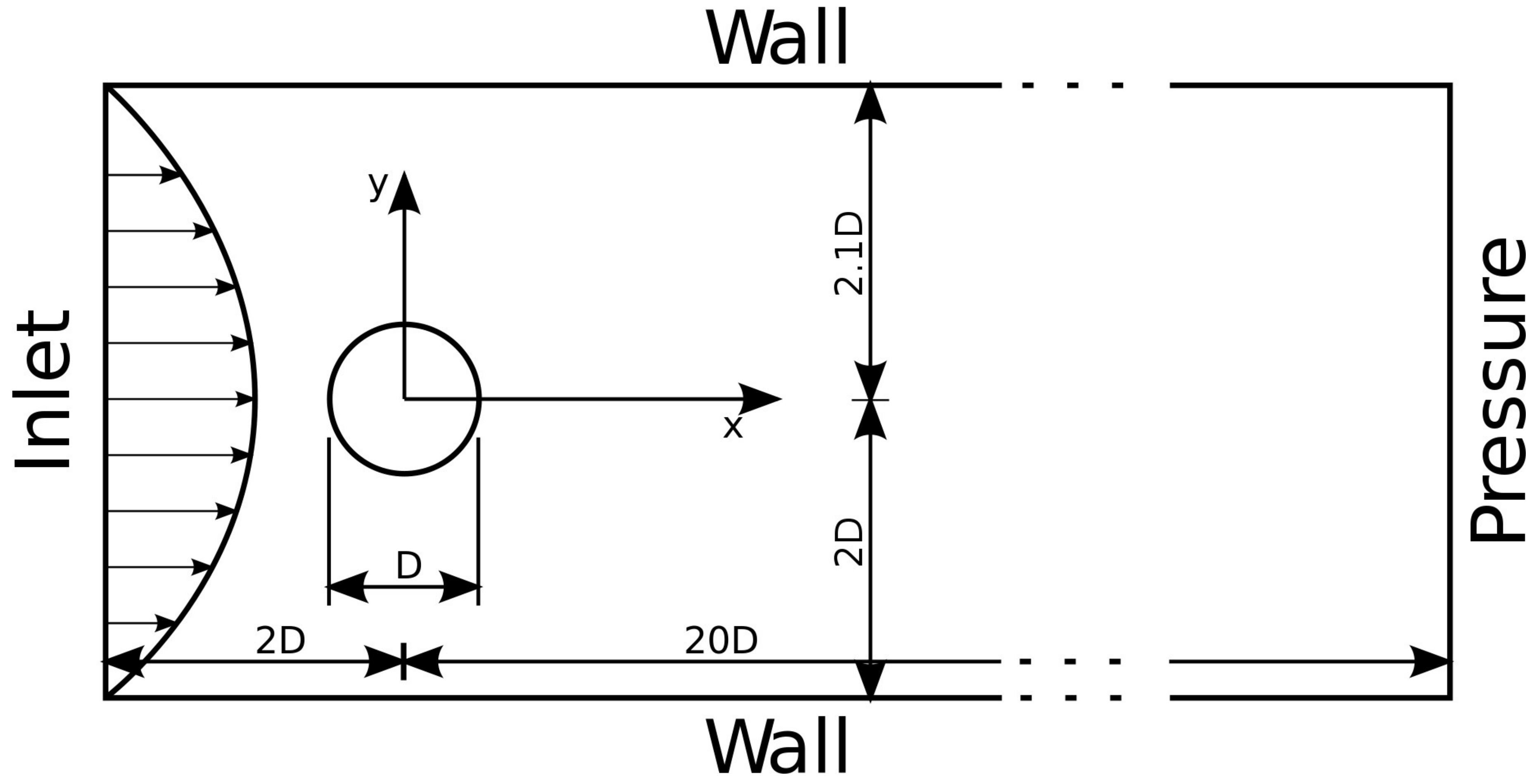
Examples: Lid-Driven Cavity Flow, Mass Conservation



