Overset Meshing in ANSYS Fluent

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Motivation for Overset Meshing in ANSYS Fluent

• Extending current capabilities
  – Better handling of relative mesh motion with small gaps (gears, pumps)

• Ease of use
  – Perceived simplified mesh generation for complex geometries
  – Avoid remeshing failures and setup issues as in dynamic mesh
  – Easier configuration changes and part swapping

• Solution quality
  – Overset grids maintain grid quality during mesh motion
  – Locally structured meshes in a generally unstructured grid
Overset in ANSYS Fluent

• Fluent 17.0 (2016)
  – Pressure-based solver
    • Coupled scheme for pressure-velocity coupling
    • Steady-state and transient
  – k-eps and standard k-w turbulence models
  – Single phase and Volume of Fluid (VOF) multiphase
  – All element (polyhedra) and mesh types
  – Adaptive mesh refinement
  – Fully parallel

• Fluent 18.0
  – Density-based solver
  – Dynamic Mesh (rigid and deforming)
Overset in ANSYS Fluent

• User interface with minimal input required to handle all supported topologies
  – No connectivity information required
  – Requires automatic detection of matching (overlapping) geometry
  – User specifies set of background and component grids to be paired in overset interface

– Optional inputs
  • Global grid priorities to favor zones in the assembly process
  • Local cell priorities to favor cells based on size or boundary distance
Overset in ANSYS Fluent

- **Overset interface**
  - Pairs multiple component grids with multiple background grids
  - Needs to have at least one background and one component grid

- **Background grid**
  - Cell zone which does not have a boundary zone of type overset. Multiple background grids have to be conformally connected.

- **Component grid**
  - Cell zone which has at least one boundary of type overset. Component grids can be conformal.

- **Overset boundary**
  - Boundary condition to designate that component grids are intended to communicate with other grids
Overed in ANSYS Fluent

• Overlapping boundaries
  – Automatic detection of matching/overlapping geometry of same boundary condition type (wall, symmetry, inlet...) during hole cutting

• Intersecting wall boundaries require collar grids
  – Collar grids generate boundary overlaps and remove the actual intersection
Hole Cutting

- **Direct hole cutting**
  - Face zones are identified as of *cut*, *overset*, or *interior* type
  - Faces of cut zones cut faces of interior zones and mark cut cells
    - Face candidates filled into kd-tree
    - Overlapping cut faces are considered to belong to the same geometry and do not cut
      - Requires robust marking/protection of overlapping cut faces. Tolerances based on adjacent cell height and local feature angles.
  - All face types triangulated for fast tri-tri intersection test
  - Cells outside the computational domain are marked by flood filling
    - Requires reliable marking of seed cells
    - Requires sufficient matching of overlapping cut zones (no leaks)
      - Thin-cut correction to prevent leaks in inflation layers
Overlap Minimization

- Reduce overlap by converting additional cells into dead cells
  - Mark temporary receptor cells on maximum overlap grid
  - Flood fill additional receptor cells if cell finds valid donor cell with
    - Higher grid priority (optional), or
    - Higher cell donor priority
      - Inverse of local average cell size or boundary distance
      - Grid priority overrides cell donor priority
  - Bounding cell search using octree and neighbor walk
    - Cached bounding cells with moving mesh
  - Remove solve cell islands (due to irregular unstructured grids)
    - Flood fill solve cells from cut face zones and convert unreached solve cells to receptors, if permissible
  - Convert unnecessary receptors to dead cells
Overlap Minimization

- Cell donor and grid priorities
  - Can be combined

Cell size based donor priority

Boundary distance based donor priority

Grid priorities
Donor Search

• Bounding cell with highest cell donor priority is principal donor
  – Byproduct of overlap minimization
  – Cache bounding cells in moving mesh simulations
    • Starting point for neighbor walk
  – Donor stencil includes face or node connected cells
  – If only receptor cell is found, option to accept closest connected solve cell
    • Reduces orphan cells where overlap is minimal
  – In transient simulations, exclude donors which were dead cells in previous time step
Parallel Overset Meshing

- General implementation to allow any available partitioning method
  - Replicating mesh as “extended zones” as needed in order to make hole cutting, overlap minimization, and donor search local operations
    - Face and cell zones replicated based on overlapping axis-aligned bounding boxes
      - Cut face zones extended for hole cutting
      - Component and background cell zones extended for minimization and donor search
  - Parallel performance depends on partitioning
    - Size of extended zones $\rightarrow$ intersection time
    - Size of parallel neighborhood $\rightarrow$ solution exchanges
    - Distribution of solve cells $\rightarrow$ solver scaling
Parallel Overset Meshing

