Curvilinear Gridding and Connectivity Best Practices within the LAVA Framework

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Computational Aerosciences Branch
NASA Ames Research Center

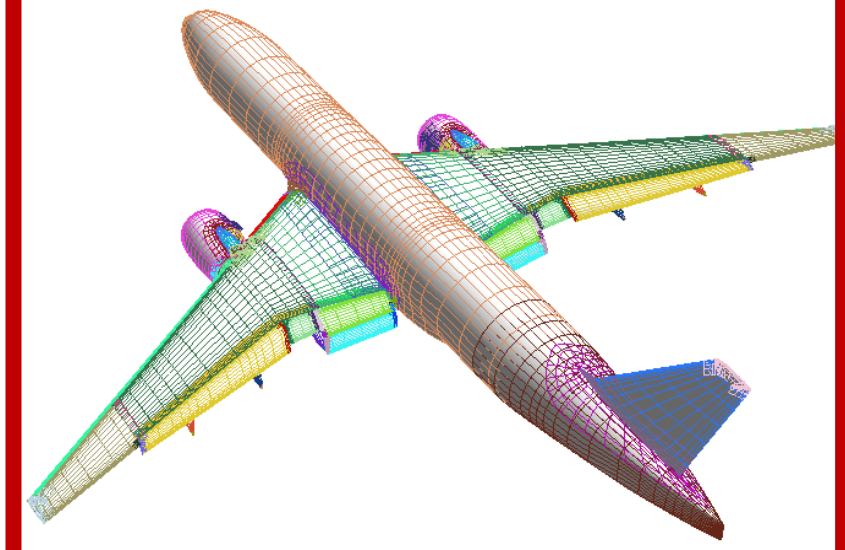
Advanced Modeling and Simulation (AMS) Seminar Series
NASA Ames Research Center
October 27th 2026

Launch, Ascent, and Vehicle Aerodynamics Framework

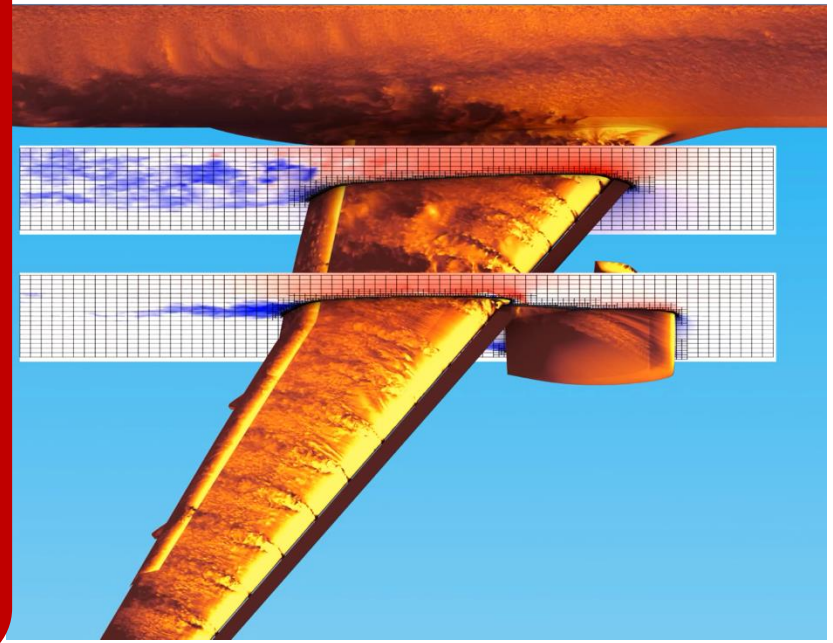
WWW.NAS.NASA.GOV/LAVA/



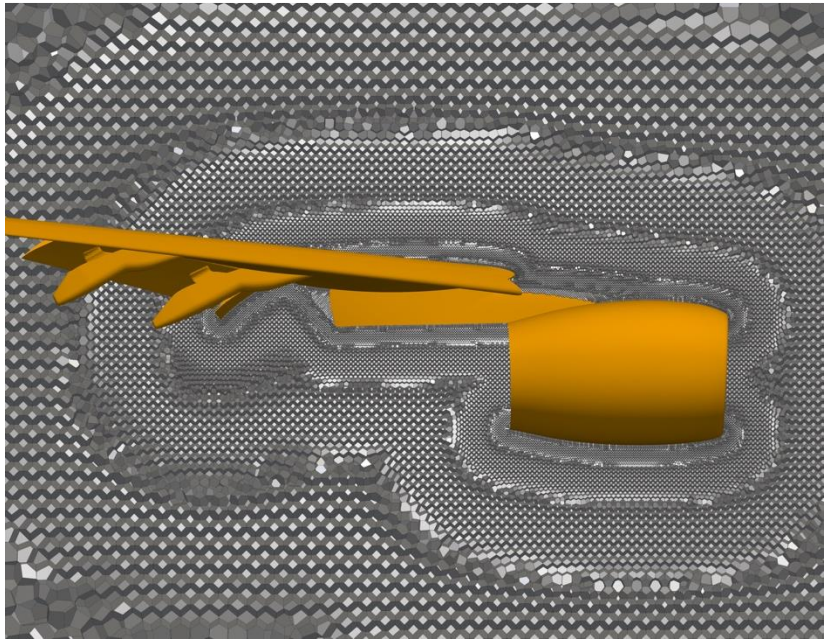
Structured Curvilinear



Cartesian

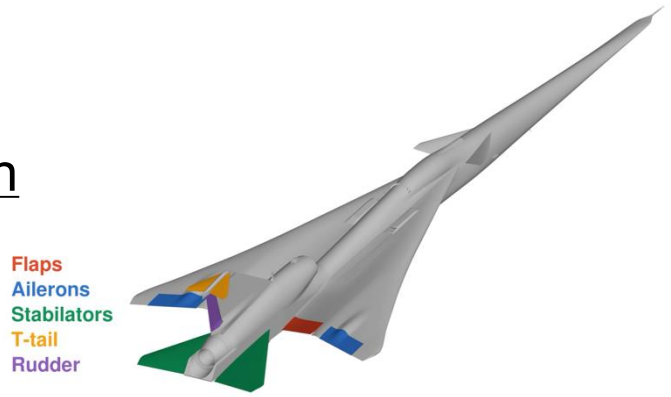


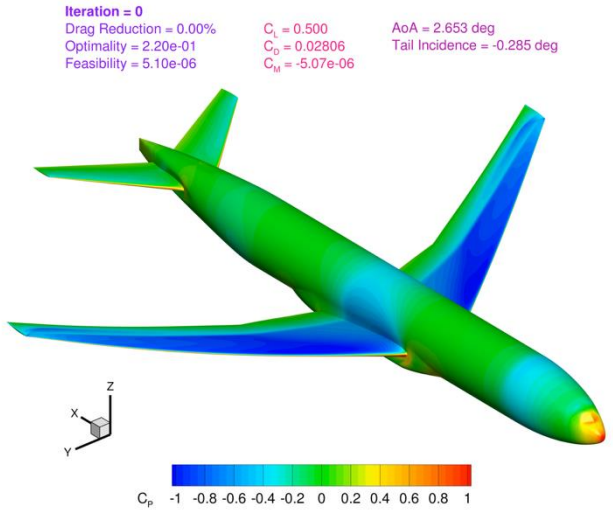
Unstructured Polyhedral



Application Focus

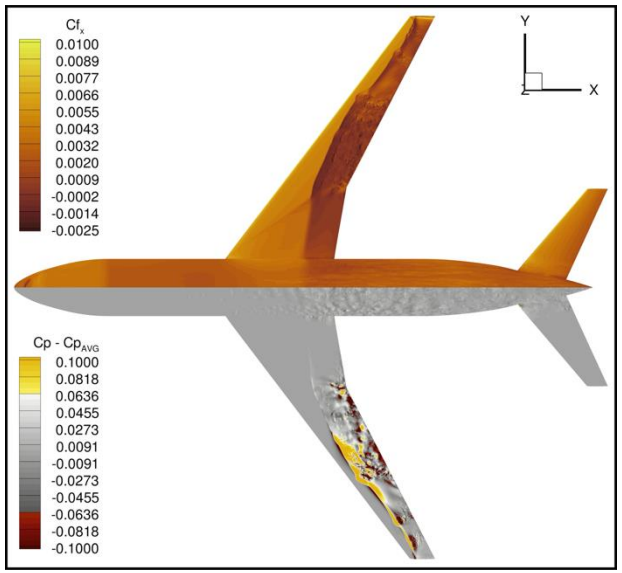
Database Generation
[X-59]

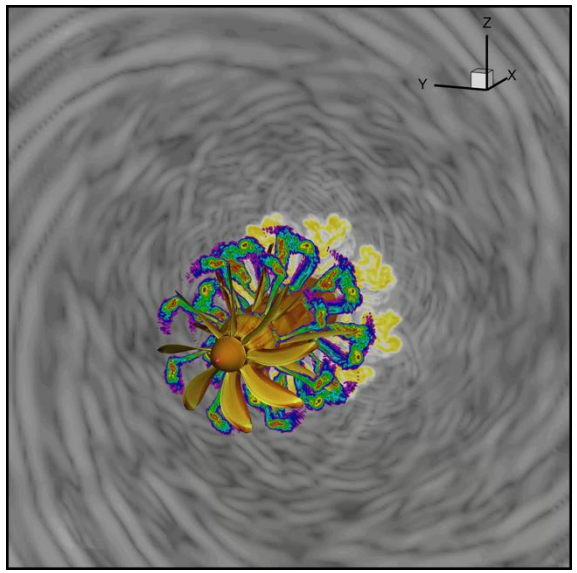




MDAO
- Aeroelastics
- Aero Shape Optimization
[CRM Shock Removal]

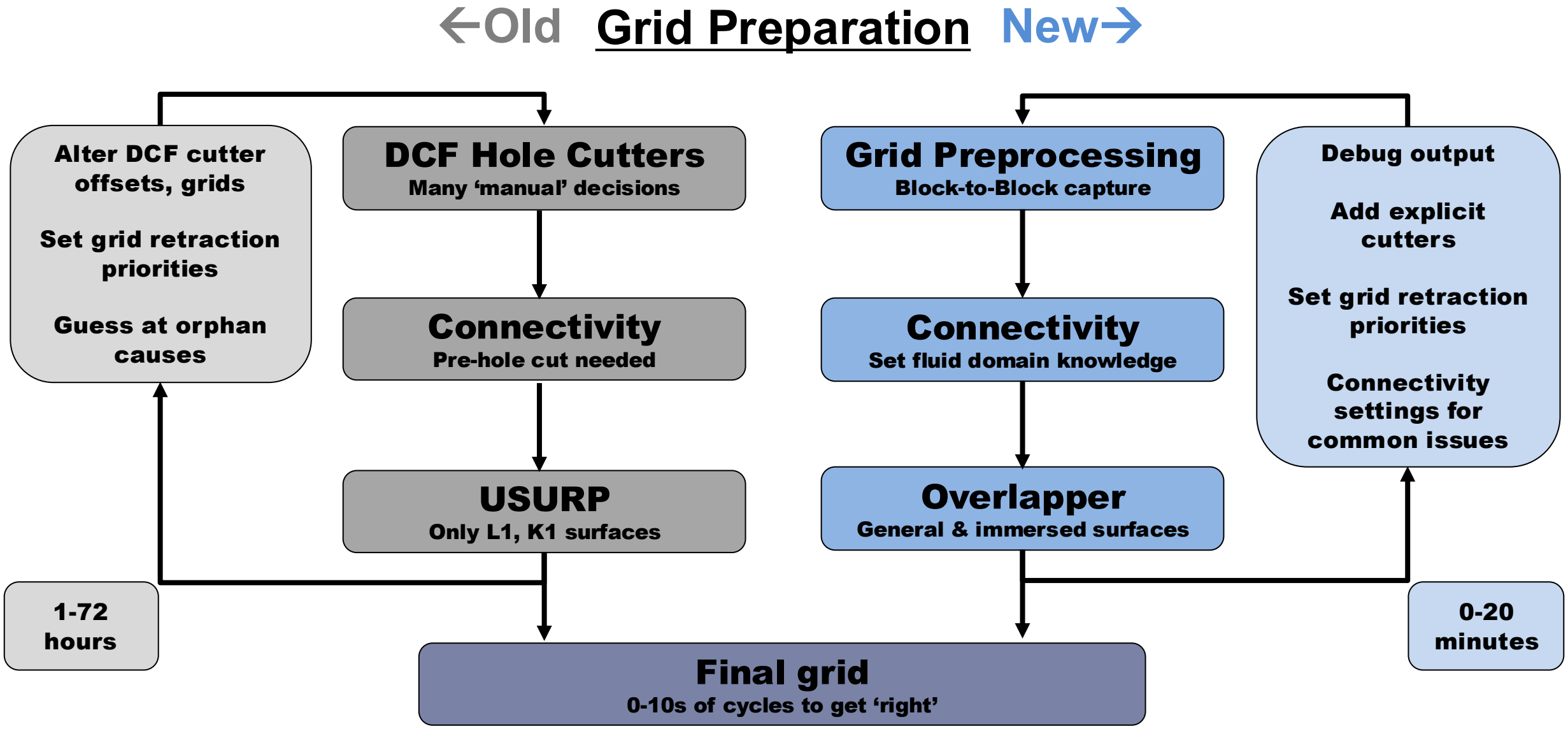
Hybrid RANS-LES
[DPW8 Buffet WG]





Rotating Blades
[SR7-SRV]

Development Motivation



Perspective

You have a grid you want to run with LAVA Curvilinear

But

You need to get through connectivity

Takeaways

Recommended grid topologies / strategies

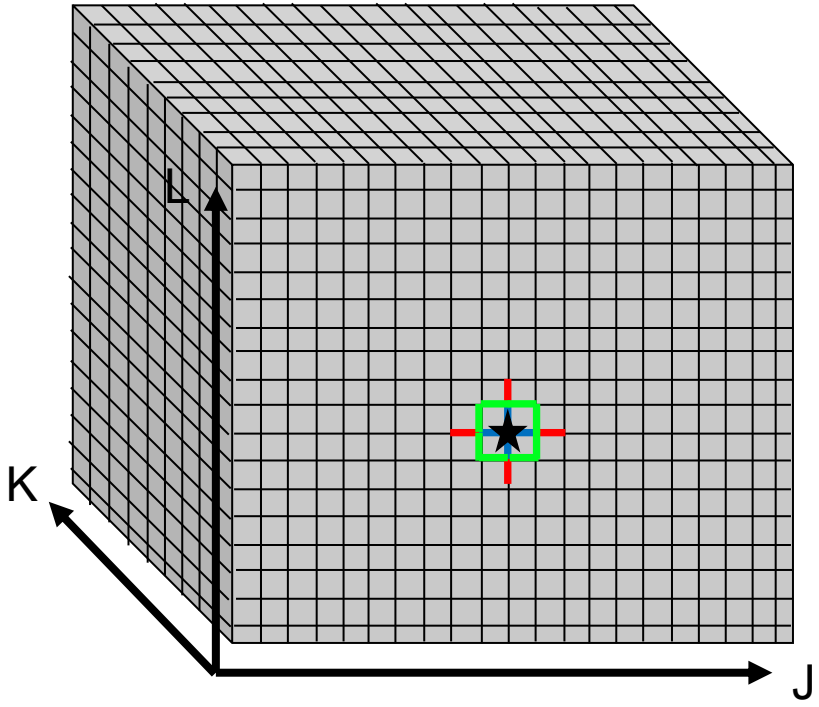
How to assess a geometry → use connectivity's options.

Debugging strategies

Identifying orphan causes/fixes

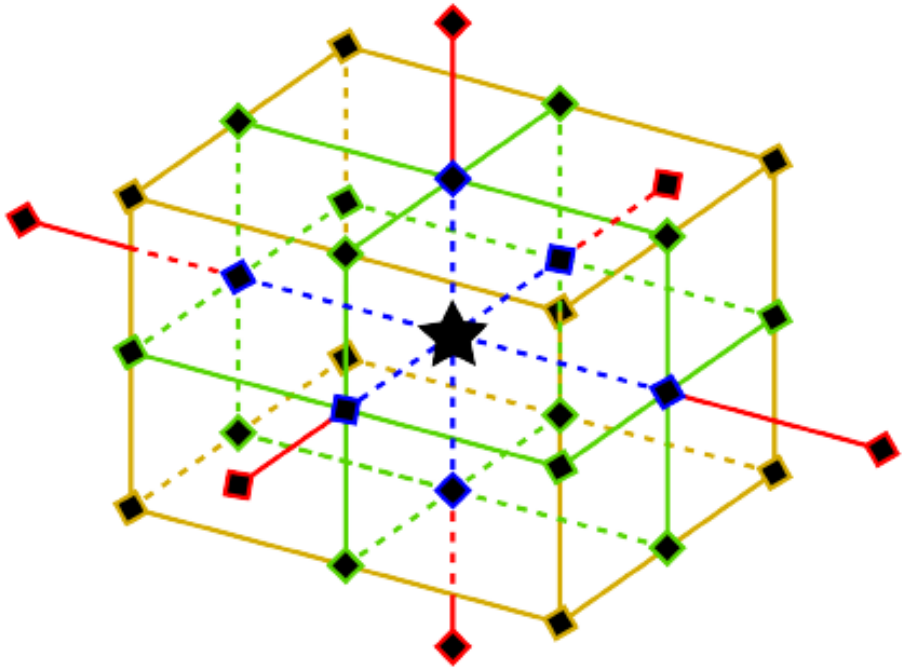
Grid Terminology

Block



All cells should have
positive Jacobians and volumes

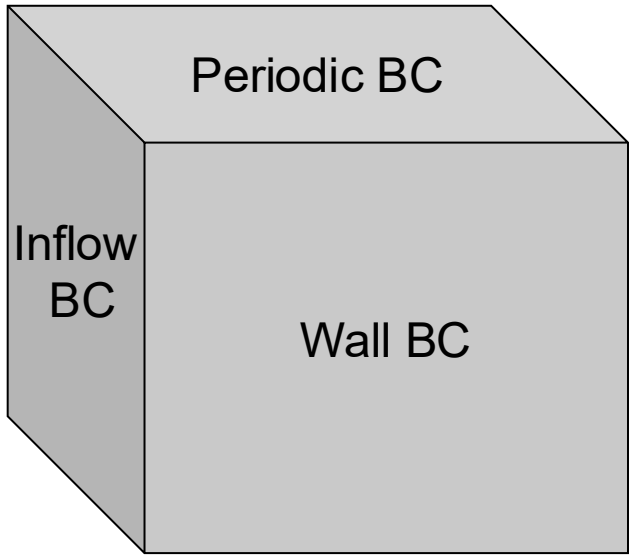
Computational stencil



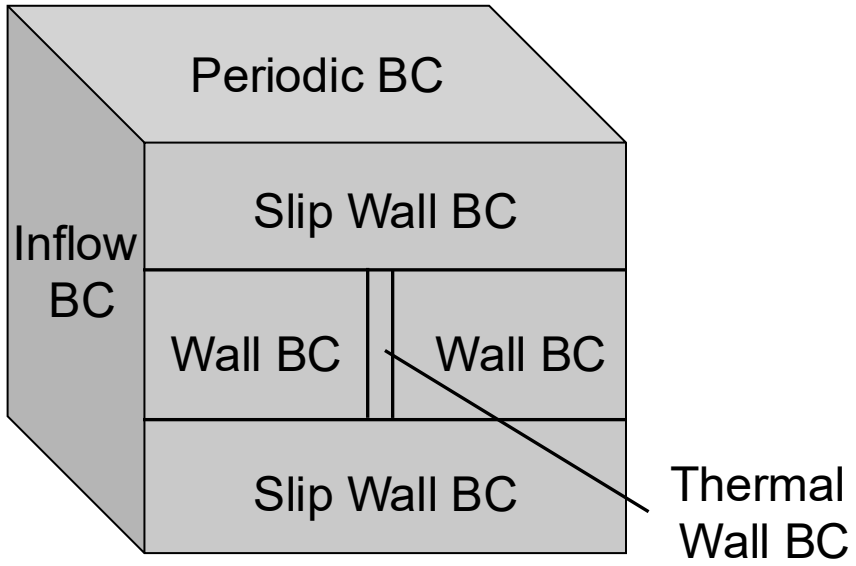
We can ‘walk’ the stencil
to get local information
(e.g. fluxes)

Grid Terminology

Boundary Conditions

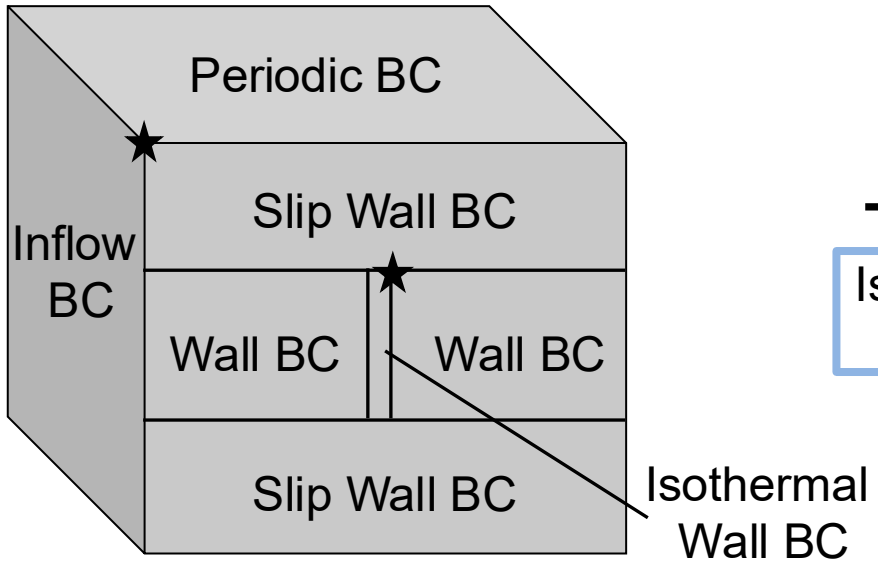


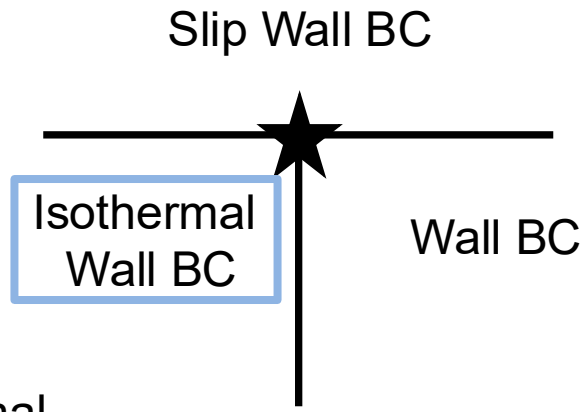
Partial Boundary Conditions



Grid Terminology

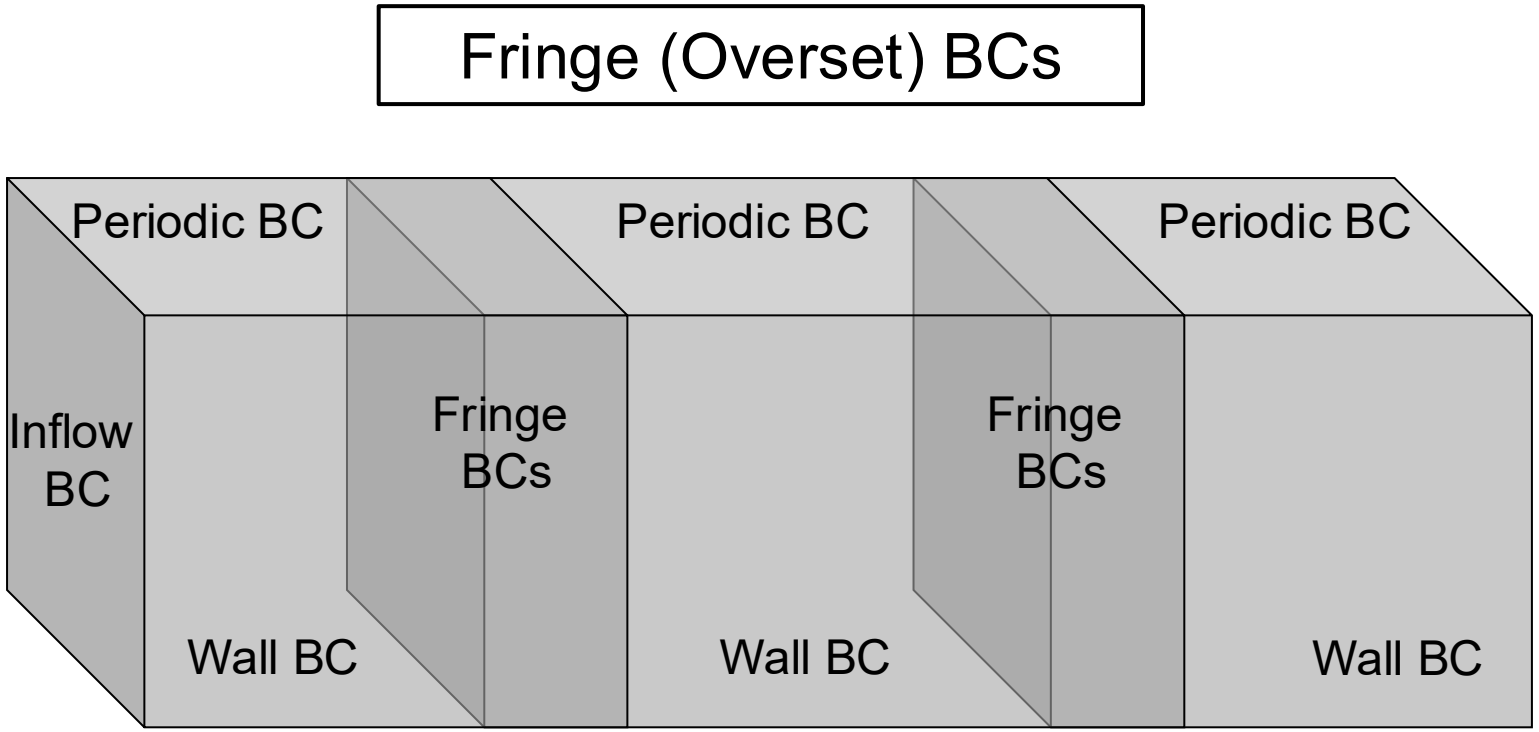
Nodal-application of Boundary Conditions





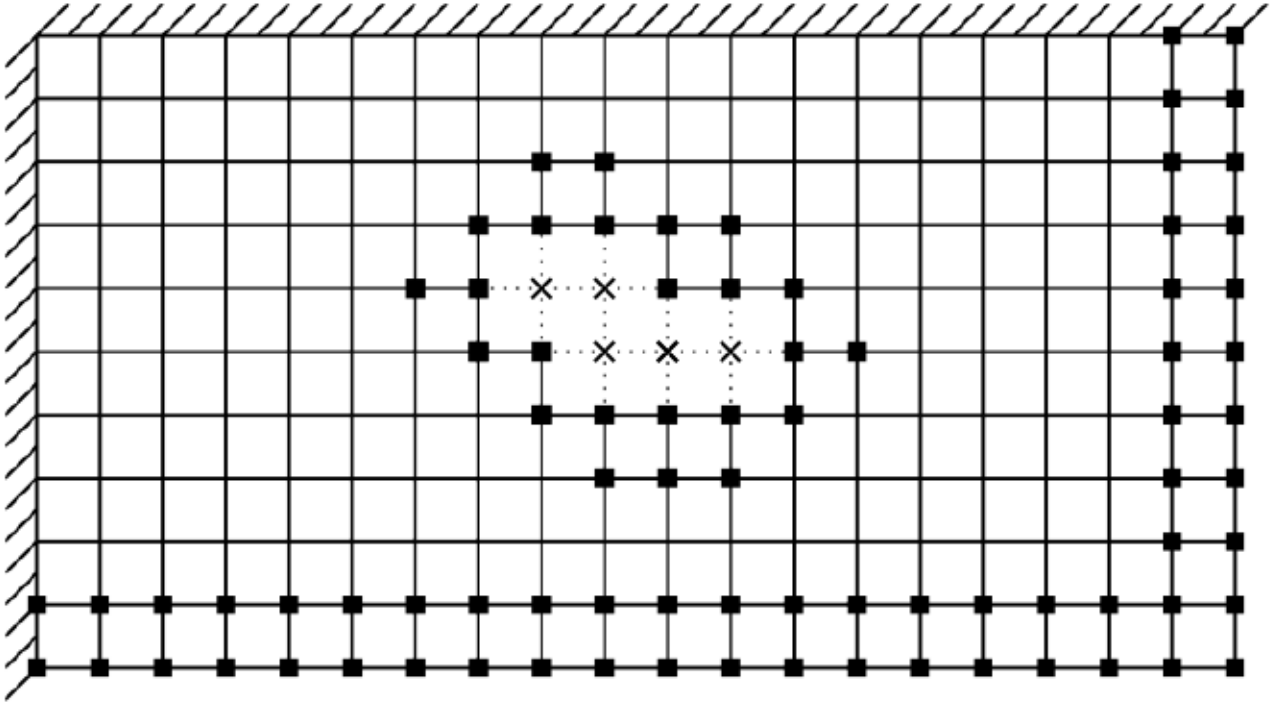
BC Priority	High
Fringe	
Subsonic Outflow	
Wall-Model Wall	
Isothermal Wall	
Adiabatic (Regular) Wall	
Slip Wall	
Inflow/Outflow	
Riemann	
Inflow	
periodic	**LOW**

