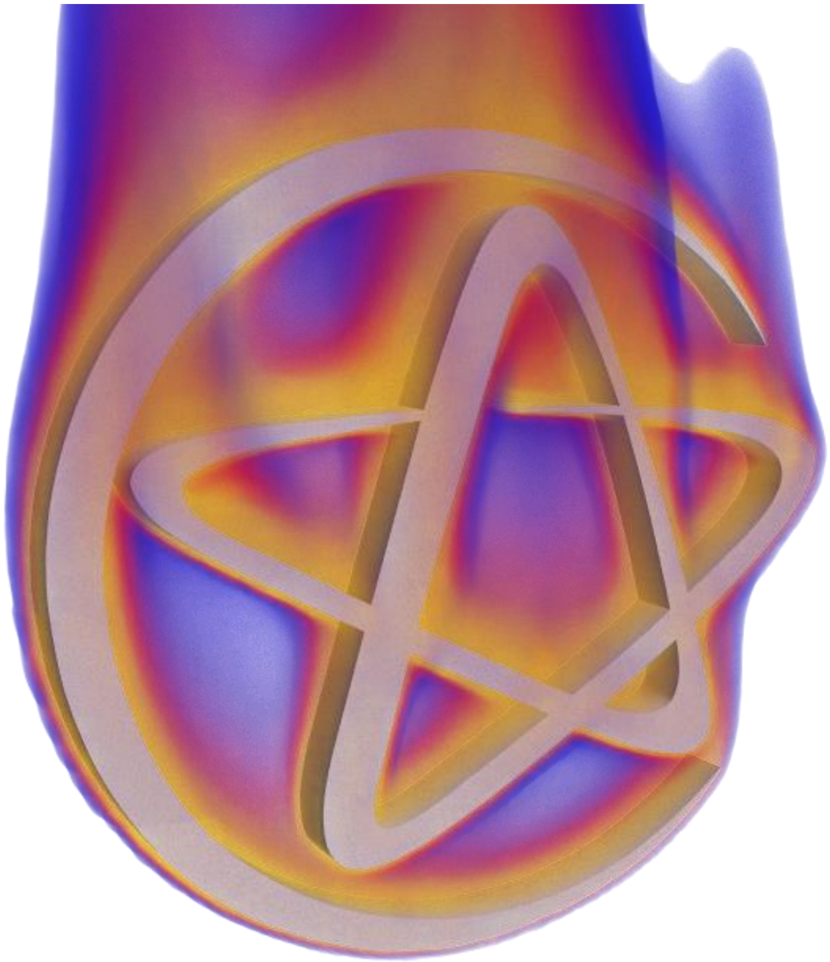
Best Practices for Modeling Heat Transfer in Simcenter STAR-CCM+

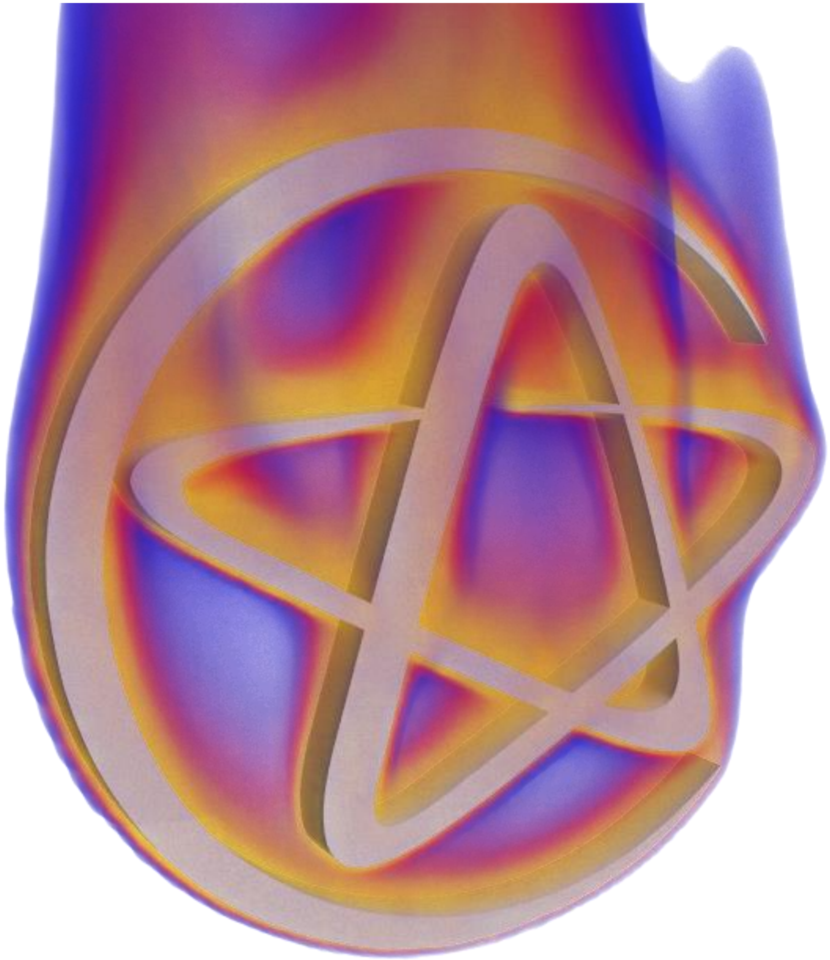
Steven Dowding

Overview



- Heat Transfer in Simcenter STAR-CCM+
- Geometry Preparation
- Meshing
- Parts Based Workflow
- Convergence
- Heat Transfer Coefficients
- Summary

Overview



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Heat Transfer in Simcenter STAR-CCM+ - Why Is Heat Transfer Important?

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Improved performance	• Improved efficiency • Emissions reduction • Smaller packaging
Increased reliability	• Wide operability • Reduce thermal stress • Longer component lifespan
Cost management	• Reduce expensive field testing • Improved operational efficiencies • Reduced maintenance costs

Heat Transfer in Simcenter STAR-CCM+

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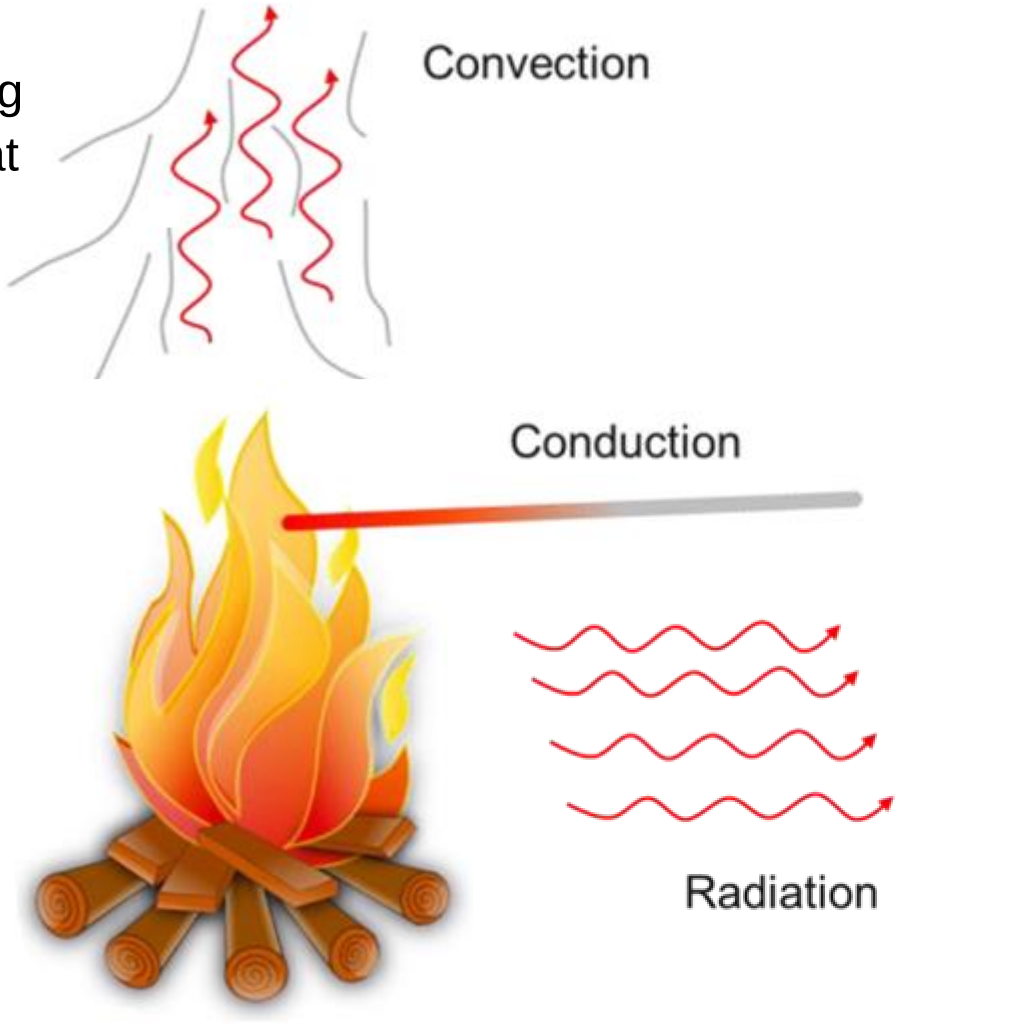
- In the context of Simcenter STAR-CCM+, when discussing heat transfer, we are generally referring to Conjugate Heat Transfer (CHT)
  - Multiple modes of heat transfer present in a system:
    - Conduction
    - Convection
    - Radiation
- What does this mean for us in terms of simulation setup?
  - Multiple Material Properties
    - Solids, liquids, gases may all be present
  - Multiple Parts/Regions
    - Communication must be allowed between them
  - Multiple Timescales
    - Solid temperature changes slow compared to fluid



Heat Transfer in Simcenter STAR-CCM+ - Solver Considerations

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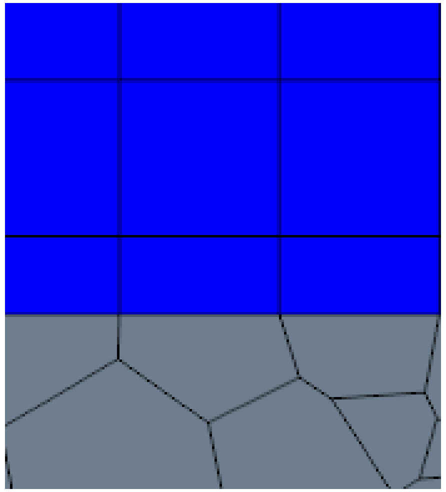
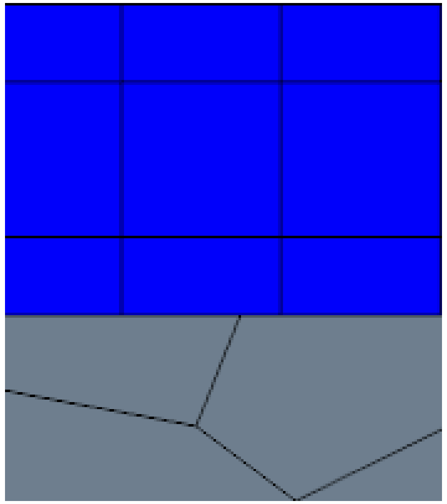
- We must turn our raw geometry into a discrete representation in order to solve our numerical equations
  - This is the process of meshing
- How this mesh is generated is important
  - Balance between numerical accuracy/solver requirements and engineer time needed to construct the mesh
- Two main types of meshes can be generated, each with its own implications for how information is exchanged
  - Conformal
    - One-to-one node matching, best accuracy from solver
    - May require more time to prepare geometry to meet requirements
  - Non-Conformal Mesh
    - Mismatch of nodes, solver needs to perform some type of face matching or interpolation
    - Less stringent geometry requirements to generate





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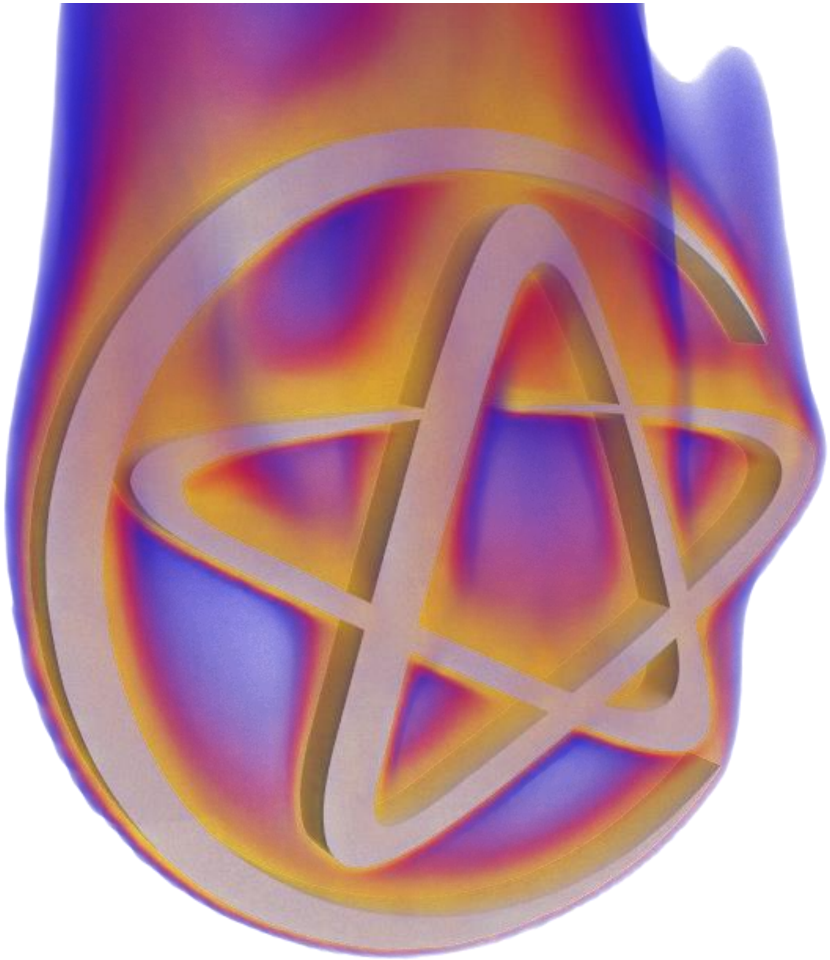

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Geometry Preparation – Enabling Communication Between Parts

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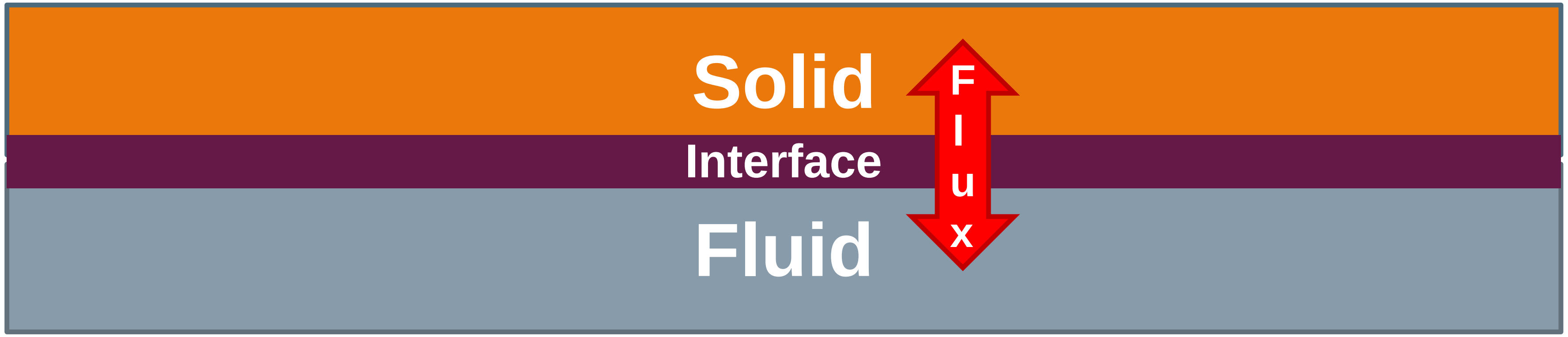
- With multiple materials present, we need to enable communication between the various parts that represent them
  - In STAR-CCM+, we create Interfaces between parts to exchange information

