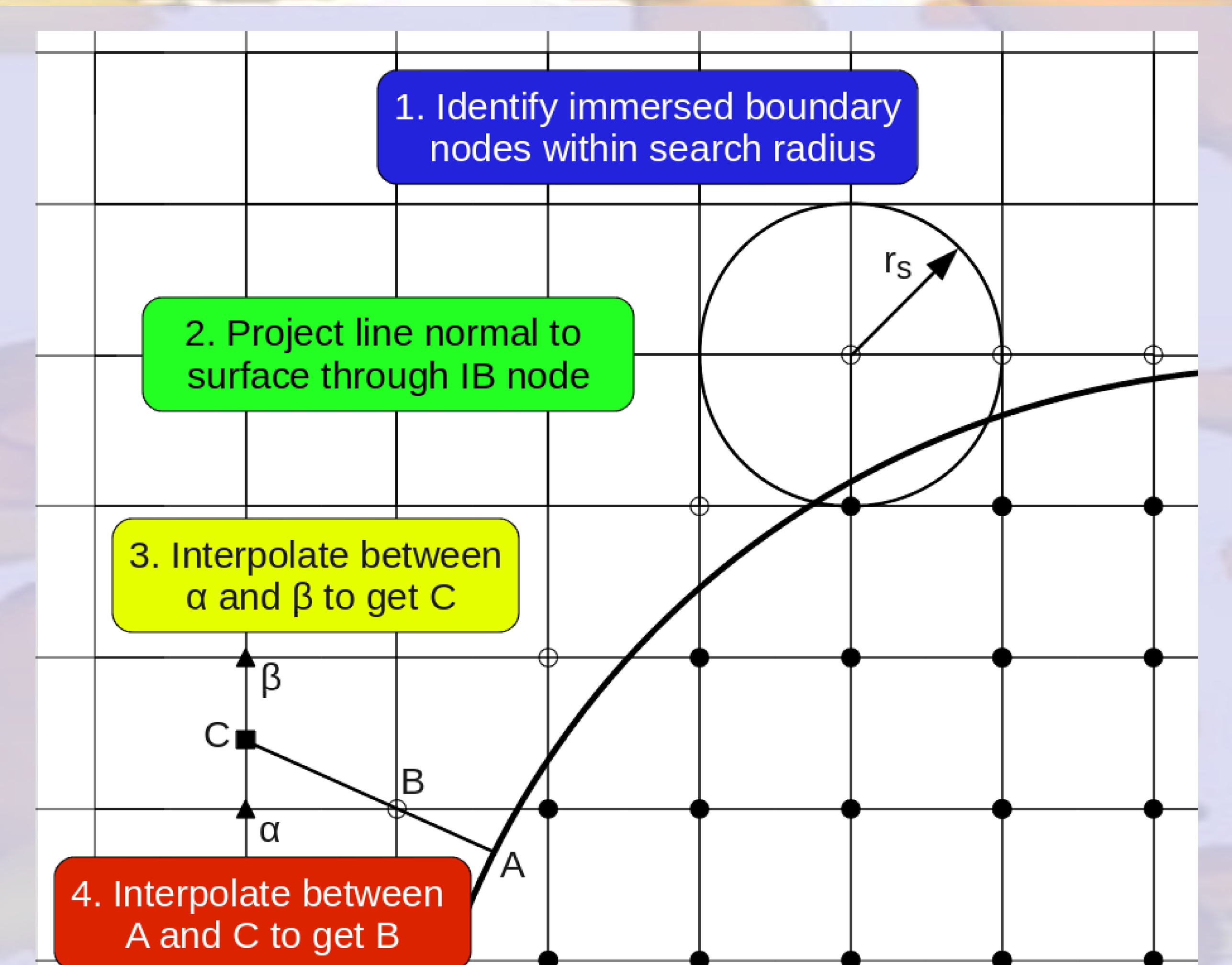
Immersed Boundary Turbulent Flow Simulations on GPU Clusters

Rey DeLeon, Kyle Felzien and İnanç Şenocak

Motivation & Objective

Immersed boundary (IB) method is a numerical technique to impose boundary conditions at fluid-solid or fluid-fluid interfaces on a fixed Cartesian mesh. **Cartesian meshes** are desirable, because mesh generation can be automated and fits well to the CUDA execution model. IB method has a variety of applications ranging from aerodynamics to fluid animation in entertainment industry. Our specific objective is to extend the IB method with a dynamic large-eddy simulation capability to model **to forecast winds over complex terrain** on GPU clusters.