Grid Terminology



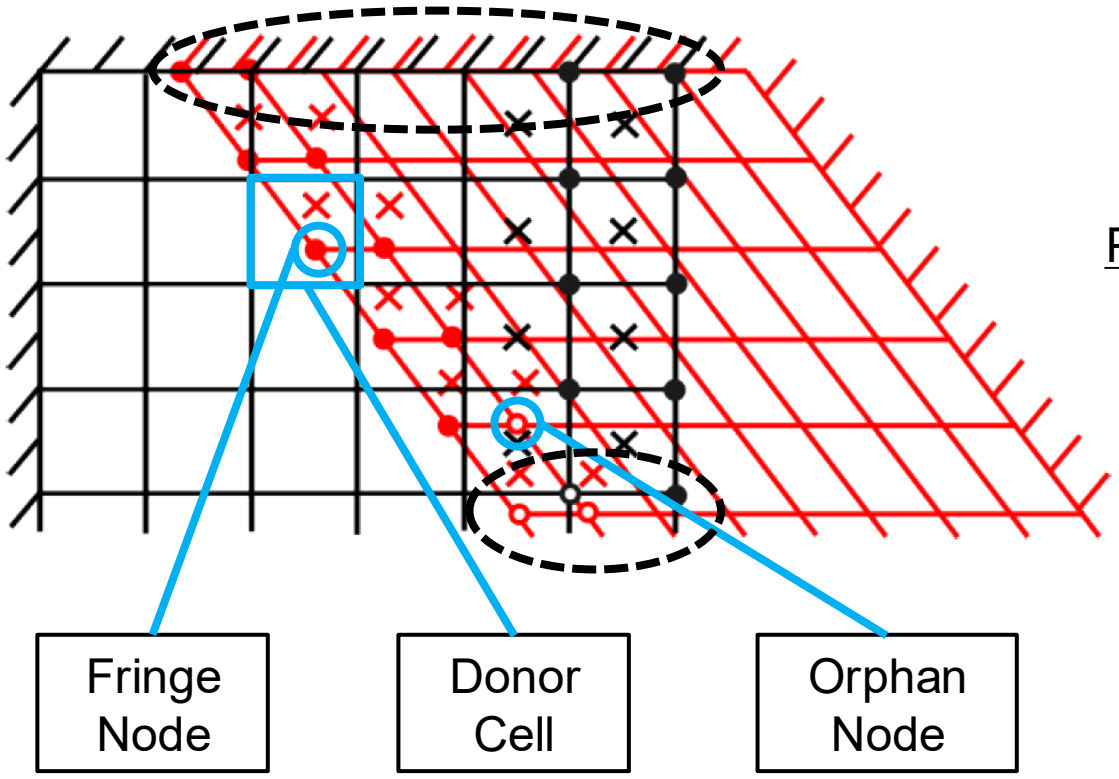
Grid Terminology

Fringe (Overset) BCs
From Holes



Grid Terminology

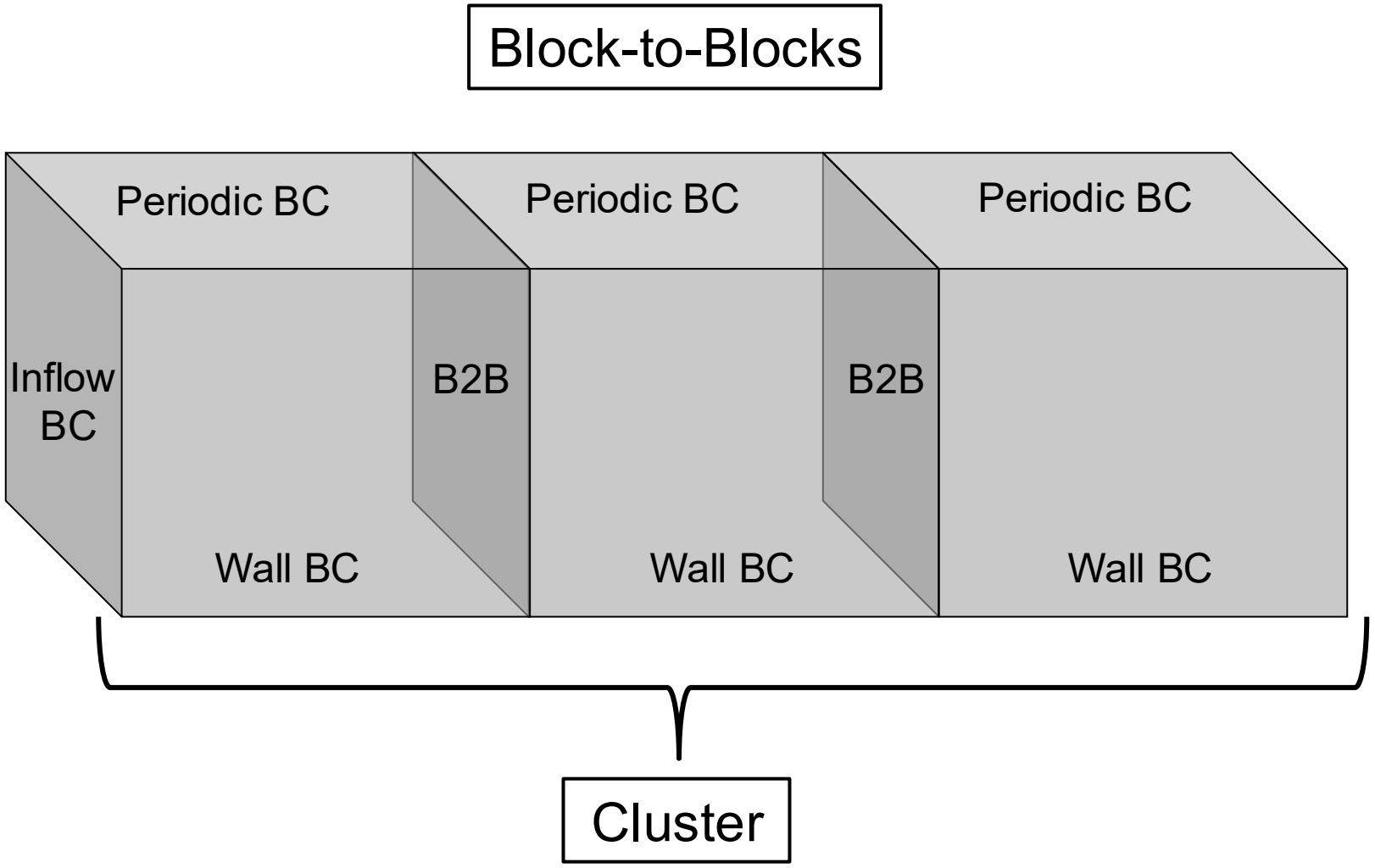
Fringe (Overset) BCs
From Holes



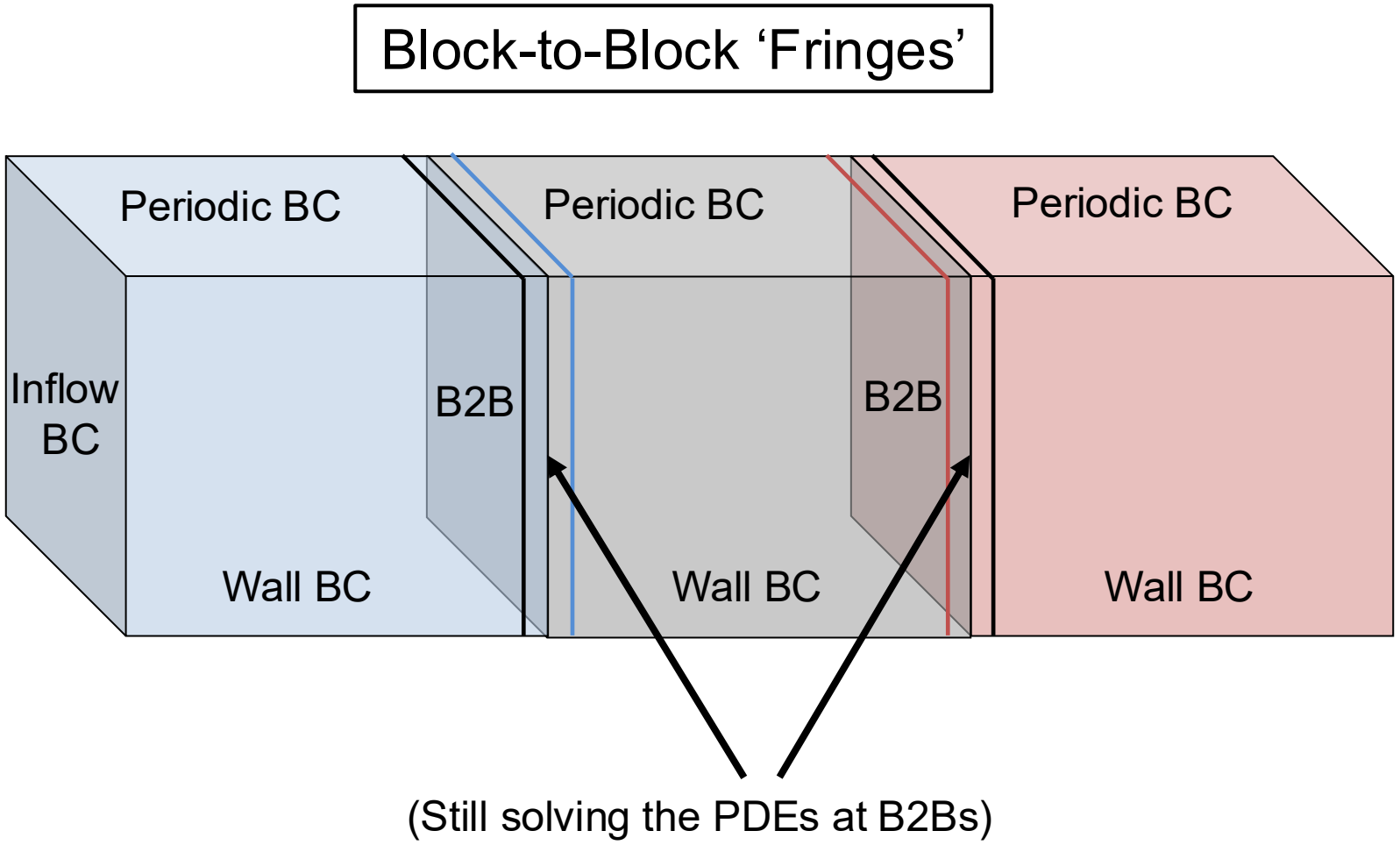
Required DQUAL of 1:
Can't interpolate from cells with fringe nodes

Points of Overlap:
Need 5, prefer 7

Grid Terminology

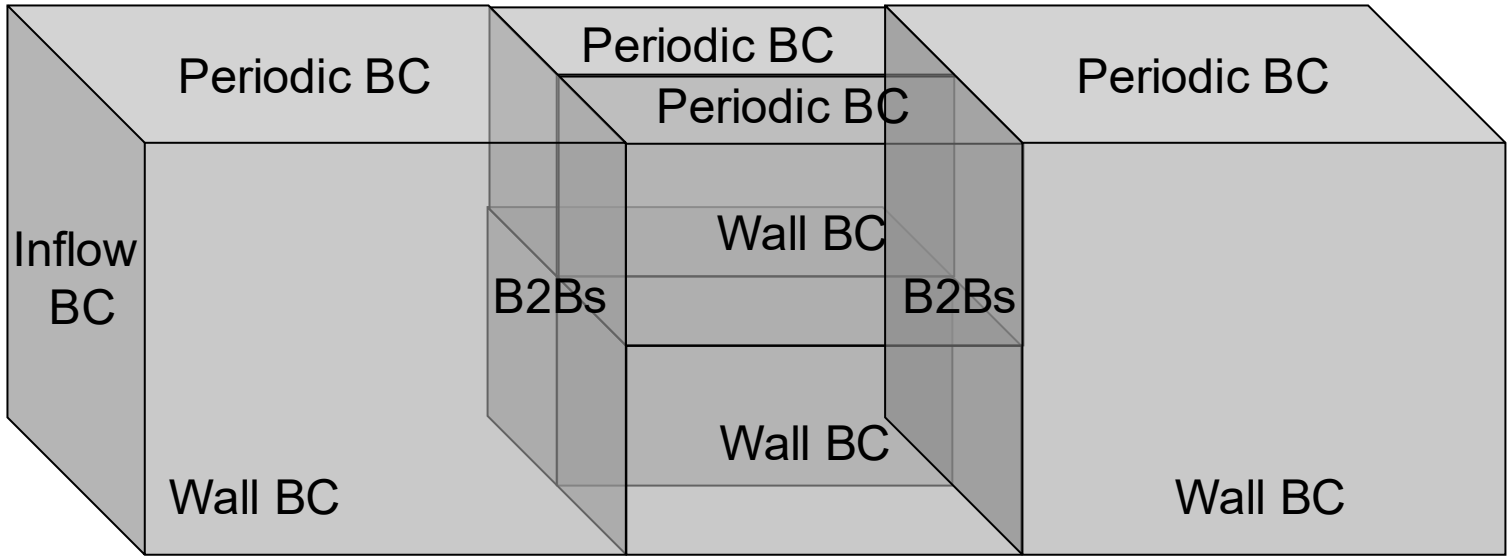


Grid Terminology



Grid Terminology

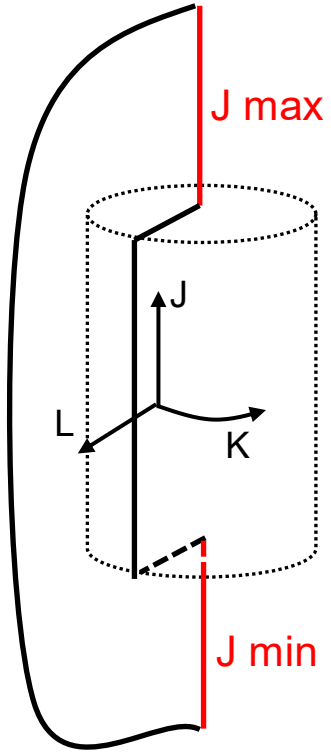
Partial Block-to-Blocks



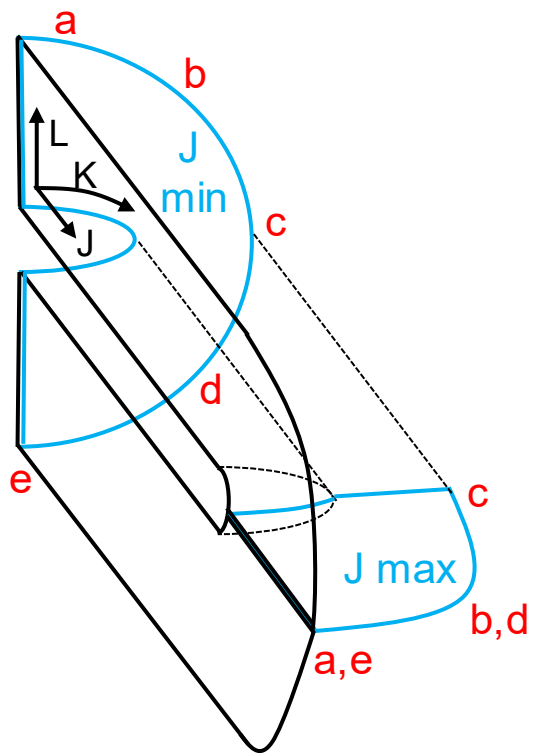
If a block side is not fringe,
it must be entirely covered with BCs and/or B2Bs.

Illegal Grid Topologies

Collapsed Axes

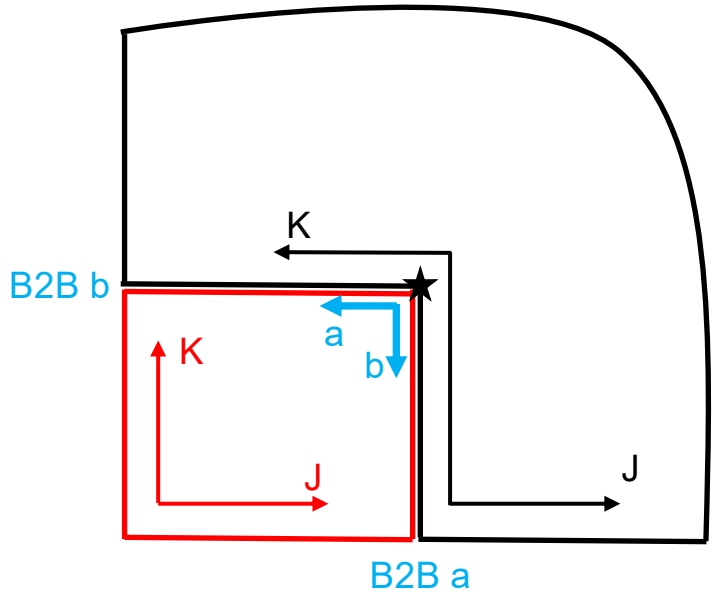


Same-Side B2Bs



Poorly posed PDEs,
Potential negative Jacobians

Spooning B2Bs



Stencil walks into another block
must be unique

Recommended Grid Topologies

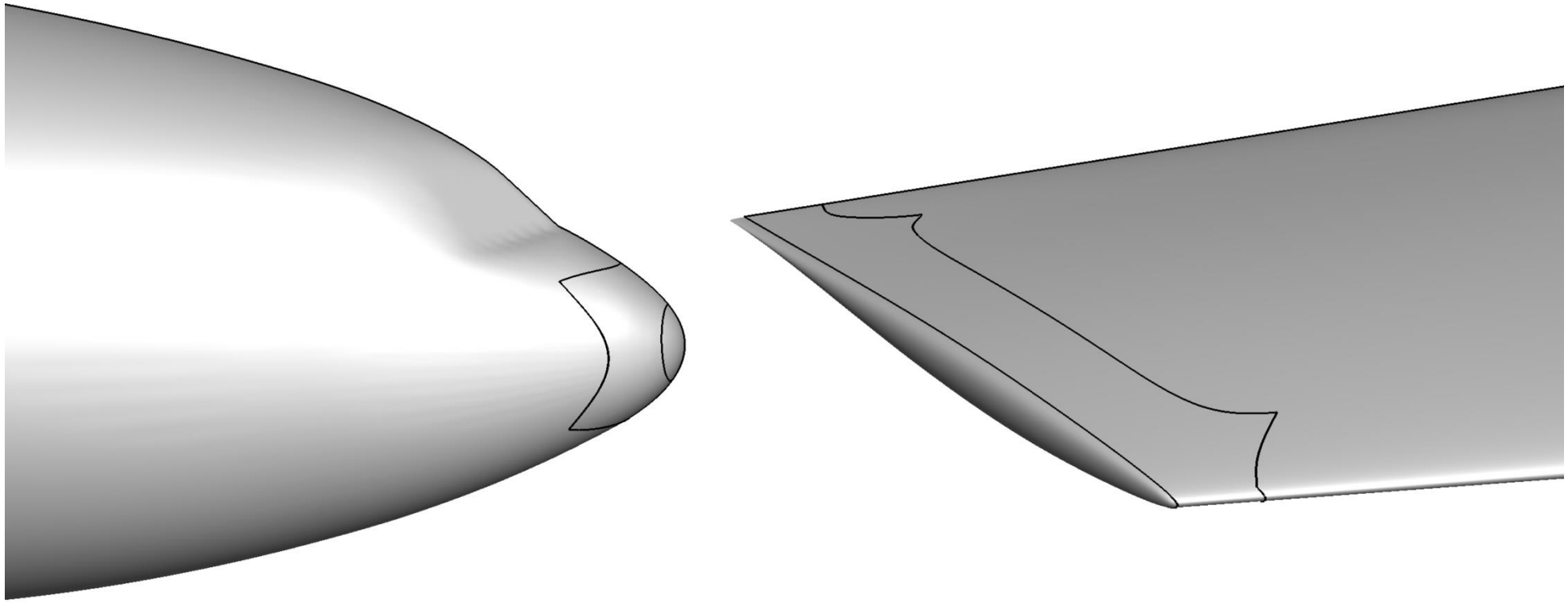
Prevent illegal topologies

Take advantage of B2Bs

Preparing for refinement

Recommended Grid Topologies

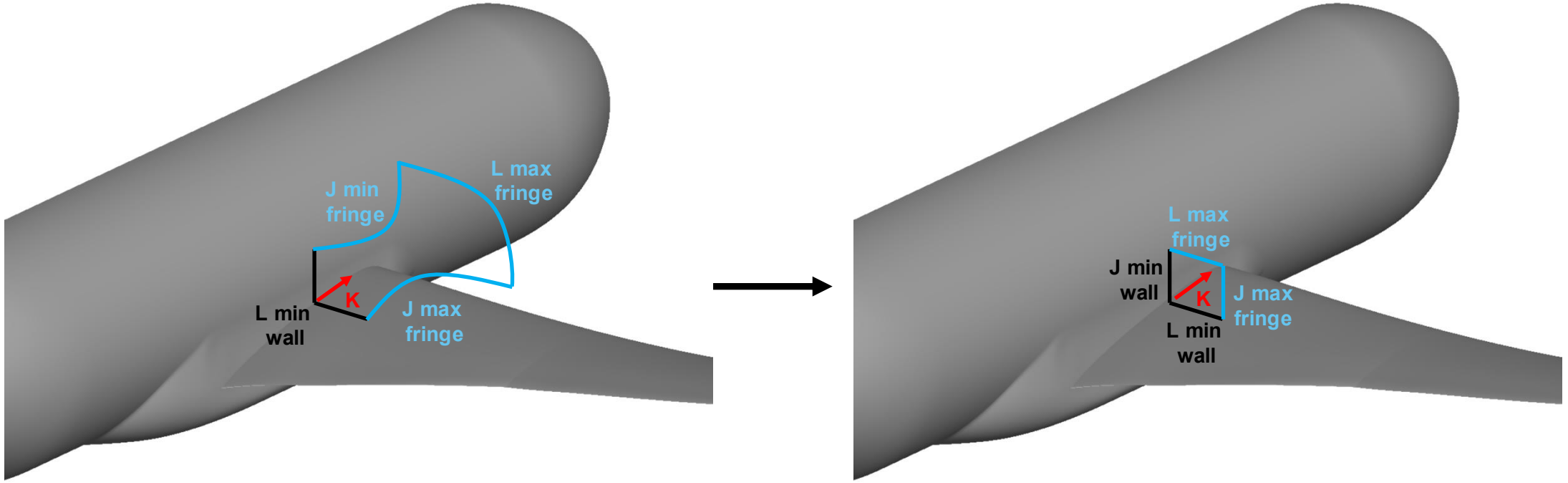
Caps



Prevents grid collapse

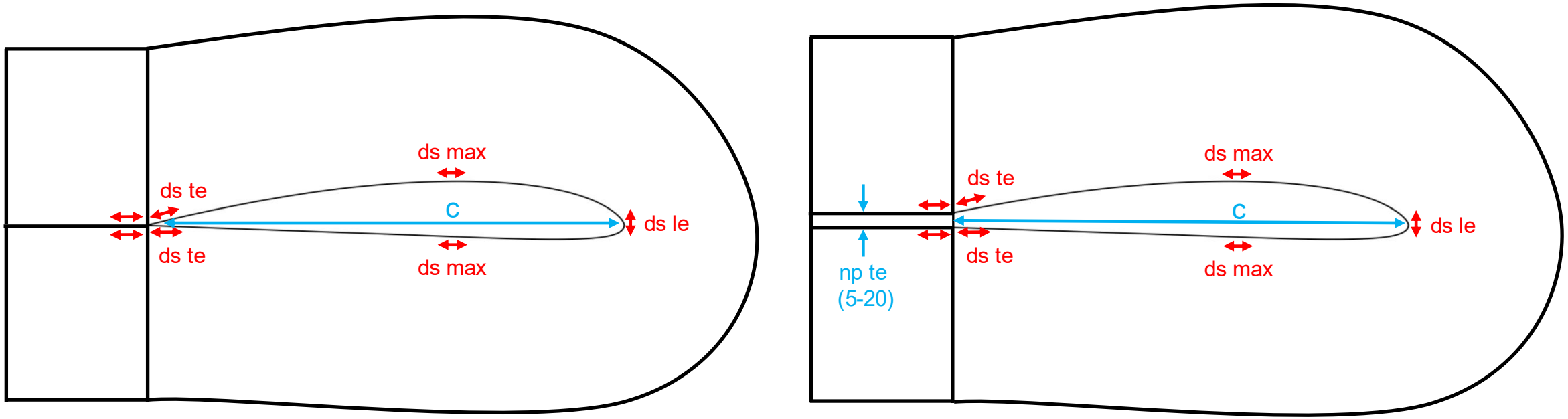
Recommended Grid Topologies

Collars



Recommended Grid Topologies

Wings



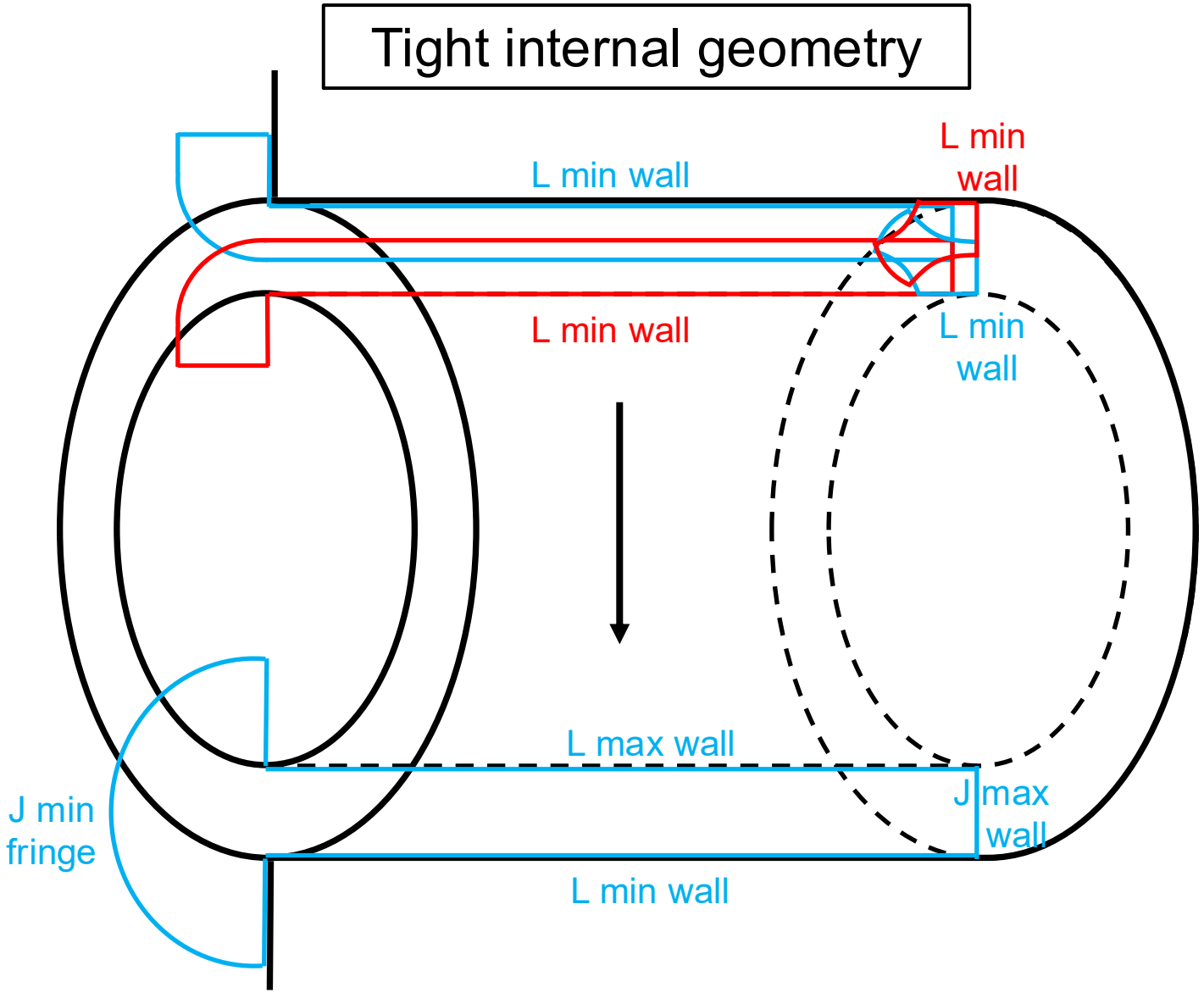
ds	% c
le	0.1
max	3.0
te	0.1

Caps and collars can follow same B2B strategy,

And **could** be B2B'ed with wing grids if grown together

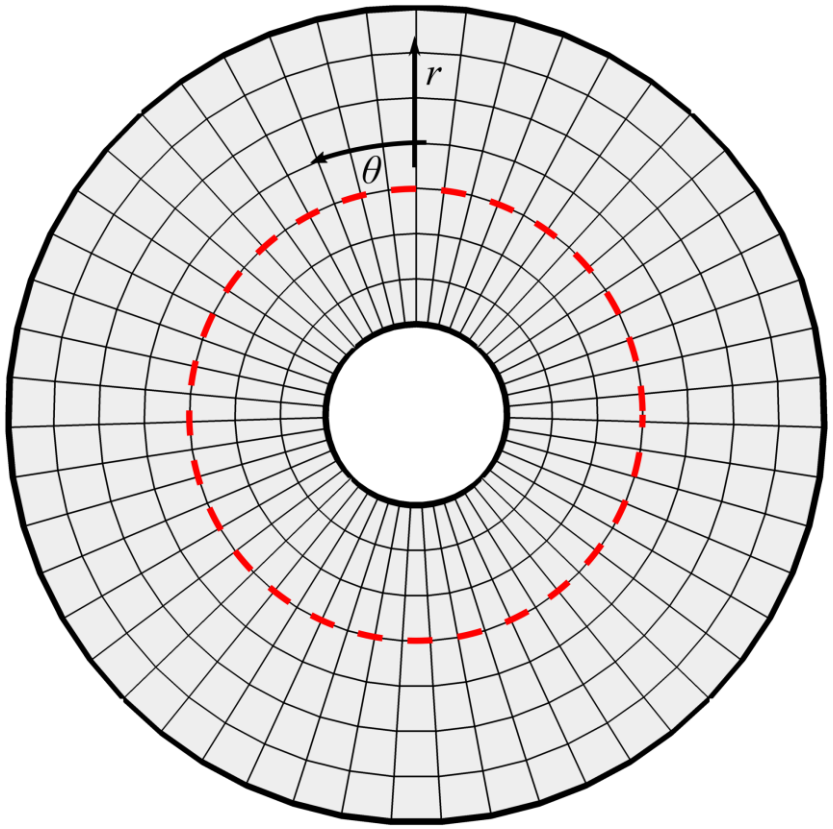
ds	% c
le	0.1
max	3.0
te	match te edge ds