Examples: Lid-Driven Cavity Flow, Mass Conservation

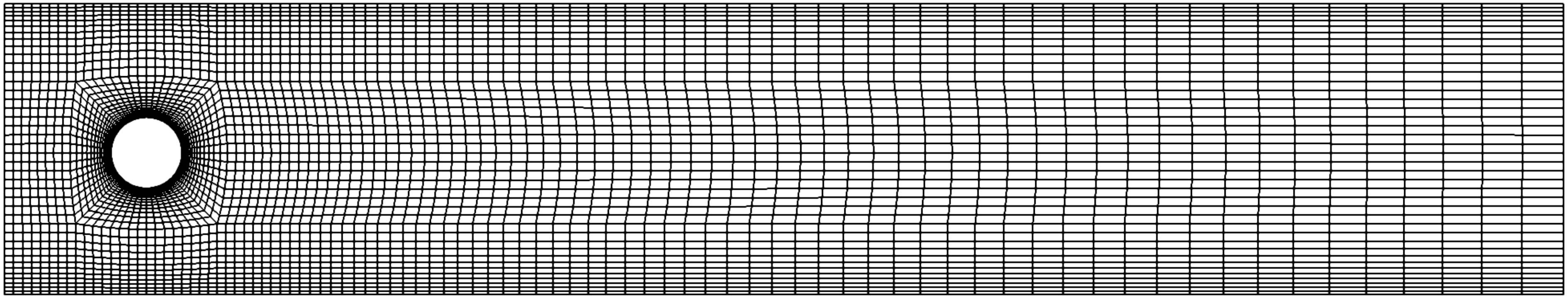


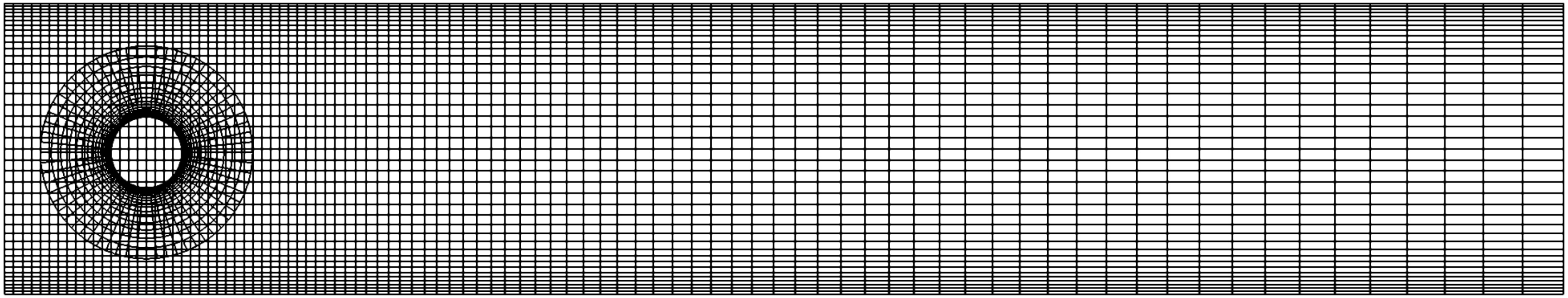
Examples: Cylinder in Channel, Setup



D=0.1m U_{mean}=0.2m/s Rn=20

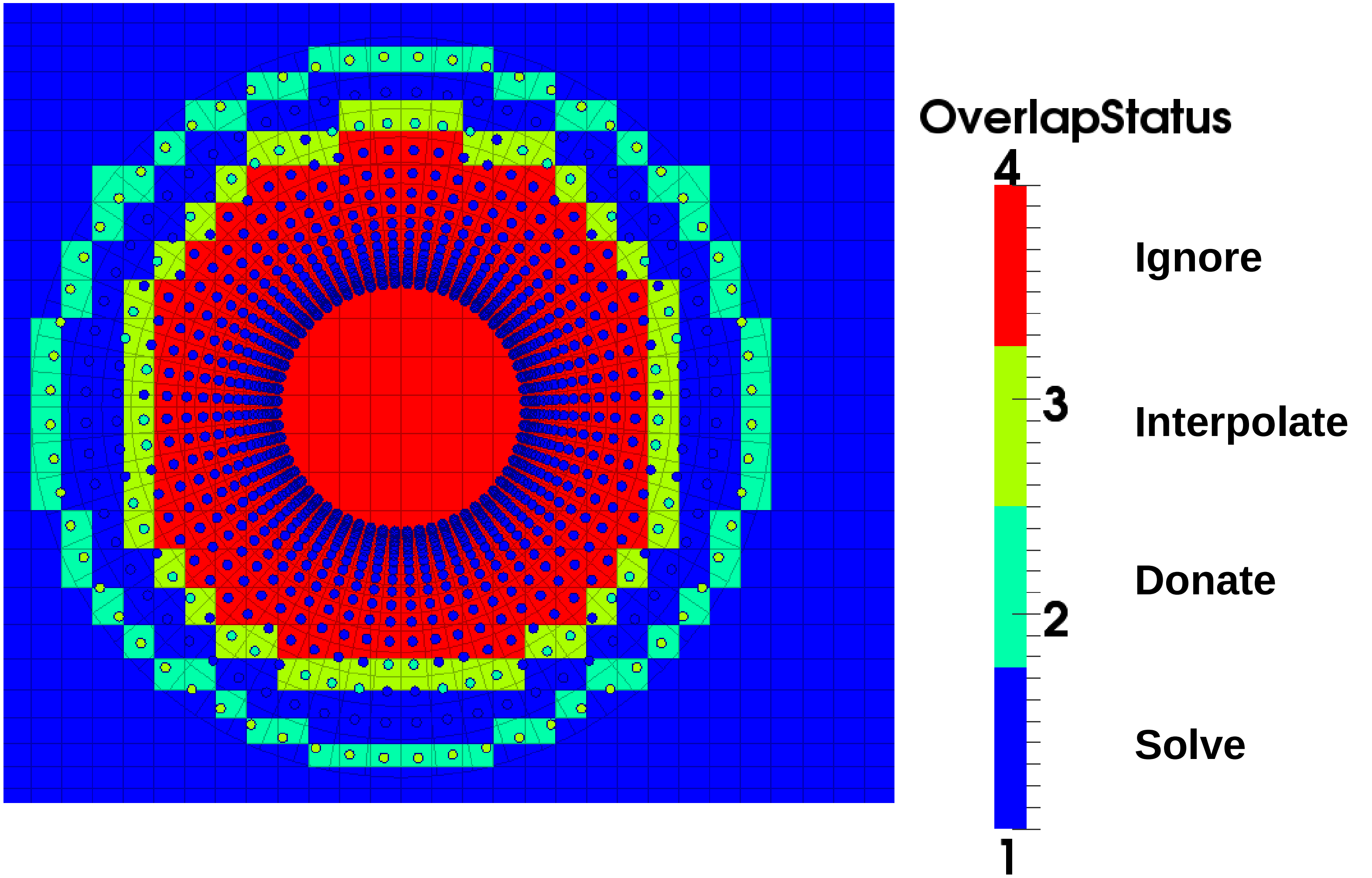