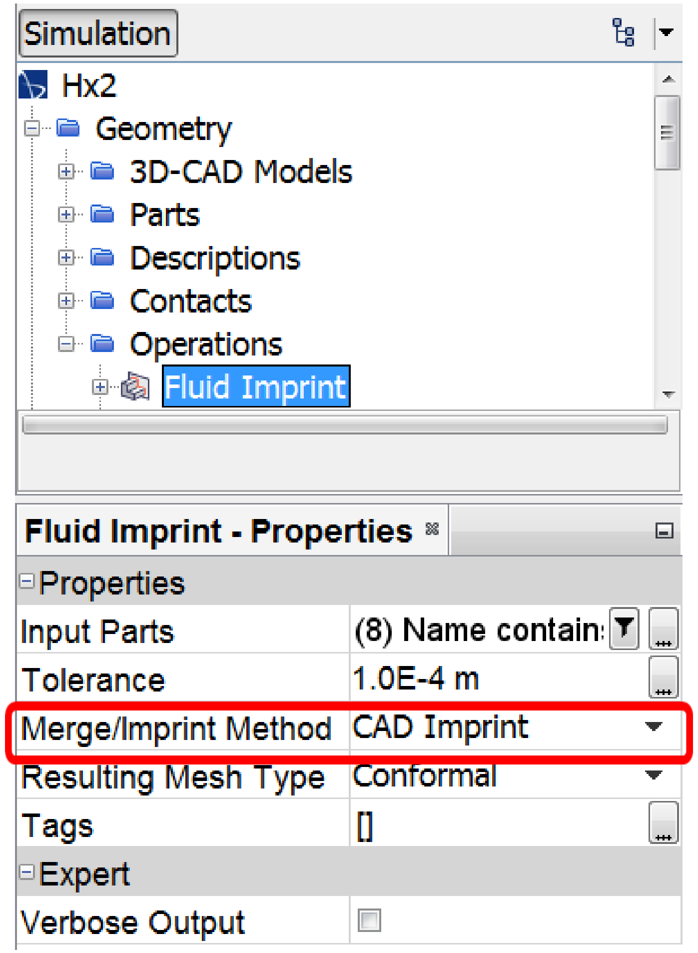


- We have several different options for how we create these interfaces:

1. Conformal Imprint
2. Non-Conformal Imprint
3. Weak Contact

Geometry Preparation – CAD Imprinting - Conformal

- When working with clean, analytical CAD, use a CAD based imprint
  - Higher quality due to use of underlying CAD representation
  - Not affected by tessellation density
  - Does not modify geometry topology
    - Will not move surfaces to make them coincident
  - Allows for use of Directed Mesher due to retention of CAD
  - Generates a conformal mesh



Geometry Preparation – Discrete Imprinting – Conformal/Non-Conformal

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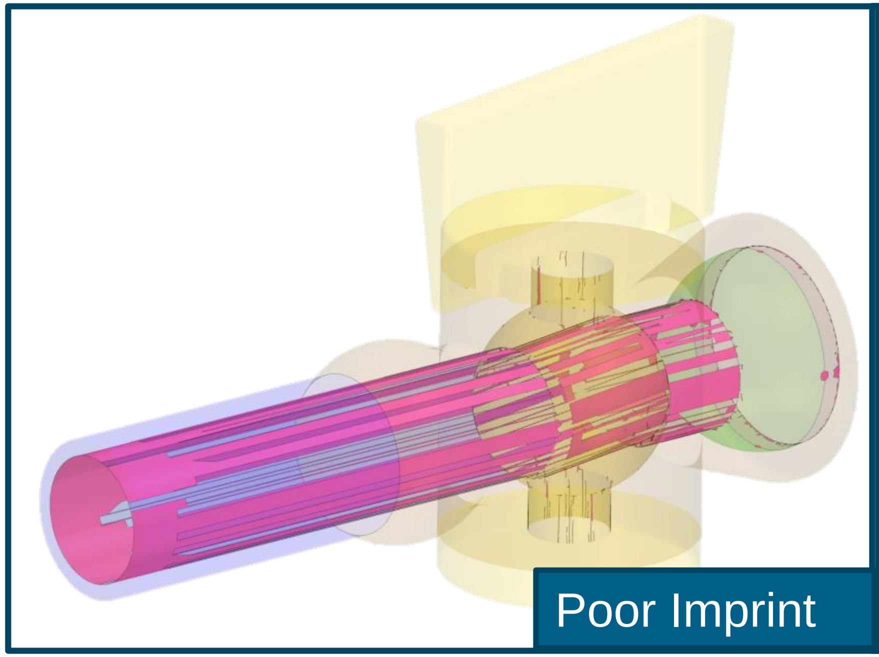
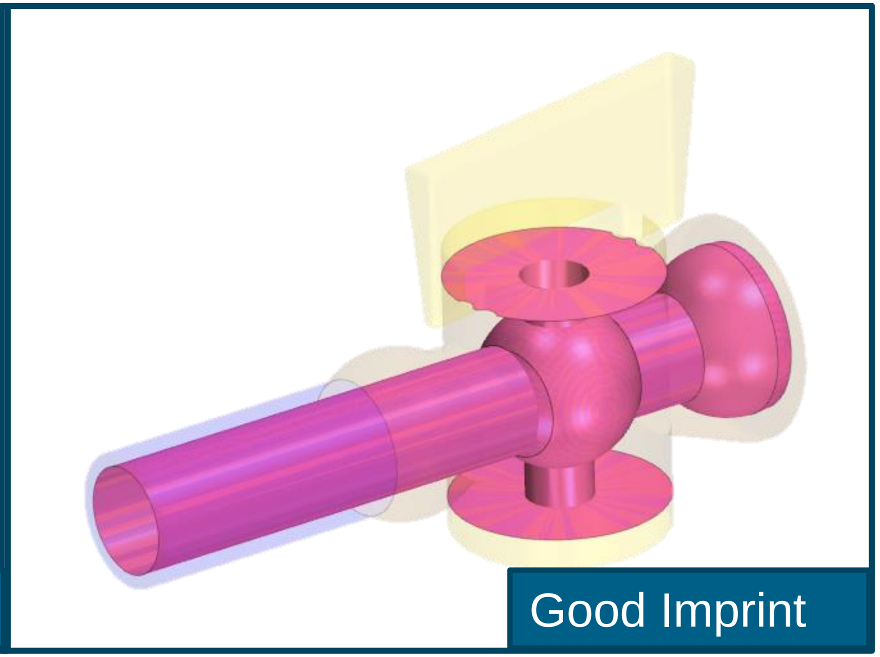
- Use Discrete Imprint when not working with CAD or coincident surfaces
  - Able to move surfaces to make them coincident at the interface
  - Cannot be used with Directed Mesher (use Extruder instead)
  - Dependent on input tessellation/tolerance
    - Higher tessellation density can increase imprint quality
    - May be difficult if varying tolerances are present
  - Imprint can be conformal or non-conformal





Geometry Preparation – Imprinting Tip – Splitting Surfaces

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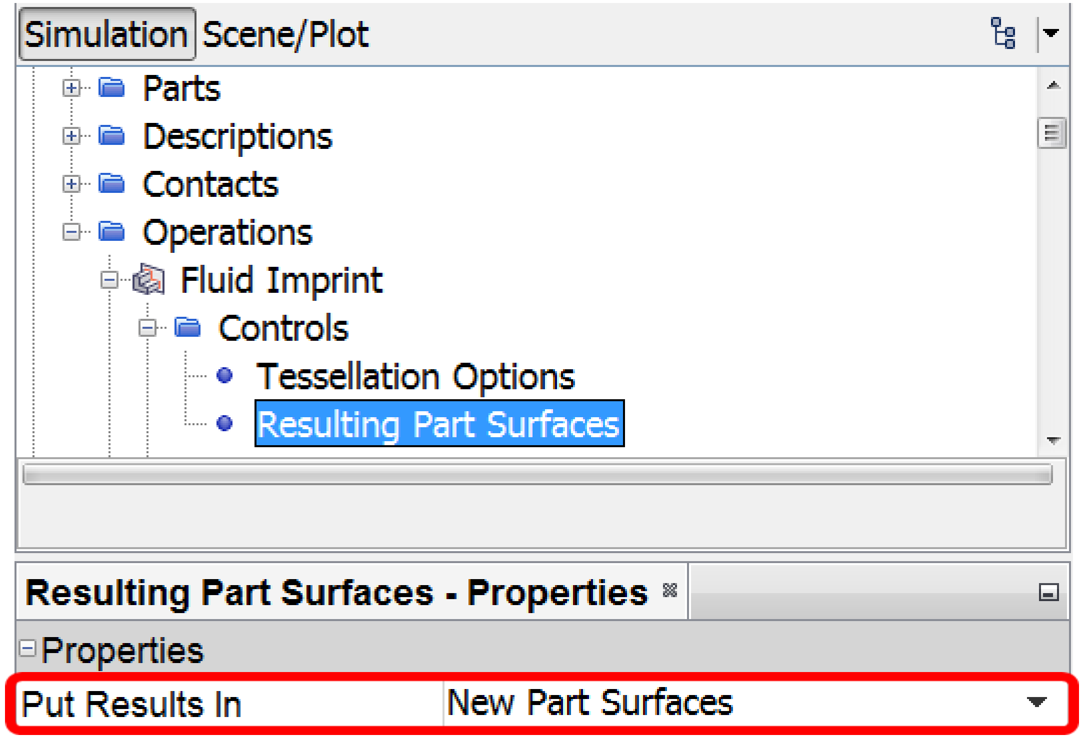
- Imprinting can be used to split surfaces as well
  - Automatically generate source and target surfaces for Directed Mesher
  - Automatically separate interfaces into separate surfaces for post processing or custom mesh controls
- Set Resulting Part Surfaces to New Part Surfaces



Geometry Preparation – Imprinting Tip – Splitting Surfaces

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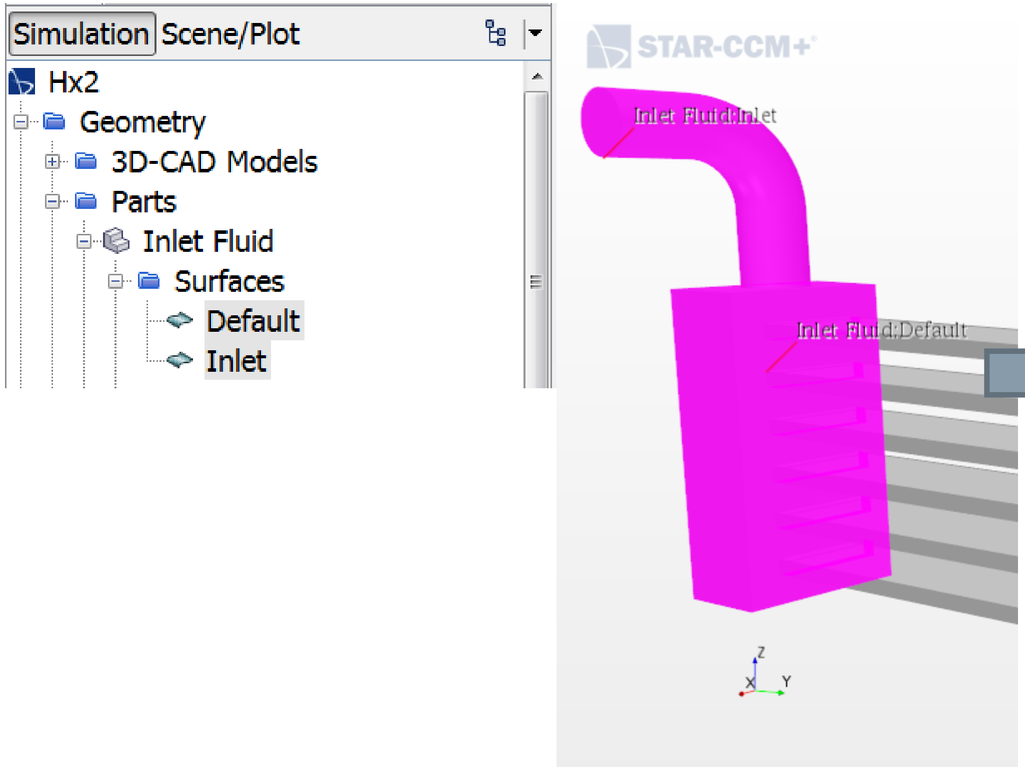
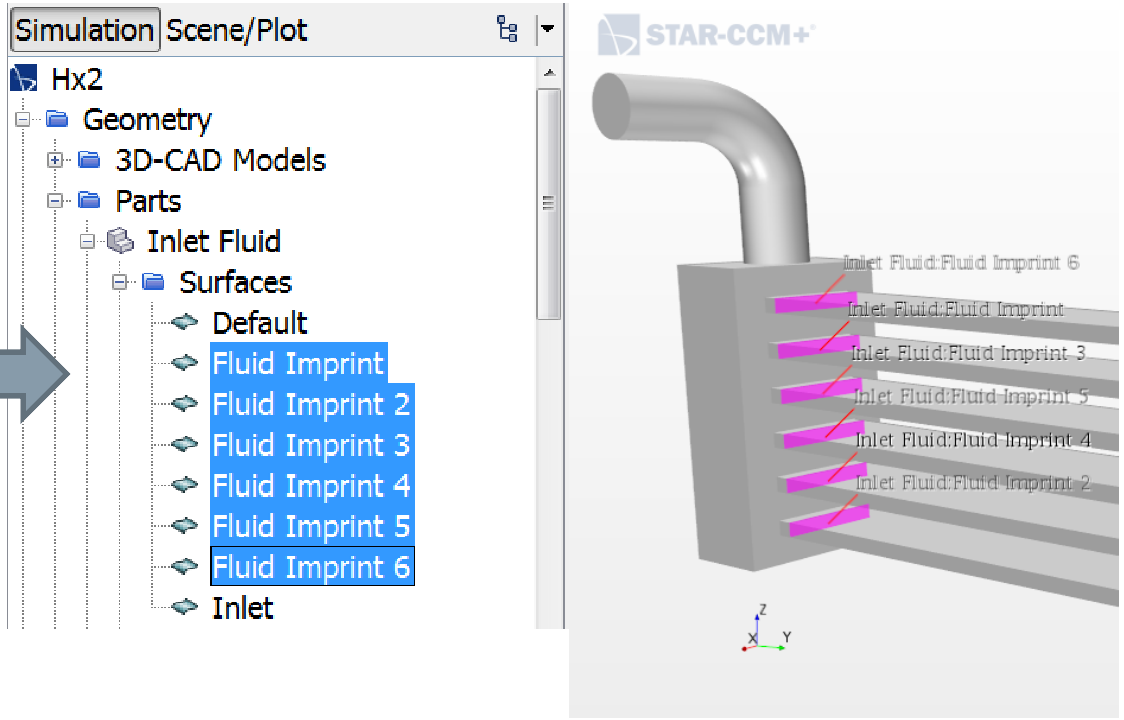
Original Part Surfaces



Resulting Part Surfaces



Geometry Preparation – Weak Contacts

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- The Weak Contact Creator can be used to generate interfaces between parts without imprinting them
  - This means that surfaces are not moved
    - Can be more robust (less “breaking” of complex geometries)
  - Surfaces are also not split
    - No irregular feature curves which can be generated by an imprint
  - Interfaces are always non-conformal in nature
  - Essentially tells STAR-CCM+ that the two parts are touching each other, but not exactly where
    - Lets the solver decide later exactly where the contact occurs