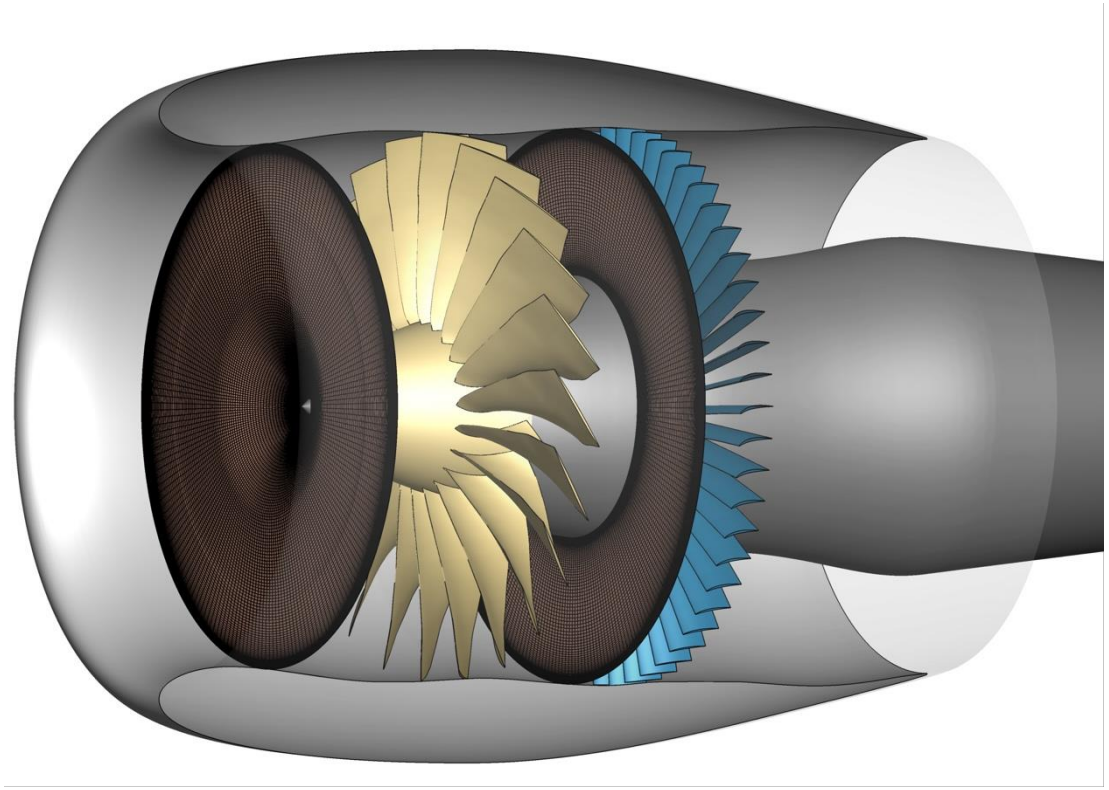
Recommended Grid Topologies



Recommended Grid Topologies

Sliding Mesh

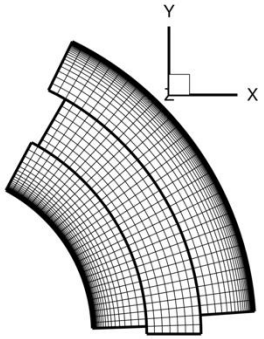




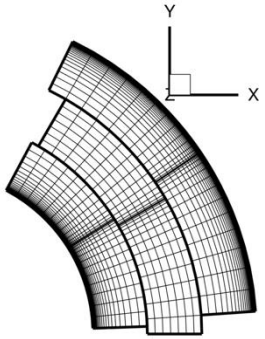
Recommended Grid Topologies

Sliding Mesh

Uniform Circumferential

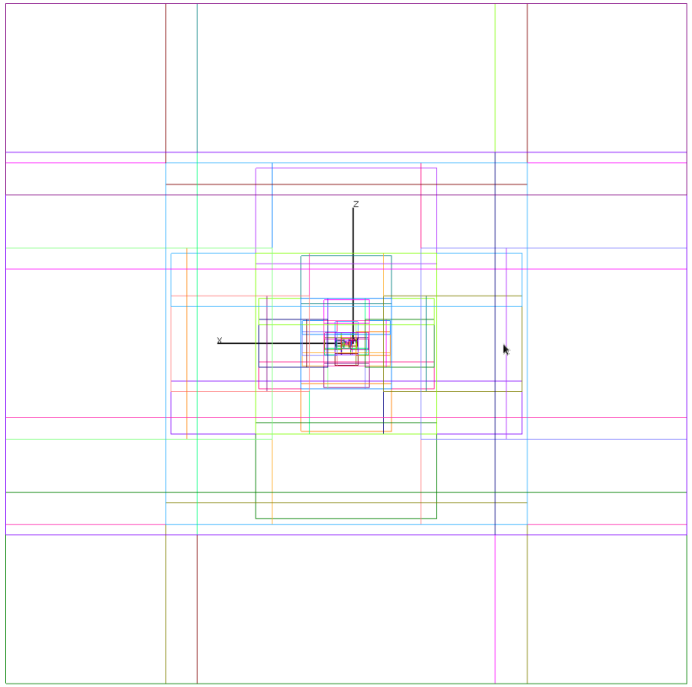


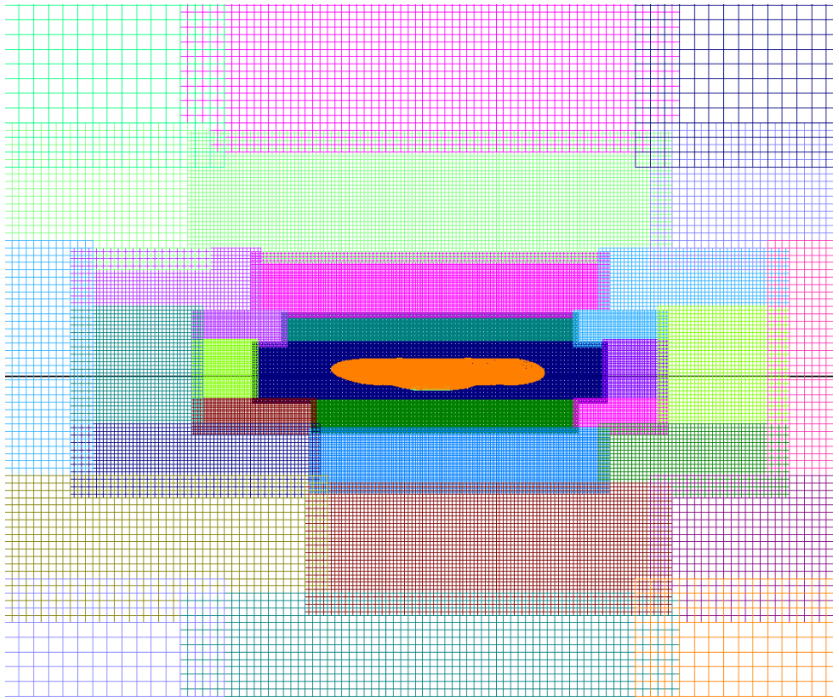
Nonuniform Circumferential



Recommended Grid Topologies

Oct Far Field Generation





1) Provide triangulated surface

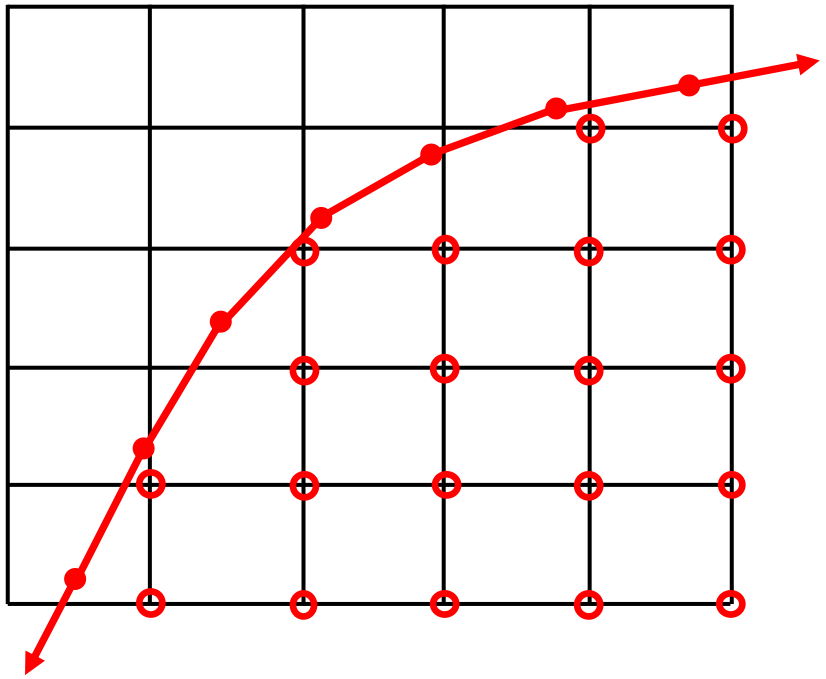
2) State nearbody dx size

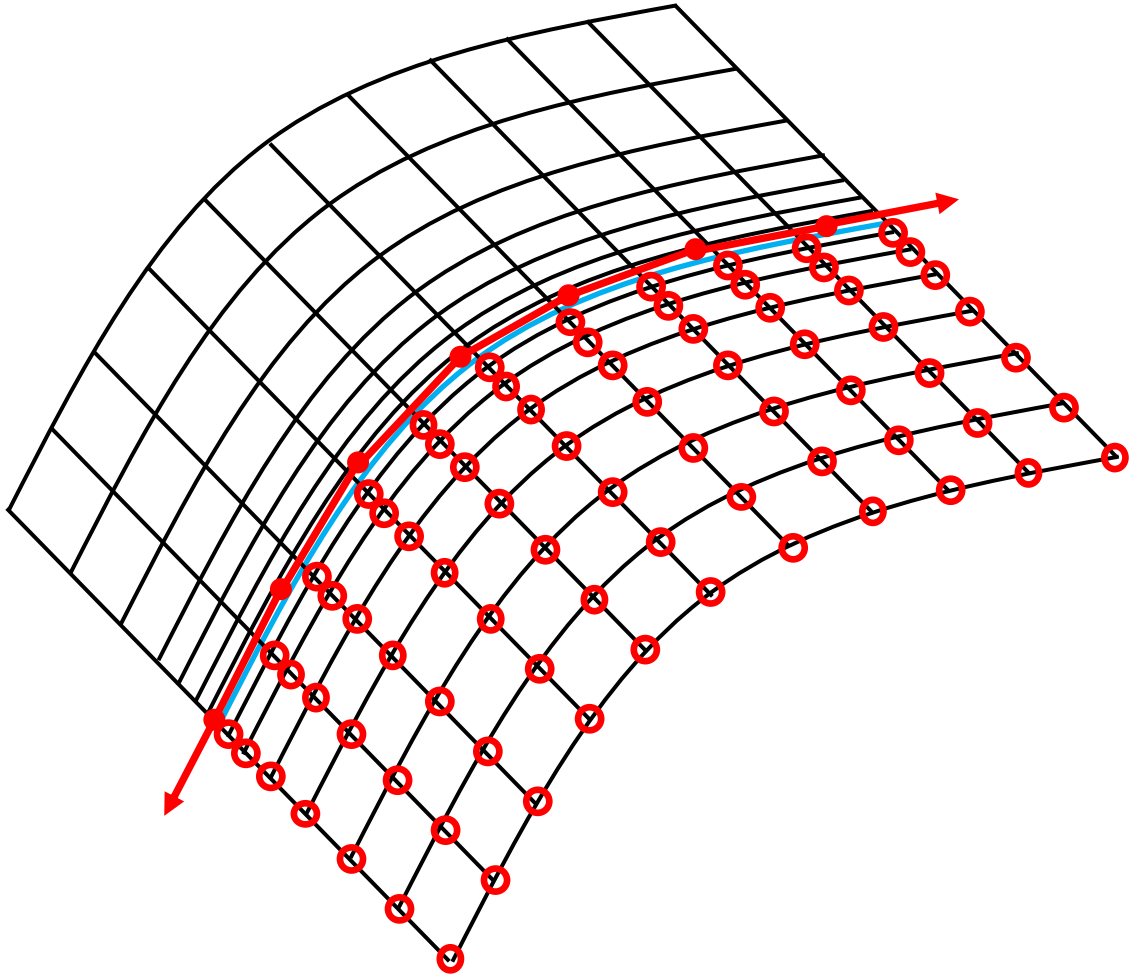
3) State domain width

4) Combine with nearbody grid

Recommended Grid Topologies

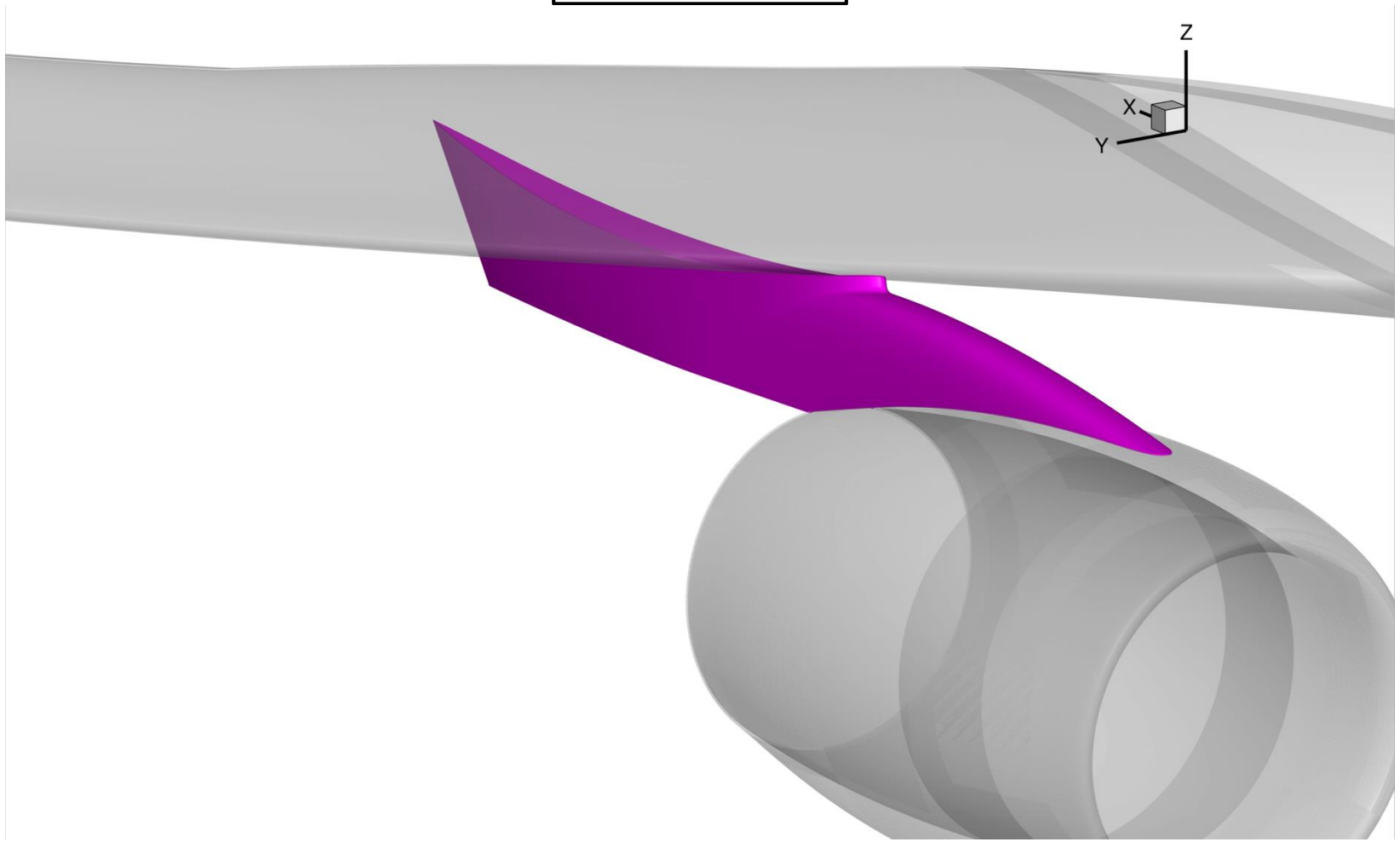
Immersing





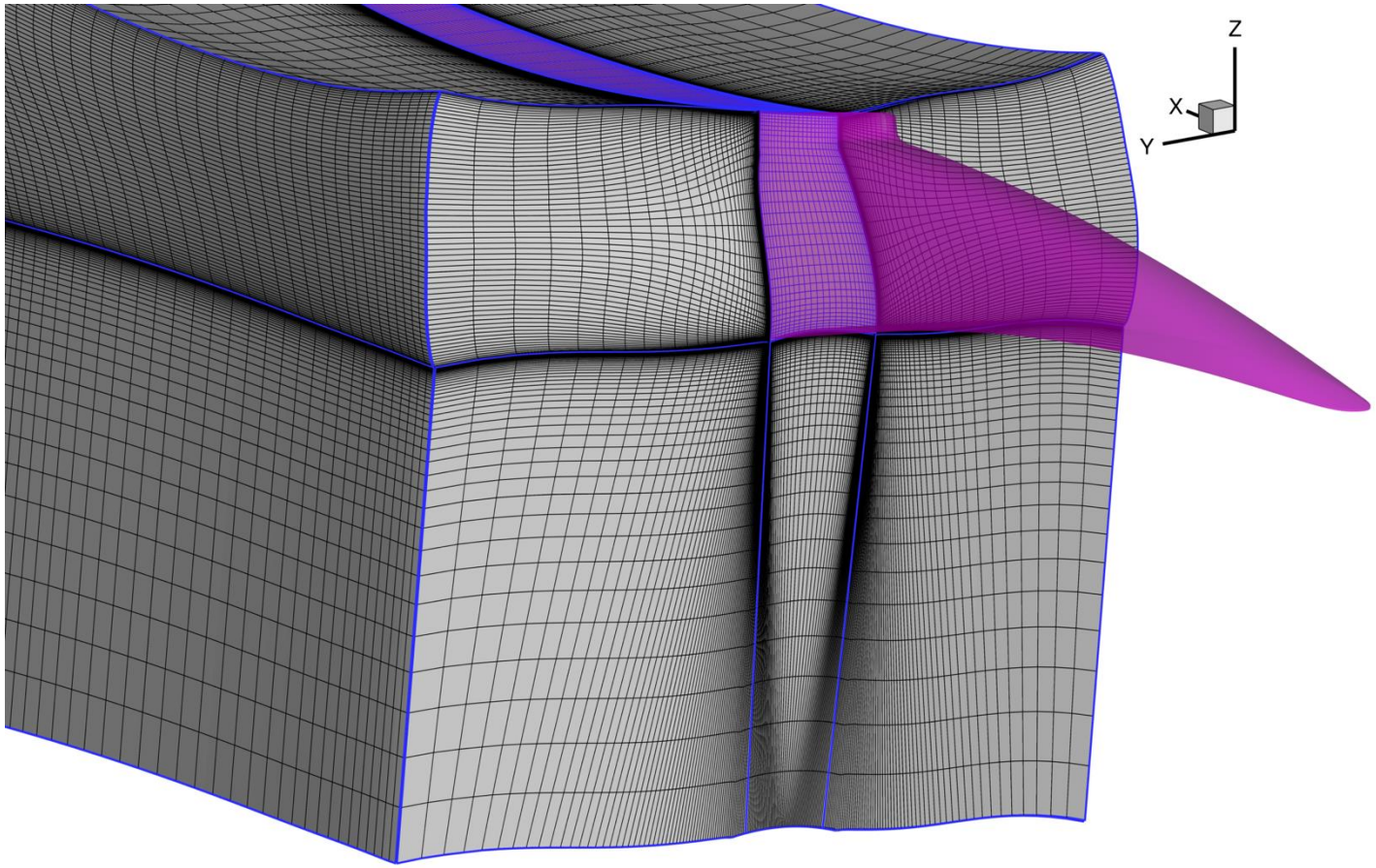
Recommended Grid Topologies

Immersing



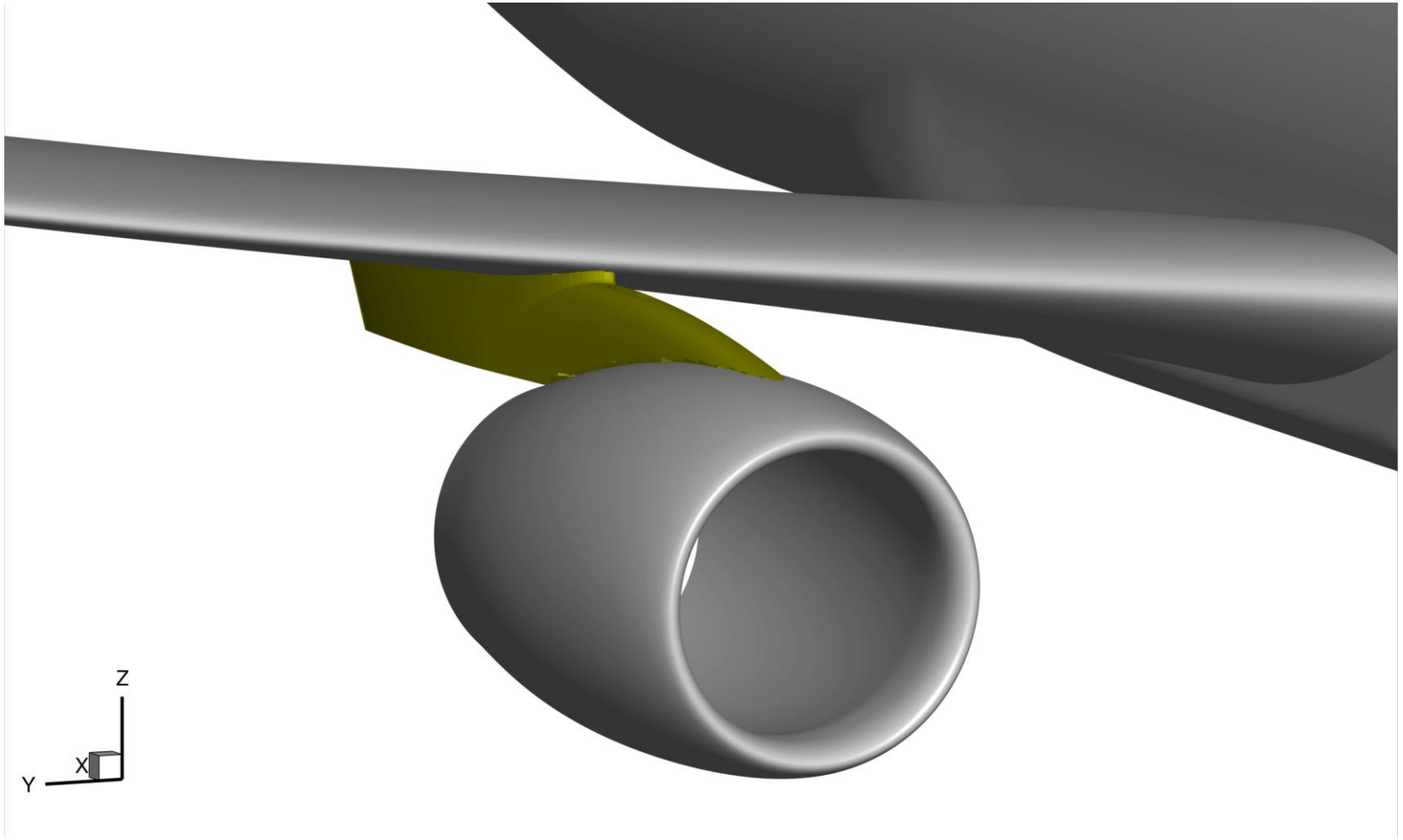
Recommended Grid Topologies

Immersing



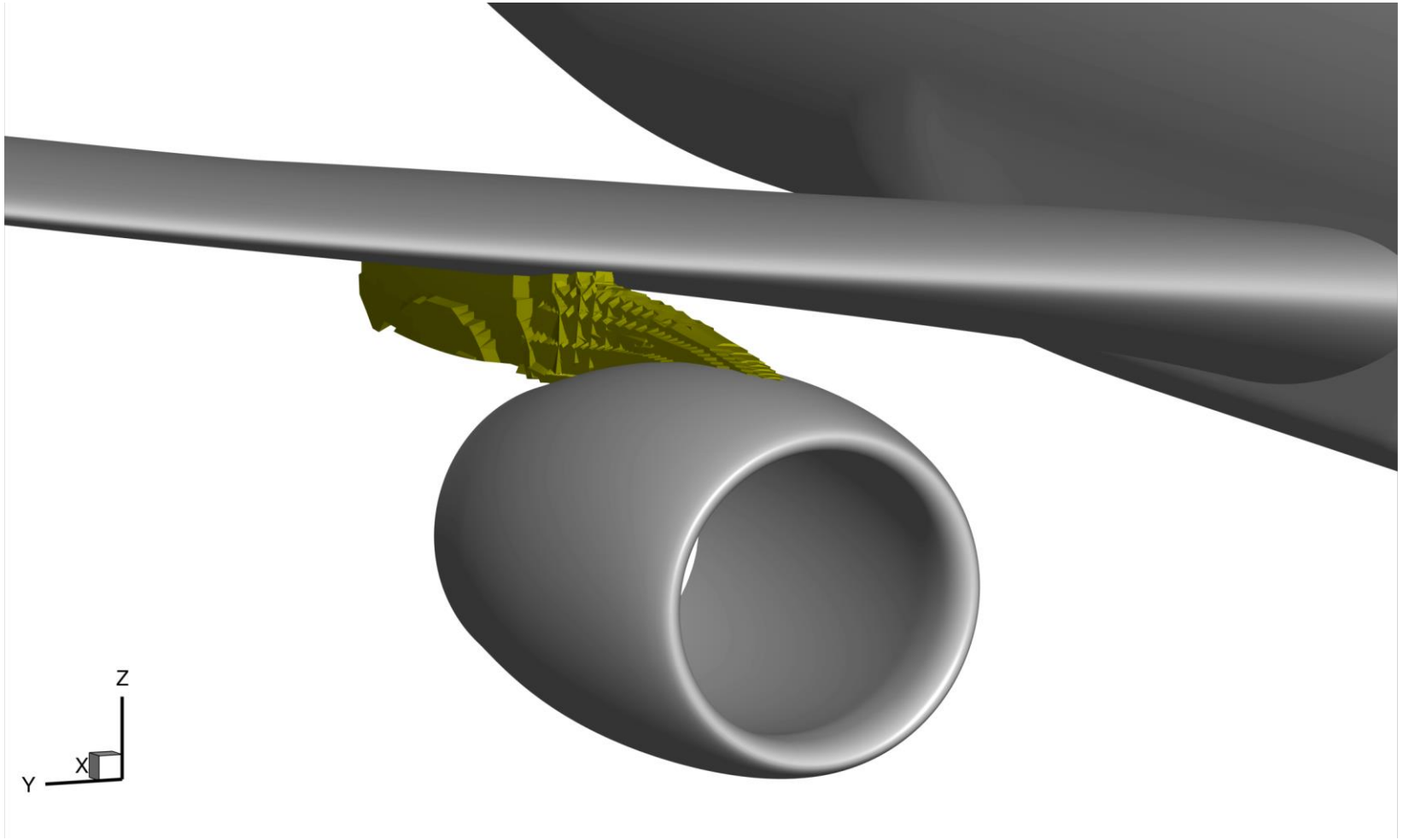
Recommended Grid Topologies

Immersing



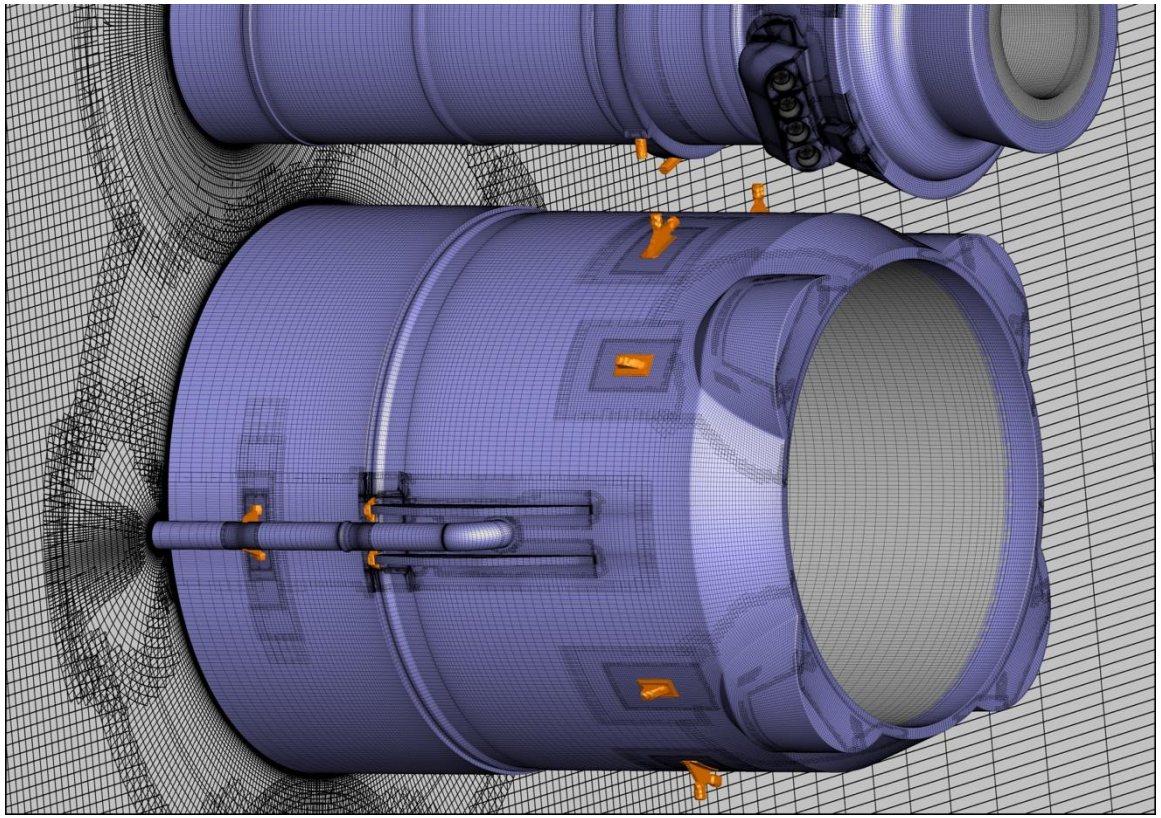
Recommended Grid Topologies

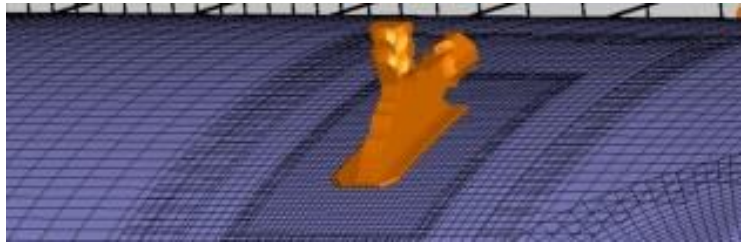
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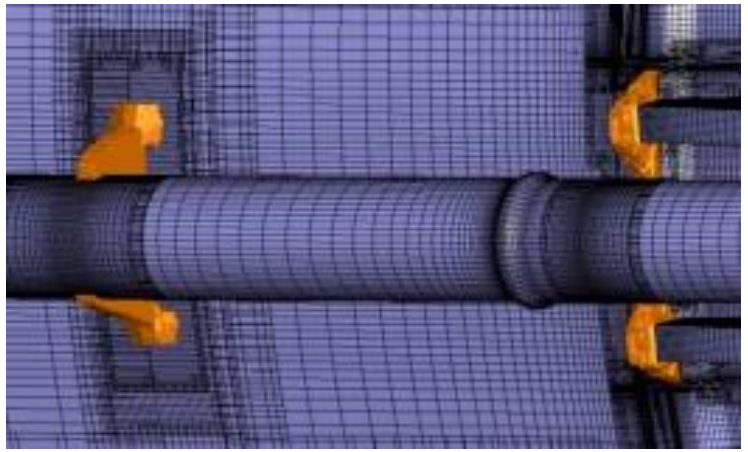
Recommended Grid Topologies

Immersing



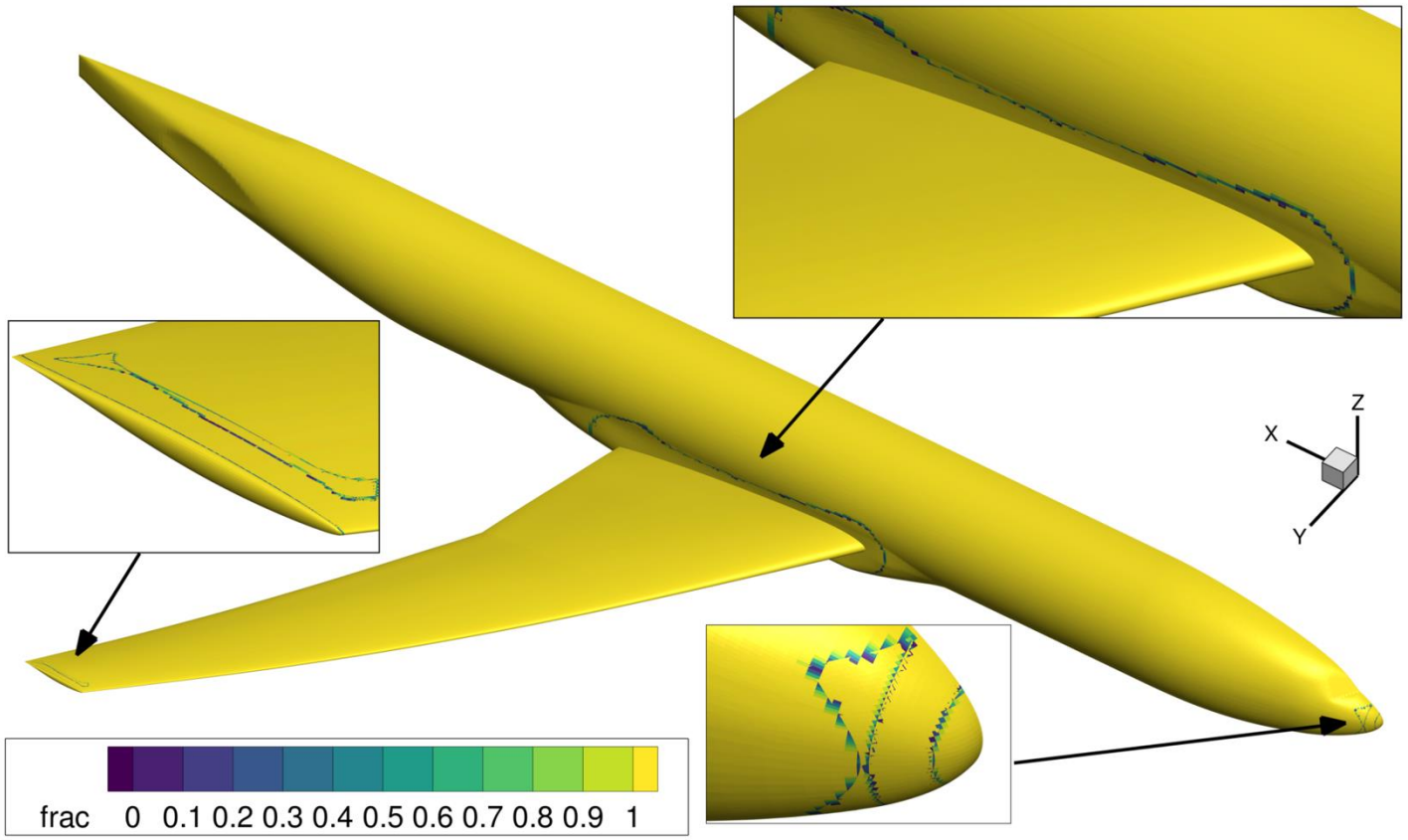


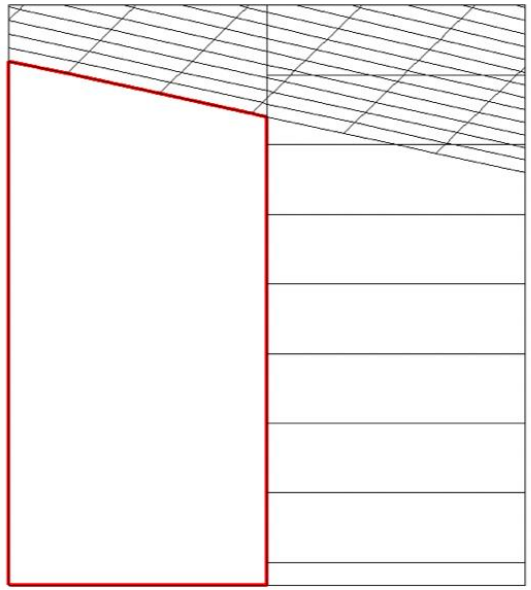




Overlapper Panel Weight Generation

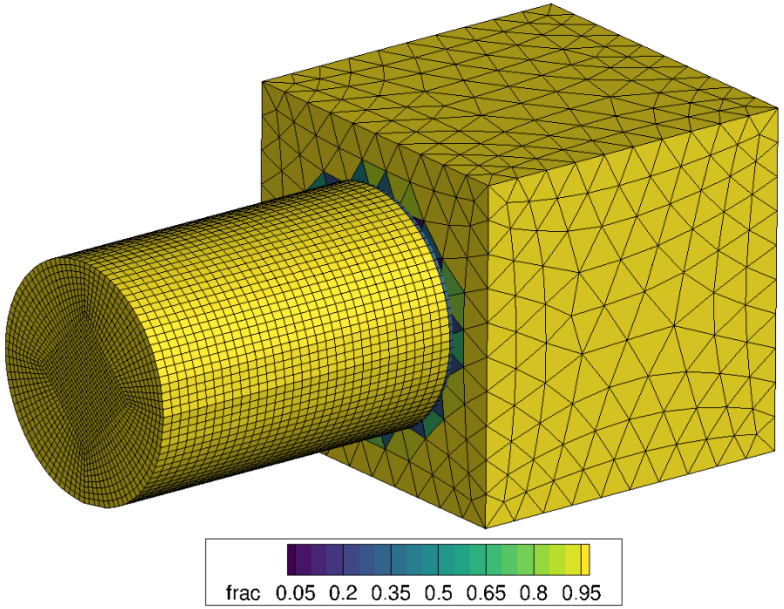
Wall Unit Area Weights

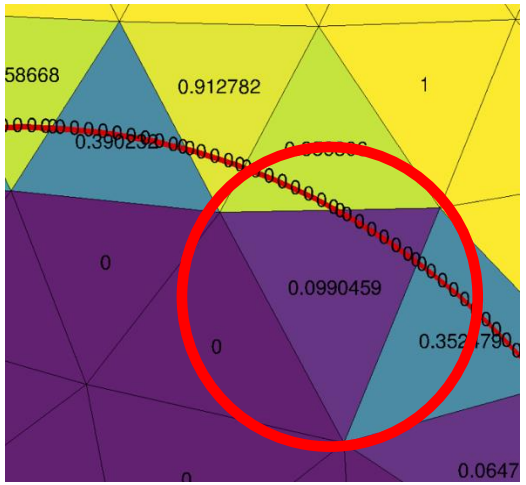


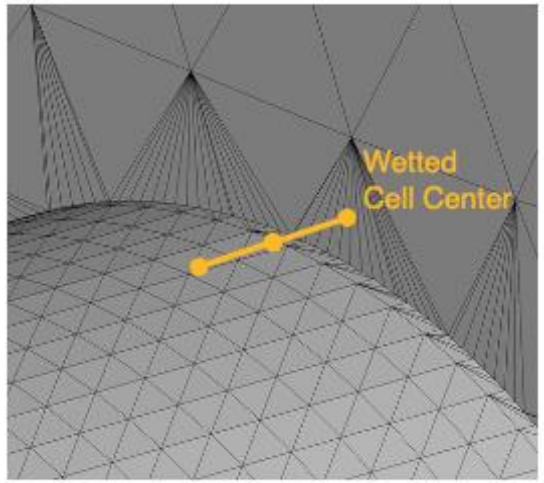


Overlapper Panel Weight Generation

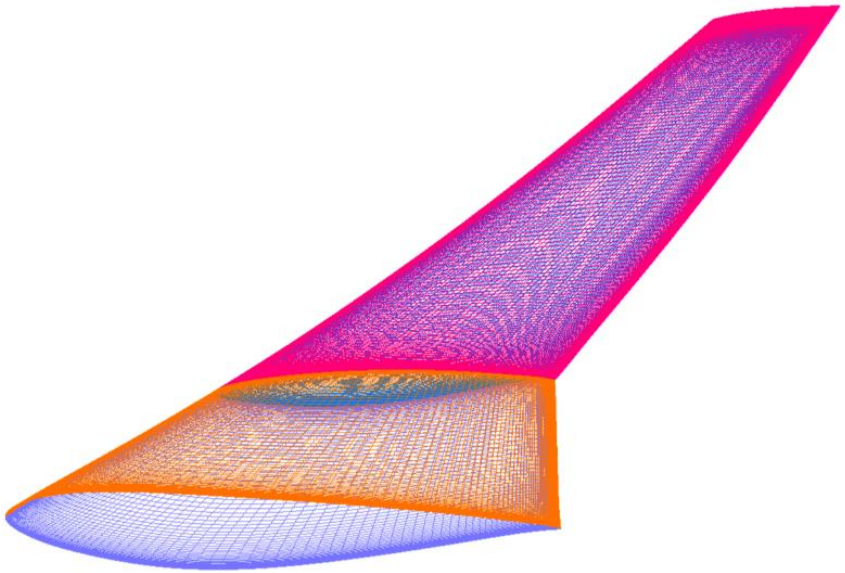
Immersed Intersection Weights

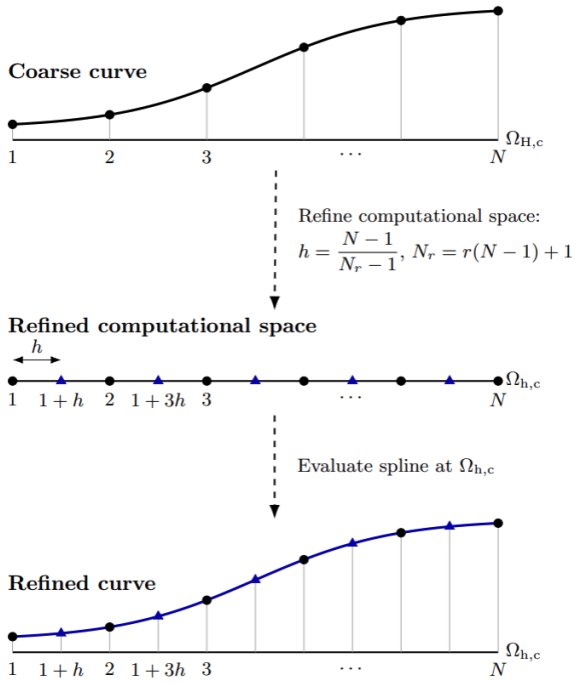


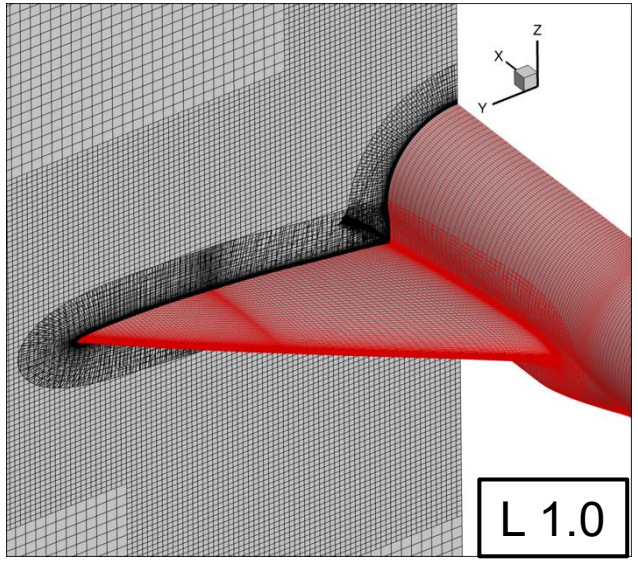


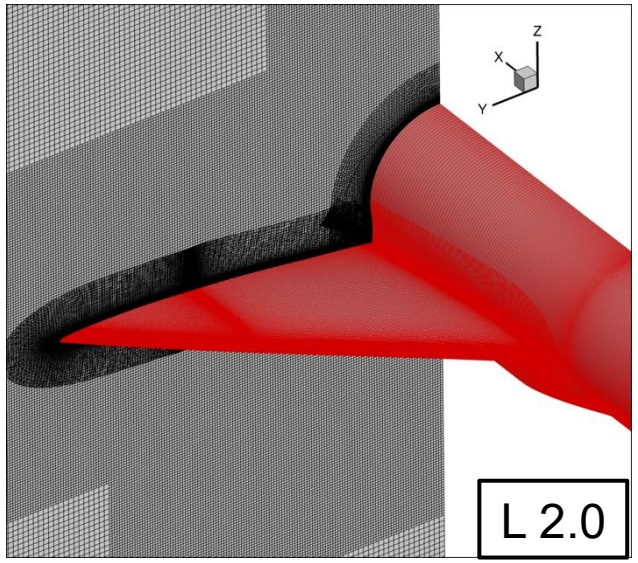


Refinement




Coarse curve
$\Omega_{H,c}$
1
2
3
$\cdots$
N
Refine computational space:
$h = \frac{N-1}{N_r - 1}$, $N_r = r(N-1)+1$
Refined computational space
h
$\Omega_{h,c}$
1
$1+h$
2
$1+3h$
3
$\cdots$
N
Evaluate spline at $\Omega_{h,c}$
Refined curve
$\Omega_{h,c}$
1
$1+h$
2
$1+3h$
3
$\cdots$
N


Z
X
Y
L 1.0


Z
X
Y
L 2.0

Getting Started

Input File

```
grid :
  curv :
    gridFile : grid.x
    bcfile : grid.bc
    fileType : plot3d

curvSolver :
  task : connectivity

B2BExtractor :
  extractB2Bs : True

#overset :

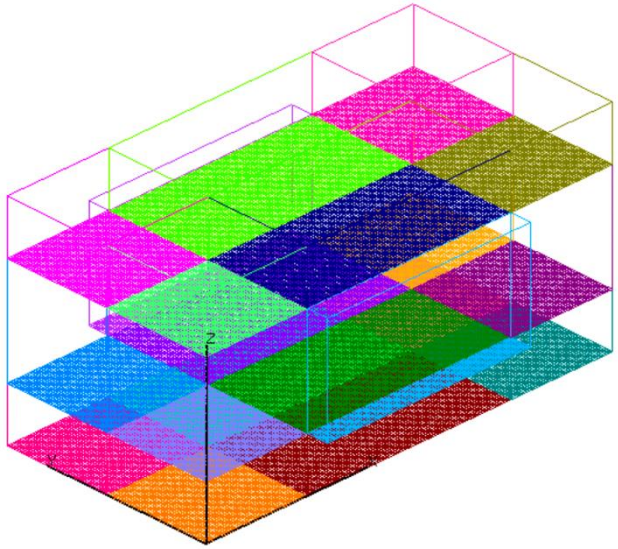
bc :
  -
    names : [fuse,wing,tail]
    type : BCWallViscous
    location : onbody
  -
    names : [symm]
    type : BCSymmetryPlane
    location : offbody
    symplaneorigin : [0.0, 0.0, 0.0]
    symplanenormal : [0.0, 1.0, 0.0]
    projectnodes : true
  -
    names : [far]
    type : BCfarfield
    location : offbody
```

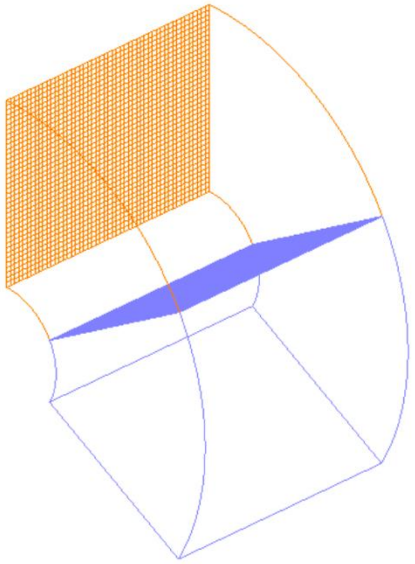
```
rotatingMesh:
  -
    zones : [6-8,11-13,27-37]
    omega : -57.74128104
    axis1 : [-1.0,0.0,0.0]
    axis2 : [ 1.0,0.0,0.0]
```

```
immersedBoundaries:
  -
    fileName : immGeom_PYLON.i.tri
    fileType : tri
    bcname :   pylon

bc :
  -
    names :    [pylon]
    type :     BCWallViscous
    location : offBody
```

Automatic B2B Extraction

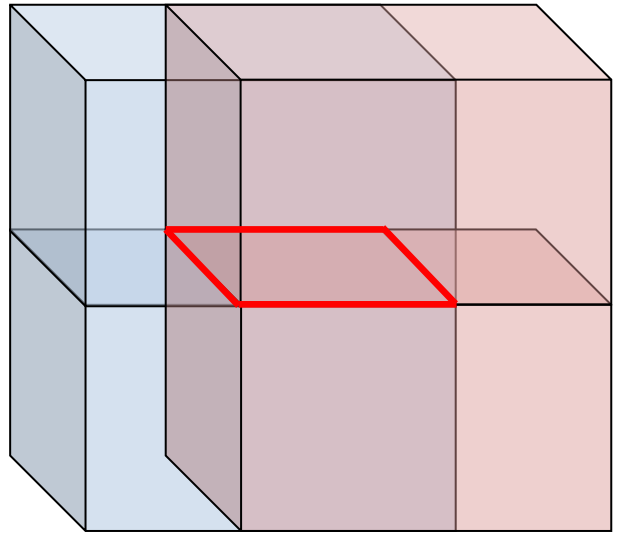


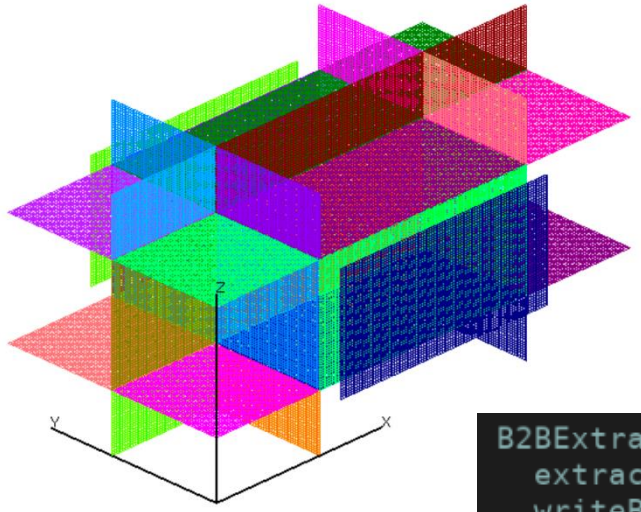


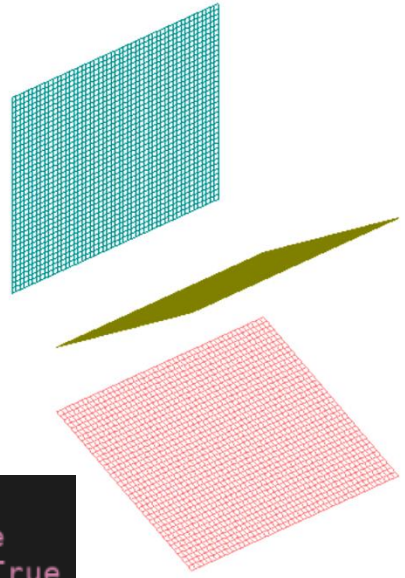
Must state periodic conditions

```
B2BExtractor :
  extractB2Bs: True
  transformations:
    -
      type : translation
      translationVec : [0.0, 1.2, 0.0]
    -
      type : rotation
      rotAxisBeg : [0,0,0]
      rotAxisEnd : [1,0,0]
      rotAxisAng : 120
```

Optionally disallow partial B2Bs
to ignore multiple point-matching





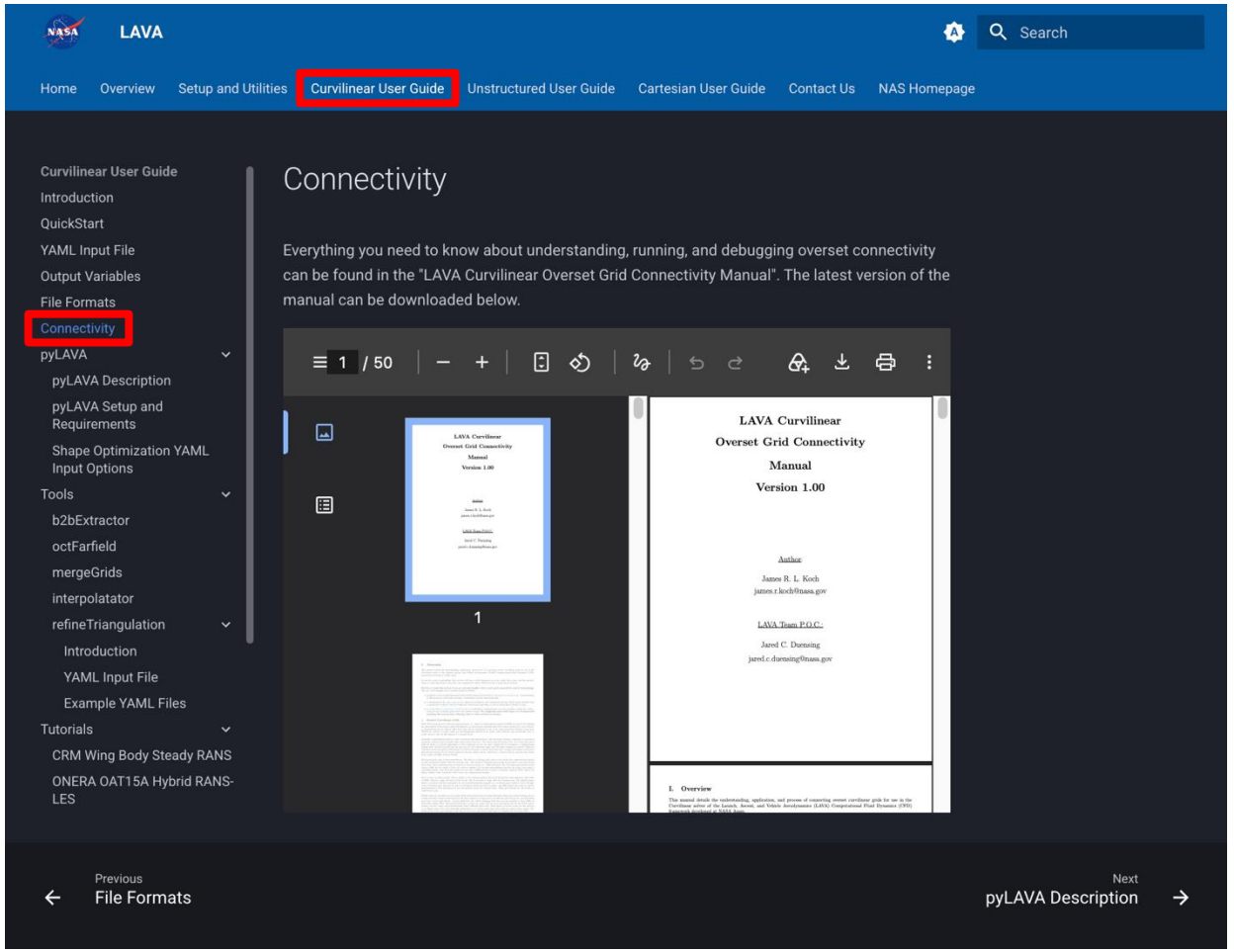


```
B2BExtractor :
  extractB2Bs: True
  writeB2BZones : True
```

```
B2BExtractor :
  extractB2Bs: True
  onlyFullB2Bs : True
```