Examples: Cylinder in Channel, Setup



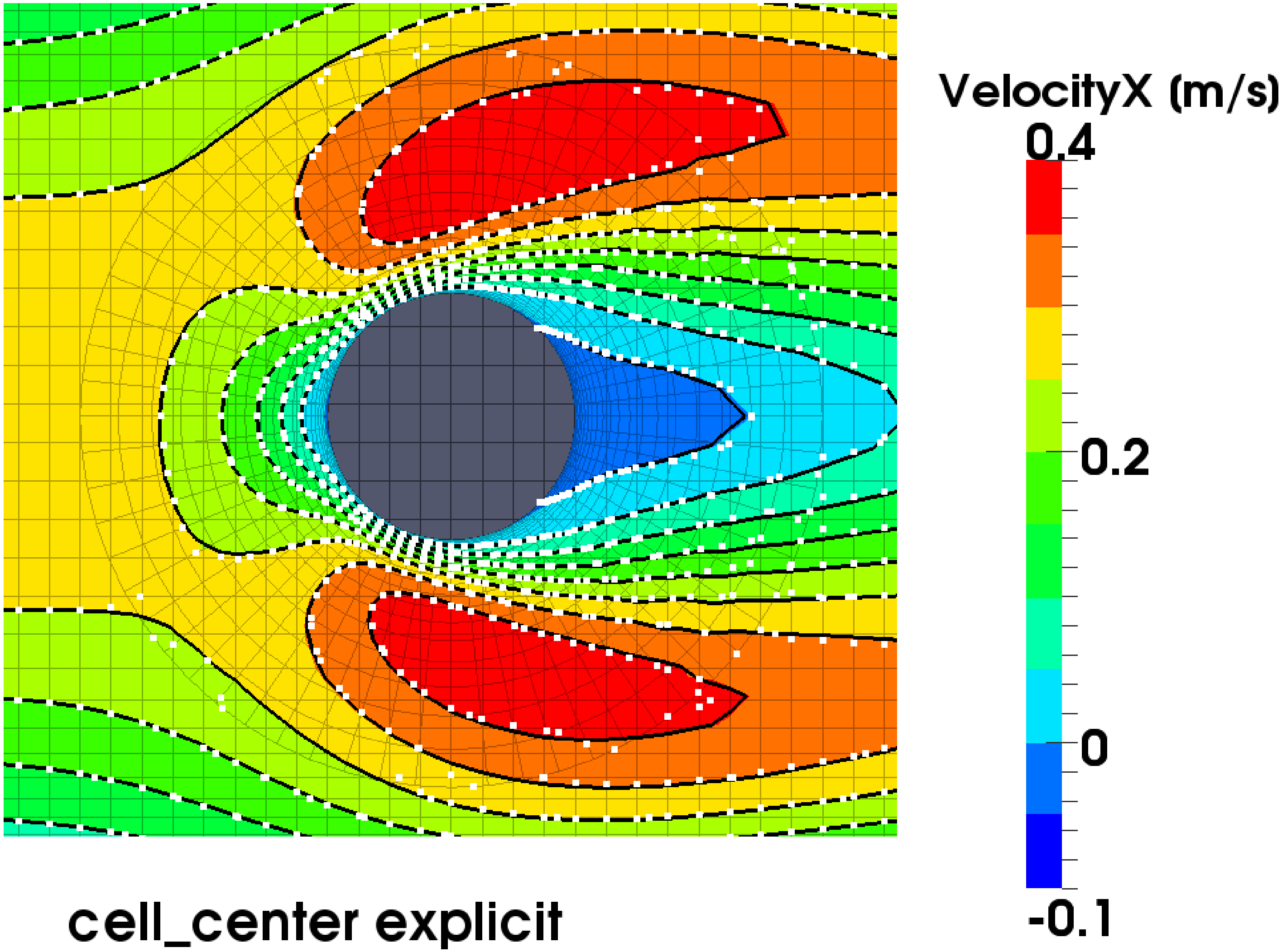


	Number of Cells
Single Grid	4544
Overlapping Grids	4960

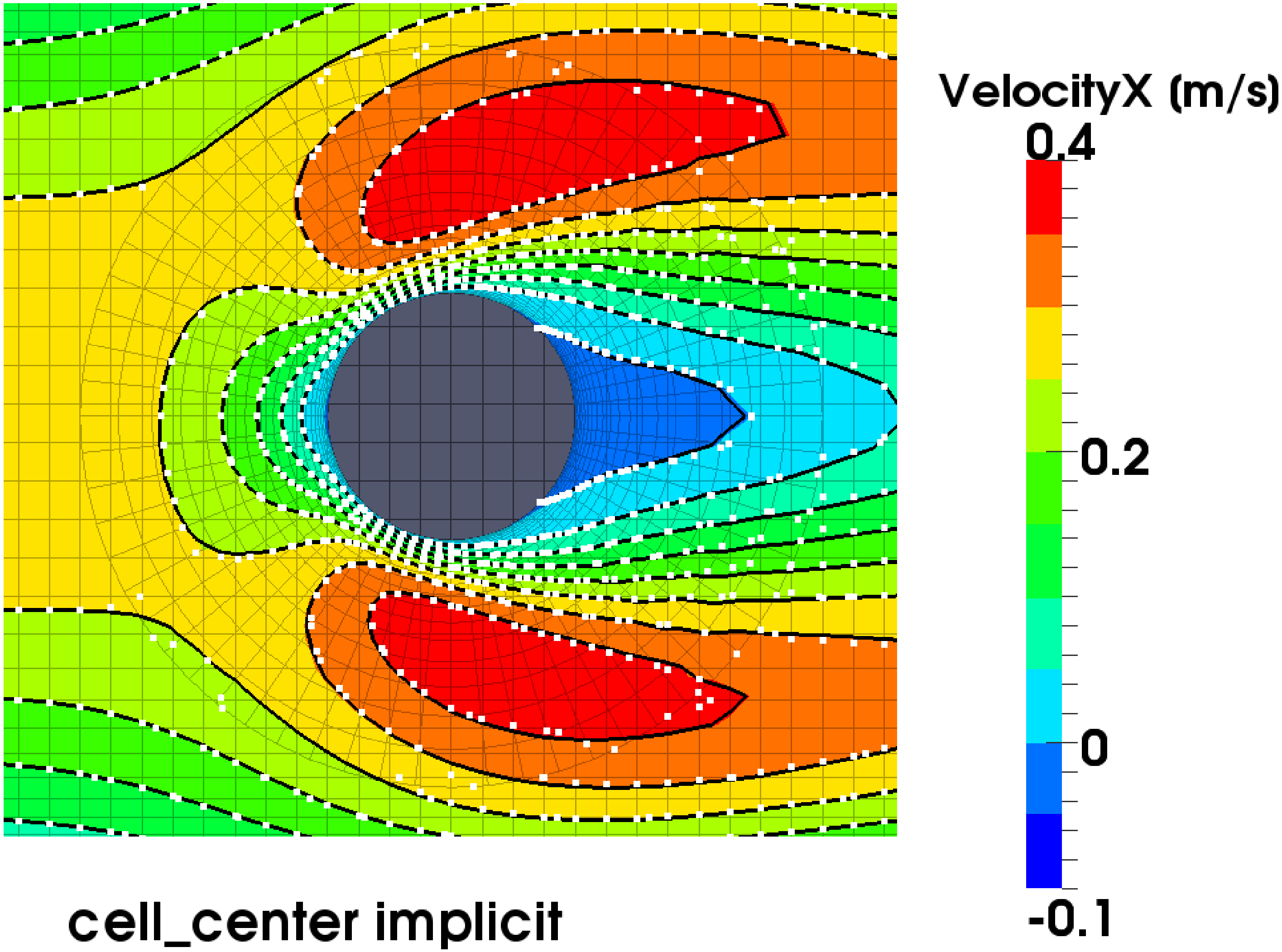
Examples: Cylinder in Channel, Cell Status