Geometry Preparation Overview

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Conformal

- Can use CAD based imprint if CAD is available for higher quality
- Can use Discrete Imprint for tessellated surfaces or when small tolerances are present
- Will move the surfaces to make them coincident

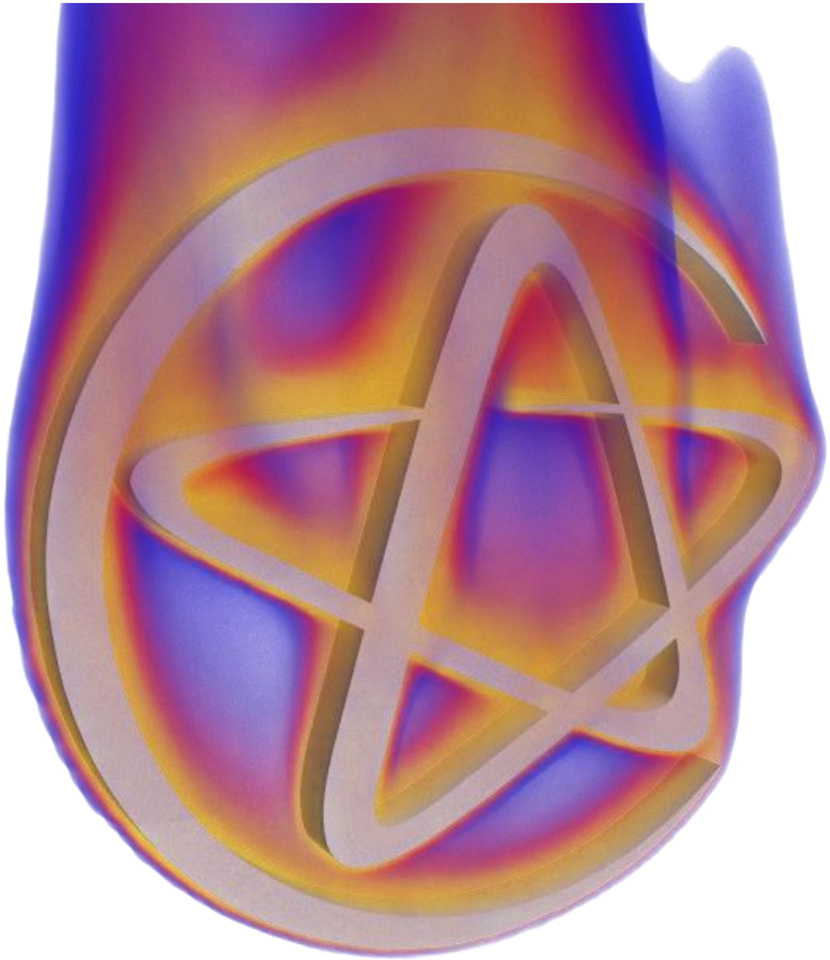
Non-Conformal

- Use non-conformal Discrete Imprint
- Will not move surfaces to make them coincident, but will still split surfaces
- Best used if tolerances are small, but moving surfaces would cause errors in geometry

Weak Contact

- Will not move or split surfaces
- Essentially allows the solver to compute the exact interface later on
- Best used with complex geometries or those with larger/varying tolerances
- Use in conjunction with Mapped Contact Interface

Overview



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Meshing

- When deciding how to generate our mesh, we need to consider
  - How did we prepare the geometry
  - What type of mesh/interfaces are we trying to achieve
- As with geometry preparation, we have three main paths to consider
  1. Conformal mesh/interfaces
  2. Non-conformal mesh/interfaces
  3. Non-conformal mesh/Mapped Contact Interface (weak contact)
- Which one of these options is most appropriate depends on how we have prepared our geometry, and what our domain looks like

Meshing – Conformal Meshing/Interfaces

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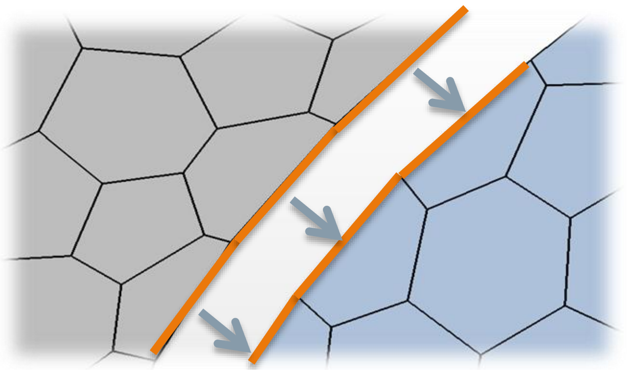
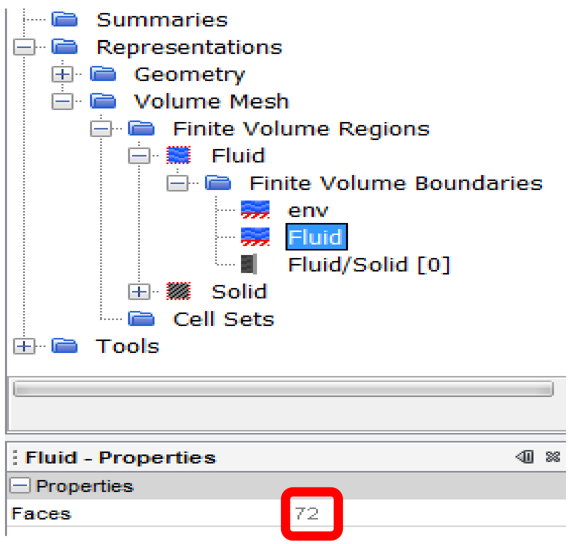
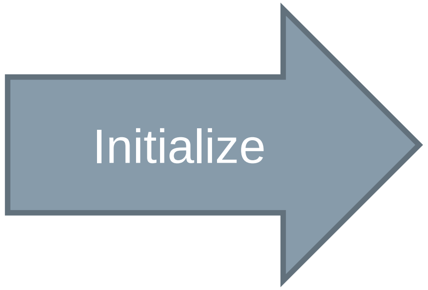
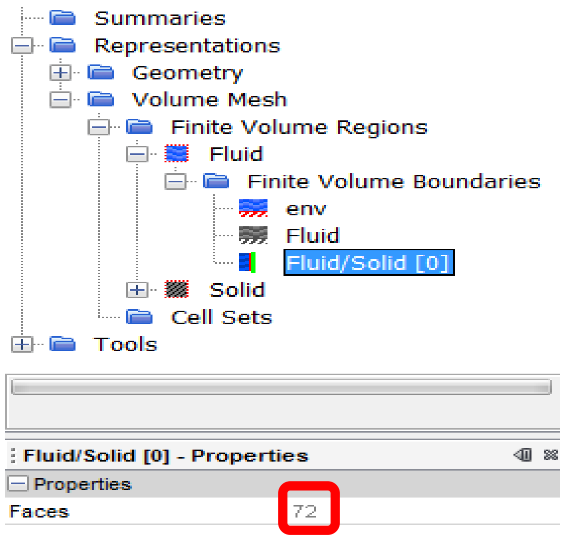
A conformal mesh is desirable for accuracy, so what exactly is a conformal mesh?

- Cells share the same vertices at the interface
- One-to-one face match
- Smooth heat transfer across regions
- Not much to worry about in terms of the interfaces









Meshing – Conformal Meshing

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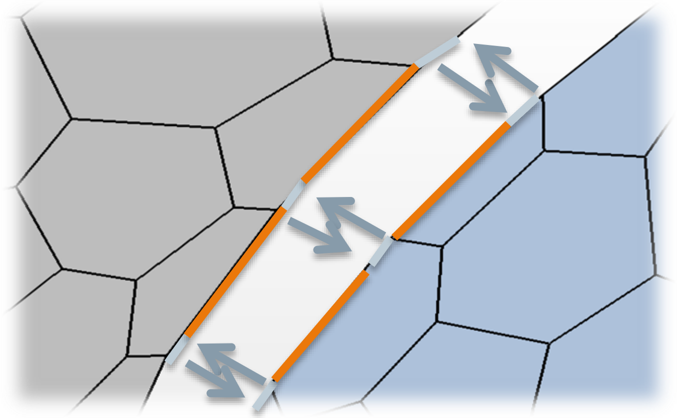
So, a conformal mesh is preferred…..how do I generate one?

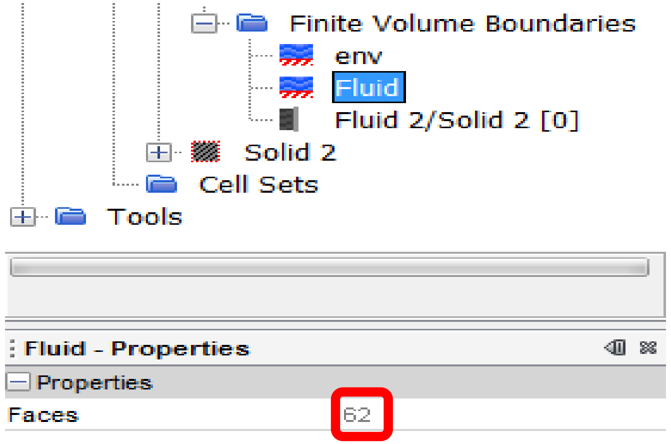
Requirements:

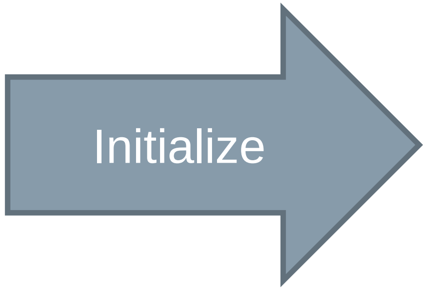
- Geometry must be imprinted
  - Either CAD imprint or Discrete conformal
- Parts must be in the same mesh operation
  - Per-part/concurrent meshing disabled
- Polyhedral mesher must be used
  - Trimmed cell mesher does not guarantee conformality between regions

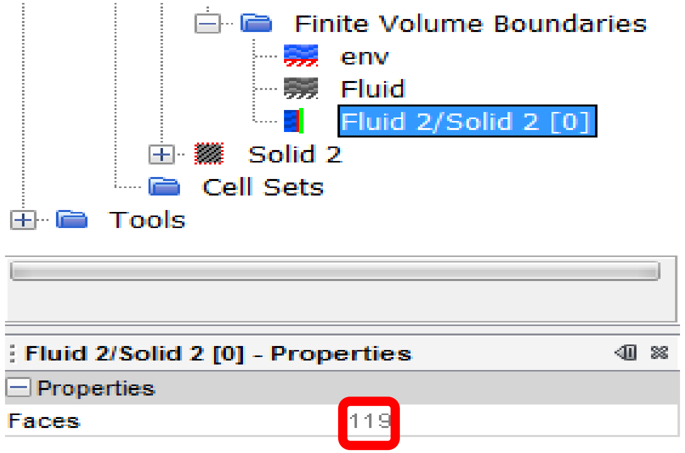
Meshing – Non-conformal Meshing

- What if I can't generate a conformal mesh?
  - Sometimes, geometry is too complex or dirty to create conformal interfaces
  - Per-part or concurrent meshing is desired for efficient meshing or large numbers of parts
- That's OK!
  - Use non-conformal imprint
- STAR-CCM+ will automatically attempt to split faces at the interface in order to achieve a match



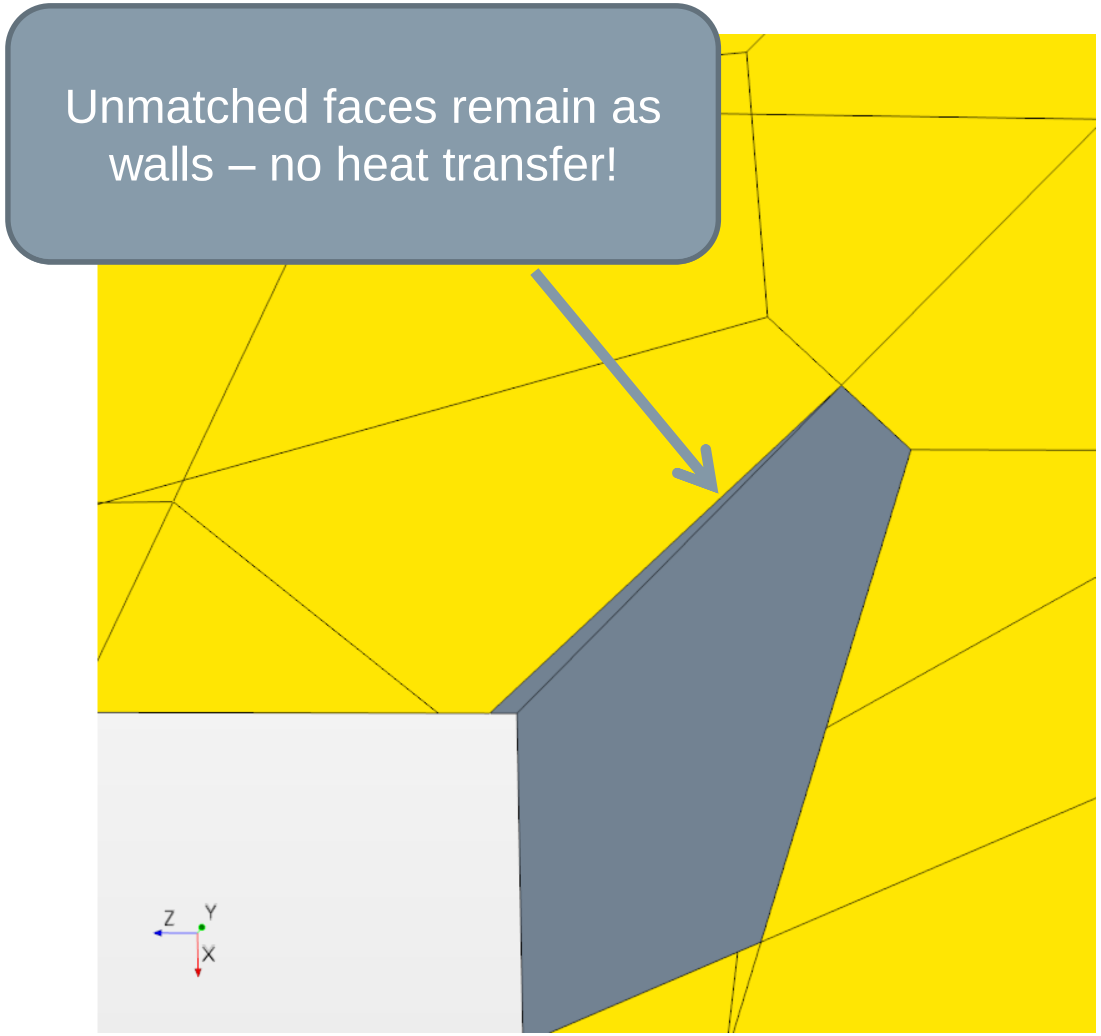






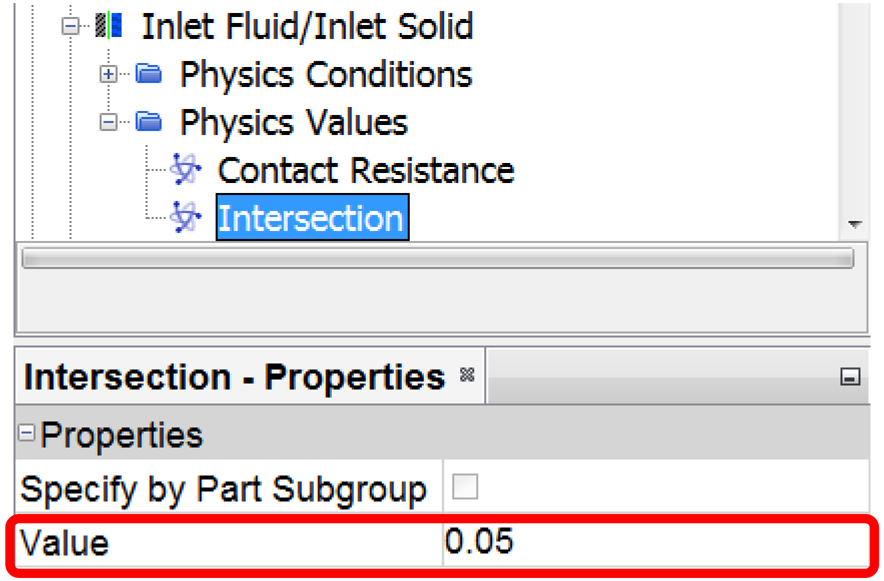
Meshing – Non-Conformal Meshing

- When generating a non-conformal mesh, face matching at the interface is important
  - If there are large gaps or changes in mesh resolution across the interface, the solver may not be able to split and match all faces
- Umatched faces will not be included in interface calculations
  - Effectively treated as walls, meaning they are adiabatic
- These faces can be visualized in a mesh scene
  - Unmatched faces show as default grey wall