Connectivity

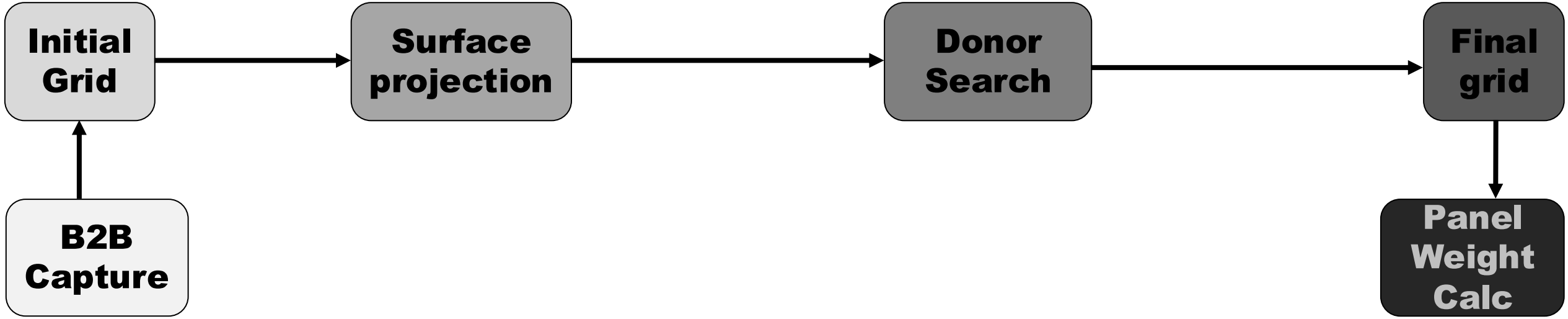
Manual



https://dev.lava-pages.nas.nasa.gov/lava_developer/lava_docs_production/curv_docs/connectivity/

Connectivity

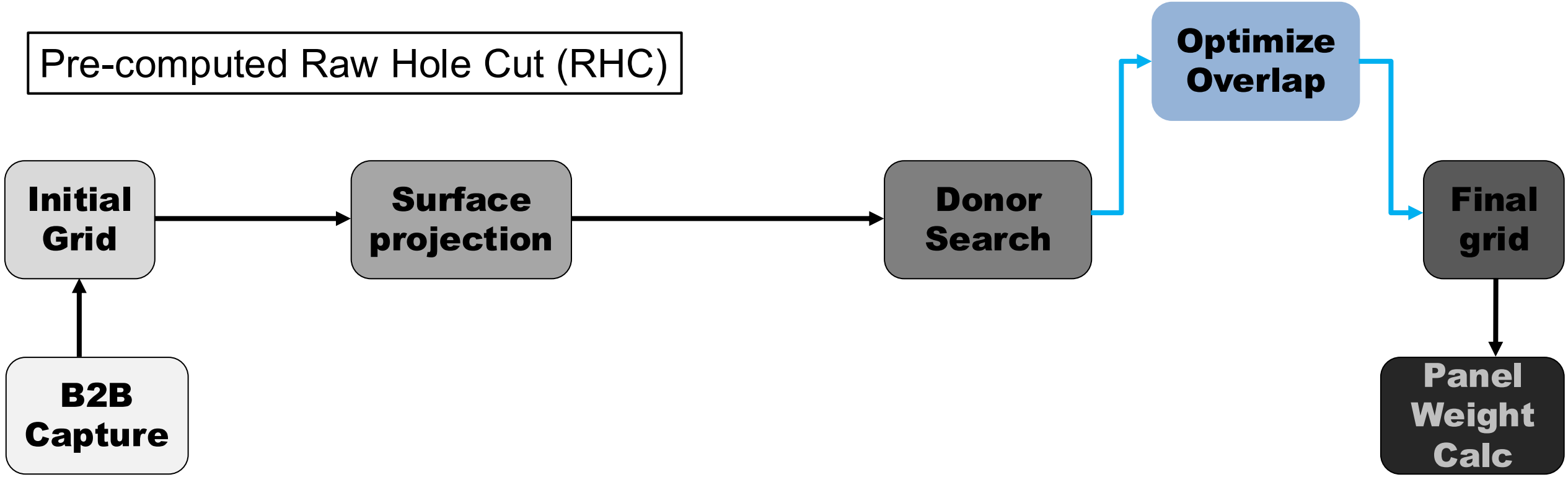
Pre-computed hole cut **(assumed DQUAL of 1)**




```
overset :
  useExistingHoleCut : True
  optimizeOverlap : False
```

Connectivity

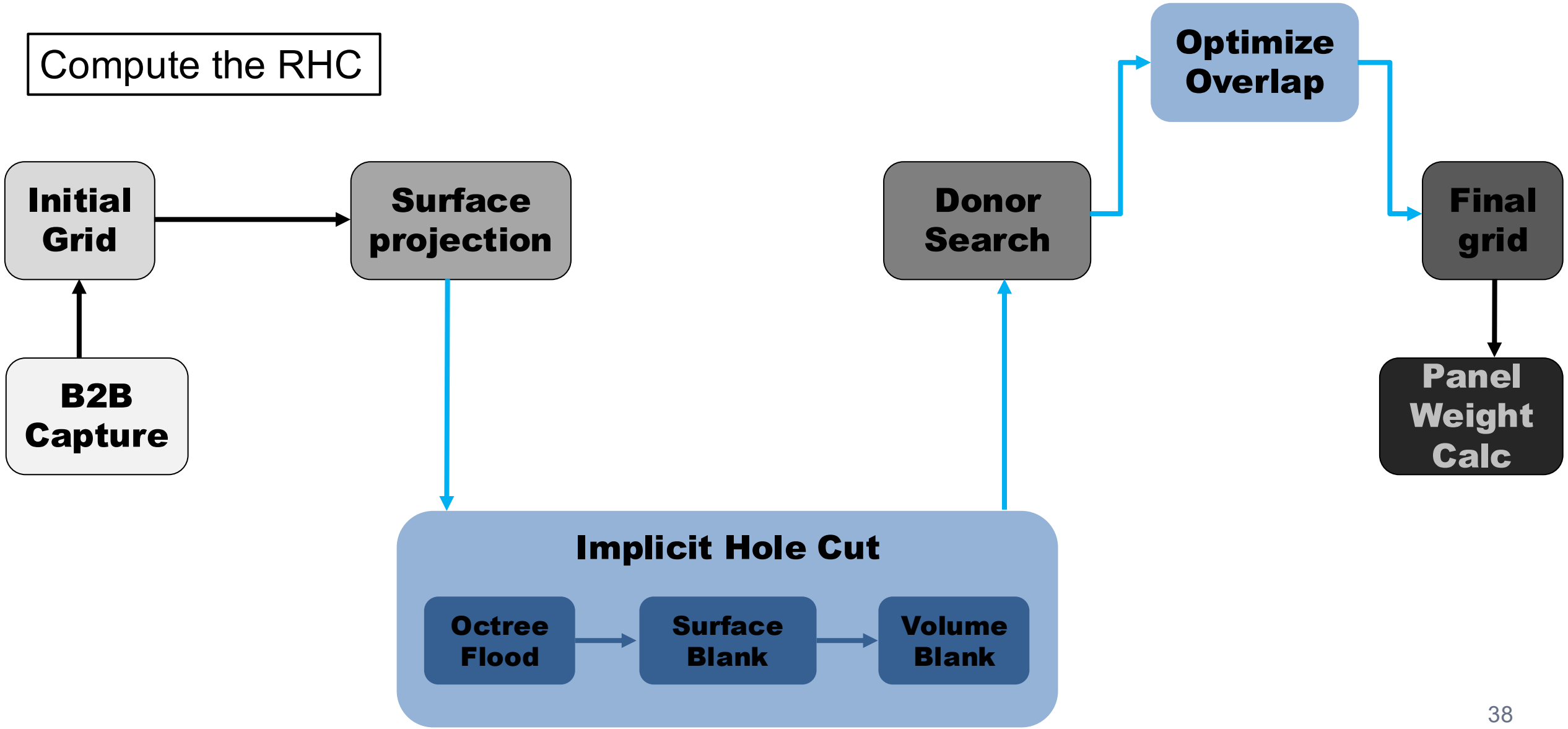
Pre-computed Raw Hole Cut (RHC)




```
overset :
  useExistingHoleCut : True
```

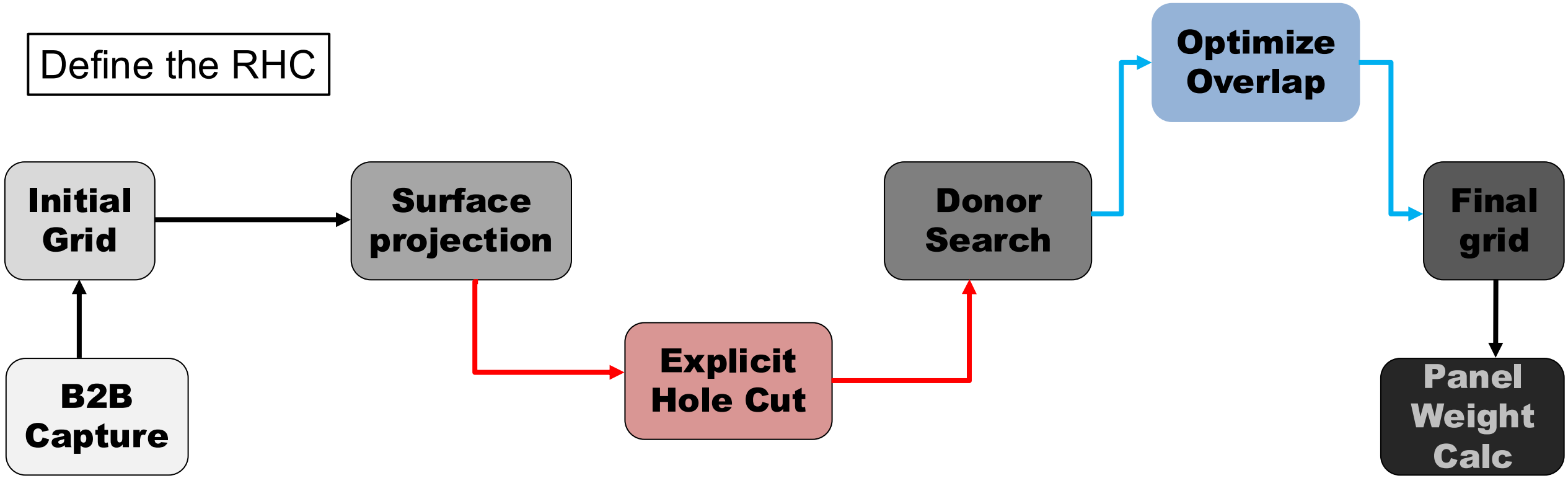
Connectivity

Compute the RHC



Connectivity

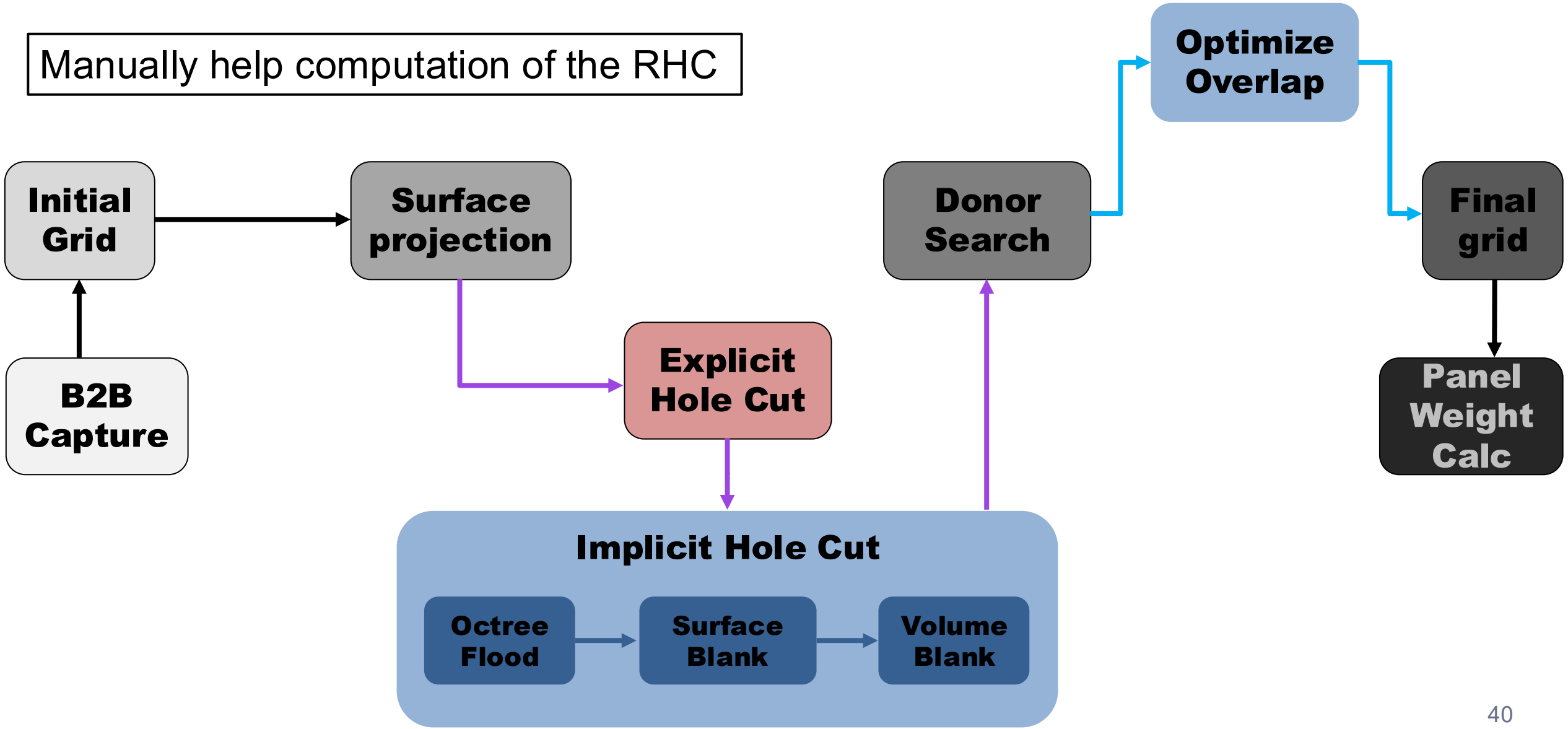
Define the RHC



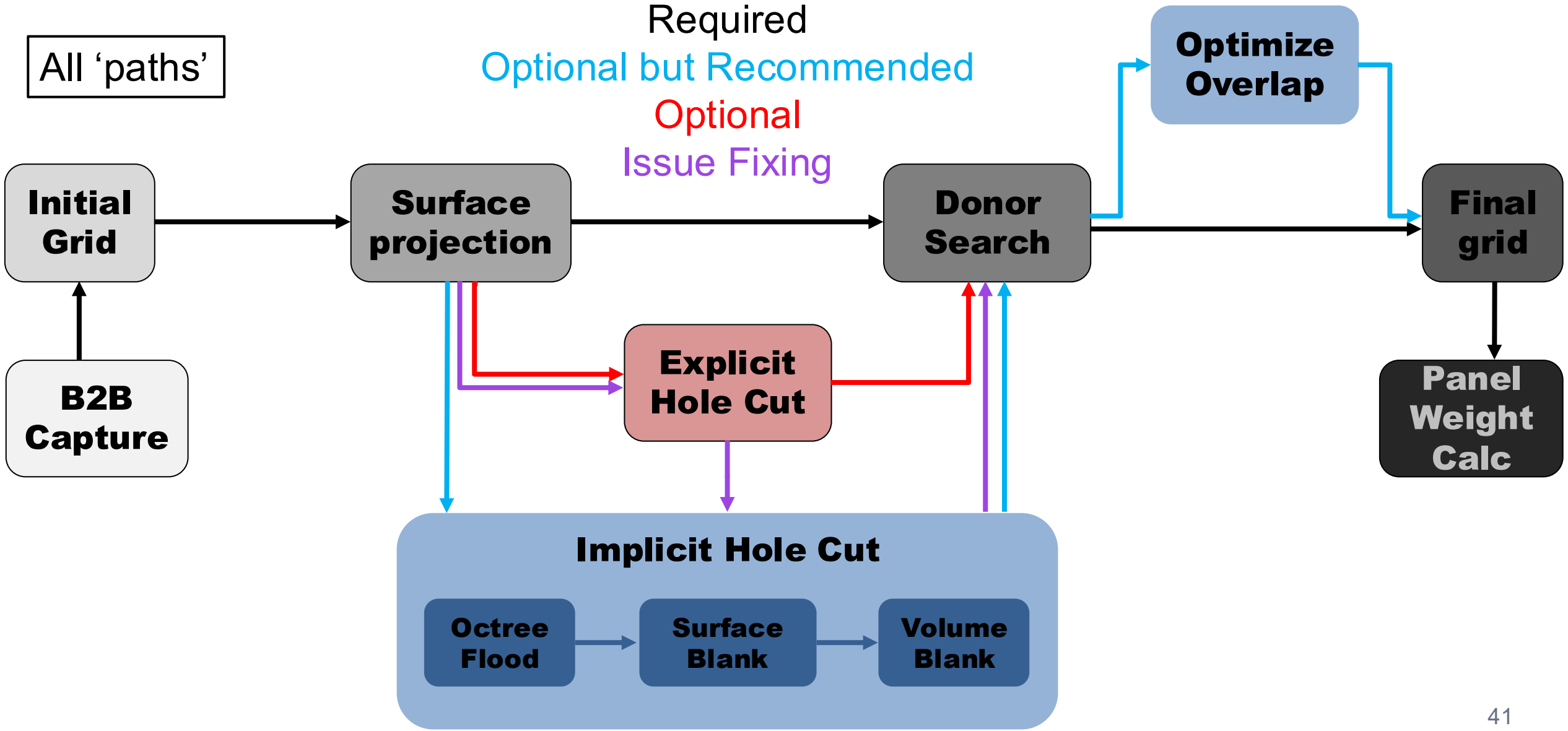

```
overset :
  performHoleCutExplicitly : True
```

Connectivity

Manually help computation of the RHC

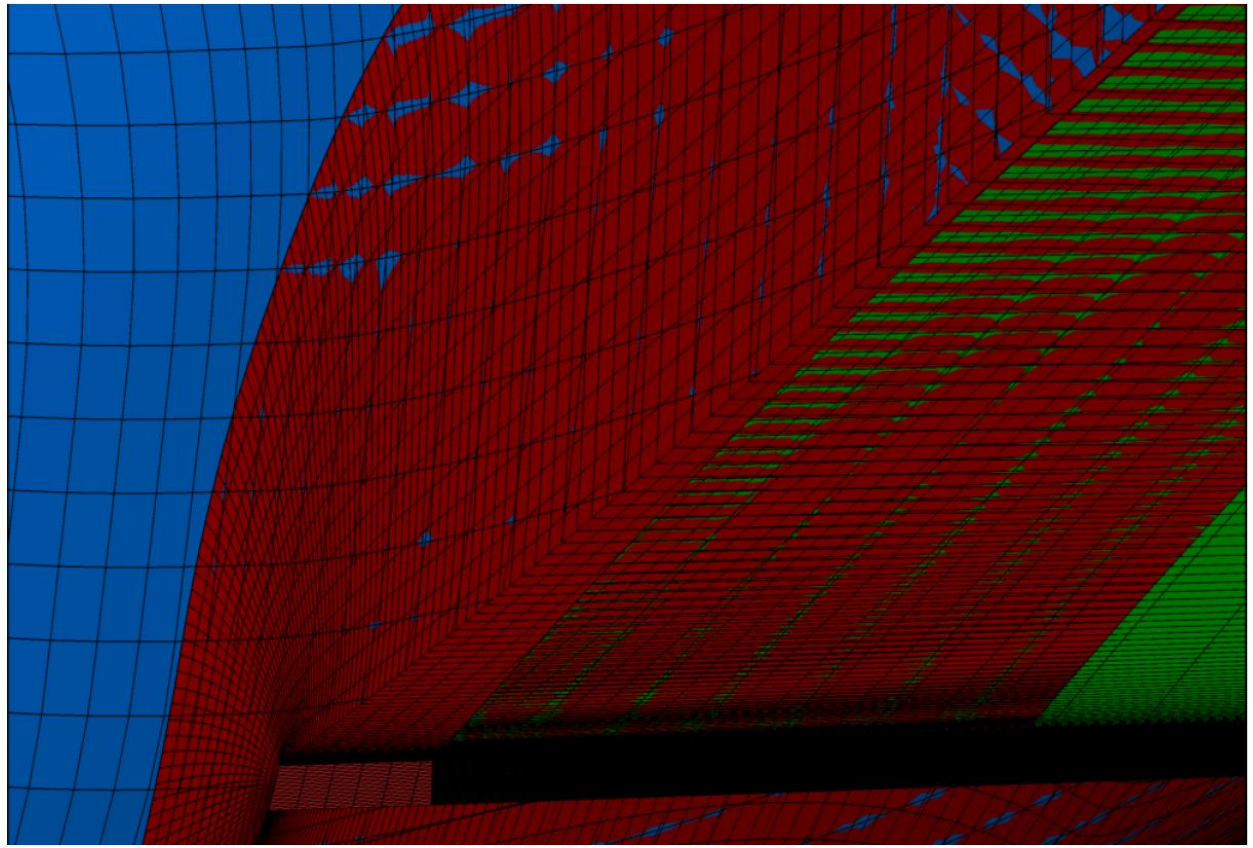


Connectivity



Connectivity

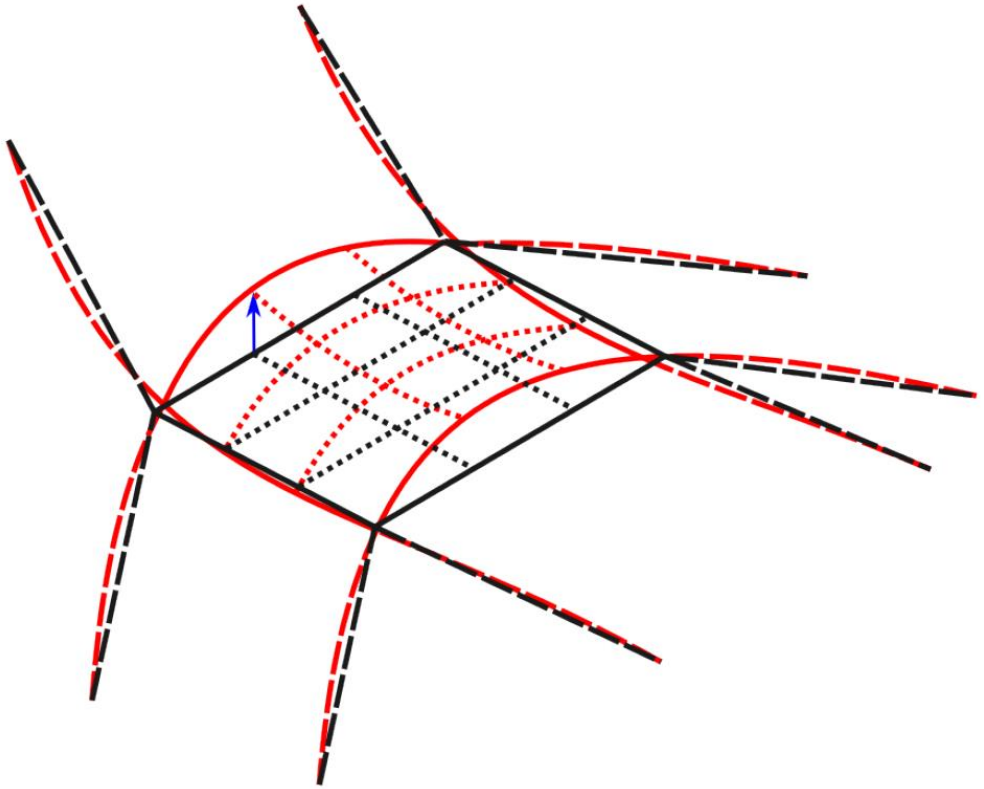
Surface Projection



Connectivity

Surface Projection

e_{ave} : Average edge length
h_{max} : Max Bezier height
f_{edge} : Edge factor (0.1)
f_{curv} : Curvature factor (1.0)