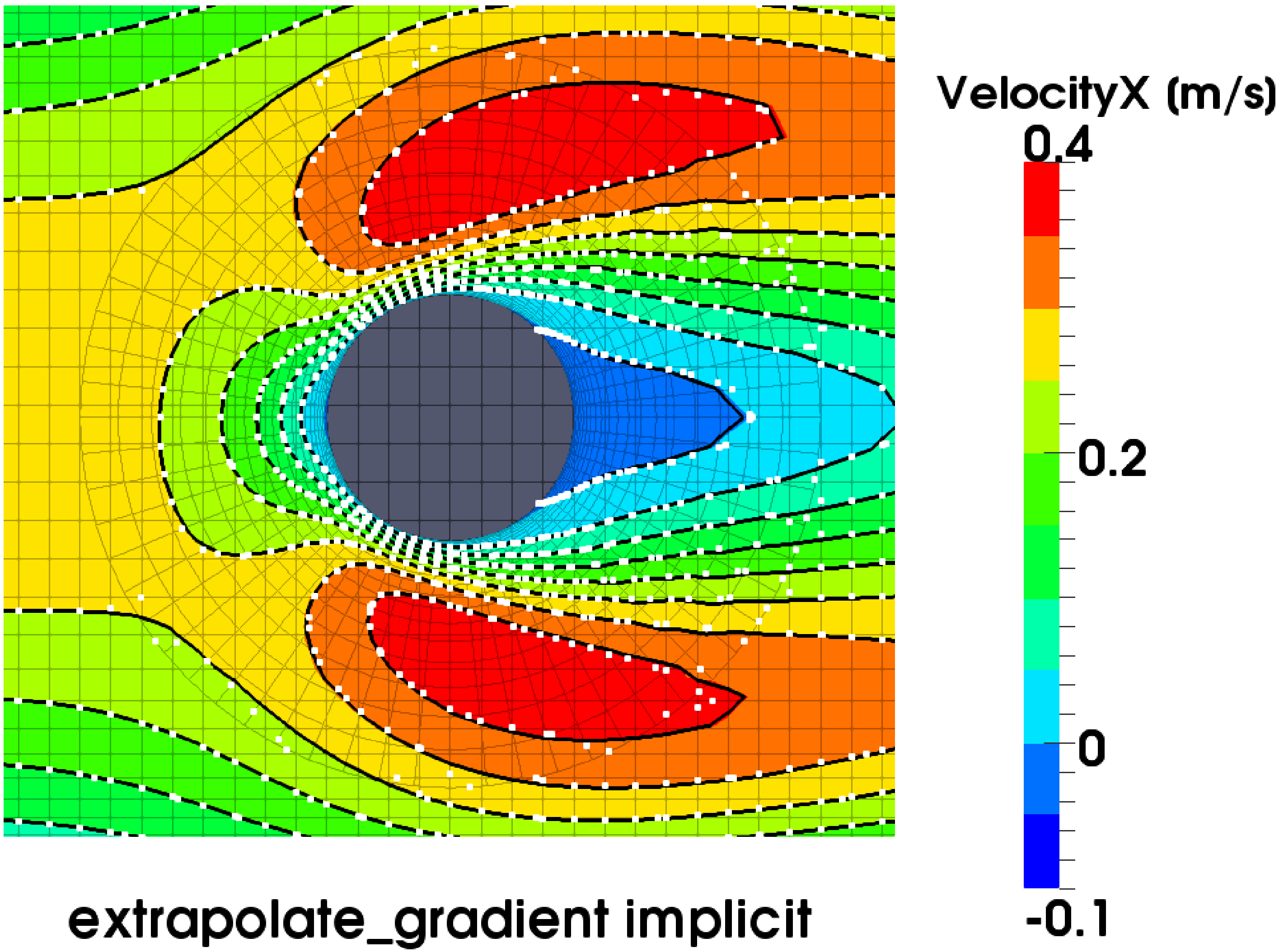
Examples: Cylinder in Channel, Horizontal Velocity



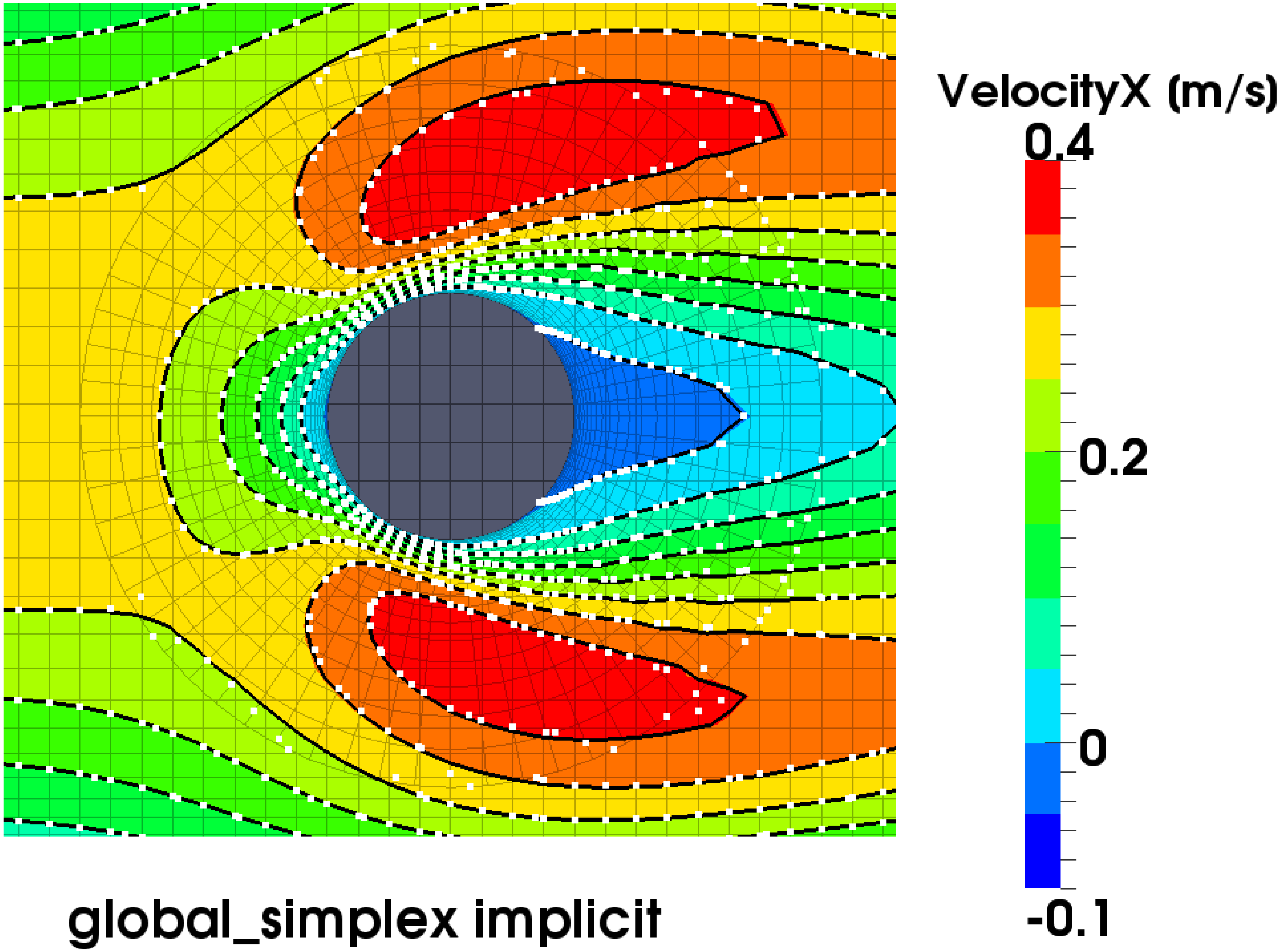
Examples: Cylinder in Channel, Horizontal Velocity