Meshing – Non-Conformal Meshing

- Ensure high matching across the interface (>98%)
  - Generating similar cell sizes on both sides of the interface can help in achieving higher matching
  - Can increase interface intersection tolerance to attain greater matching
    - Generally, if you need to go higher than 0.1, should consider repairing the geometry or using a Weak Contact/Mapped Contact Interface instead



Meshing – Non-Conformal Weak Contact

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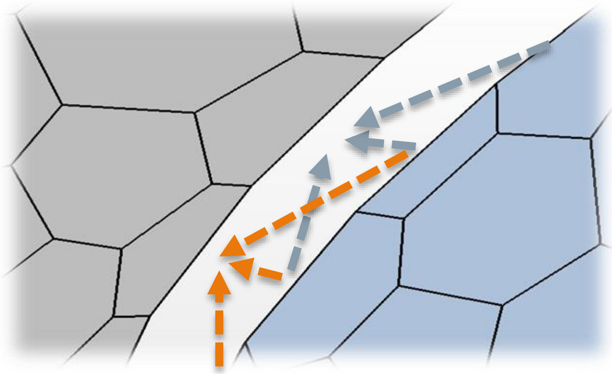
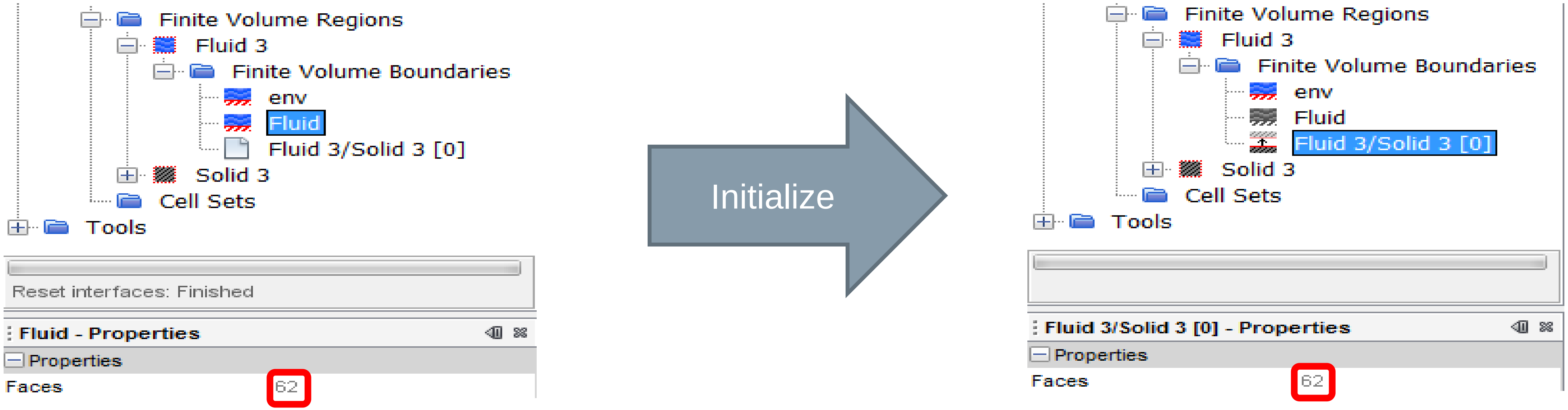
- Useful for very dirty geometries (where moving or splitting faces would cause issues) and when good matching using a regular non-conformal interface cannot be achieved
  - Can make use of concurrent meshing
  - Attempts no interface intersection
    - Uses proximity based data mapper to calculate heat transfer across interface (Mapped Contact Interface)
    - Not guaranteed to conserve energy





Meshing – Non-Conformal Weak Contact

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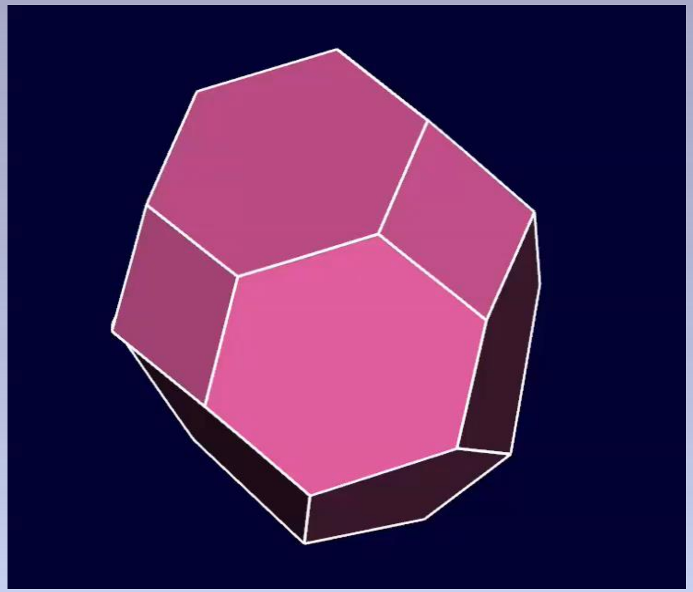
- Similar to a regular non-conformal mesh, ensuring similar cell sizes on both sides of the interface is important
  - Helps ensure more accurate mapping and energy conservation

Meshing – Mesh Model Setup

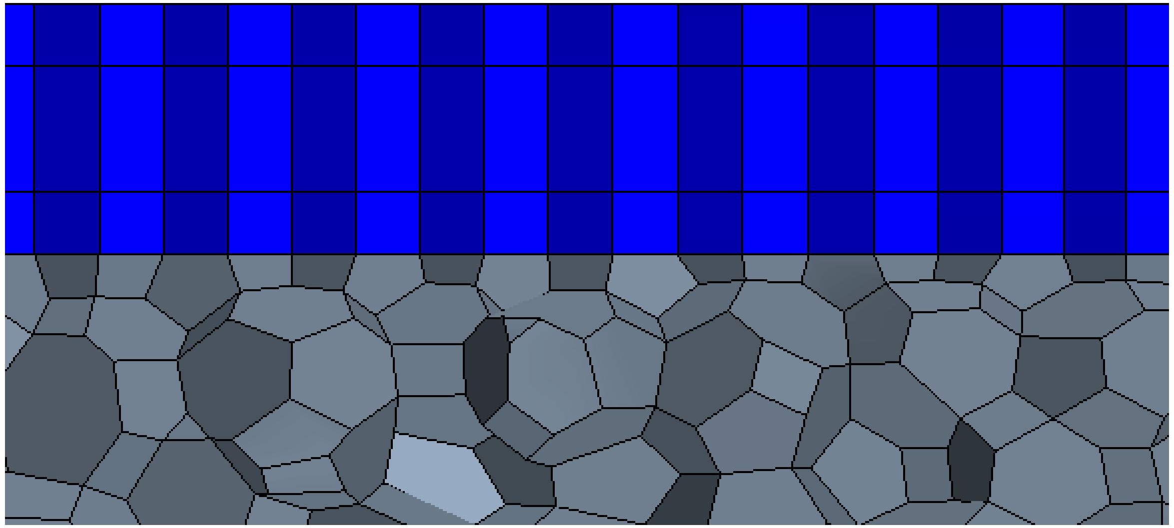
- Polyhedral Mesher Recommended
  - More effective for complex flows
  - Accurately captures complex geometric shapes
  - Can be used in conjuction with Thin Mesher
  - Can generate a conformal mesh

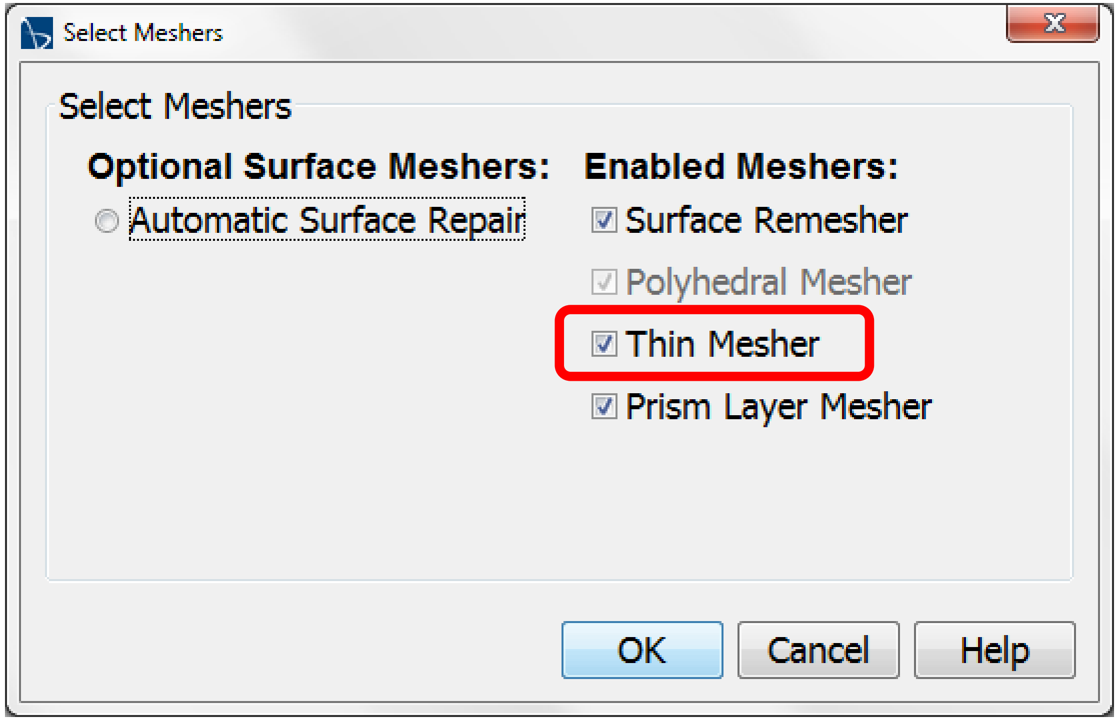


Polyhedral Cell

Meshing – Thin Meshing

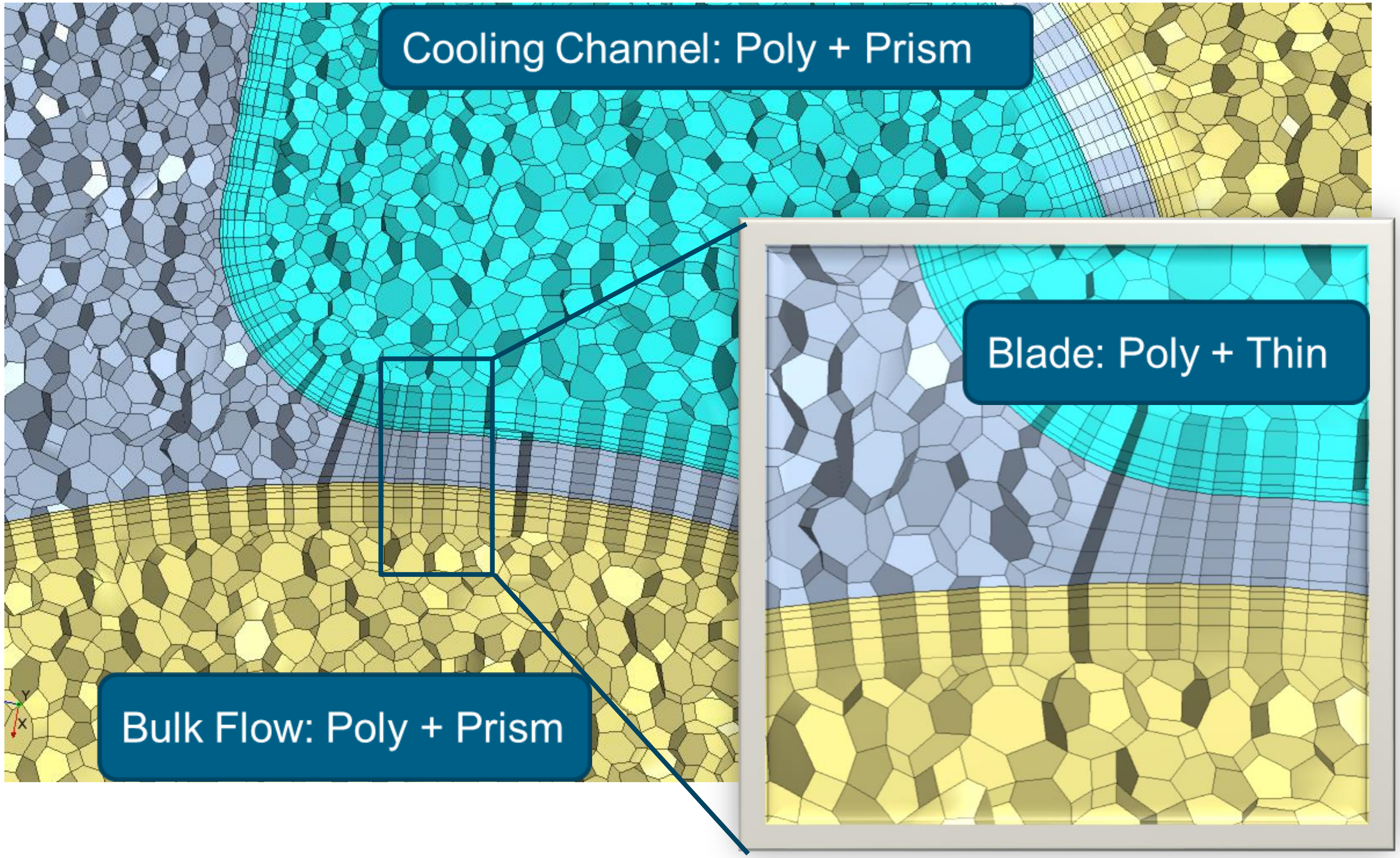
- Thin Mesher should be used when thin parts are present
  - Produces higher quality prismatic cells which fit better into thin areas
  - Reduces mesh count compared to packing a large number of very small poly cells to produce the desired mesh resolution





Meshing – Thin Meshing

- Thin Mesher automatically detects thin regions, and generates prismatic cells
- Automatically transitions back to poly in bulk areas
- Mesh is fully conformal (in transition from thin to poly cells) as well as between parts (if all other requirements are met)