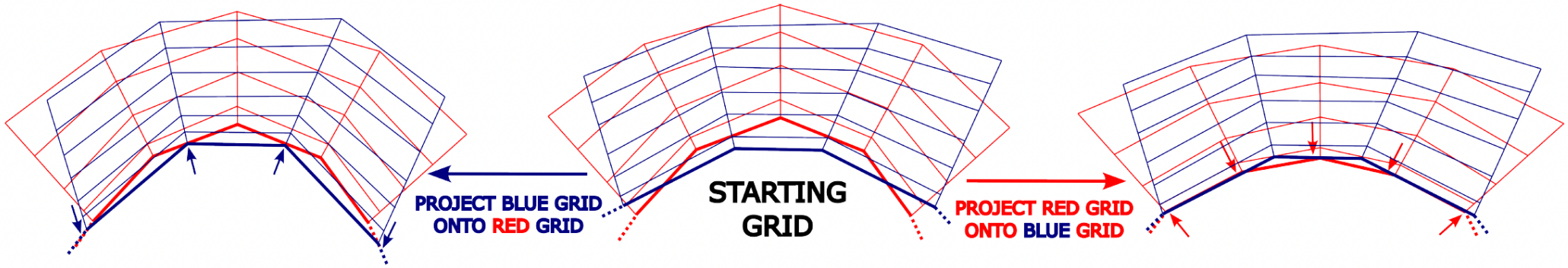


A: e_{ave}
B: $e_{ave} * f_{edge}$
C: h_{max}
D: $h_{max} * f_{curv}$

Deviation: $\max(e_{ave} * f_{edge}, h_{max} * f_{curv})$

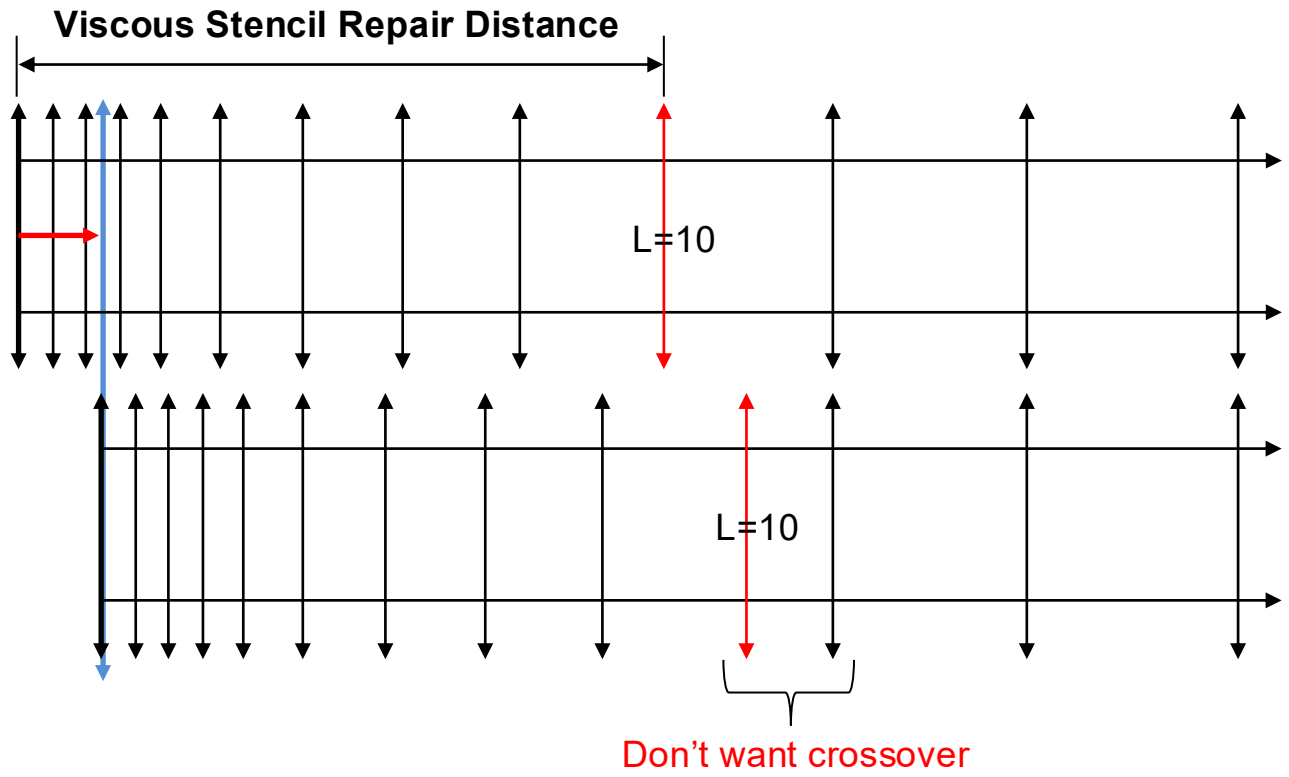
Connectivity

Donor Search



Connectivity

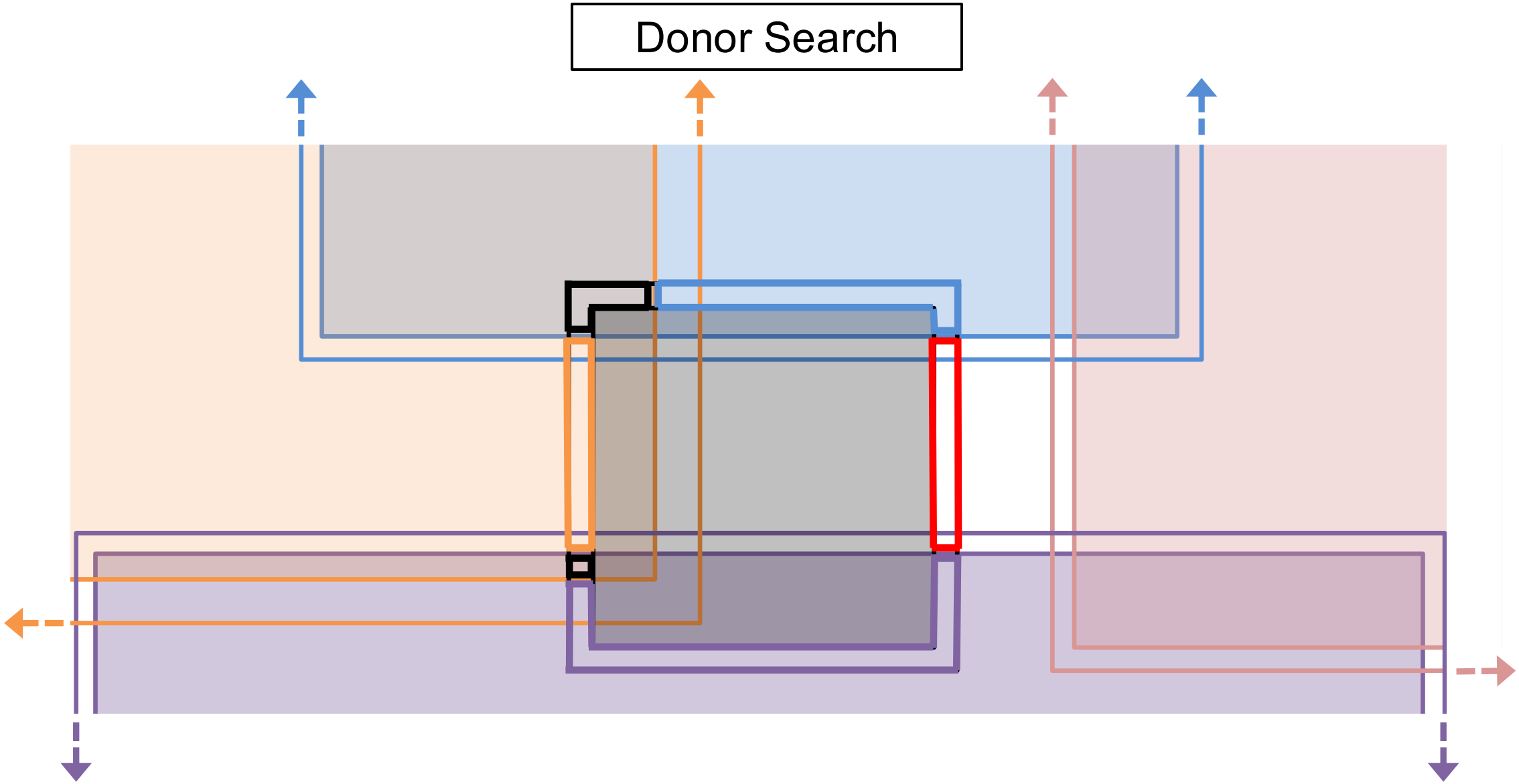
Donor Search




```
overset :
  viscousStencilRepairDist : 0.001
```

```
overset :
  repairInviscidStencils : True
```

Connectivity



Connectivity

Donor Search

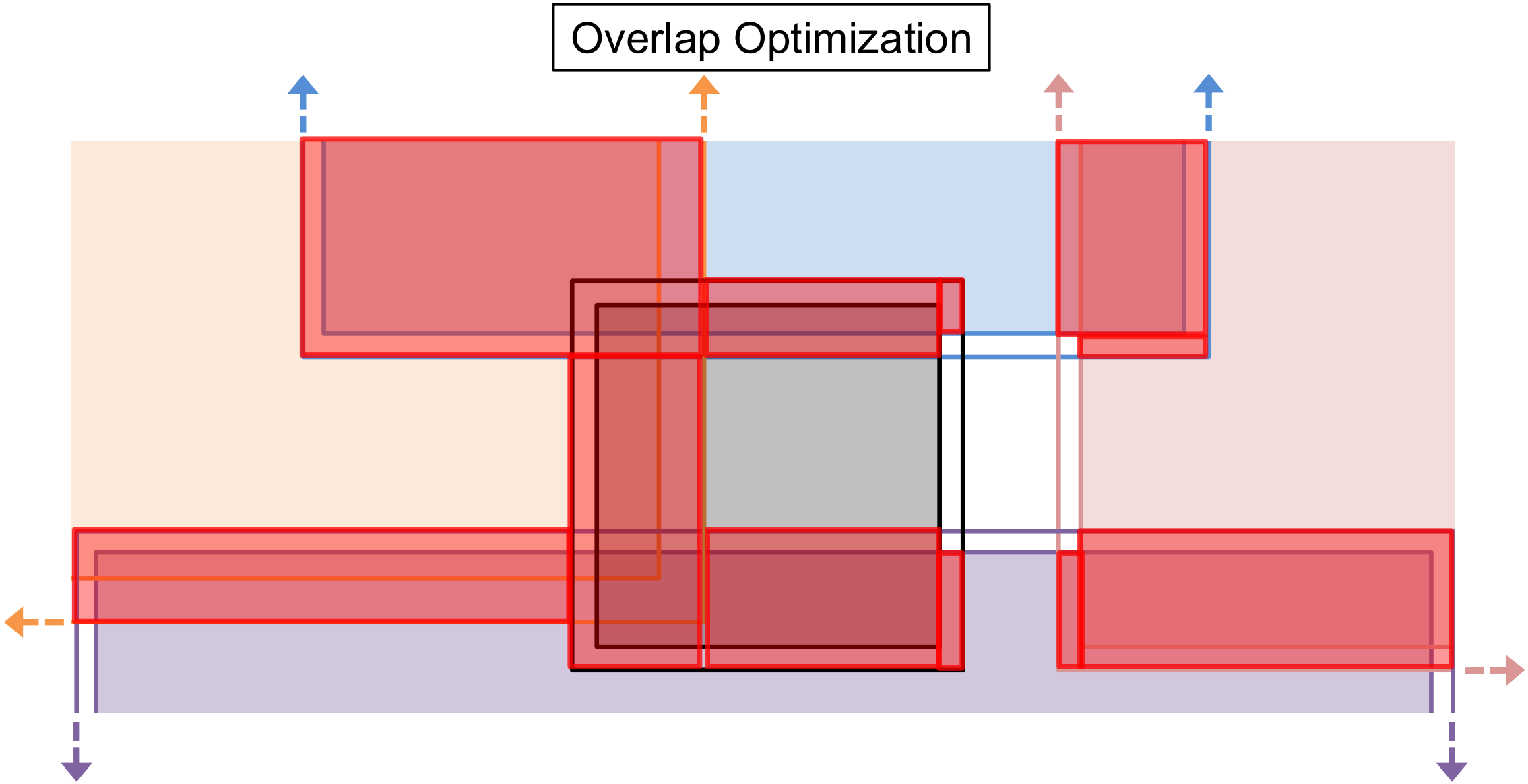
$$qual_{final} = (qual_{cell} * priority) + i_{grid}$$

Release cell quality: inverse volume

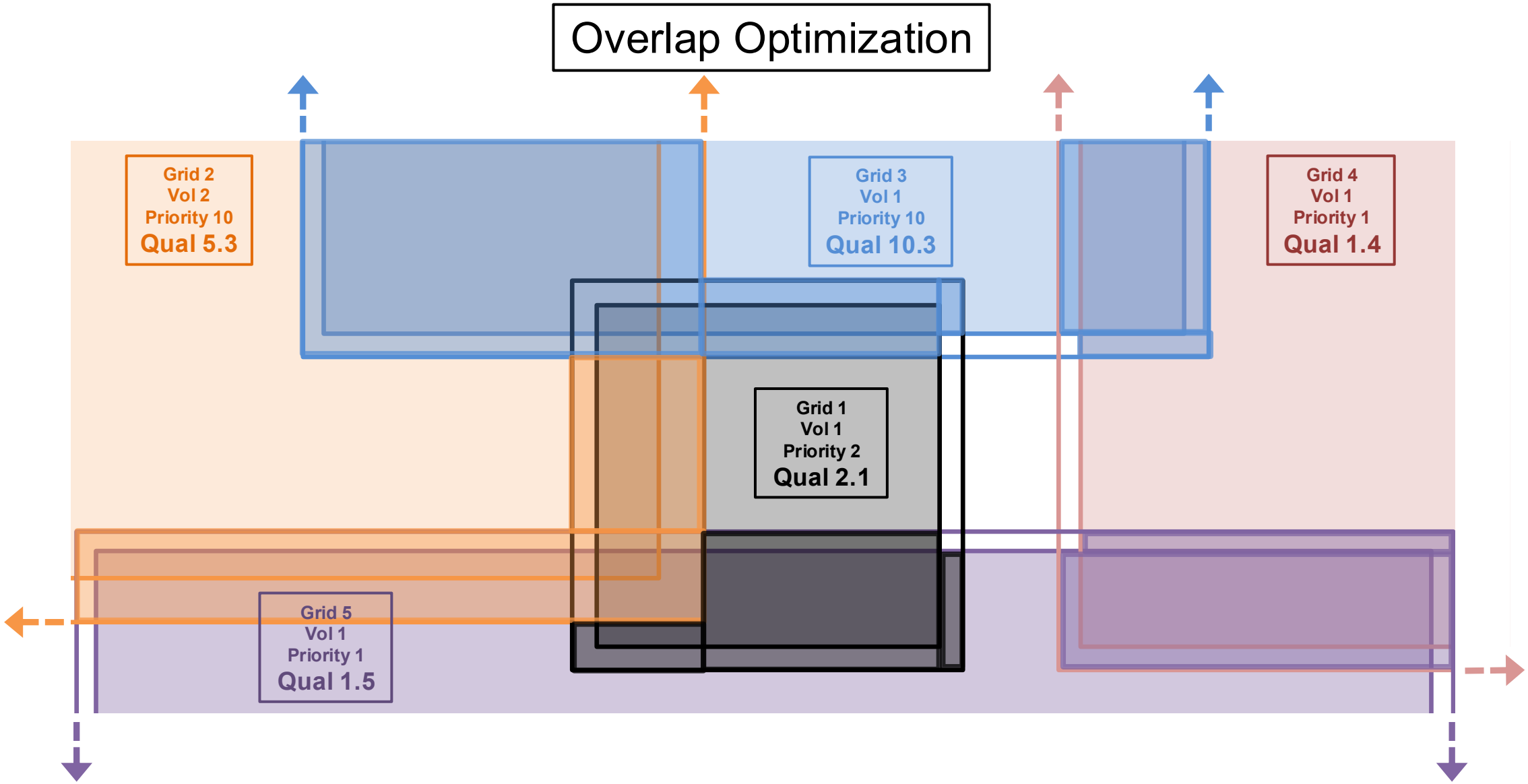
```
overset :
  zoneSpecific:
   -
     # All non-nose or collar near-body zones.
     zones :    [1,9-22,29-40]
     priority : 100.0
   -
     # All nose and collar near-body zones.
     zones :    [2,3-8,23-28]
     priority : 1000.0
```

```
overset :
  writePostHoleCutGrid : True
```

Connectivity

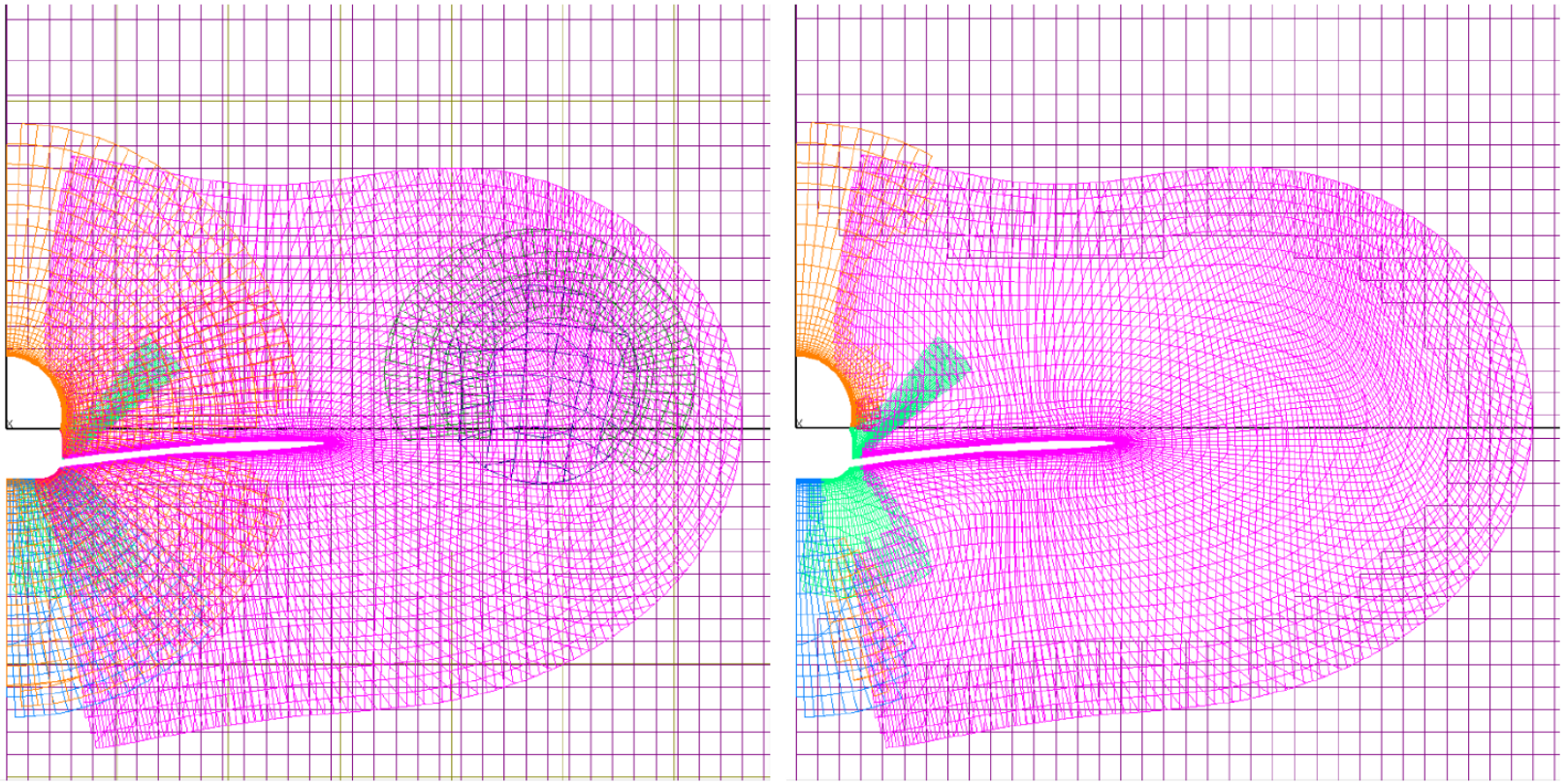


Connectivity



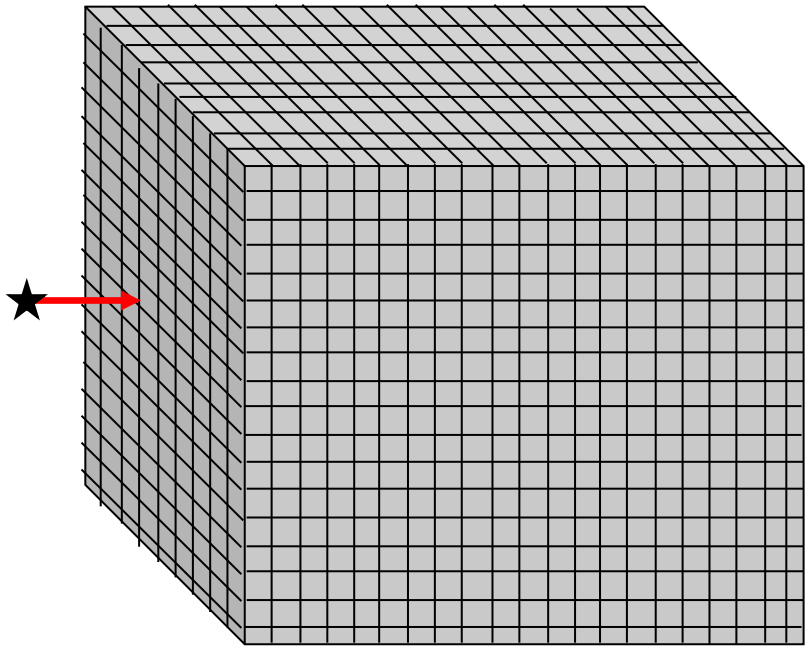
Connectivity

Overlap Optimization



Connectivity

Orphan Donor Search



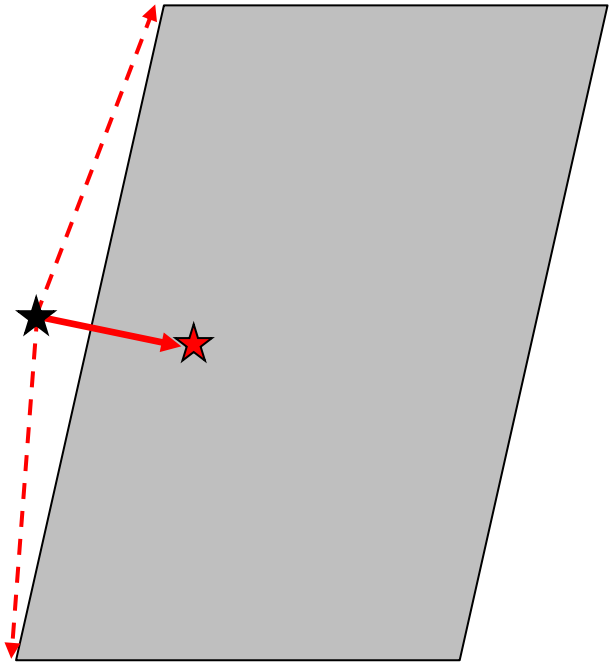
Illegal donation node if:

Blanked

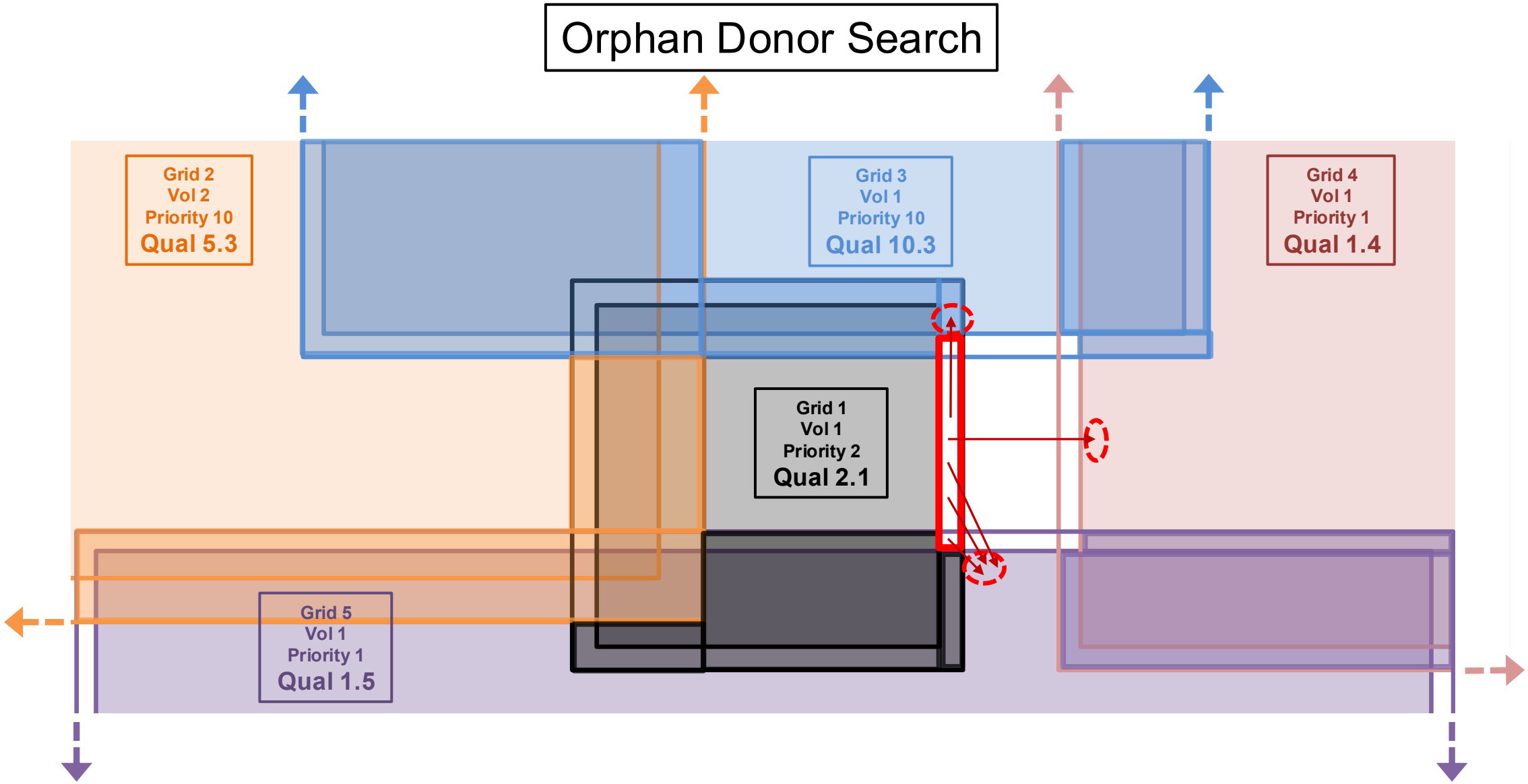
Fringe

Orphan

BC



Connectivity



Connectivity

Implicit Hole Cut

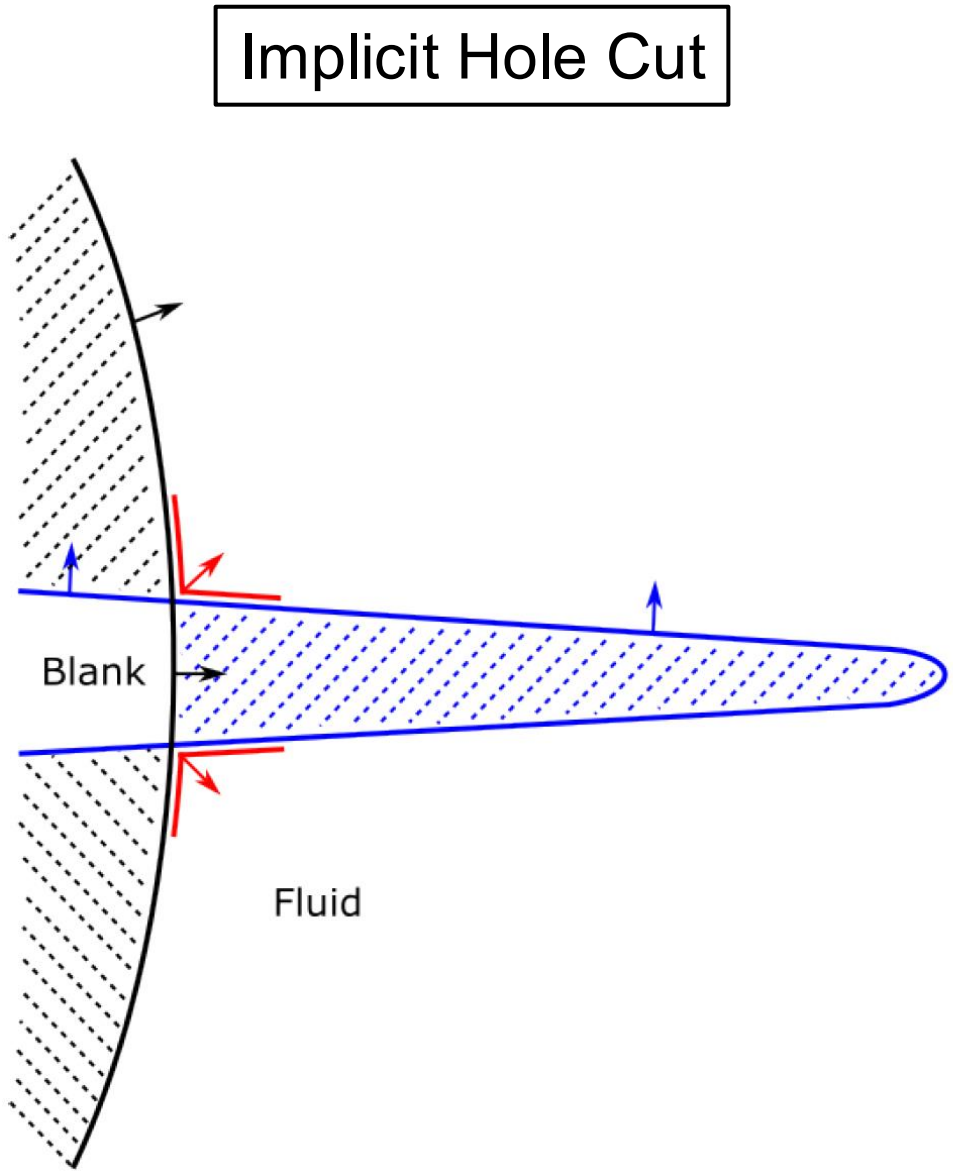
Resolve the geometry with an octree

Divide computational domain between inside and outside the geometry

Remove hanging surfaces

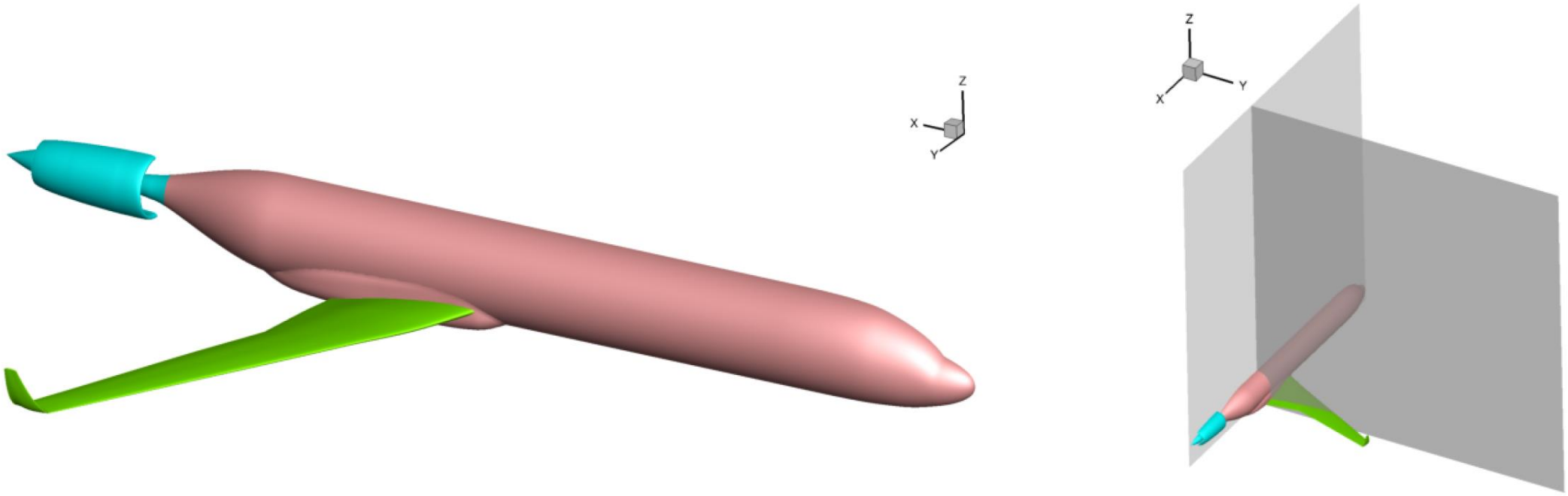
Blank all grid inside / intersecting surface