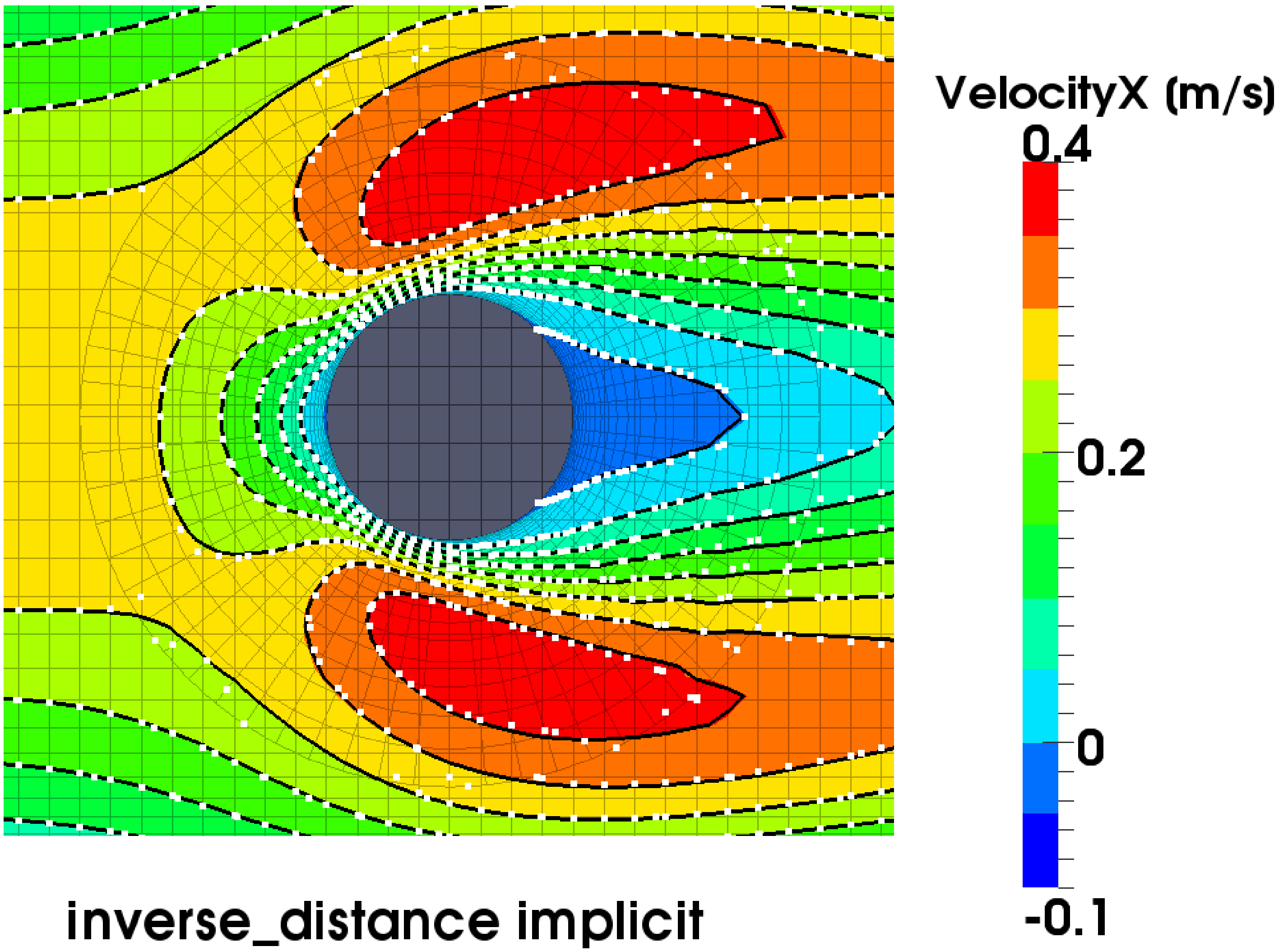
Examples: Cylinder in Channel, Horizontal Velocity



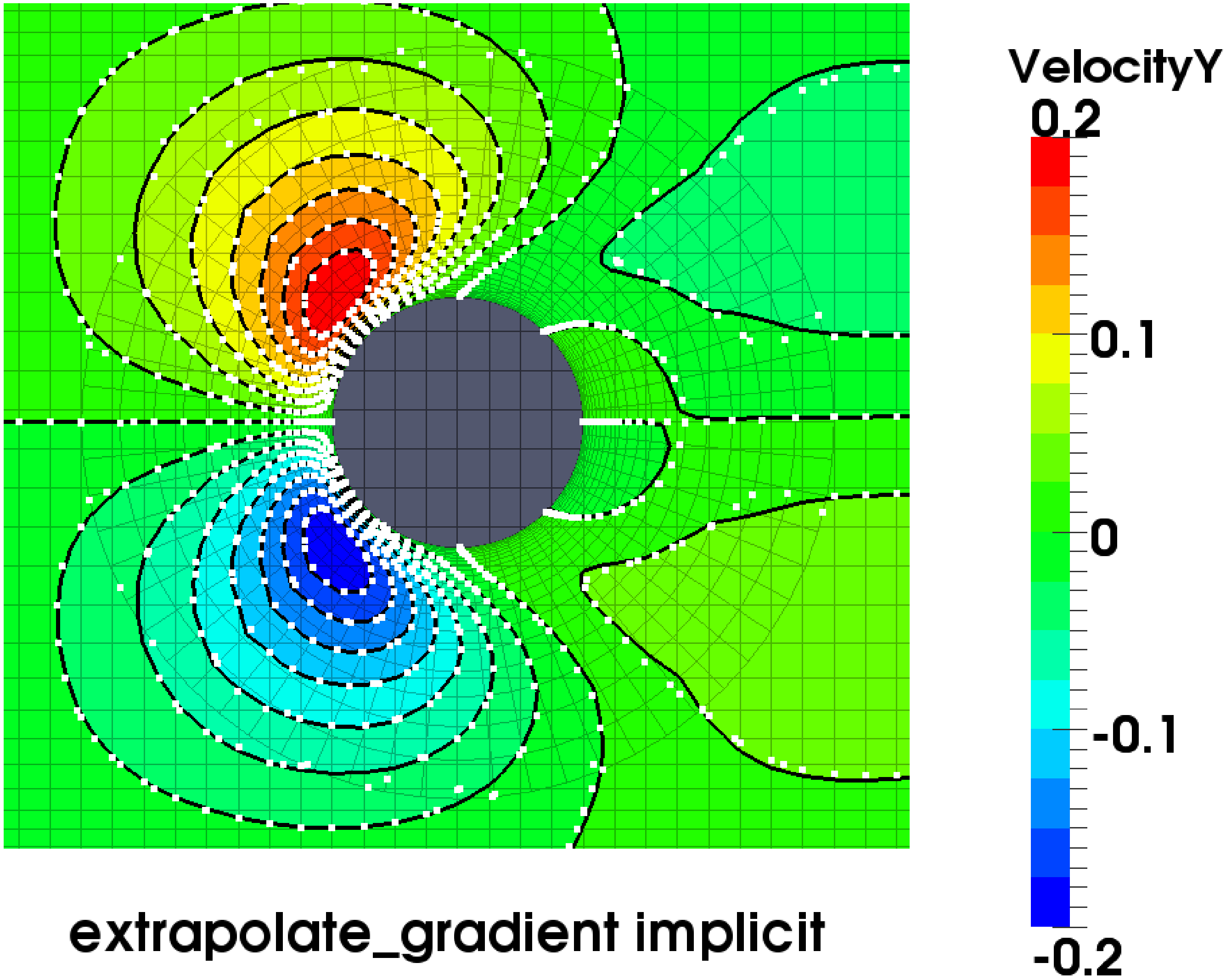
Examples: Cylinder in Channel, Horizontal Velocity