Meshing – Mesh Quality

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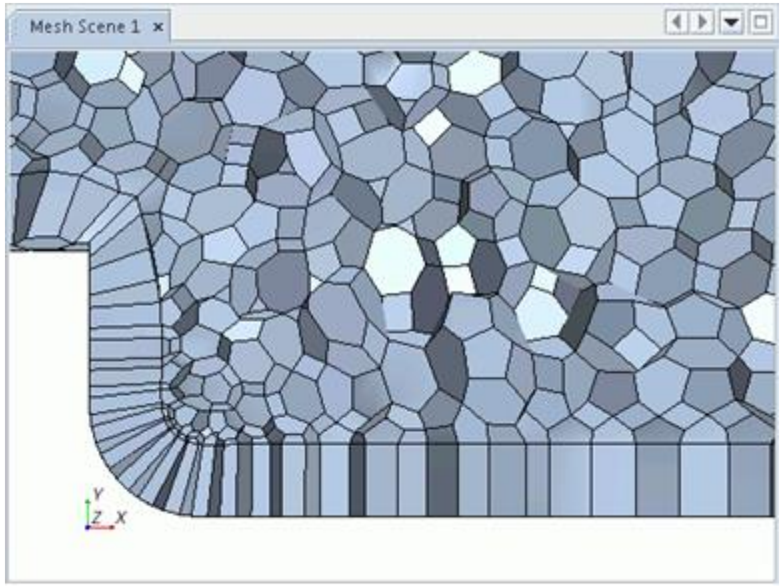
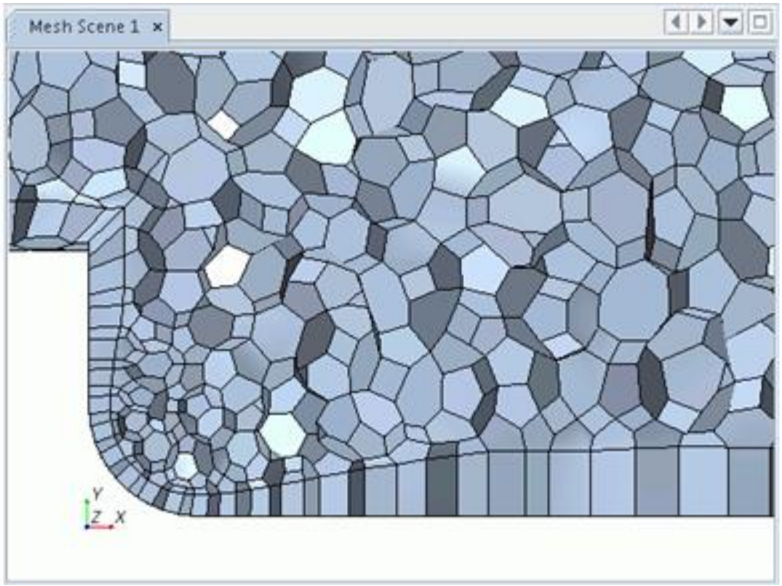
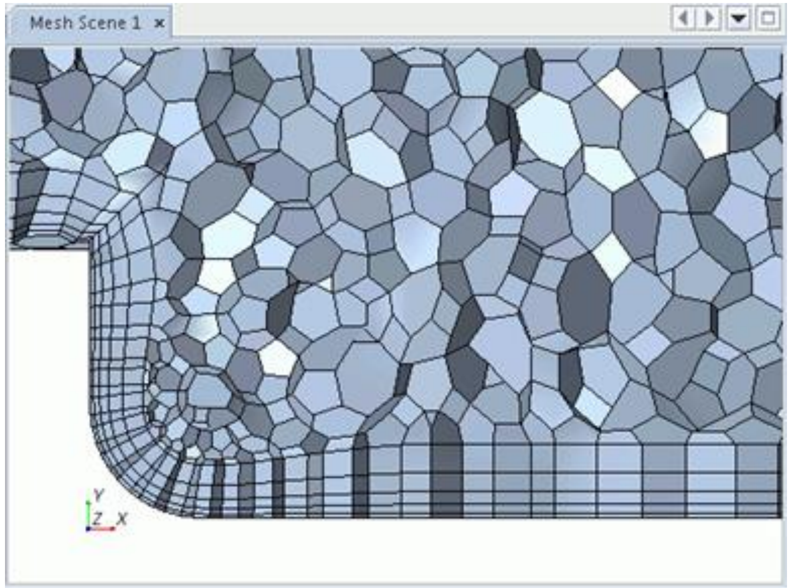
- Ensure smooth transition from prisms to core volume mesh – enough layers to resolve boundary layer
  - Setting Near Core Layer Aspect Ratio (NCLAR) on Prism Layer mesher can help with this (0.5-1.0)
    - Will reduce prism layer thickness to prevent last prism layer from having higher aspect ratio than first volume cell



BAD
NCLAR= 0,
Bad Transition, Bad Resolution



BETTER
NCLAR= 1.0,
Better Transition, Bad Resolution



BEST
NCLAR= 1.0, Added Layers
Better Transition, Better Resolution

Meshing Overview

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Conformal	Non-Conformal	Weak Contact/Mapped Interface
• Highest geometry preparation requirements • Most accurate from solver standpoint • Requires conformal imprint (either CAD or Discrete) • All parts must be meshed in the same operation using Polyhedral Mesh • Cannot make use of concurrent meshing for large assemblies (will break conformality)	• Fewer requirements on geometry preparation (do not need to make surfaces coincident) • Requires non-conformal Discrete Imprint • Can make use of concurrent meshing • Can make use of other mesh types, such as Trimmed Cell Mesher • More due diligence needed to ensure high face matching on interface	• Least requirements on geometry preparation • Will not move or split surfaces • Essentially allows the solver to compute the exact interface at runtime • Best used with complex geometries or those with larger/varying tolerances • Most due diligence required at the interface to ensure energy conservation due to use of mapping approach

Overview

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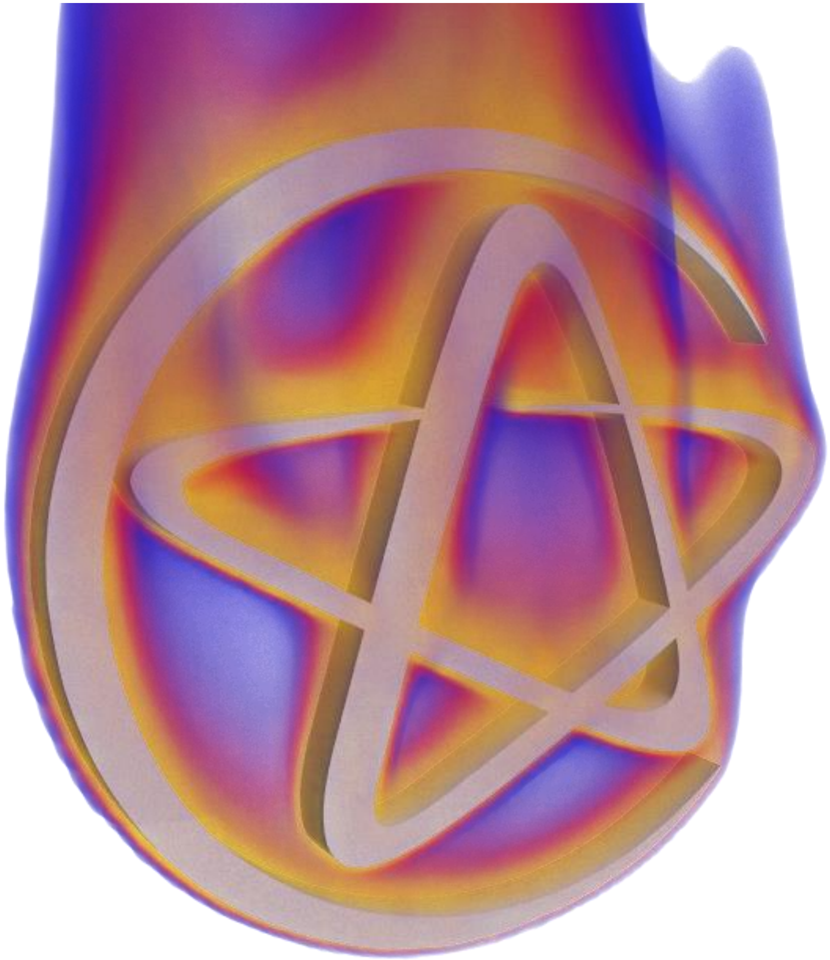

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Parts Based Workflow

- Why parts based?
  - Improves scalability and usability, both in terms of hardware usage and engineer interaction
  - Clearer simulation setup
    - Less clutter
    - Easier sim tree navigation
    - Less entities requiring engineer’s time to setup
  - Improved scalability
    - Numerically more efficient for the solver
- Improvements realized through several reductions
  - Reduced number of Continua, Regions, and Boundaries
    - Single region can represent multiple solid materials
    - Single continua can represent multiple solid physics
    - Single interface can represent multiple part contacts
  - Less engineer time required to perform setup and provide inputs due to simplification of the user interface

Parts Based Workflow – Motivation: VTM Case

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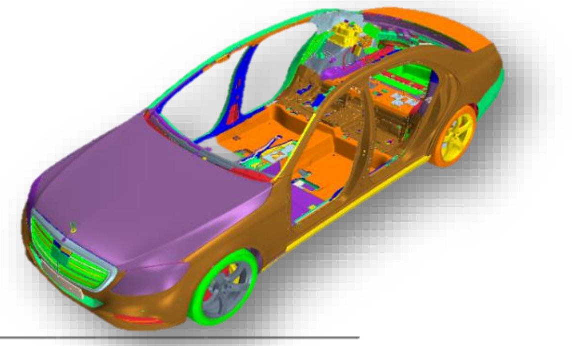
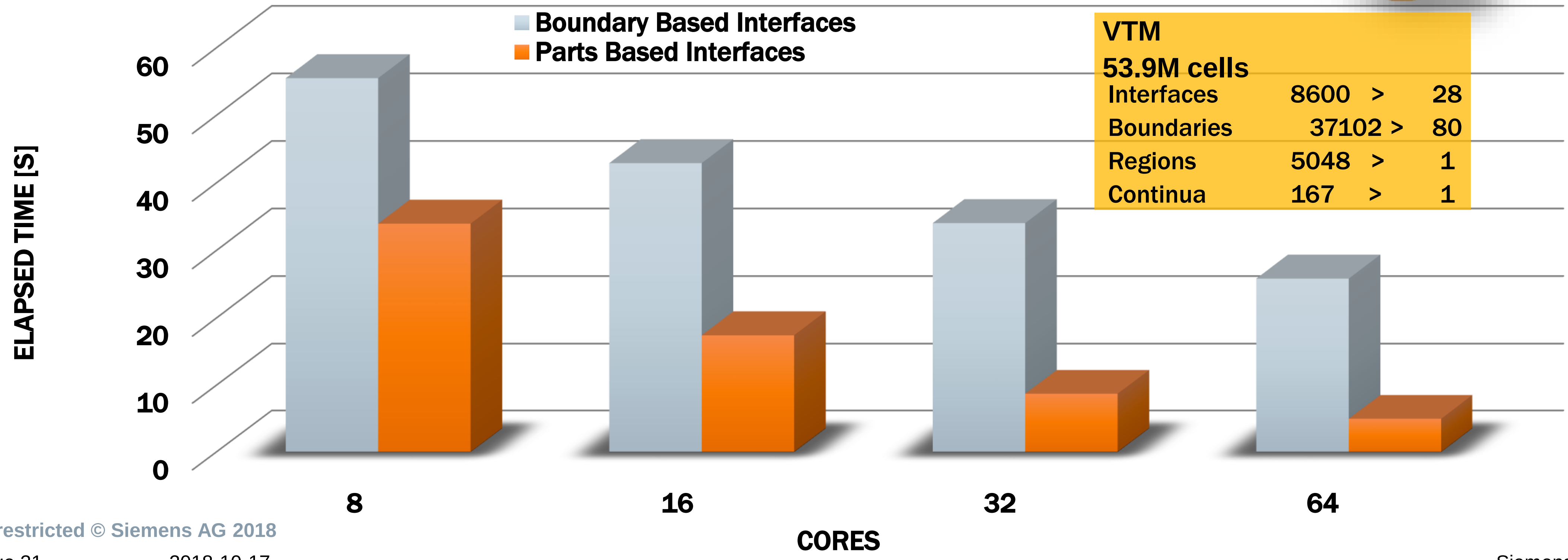
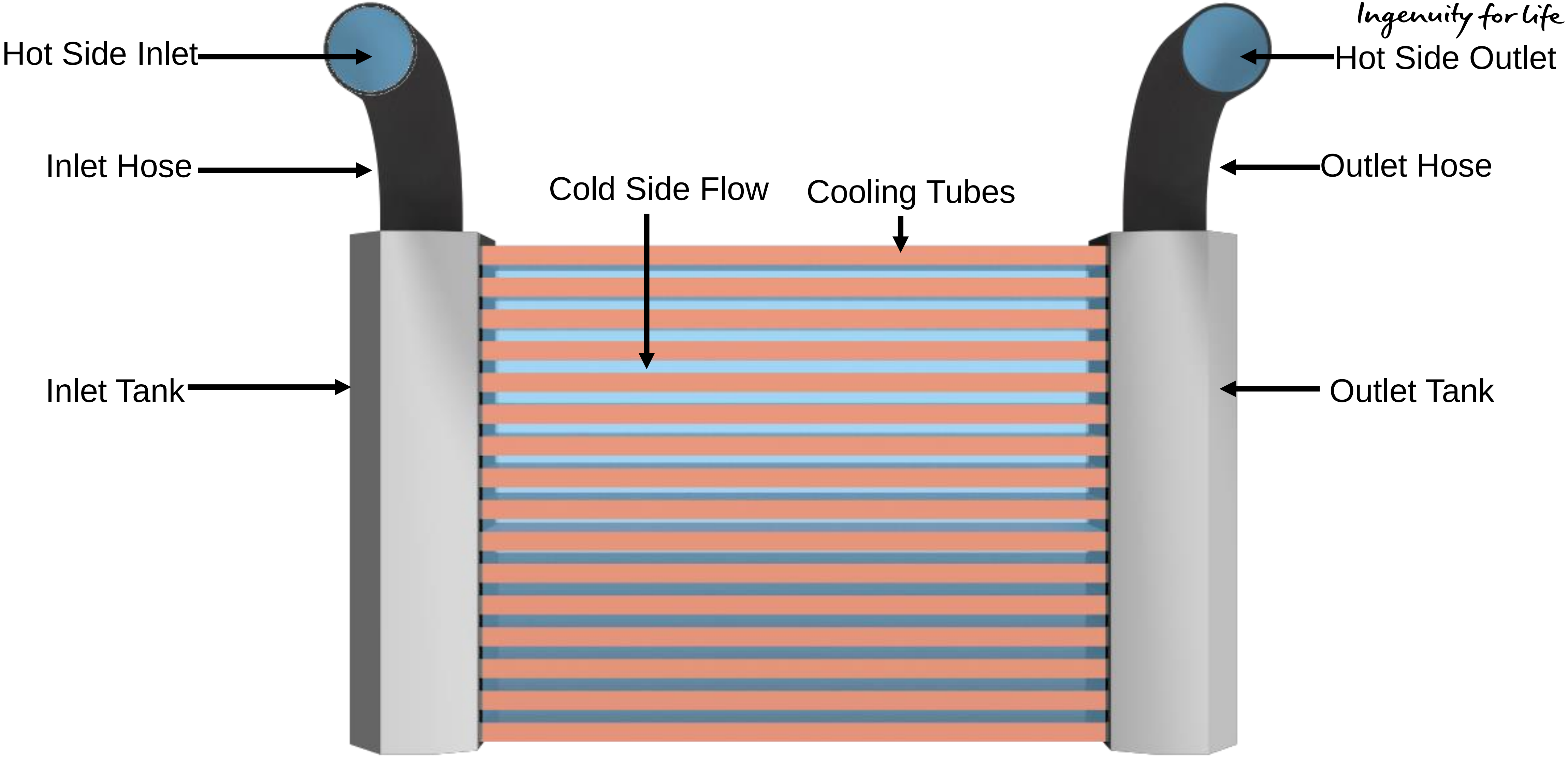