Connectivity



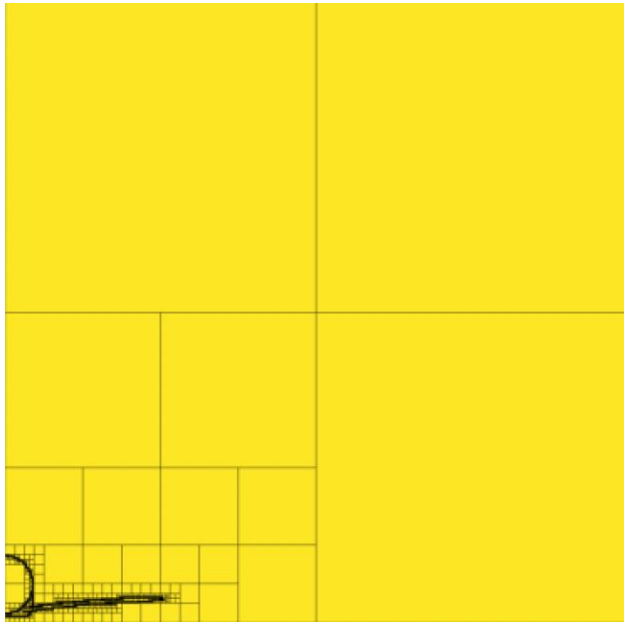
Connectivity

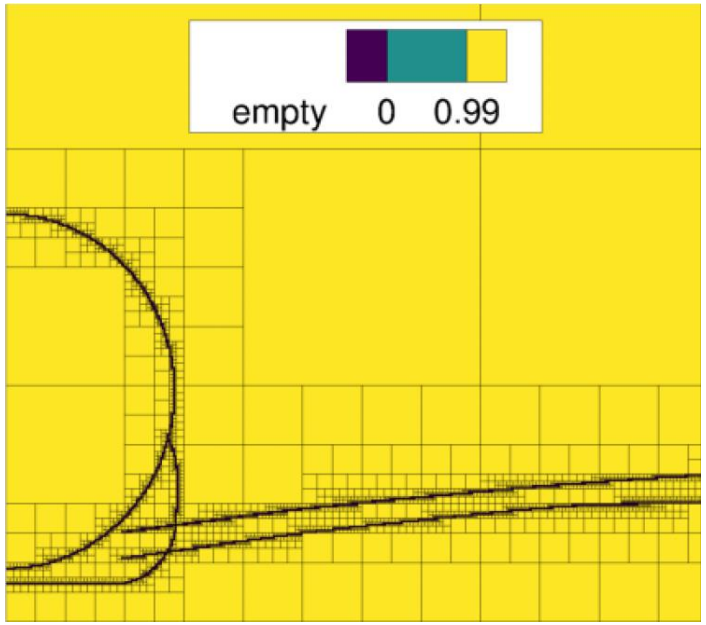
Implicit Hole Cut

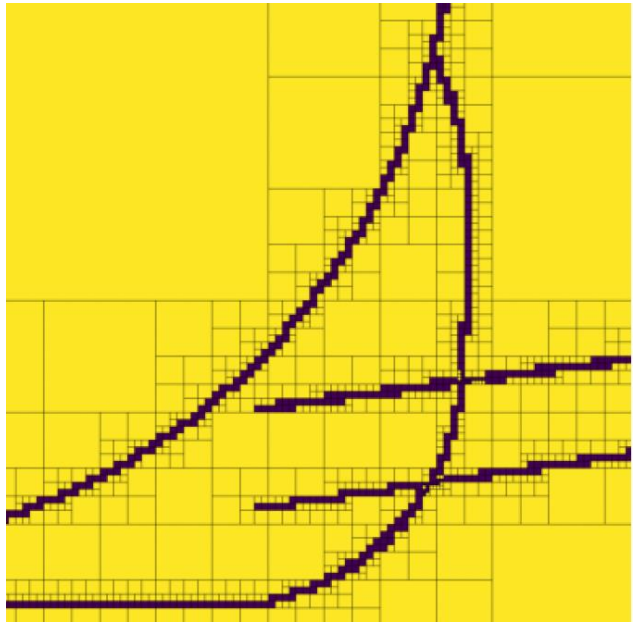


Connectivity

Implicit Hole Cut



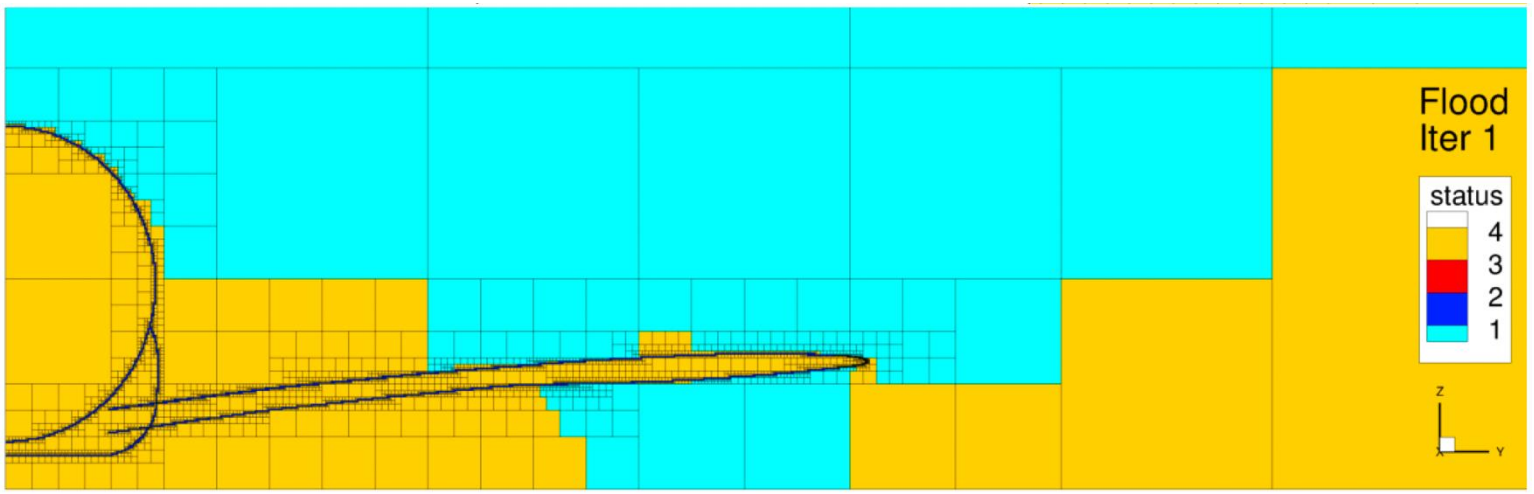


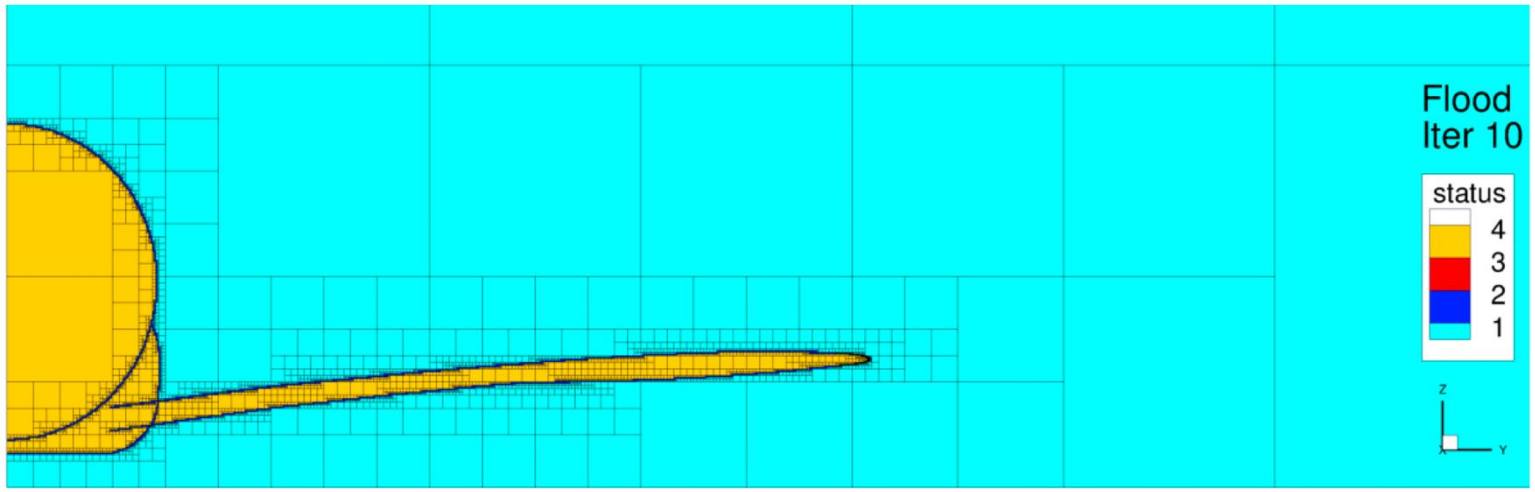


```
overset :
  octTreeMaxDepth : 15
```

Connectivity

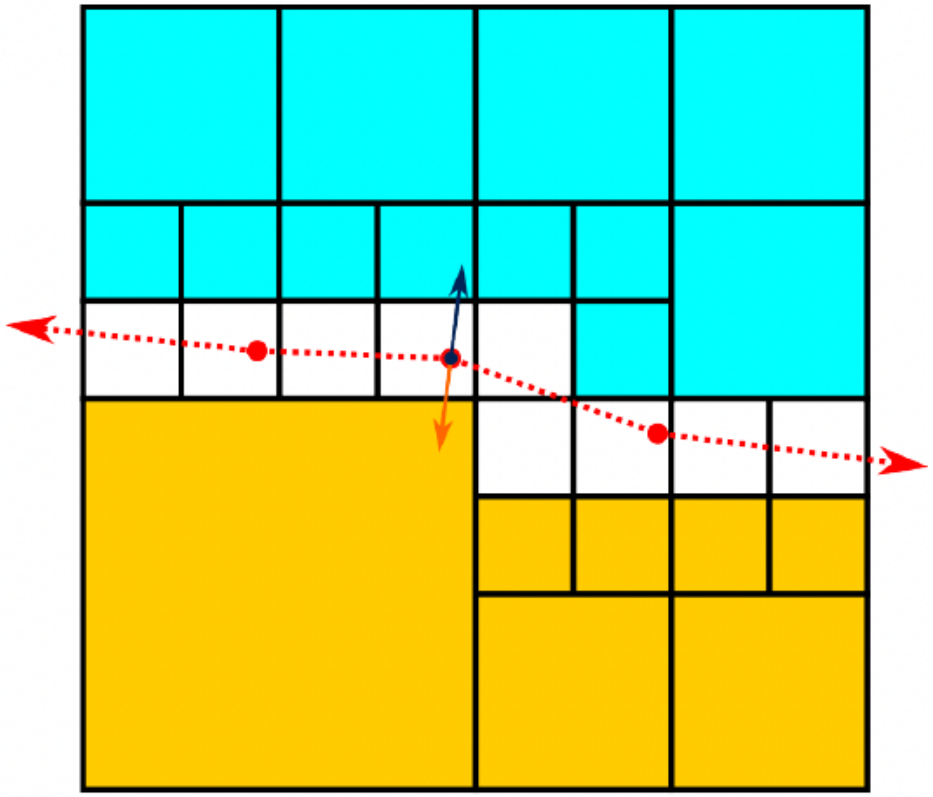
Implicit Hole Cut





Connectivity

Implicit Hole Cut



Surface nodes: on wetted surface or floating

Volume nodes: in or out

Volume edges: intersecting remaining surface

Connectivity

Explicit Hole Cut

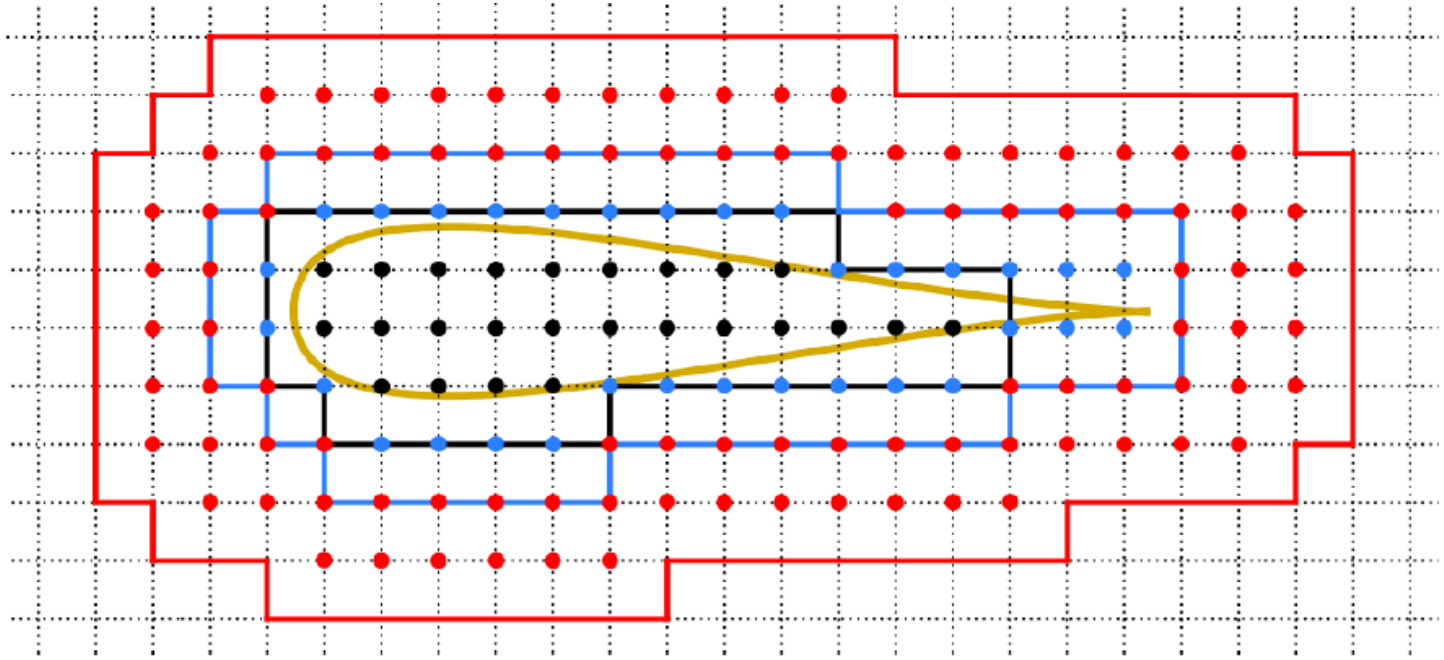
Manually defined, but very fast

Enforce symmetry conditions

Remove ambiguous surfaces which confuse implicit cut

Connectivity

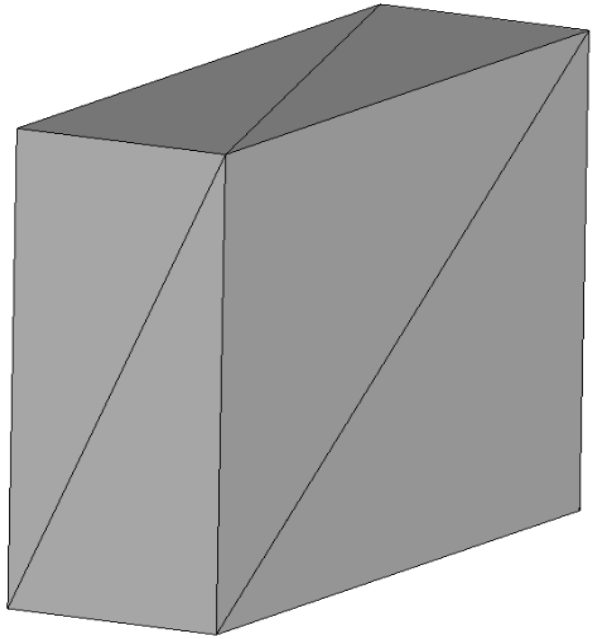
Explicit Hole Cut



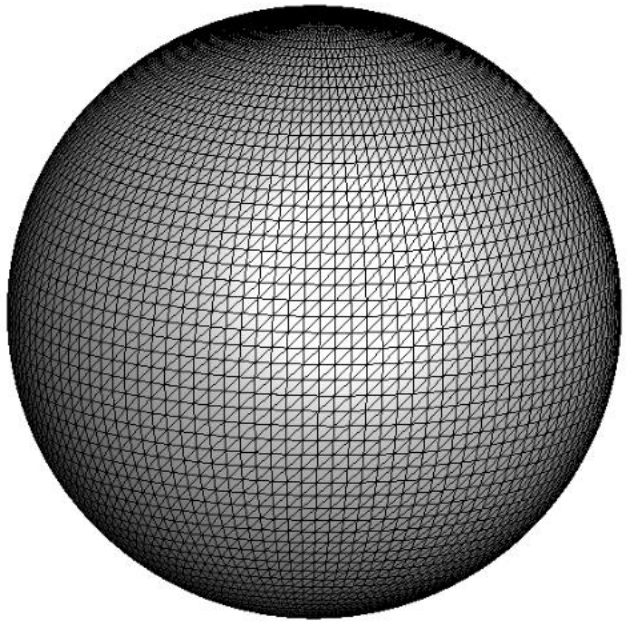
```
overset :
  explicitBlanking:
    -
      type     : surFile
      fileName : airfoil.i.tri
      fileType : tri
      offset   : [0.001]
      zones    : [1-4]
```

Connectivity

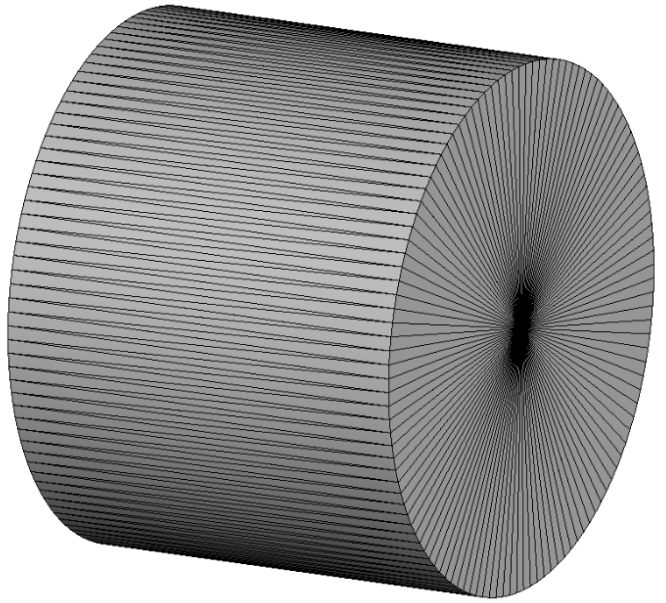
Explicit Hole Cut



```
overset :
  explicitBlanking:
    -
      type   : box
      xMin   : [-10.0, -0.5, 1.0]
      xMax   : [ 10.0,  1.5, 2.0]
      offset : [0.001, 0.0001]
      zones  : [9-10,14]
```



```
overset :
  explicitBlanking:
    -
      type   : sphere
      xMin   : [2.0, 0.25, 0.5]
      radius : [0.1]
      offset : [0.01]
      zones  : [15]
```



```
overset :
  explicitBlanking:
    -
      type   : cone
      xMin   : [2.0, 0.5, 0.0]
      xMax   : [2.0, 0.5, 1.0]
      radius : [0.025, 0.025]
      offset : [0.025]
      zones  : [13]
```

Connectivity

Explicit Hole Cut

```
overset :
  explicitBlanking:
    -
      type      : clip
      operator  : ">"
      variable  : "y"
      value     : 1.0
      offset    : [0.0]
      zones     : [13]
```

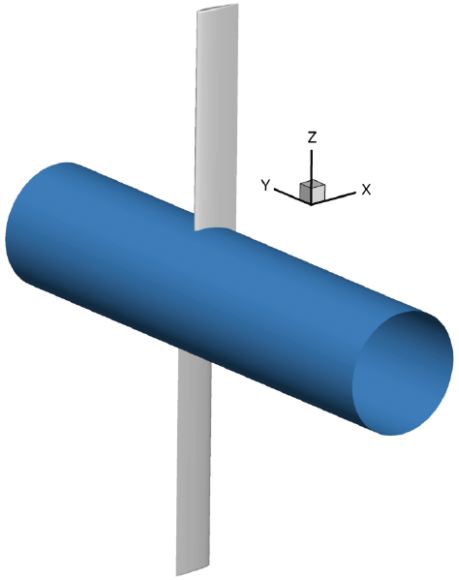
```
overset :
  explicitBlanking:
    -
      type   : jkl
      xMin   : [ 1,  1, 105]
      xMax   : [-1, -1,  -1]
      zones  : [11-12]
```

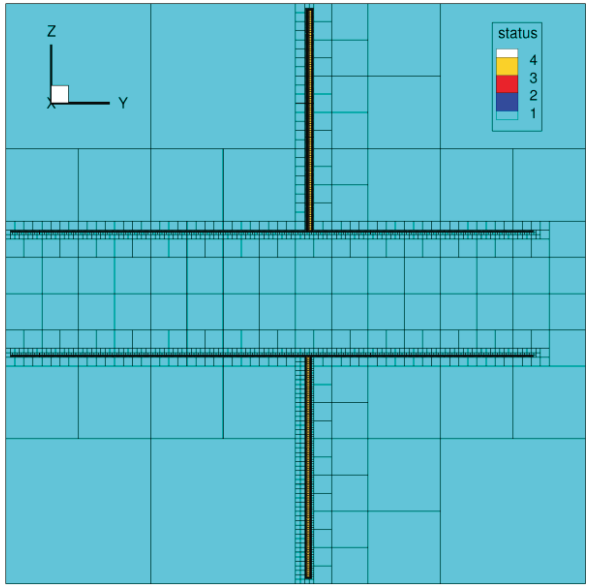
```
overset :
  writeExplicitCutters : True
```

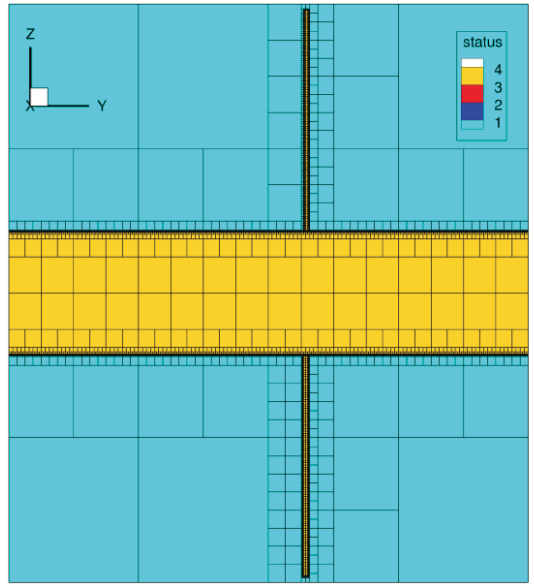
Domain and Geometry Considerations

Open Geometry

- Symmetry
- Periodic
- 2D
- Open geometry





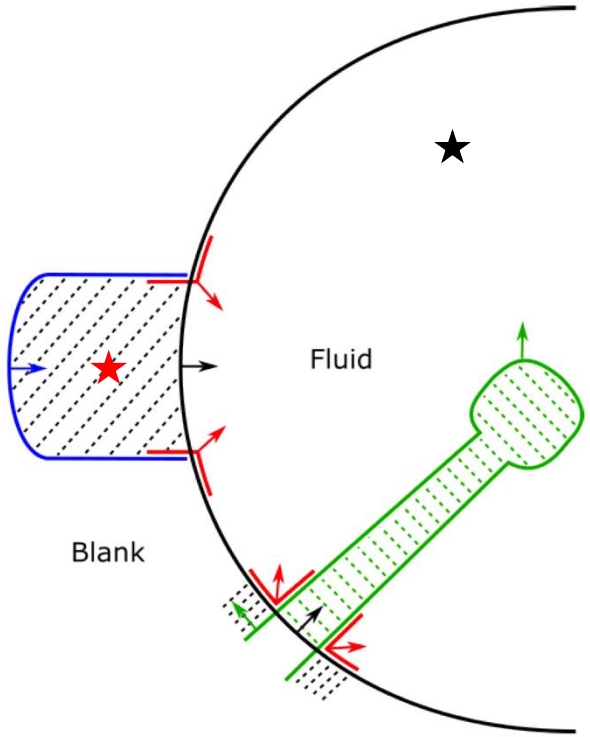


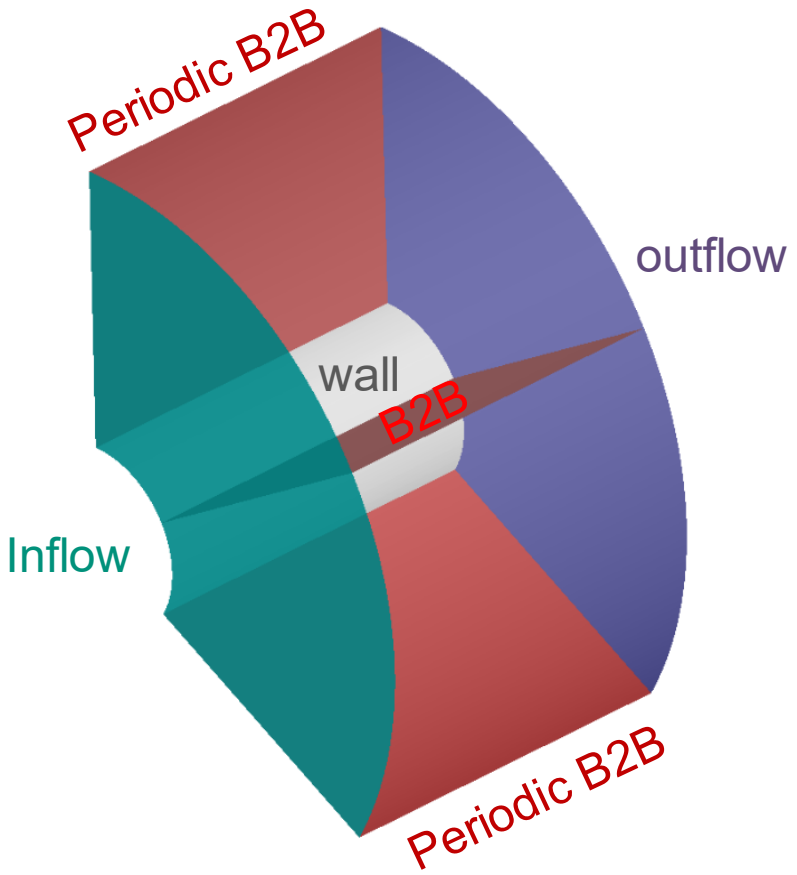

```
overset :
  octTreePadSides : [False, True, True, False, True, True]
```

Domain and Geometry Considerations

- Tunnel Flow
- ‘Appended’ Features
- Periodic Wedges

Internal / Cavity Flow






```
overset :
  octTreeFloodSeeds :
    -
      pt: [1.0, 0.5, 0.5]
    -
      pt: [3.5, -0.375, 0.57]
```

```
overset :
  internalFlow : True
```