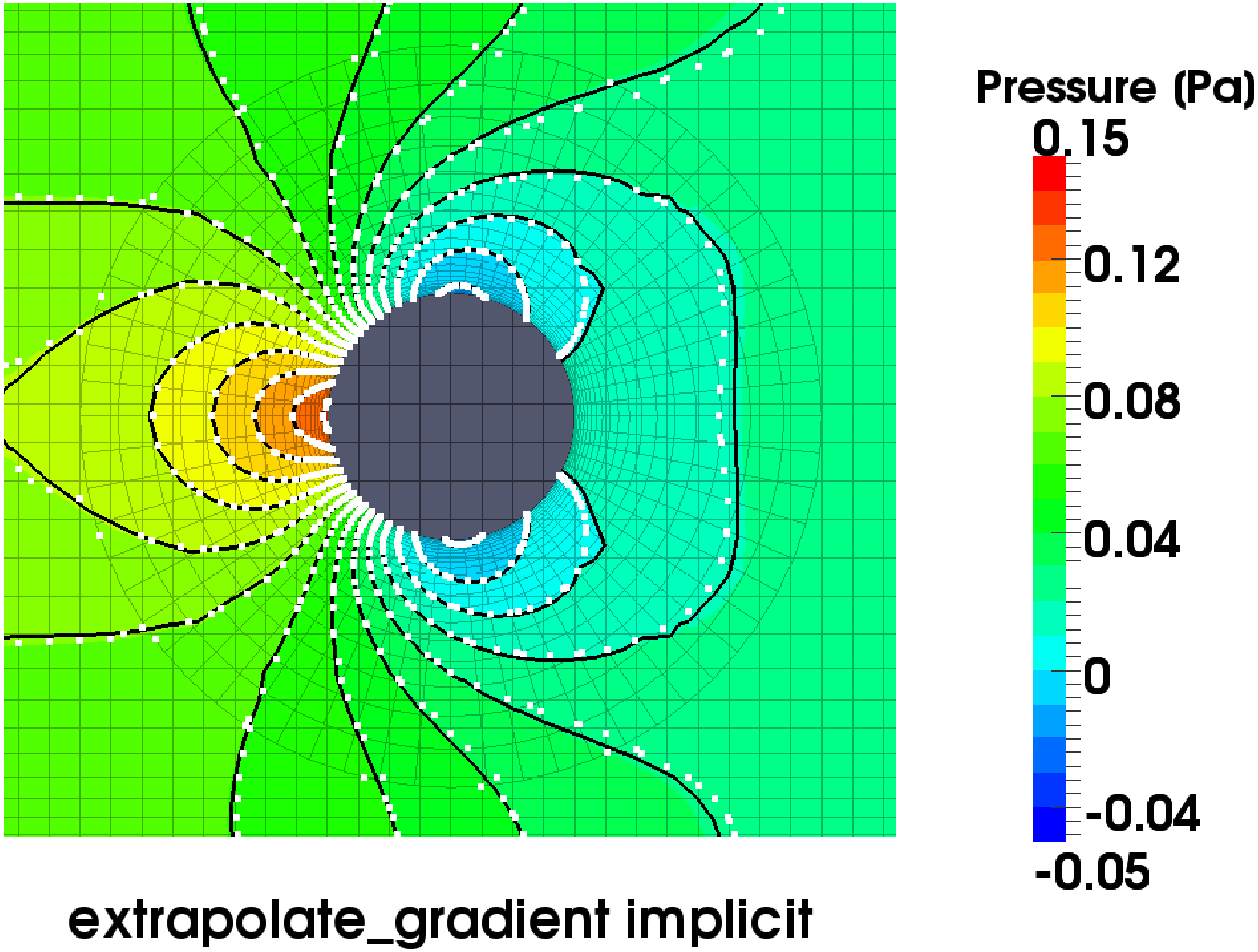
Examples: Cylinder in Channel, Horizontal Velocity



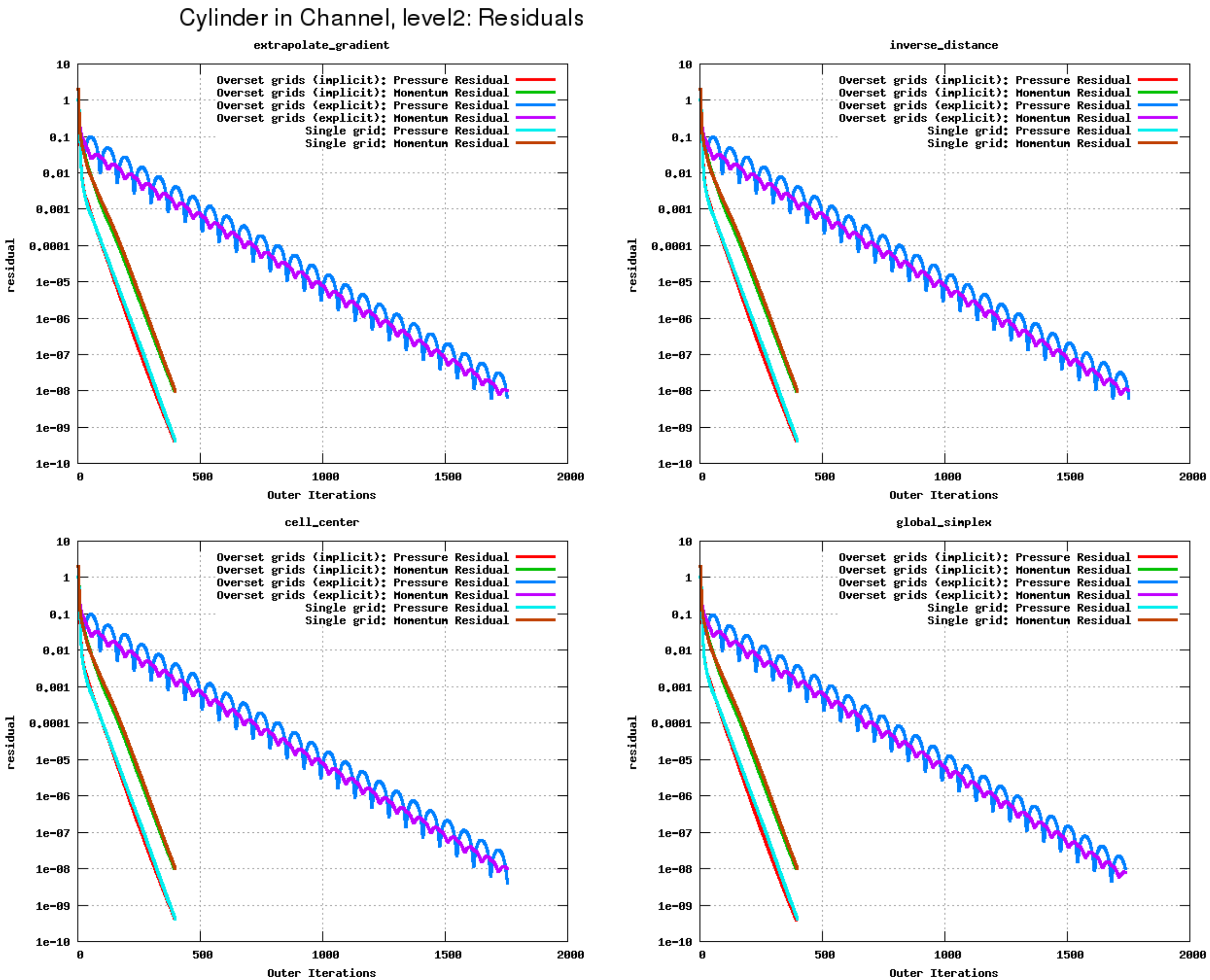
Examples: Cylinder in Channel, Vertical Velocity