Reduced solution time for large assemblies

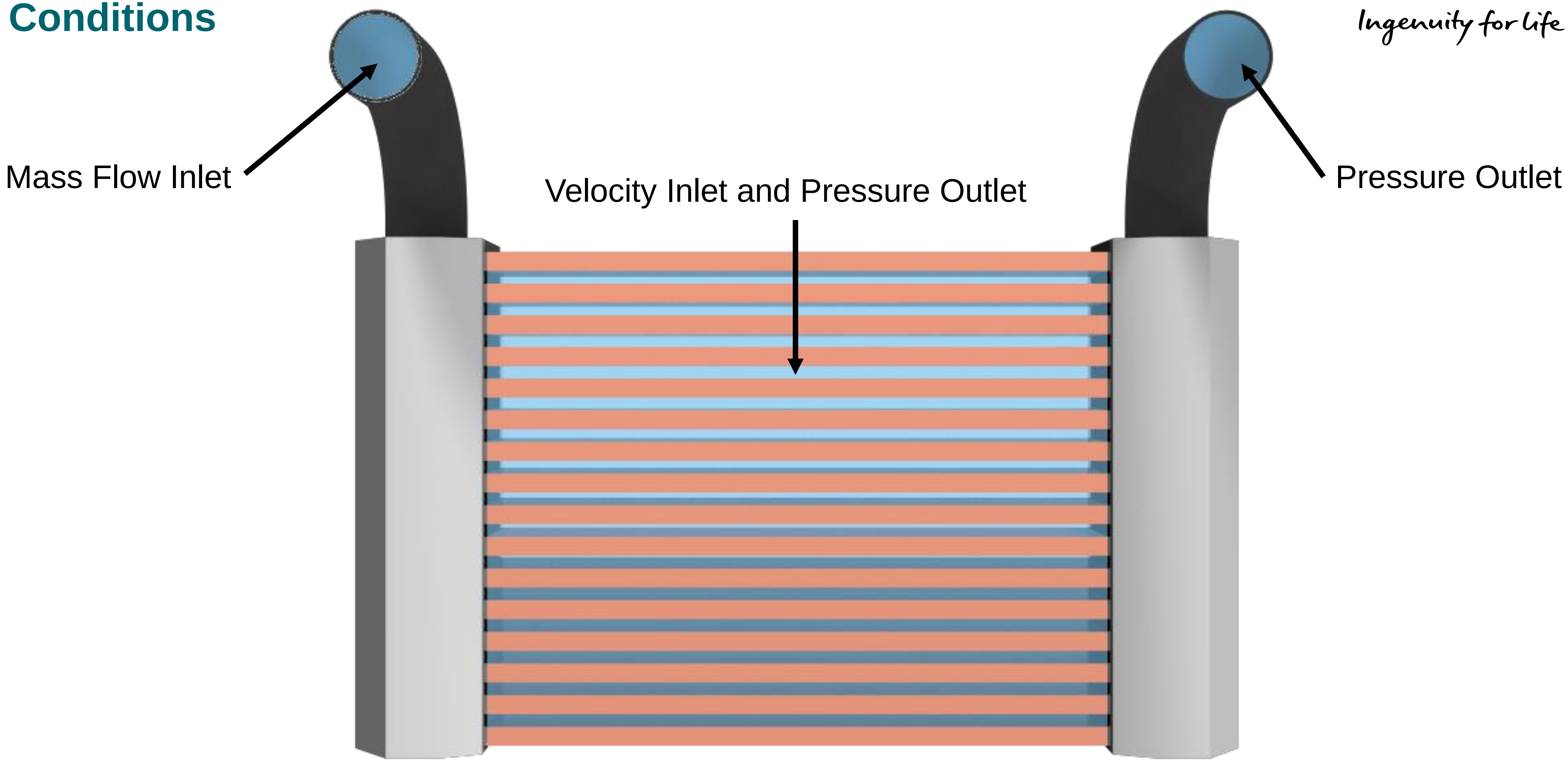
- Allows consolidation of regions, boundaries and interfaces
- Benefits seen in electronics cooling, vehicle thermal management, steam generators etc.



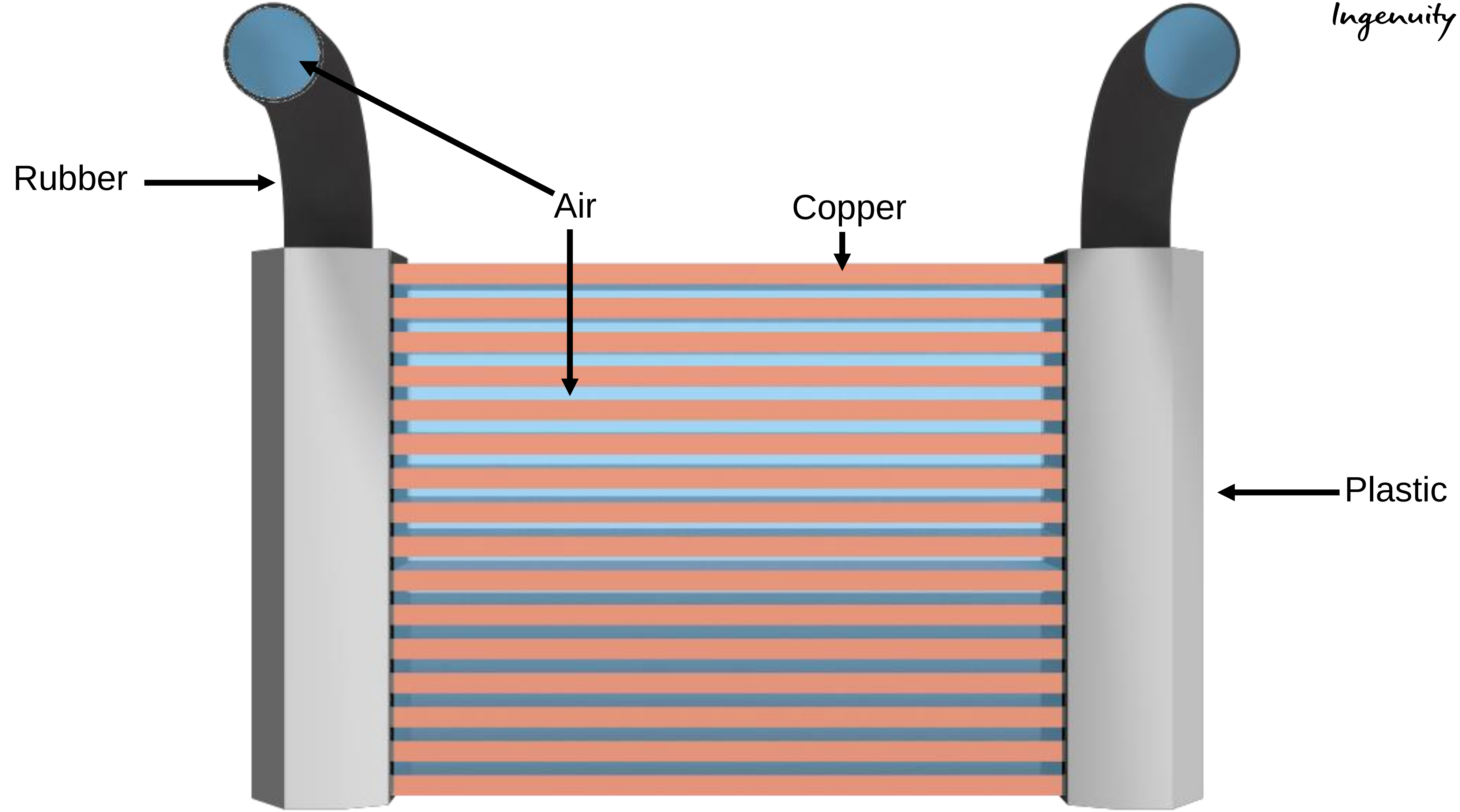
Parts Based Setup – Generic Heat Exchanger



Parts Based Setup – Generic Heat Exchanger Boundary Conditions



Parts Based Setup – Generic Heat Exchanger



Parts Based Setup – Generic Heat Exchanger Materials

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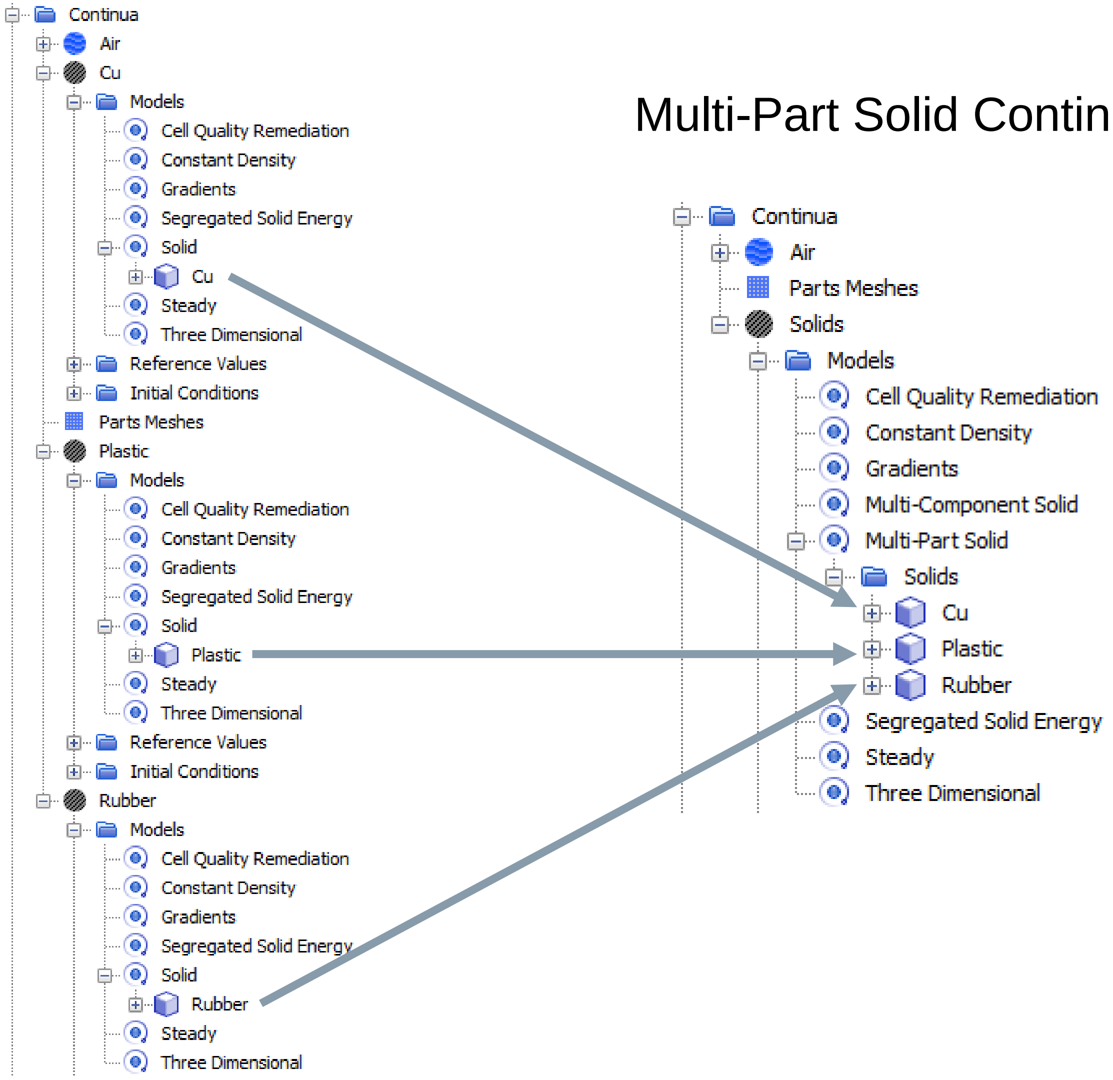
Solid Physics Continua

Multi-Part Solid Continuum



Parts Based Setup – Generic Heat Exchanger Regions

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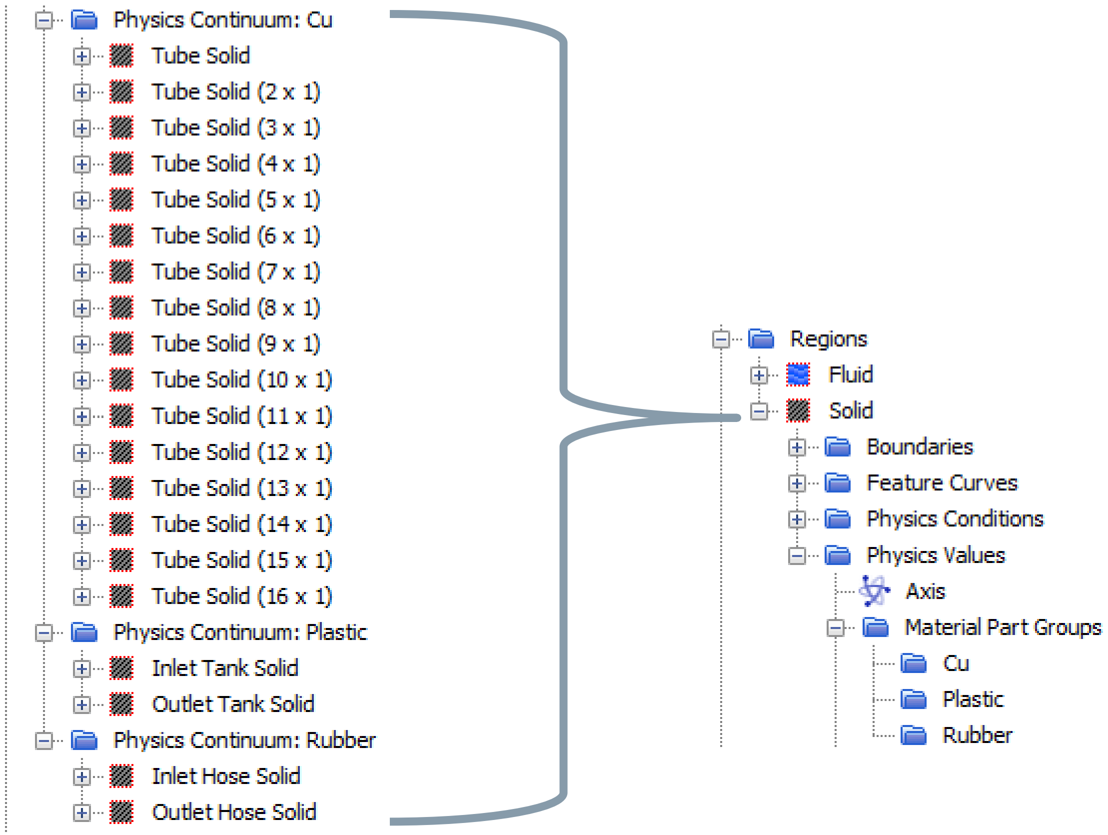