Debugging Tools

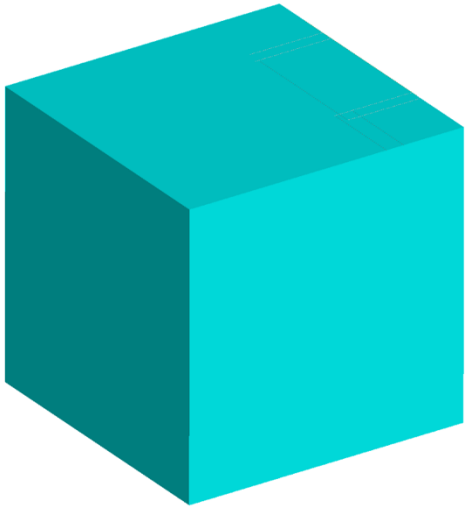


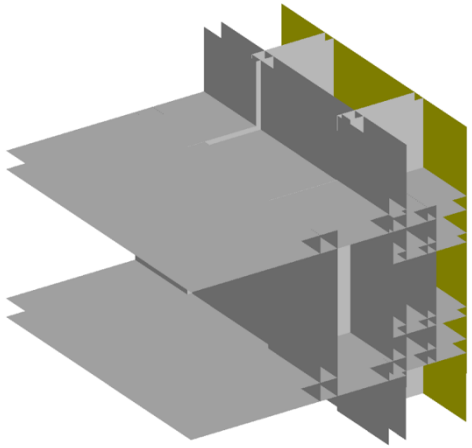
You run connectivity and …

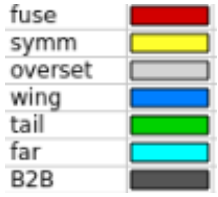
Your surfaces have been blanked
(your surface isn’t air-tight)

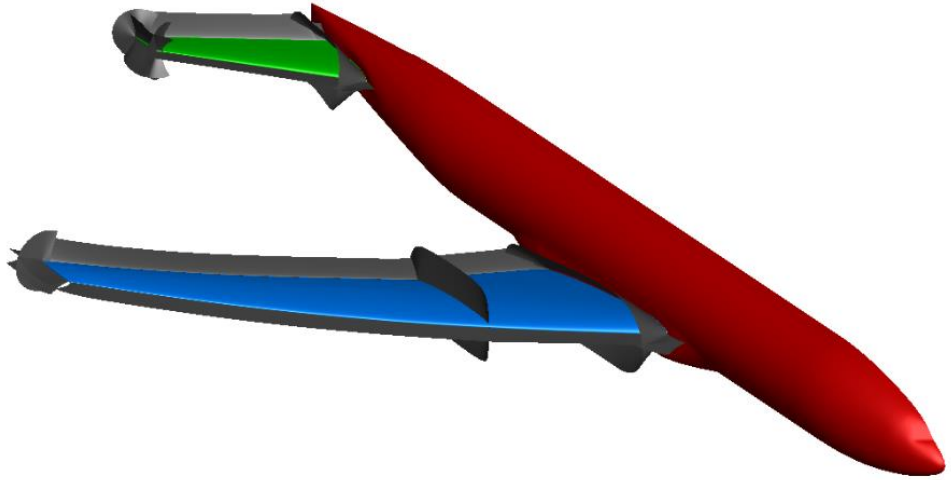
Debugging Tools

Visually Check BCs and B2Bs





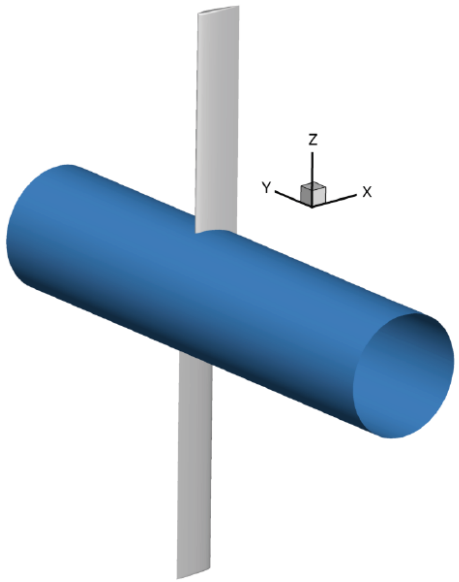


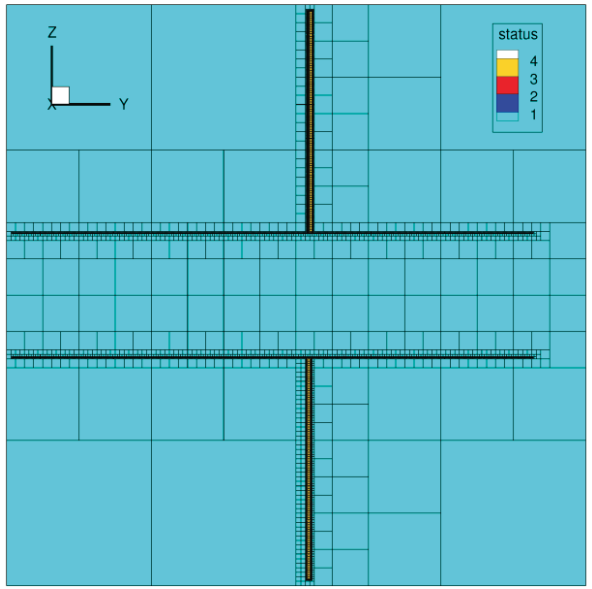


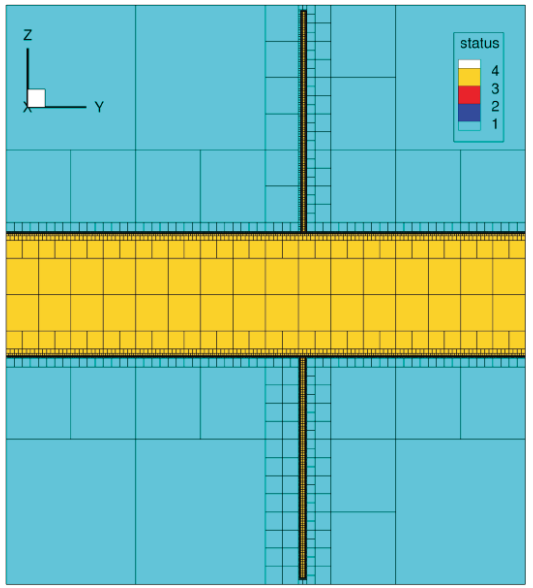
```
overset :
  writeNameGroupedBCs : True
```

Debugging Tools

Check Open Geometry Enforcement








```
overset :
  internalFlow : True
```

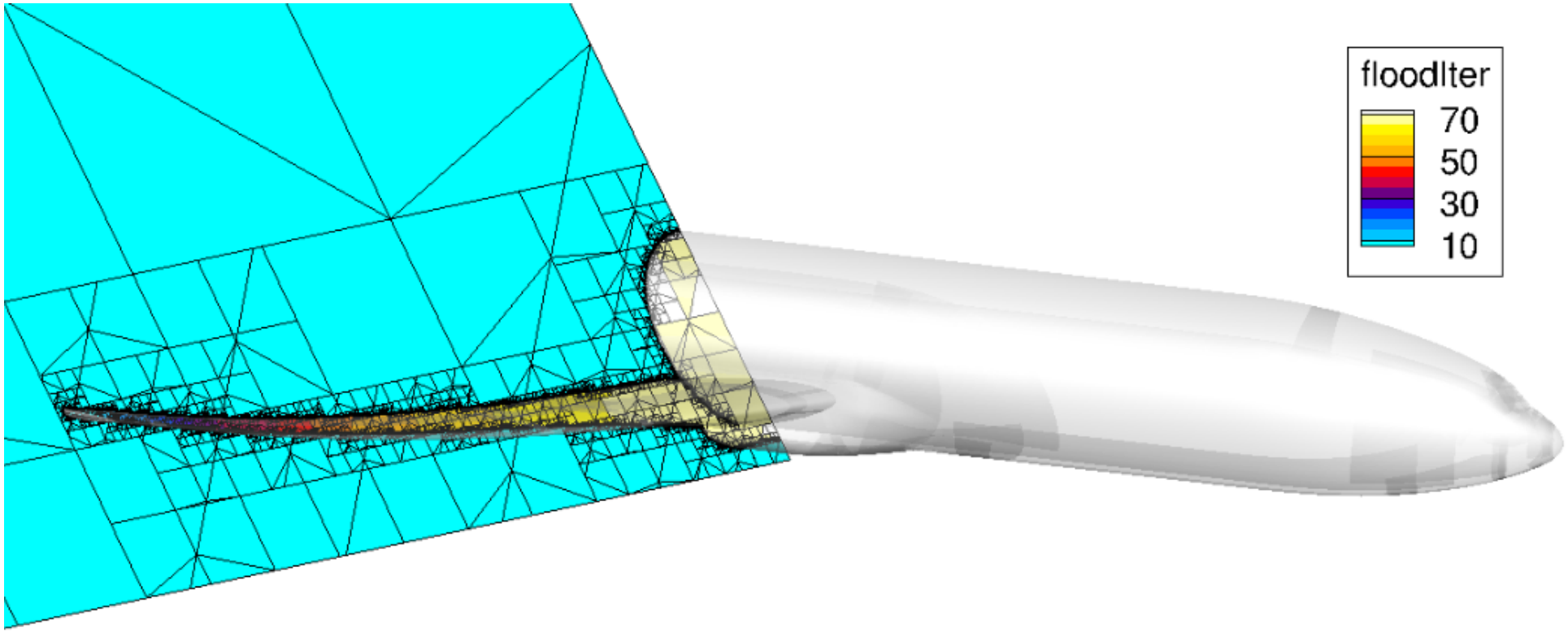
```
bc :
  -
    names : [tail_vent]
    type : BCinflowsubsonic
    location : onbody
  -
    names : [engine_inflow]
    type : BCoutflowsubsonic
    location : onbody
```

```
overset :
  explicitblanking :
    -
      type : clip
      variable : y
      operator : "<"
      value : 0.0
```

```
overset :
  octTreePadSides : [False, True, True, False, True, True]
```

Debugging Tools

Assess Octree Flooding




```
overset :
  octTreeFileName : oct.dat
```

Debugging Tools

You run connectivity and …

Orphans exist
(grids being blanked when they shouldn't)

Debugging Tools

Force Existence

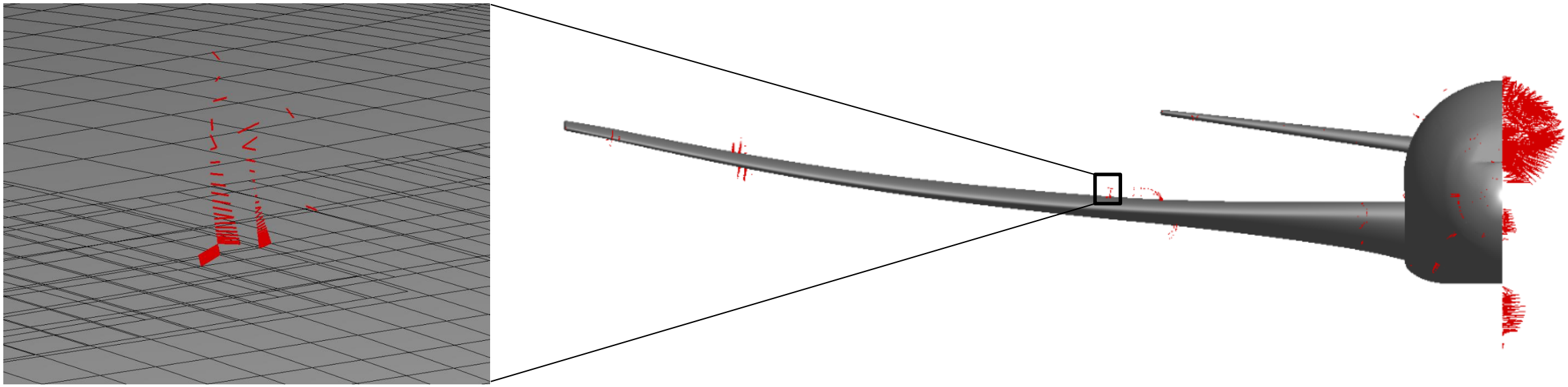
```
overset :
  zoneSpecific:
    -
      zones : [8]
      explicitJKL : [1,1,1,10,1,1]
```

Debug Node

```
overset :
  optimizeOverlap : False
  debugNode : [1,1,1,1]
```

Debugging Tools

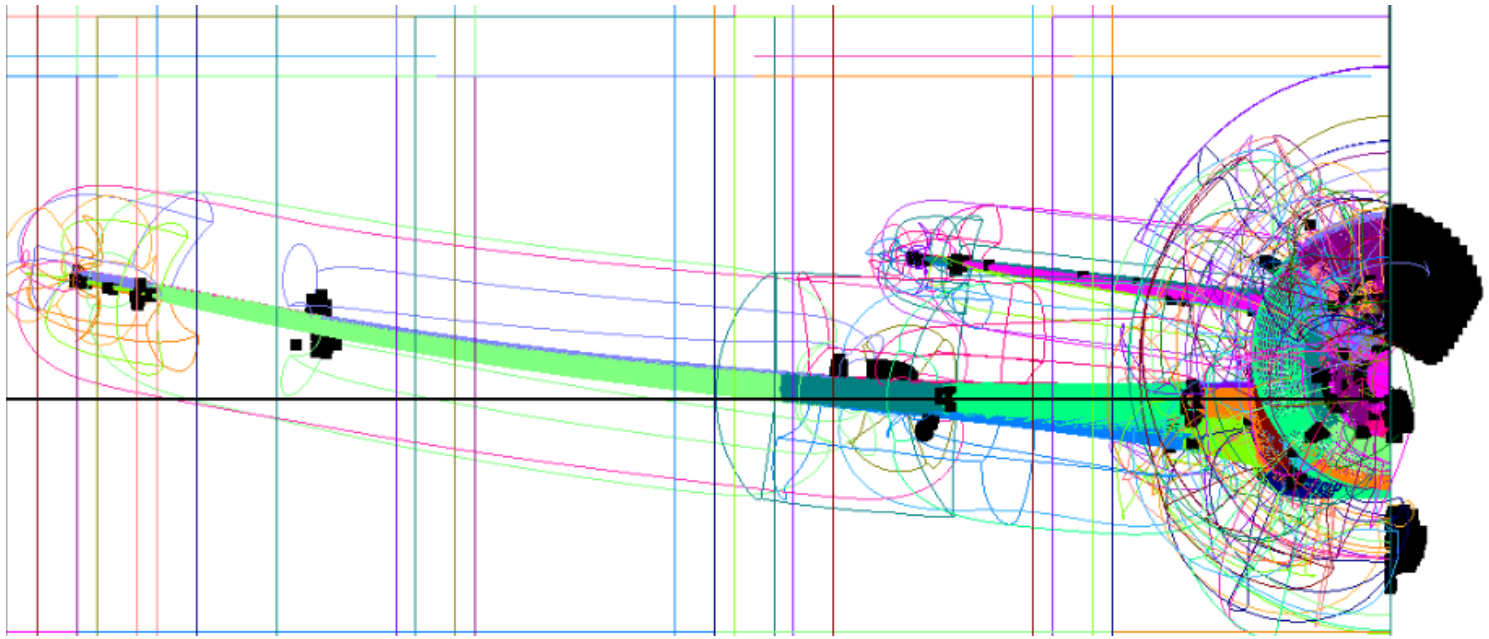
Assess Orphan Interpolation

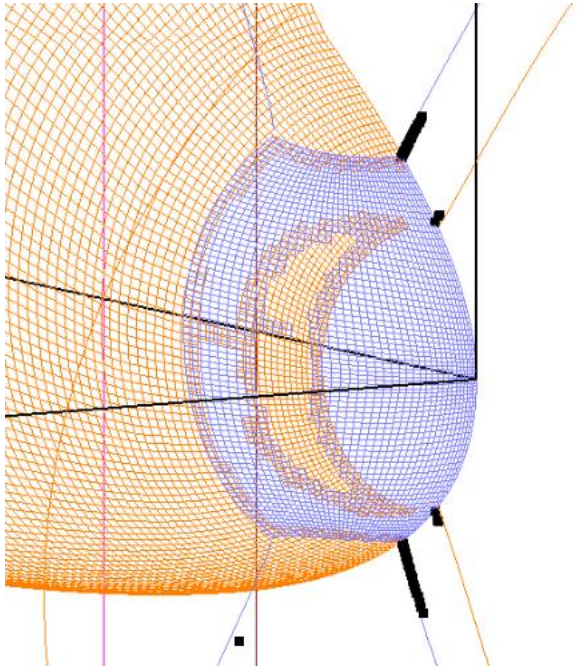


```
overset :
  writeDistBandOrphData : True
```

Debugging Tools

Orphans Outside Domain



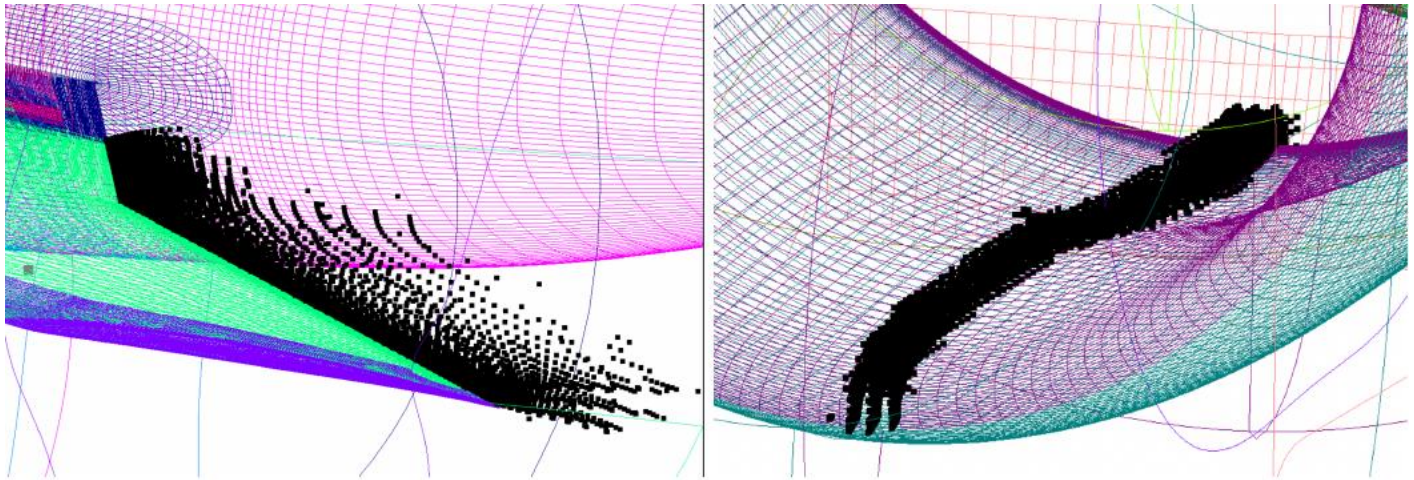


```
overset :
  explicitblanking :
    -
      type : clip
      variable : y
      operator : "<"
      value : 0.0
```

```
bc :
  -
    names : [symm]
    type : BCSymmetryPlane
    projectNodes : True
```

Debugging Tools

Orphans Near a B2B



```
B2BExtractor :
  extractB2Bs: True
  writeB2BZones : True
```

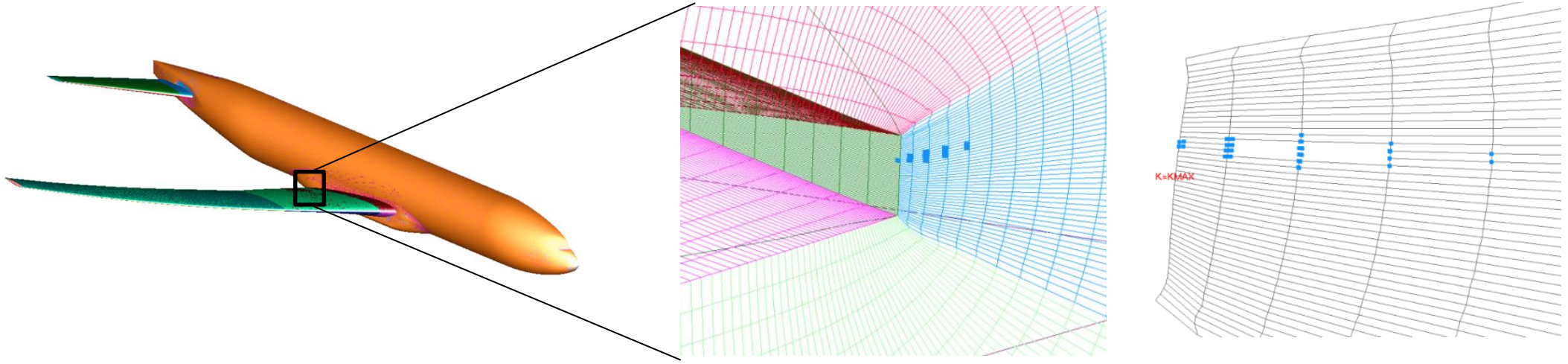
```
overset :
  writeNameGroupedBCs : True
```

```
curvSolver :
  task : connectivity
  b2bTol : 1e-10
```

```
B2BExtractor :
  extractB2Bs : True
  #onlyFullB2Bs : True
```

Debugging

Orphans Near a Wall BC

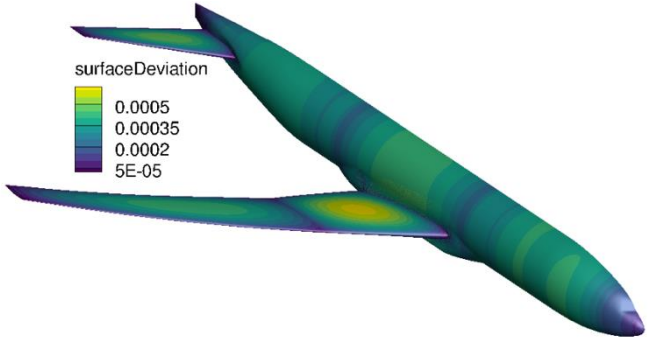


Volume edges will be cut by geometry of surfaces they aren't 'related' to

```
overset :
  zoneSpecific:
    -
      zones : [1-3]
      # 1-5 is effective range.
      curvaturefactor : 2
      # Increasing too much can find
      # very far surfaces...
      edgefactor : 0.5
```

```
overset :
  writeBodyCutEdge : True
```

```
overset :
  writeSurfDeviation : True
```



Debugging

Orphans Near Sharp Corner

Having trouble with octree In/out raycast

```
overset :
  writeUncertainNodes : True
```

```
overset :
  nSphereSurface : 100
  nSphereVolume : 100
```

```
overset :
  rayExtensionMaxIter : 10
```

```
overset :
  # Going over 20 is 'dangerous'
  #octTreeMaxDepth : 15
  octTreeMaxDepth : 17
  zoneSpecific :
    -
      zones : [3]
      octTreeMaxDepth : 17
```

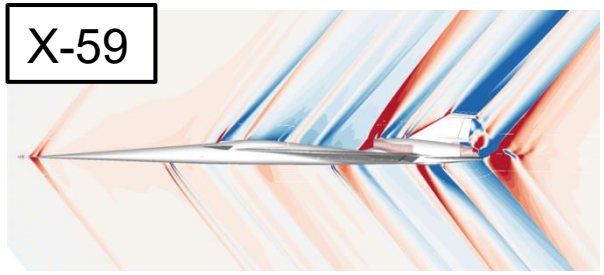
DebugNode-ing a surface node
will write '**surfaceRays.dat**' for viewing

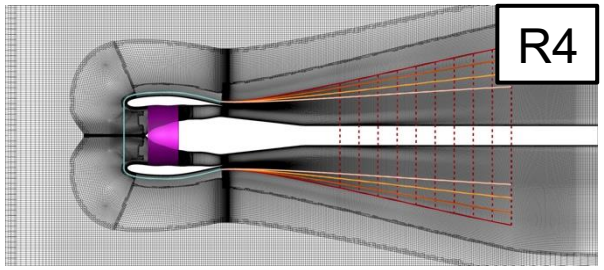
Impact on NASA Applications

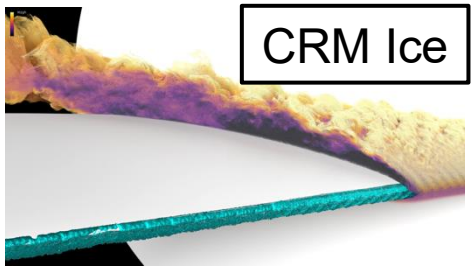
MPI-enabled in case need to re-compute during simulation
(e.g. re-computation of connectivity during X-59 design optimization).

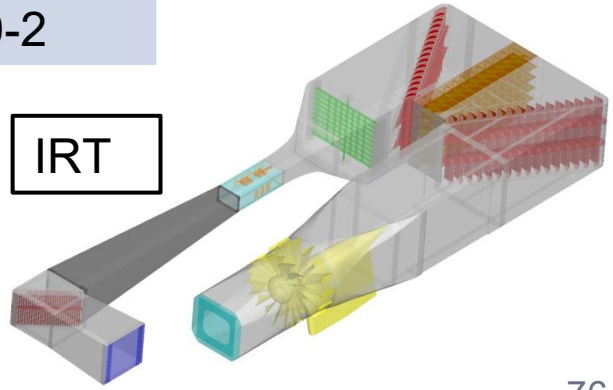
Single Rank Engineering Workstation Timings
(includes B2B extraction, connectivity, and panel weight generation)

Case	N Grids	N Nodes [Mil]	Threads	Time [min]
X-59	774	360	72	5.87
R4	627	1127	128	16.78
CRM Immersed Ice	186	609	80	2.85
IRT	1615	795	125	22.4
Generally		<300	~50	0-2









Upcoming Features

- Dynamic Connectivity.
- Aspect-ratio, solution-alignment, and immersed distance priorities.
- Refined re-distribution for residual reduction.
- Surface triangulation auto-quadding.
- Azimuthally non-uniform (spacing and width) sliding mesh wedges for multi-stage turbomachinery analysis.

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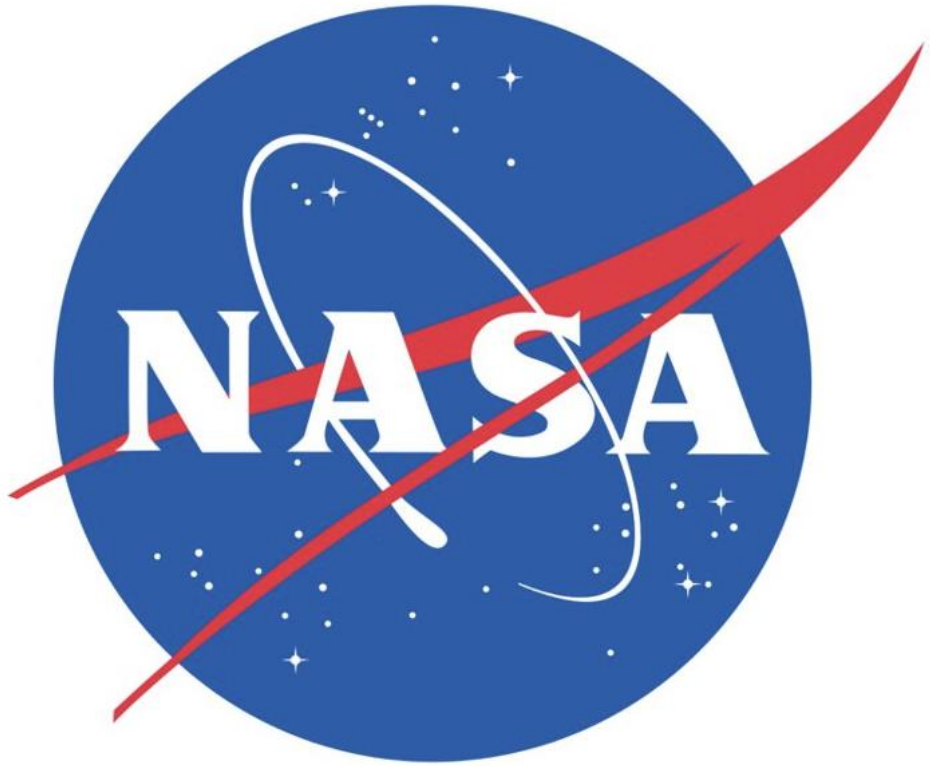
High-Speed Flight (HSF)
Subsonic Vehicle Technologies (SVT) Projects
(and their predecessors)

Computational resources:

NASA High-End Computing (HEC) Program
Advanced Supercomputing (NAS) Division

Technical advice / application solutions:

LAVA team


NASA