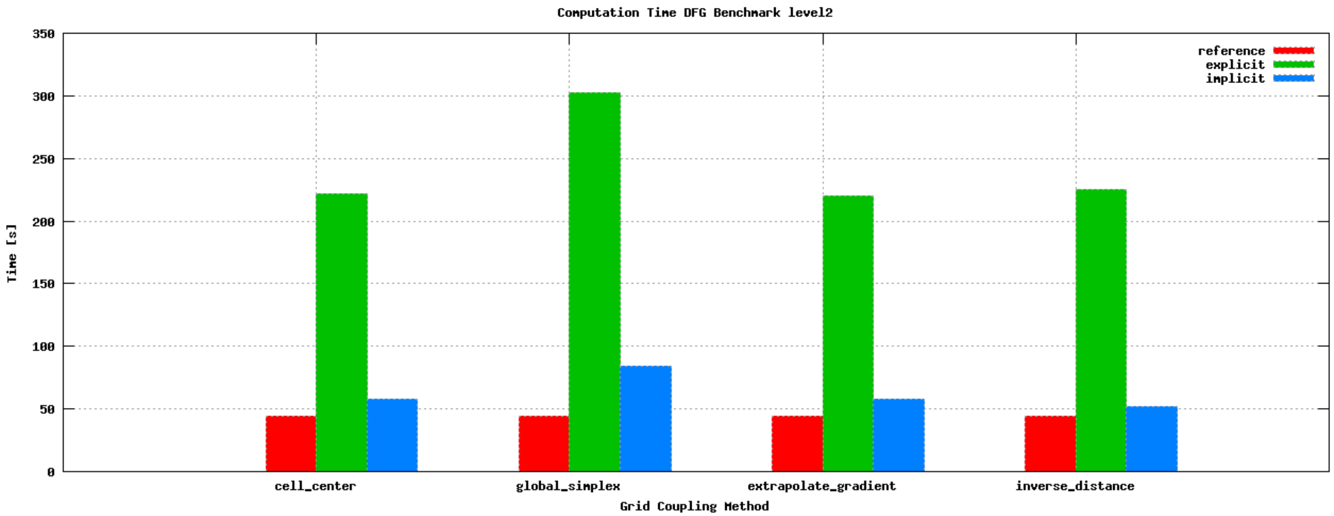
Examples: Cylinder in Channel, Pressure

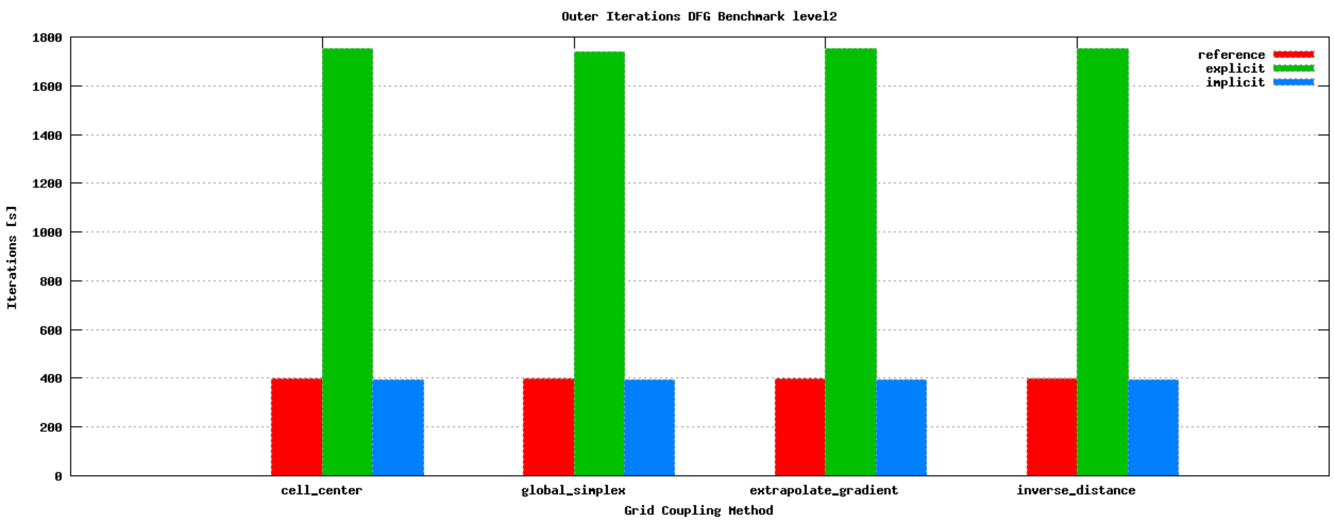


Examples: Cylinder in Channel, Residuals

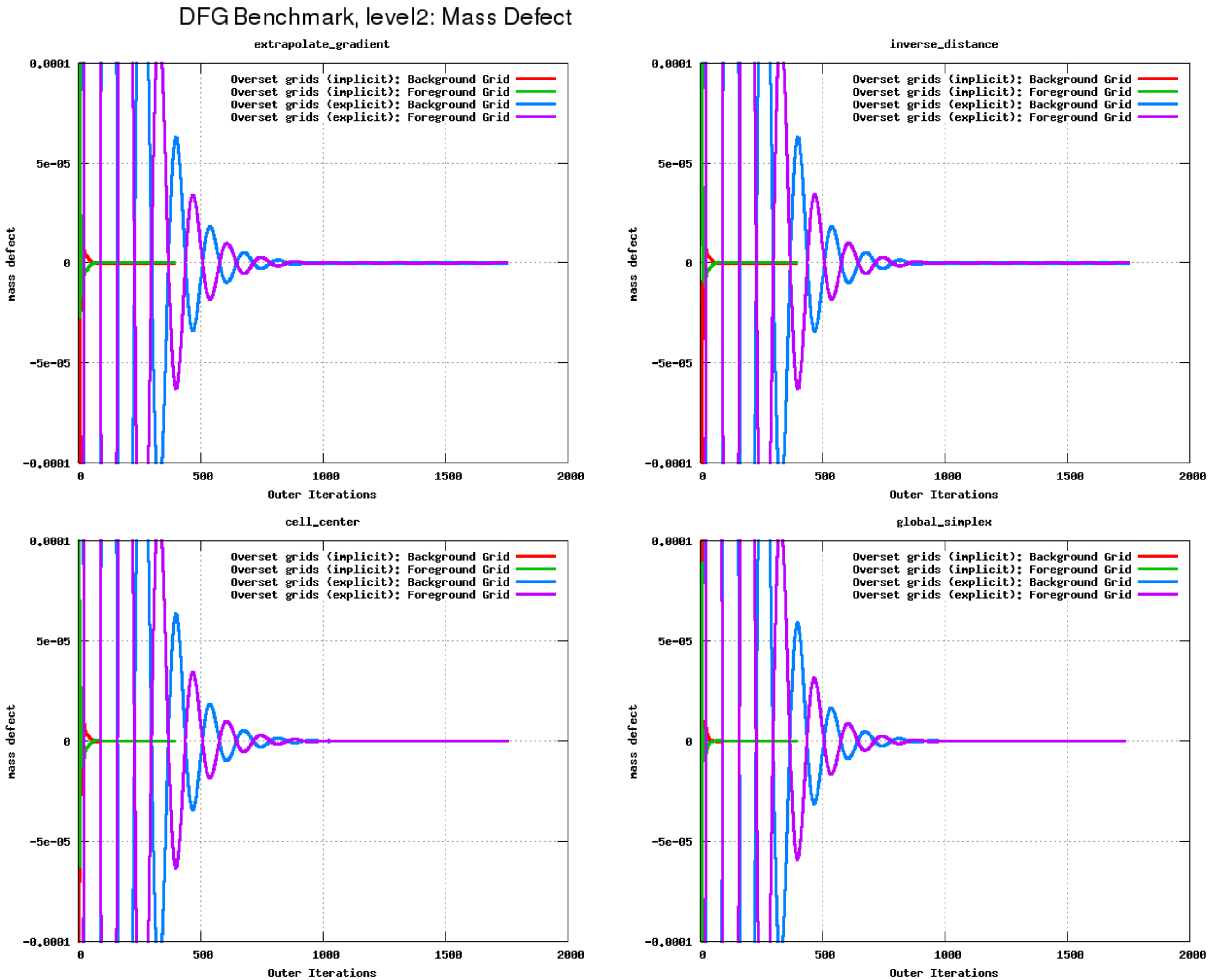


Examples: Cylinder in Channel, Performance

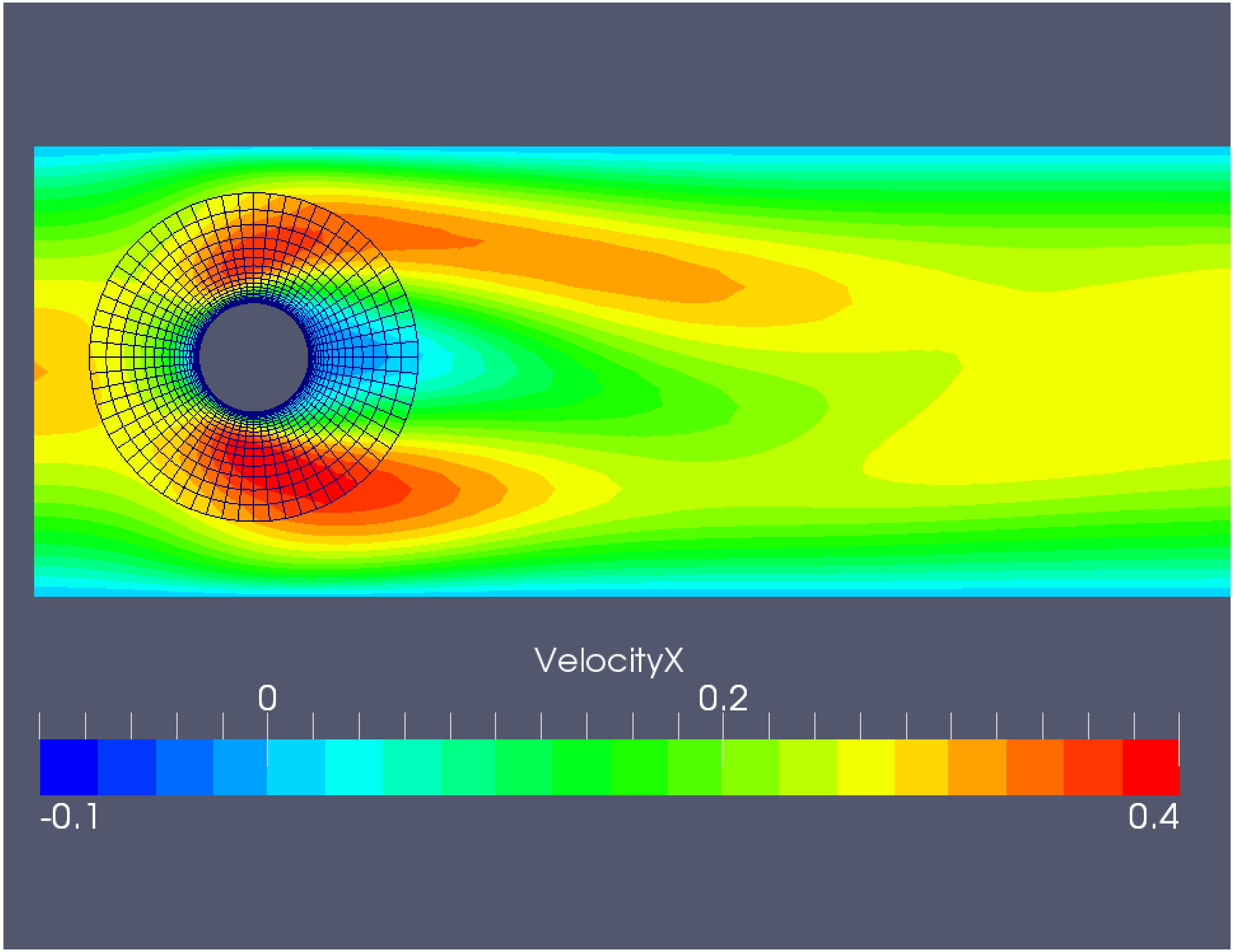




Examples: Cylinder in Channel, Mass Conservation



Examples: Oscillating Cylinder



Conclusions

- Four different interpolation schemes implemented
- Implicit and explicit grid coupling
- All methods stable and accurate
- Implicit methods
  - faster convergence
  - better mass conservation
  - enhanced effiency for complex flows (multibody, transient)

Outlook

- Extend algorithm to parallel simulations
- Evaluate robustness of interpolation methods for 'real-life' meshes
  - background vs. foreground resolution
  - aspect ratios
- Extension to >2 grid layers
- Void-space detection

Thank you for your attention!