Parts Based Setup – Generic Heat Exchanger Interfaces

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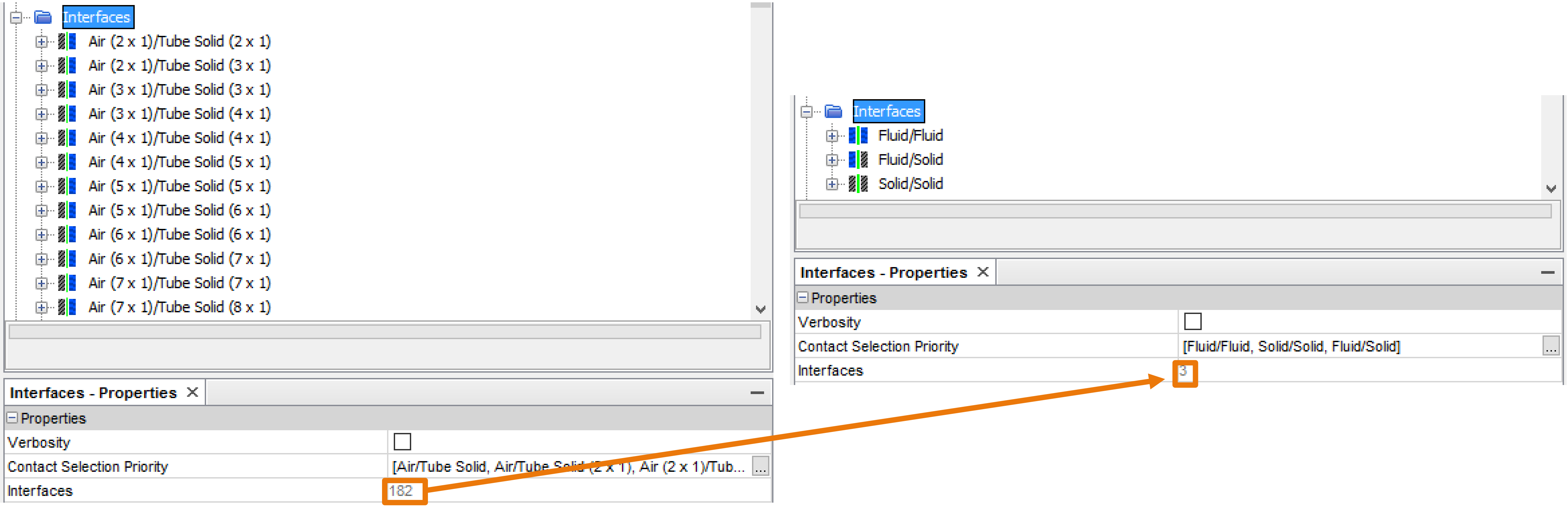

Parts Based Setup - Generic Heat Exchanger Results

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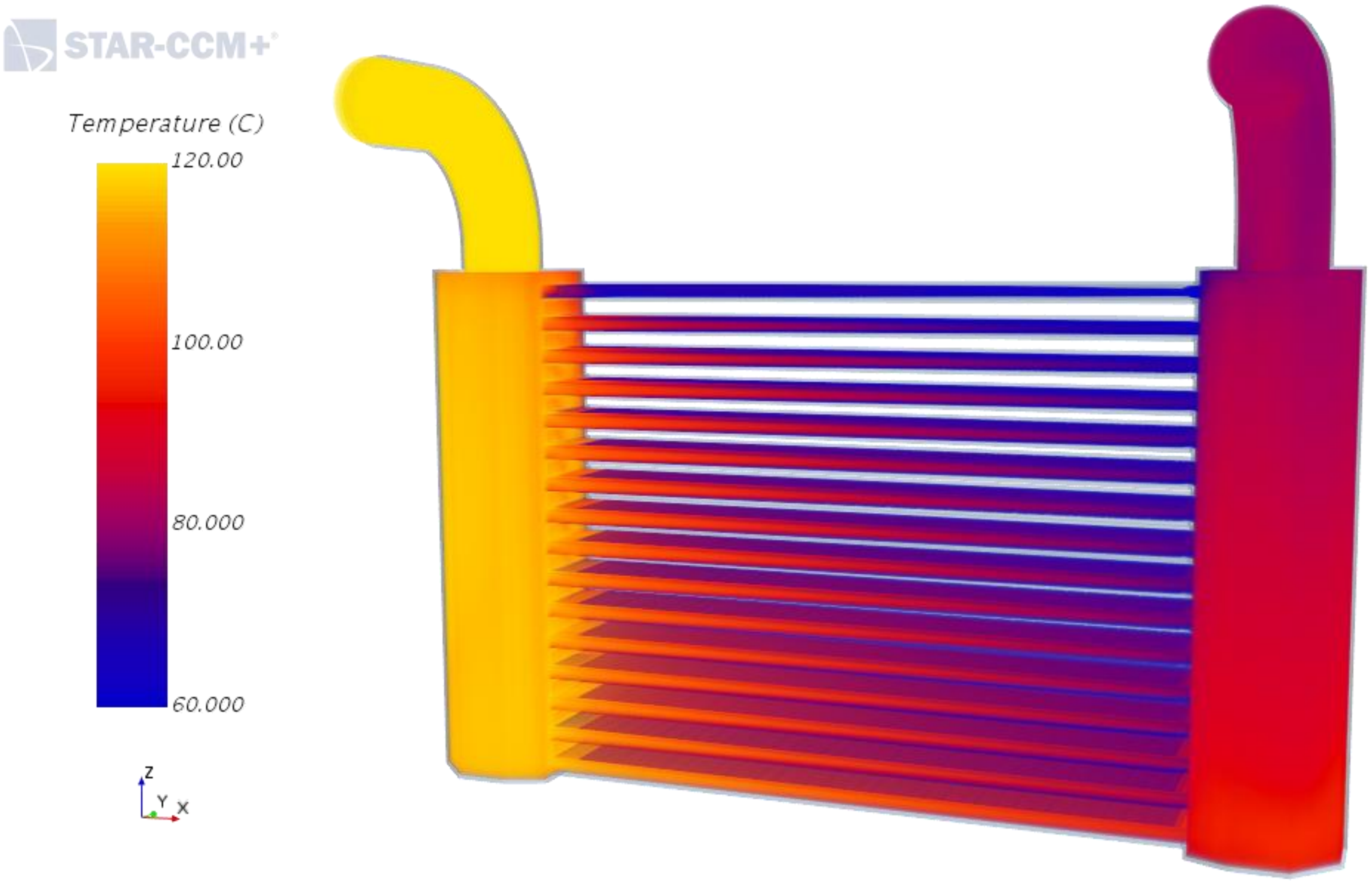
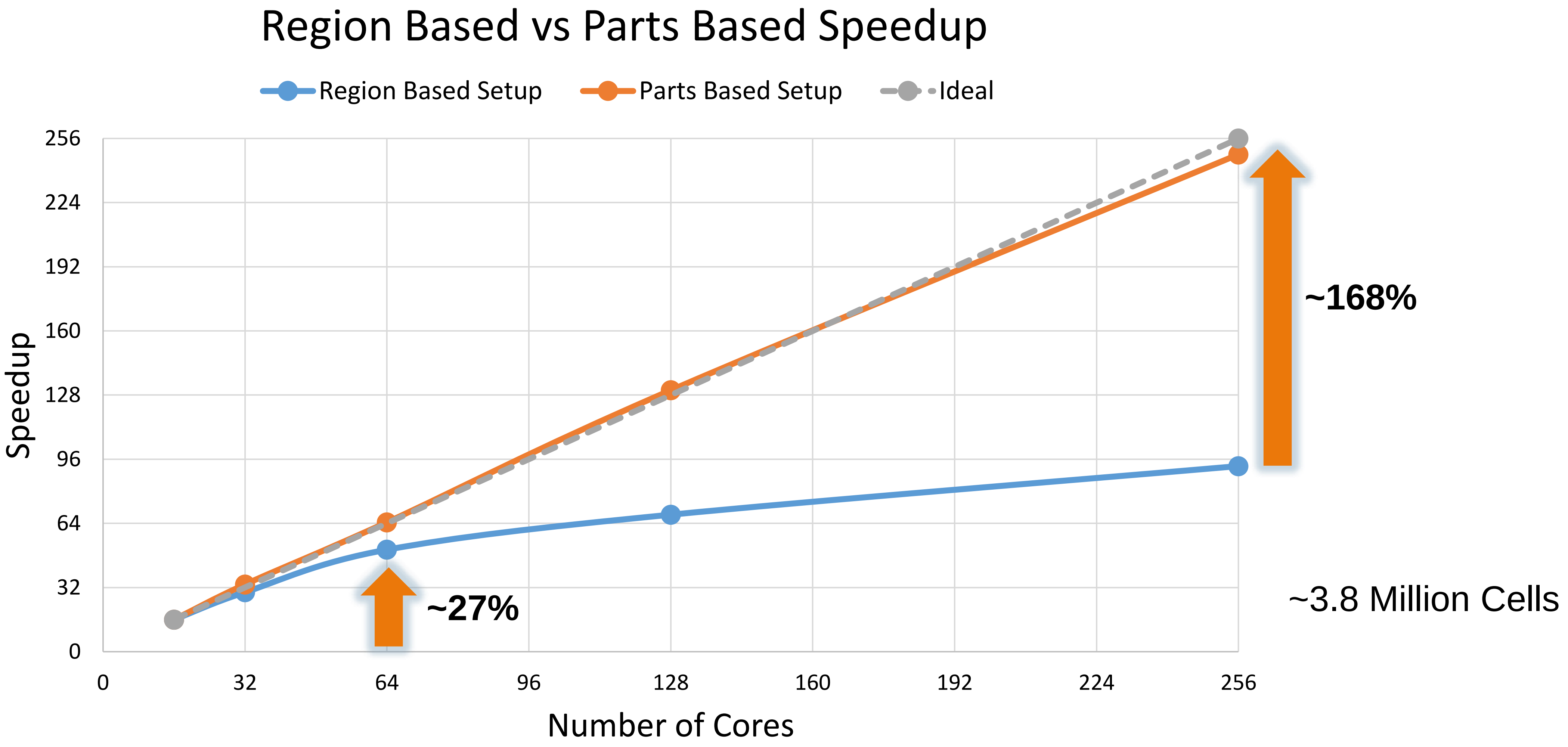
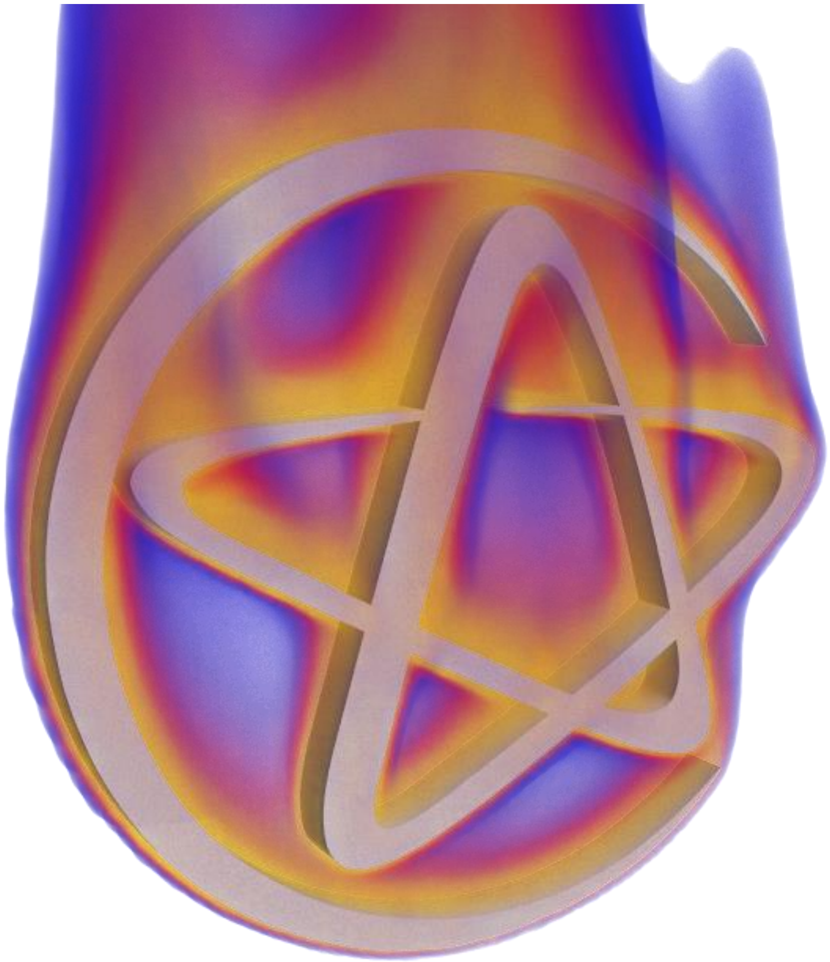


	Region Based	Parts Based
Continua	4	2
Regions	55	2
Boundaries	599	13
Interfaces	182	3
Cells	3872543	3872543

Parts Based Setup – Generic Heat Exchanger Performance



Overview



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Convergence - Under Relaxation Factors

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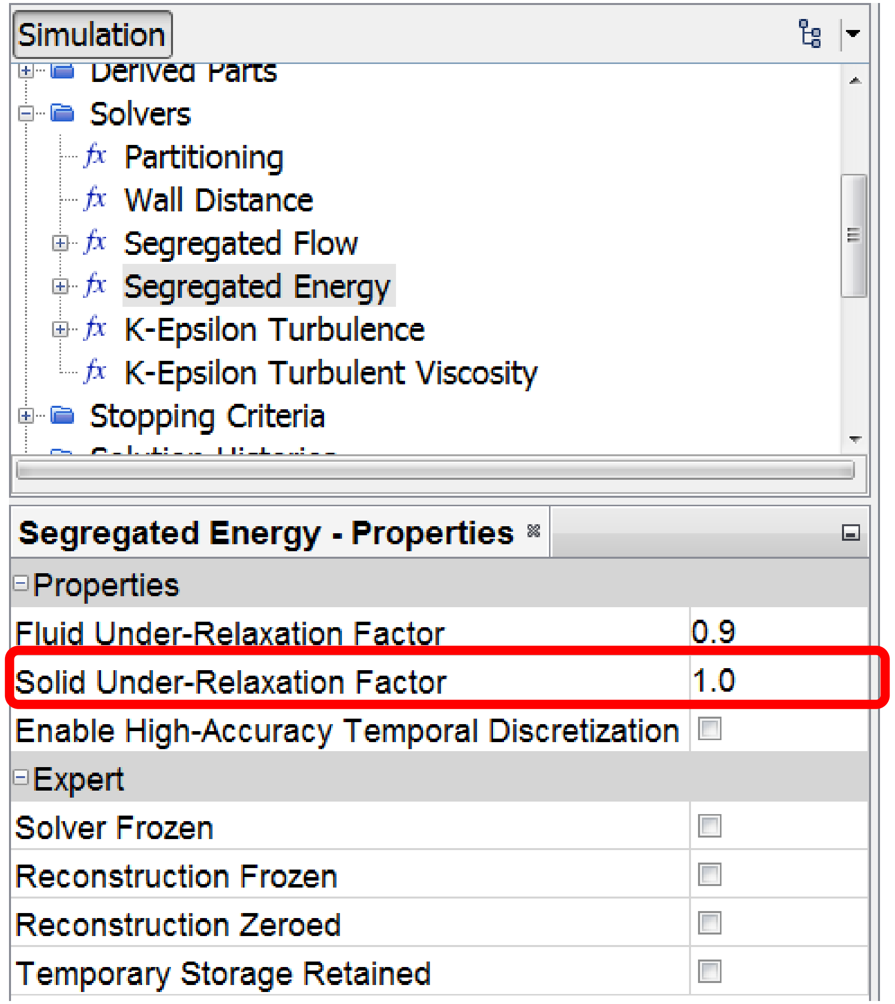
- Under Relaxation Factors (URF's) effect the speed and stability of convergence
  - Too high – solution may become unstable, or diverge
  - Too low – solution takes too long to converge