Immersed Boundary Method

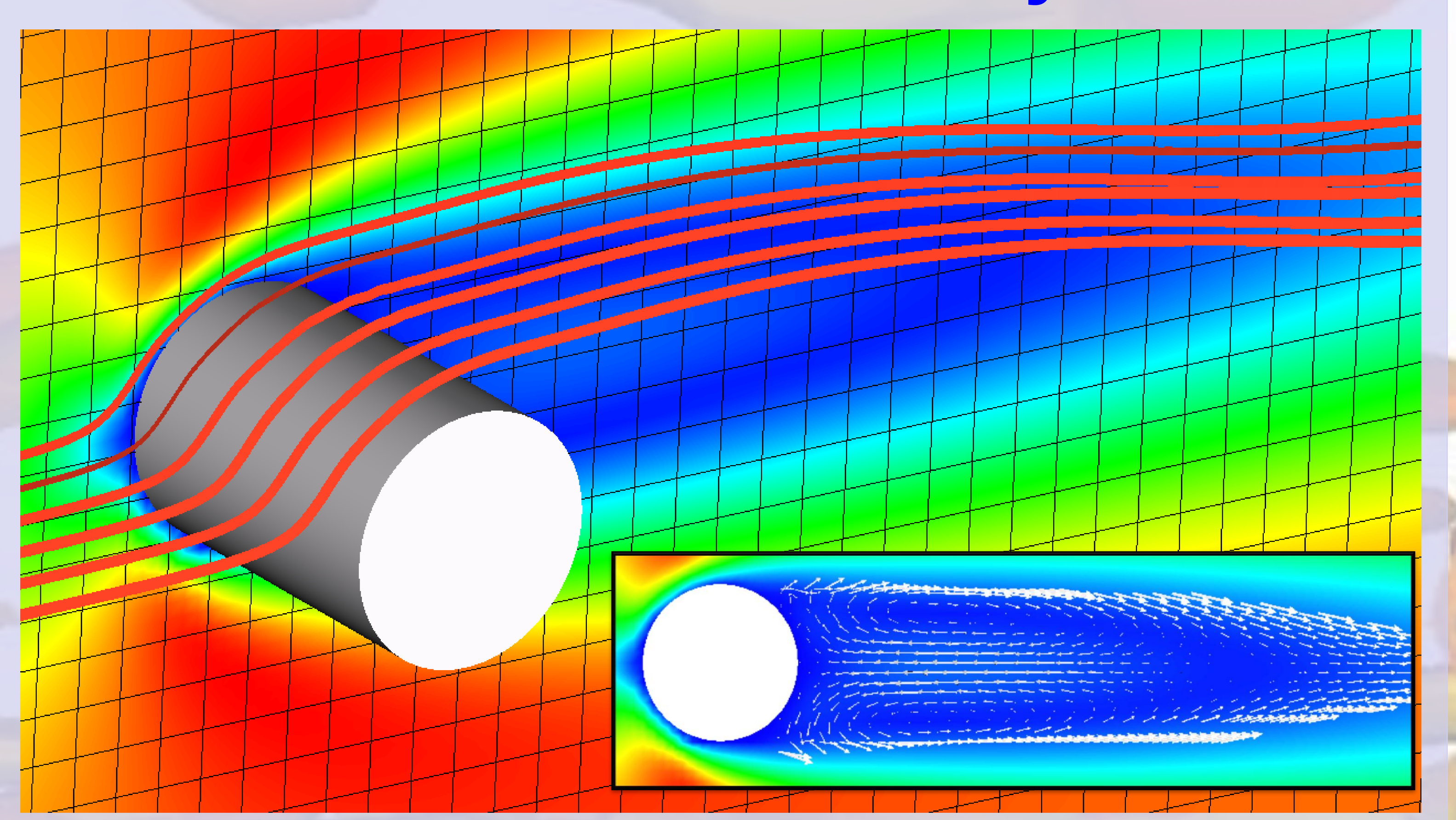
- Map an arbitrarily complex CAD geometry with a triangulated surface representation to a Cartesian mesh
- Identify fluid-solid regions on a Cartesian mesh
- Use geometrically calculated distances on an immersed boundary node stencil to impose the boundary conditions as a direct forcing in the momentum equations