- Partitioning Methods
  - Metis default partitioner
  - Option to include overset donor-receptor connectivity in partitioning (Metis-DR)
  - Option for model-weighted partitioning to distribute solve cells evenly (Metis-MWP)
    - Default for steady state calculations
  - Periodic repartitioning of domain for moving mesh
Parallel Overset Meshing

Intersection Scaling

- Metis
- Metis-DR
- Principal Axes

1.8M cells

Intersection Scaling

- Metis
- Metis-DR
- Principal Axes

1.7M cells
Parallel Overset Meshing

![Solver Scaling Chart]

The chart shows the time per iteration in seconds for different numbers of processors using two different partitioning methods: Metis and Metis-MWP. The x-axis represents the number of processors, ranging from 64 to 256, and the y-axis shows the time per iteration in seconds. The chart indicates that with 256 processors, Metis-MWP outperforms Metis in terms of time per iteration, especially when the number of processors increases. The chart also highlights that the total number of cells is 1.7M.
Transient Overset Meshing

• Caching of entities to be reused in subsequent time steps
  – Bounding cells for overlap minimization and donor search
  – Extended face and cell zones for rigid body motion
• Extended entities are moved/updated during mesh motion

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<tr>
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<th>n0 [s]</th>
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<tr>
<td>filling extended zones</td>
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<td>8.1</td>
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Moving ball

Rotor model - Hub, 4 blades, 4 collar grids
Overset Solver

Data transfer strategy

• Solution
  – Interpolate
• Gradients
  – Interpolate or compute
• Interface mass flux
  – Approximate
• Overlapped grid linear system
  – Assemble matrix with implicit coupling
Receptor Cells

- **Interpolate solution**
  - Gradients of adjacent solve cells
  - Flux evaluations

- **Solution gradient**
  - Accurate flux evaluation

- **Supply mass flux at overset interface**
  - Linearizations, Rhie–Chow flux

- **Provide inter grid coupling information to establish matrix assembly**
Interpolation

- One layer of receptor cells
- Face or node connected neighbors
  - Principal donor
  - Not always the centroid bounding cell
  - Variable number of donors
  - Optionally, neighbors from same grid (orphans and dead to solve cells)
- Interpolation methods
  - Inverse distance weighting
  - Least squares weighting
Gradients at Receptor Cells

- **Interpolate**
  - Use principal donor gradients

- **Compute**
  - Use donors to evaluate gradients

- **Resolution matching in the overlap critical for accuracy**
Moving Mesh

- **Dead to solve cells**
  - Interpolate from valid neighbors on the same grid

- **Dead to receptor cells**
  - Use valid donors
  - Orphans
    - Interpolate from same grid

- **Other cell status changes**
  - Receptor to solve & vice versa
  - Receptor to dead
  - Solve to dead
Overset Linear System

- After discretization
  - Augmented linear system of equations
- Inter grid implicit coupling
  - $A_{nb}$ defined consistent with the interpolation at the overlap region
- Receptors use interpolation equations
  - Receptors are up to date after solve
- All models are handled the same way

\[
Ax = B \\
A_p \phi_p = \sum_{nb} A_{nb} \phi_{nb} + S
\]
Unsteady Laminar Vortex Shedding

Pressure Based Coupled Solver (PBCS)
2nd order in time, \( dt = 0.01s \)
Range of Reynolds (60-160)

<table>
<thead>
<tr>
<th>Grid Size</th>
<th>Elements</th>
<th>Strouhal no. (Exp - 0.1692)</th>
<th>Error (%)</th>
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<td>Fine</td>
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Turbulent Flow in U-Bend

Regular

Overset

Skin friction coefficient

Pressure outlet

Velocity inlet

Residuals
- continuity
- x-velocity
- y-velocity
- k
- omega
AePW-2: Turbulent Steady State External Flow

- 4.78 M elements, AoA = 3°, Ma = 0.7
- PBCS, SST k-omega

Note: More details about experimental setup is available at http://nescacademy.nasa.gov/workshops/AePW2/public/
AePW-2: Transient Flow with Rigid Body Motion

PBCS, 1st order transient, SST k-omega

- Experimental
- Overset
- Regular (coarse)
- Regular (medium)

Frequency Response Function

Drag

Lift

- Regular
- Overset
Booster Separation

Overset Mesh
Hexahedral mesh with inflation, 1.67M cells

Dynamic Mesh
Hybrid mesh with inflation, 6M cells

6DOF Rigid Body Motion
Booster Separation

Original mesh quality preserved in overset mesh
Booster Separation

Overset Mesh Solution

Dynamic Mesh Solution

Preserves quality of shocks

Contours of pressgrad (Time=0.0000e+00)