Turbulent Flow Simulation

Three primary numerical techniques:

- **Reynolds-Averaged Navier-Stokes (RANS)** - computationally inexpensive but resolves no flow structures. Not ideal for highly separated flows (e.g., flow over mountains)
- **Large-eddy simulation (LES)** - resolves large flow structures and requires significant computational resources
- **Direct Numerical Simulation (DNS)** - resolves all scales of flow but extremely computationally expensive

Flow Over a Circular Cylinder



Lagrangian Dynamic LES Model

Turbulent eddy viscosity:

$$\nu_t = (C_S \Delta)^2 \sqrt{2\bar{S}_{ij}\bar{S}_{ij}}$$

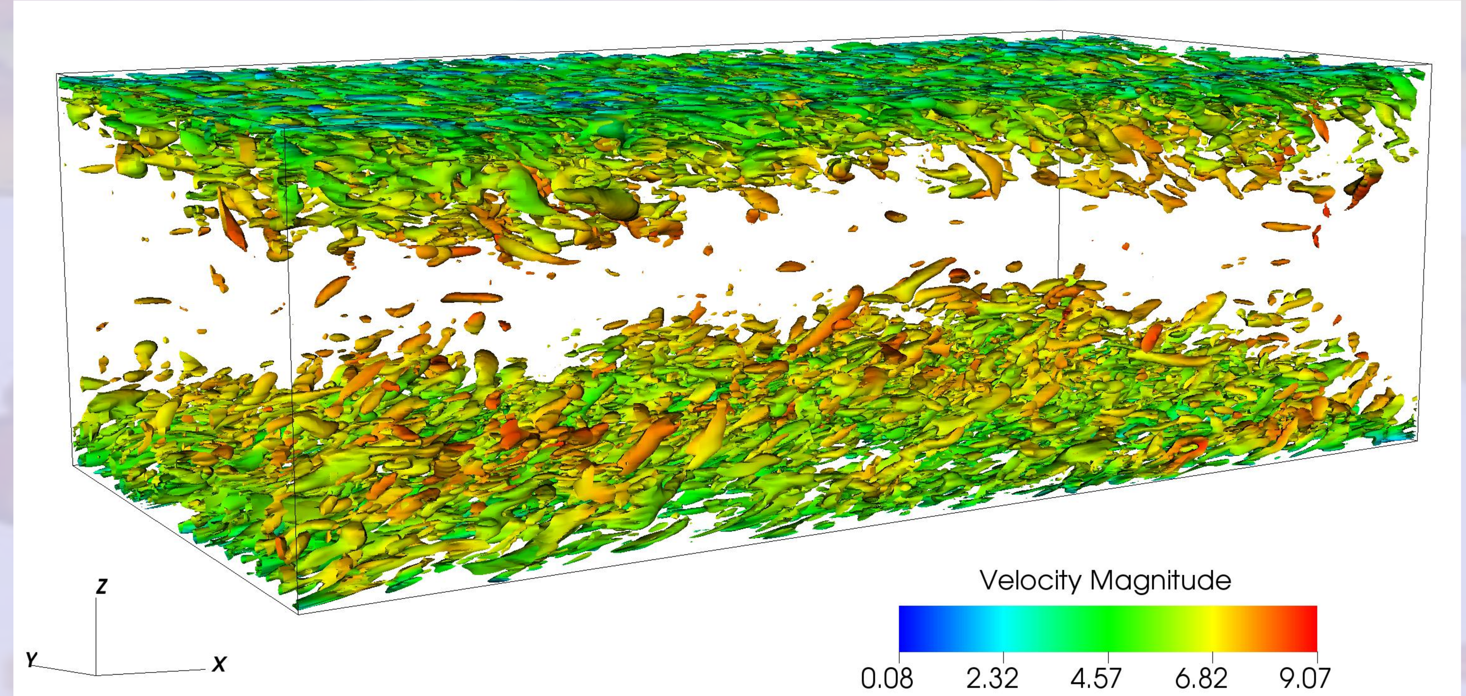
Dynamically calculates C_S along flow pathlines without requiring homogeneous directions and is suitable for complex geometry.

Meneveau et al., J. Fluid Mech., Vol. 319, 1996, pp. 353 – 85

GIN3D

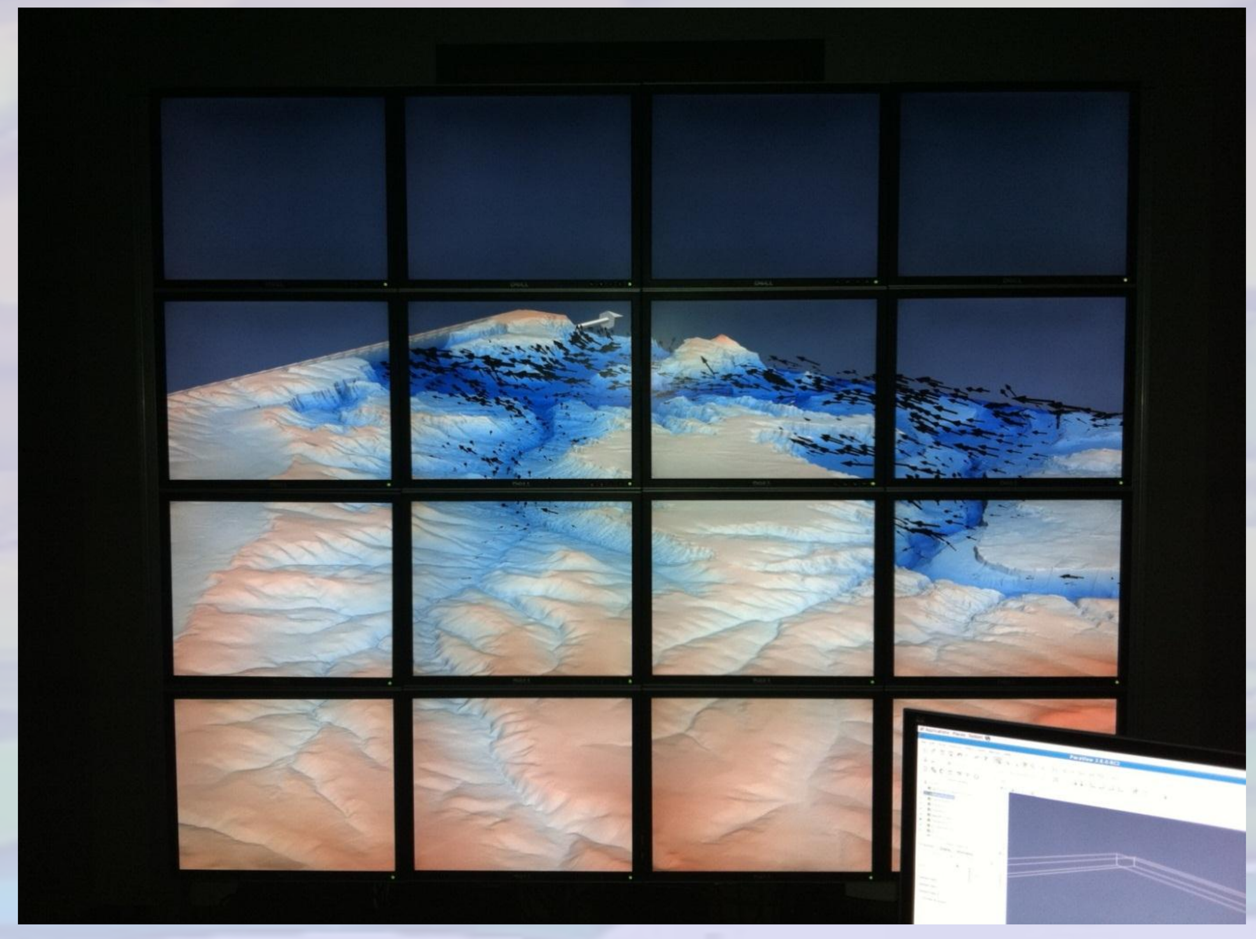
- Massively parallel MPI-CUDA incompressible flow solver
- Amalgamated geometric multigrid solver for Poisson Equation
- Second order central difference and Adams-Bashforth schemes on a staggered mesh

LES of Channel Flow – Vorticity Isosurfaces Colored by Velocity Magnitude



Future Work

Couple LES technique using the Lagrangian dynamic turbulence model with the Immersed Boundary method to forecast winds over complex terrain.



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