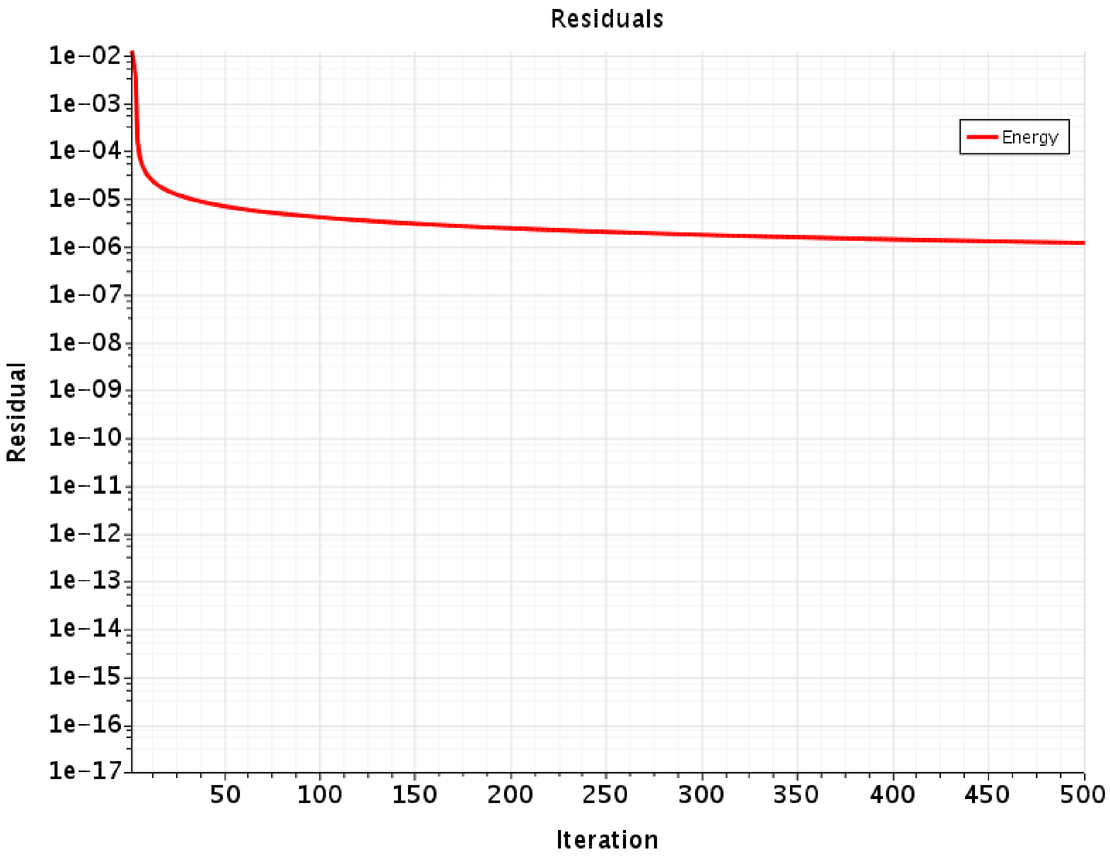
Convergence - Under Relaxation Factors

- Solid Energy URF can be increased
  - Default value of 0.99 is stable, but causes slow convergence
  - Can be increased to 0.9999 or 1.0

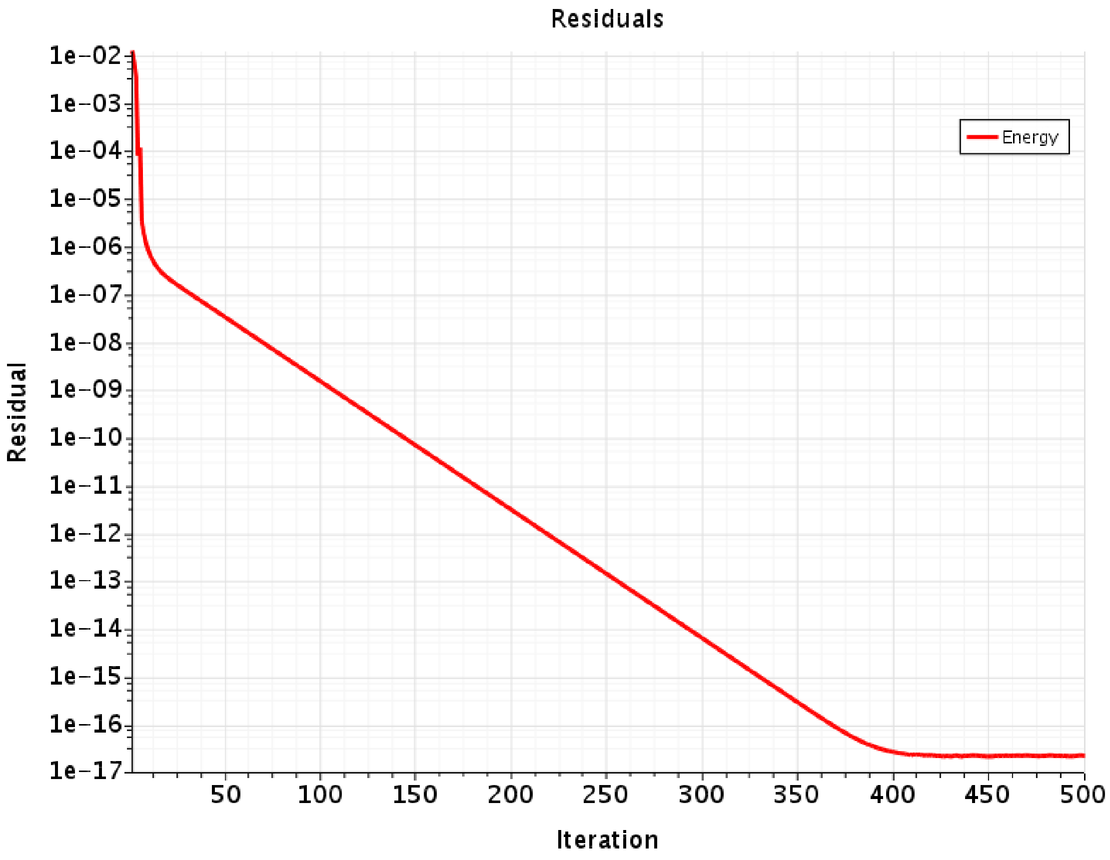


Convergence – Effect of Solid Energy URF

Solid Energy URF = 0.99



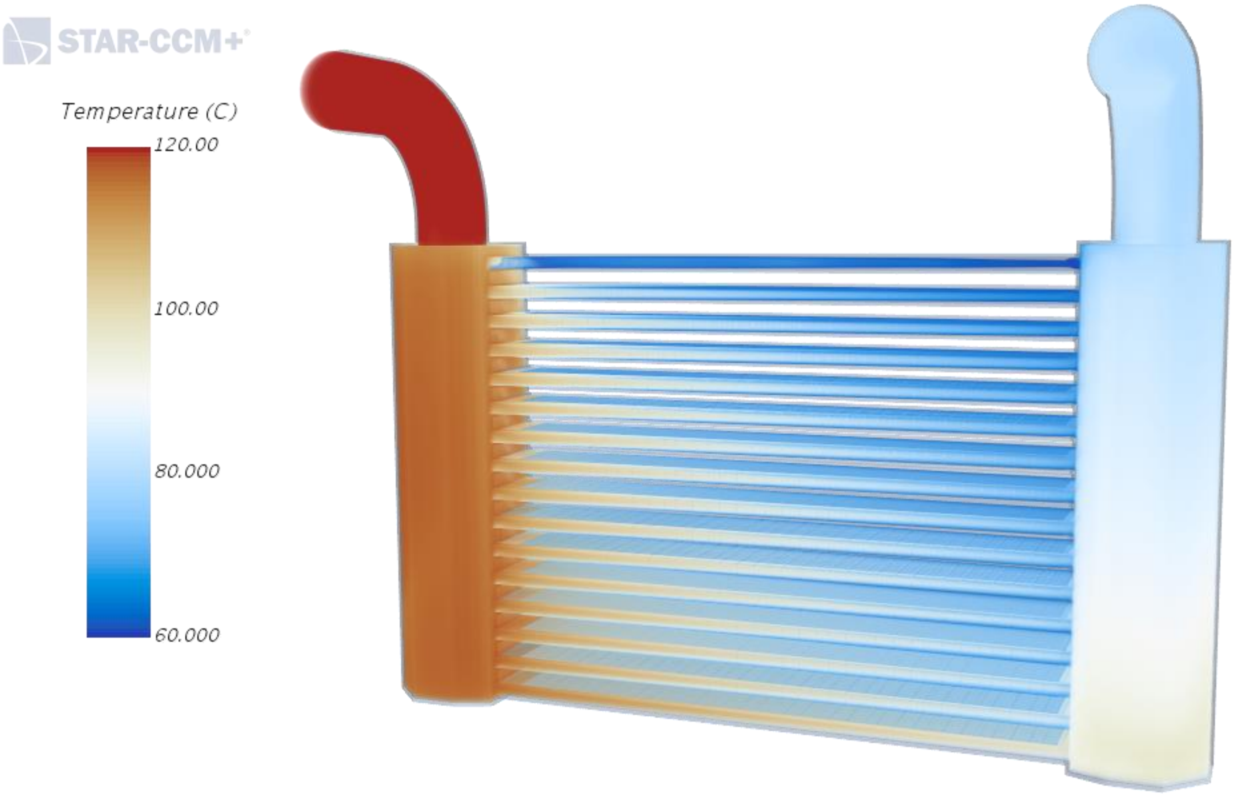
Solid Energy URF = 1.0



Convergence – Monitoring Convergence

- How do we know solution has converged?
- Are residuals enough?

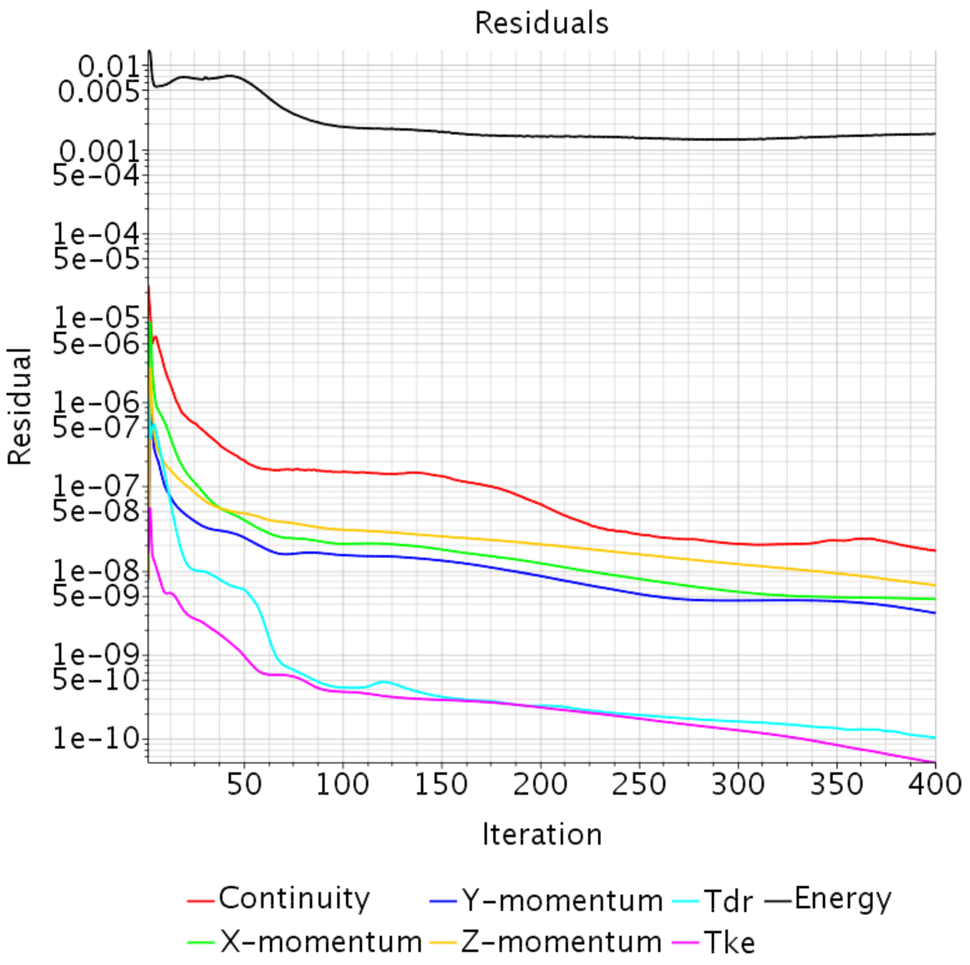
- Lets take a look at our previous example



Convergence – Monitoring Convergence

- Looking at the residuals, we might think this simulation is converged
  - Values are low
  - Most have dropped a few orders of magnitude

- But lets take a deeper look at some engineering quantities of interest

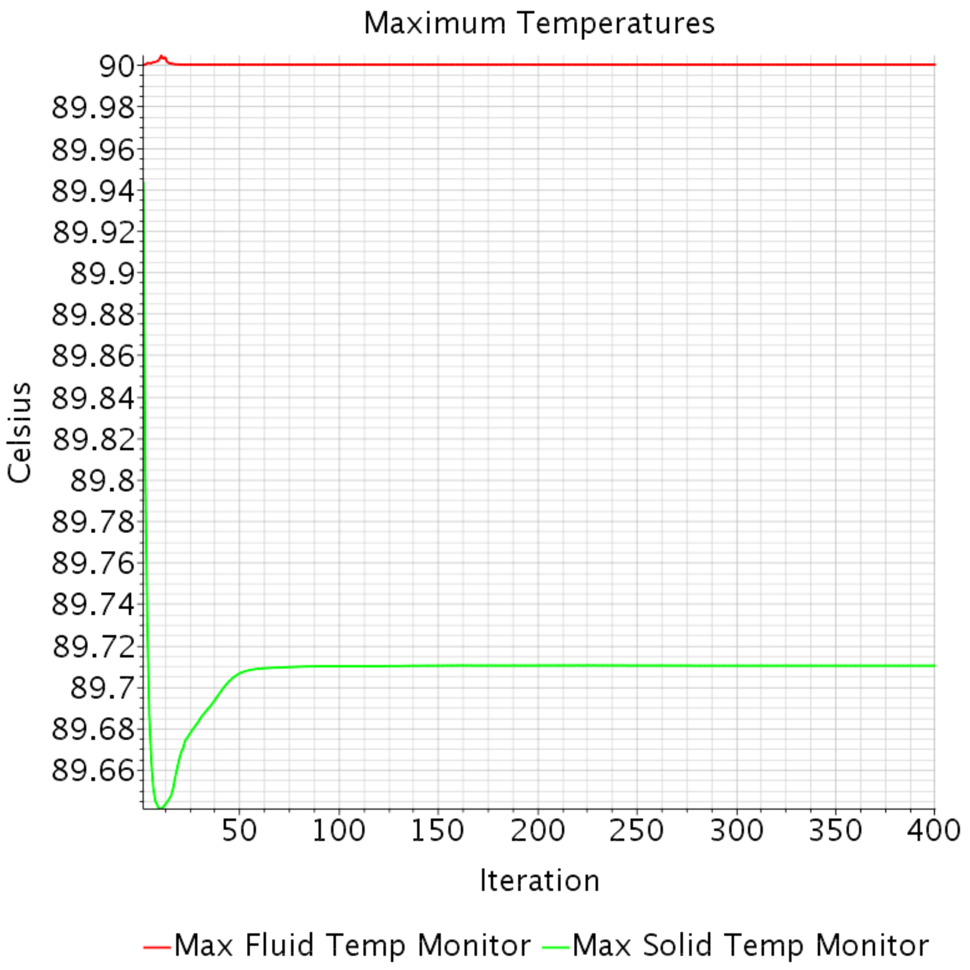


Convergence – Monitoring Convergence

- Maximum Temperatures
  - Use Maximum Report
  - Monitor near locations of interest
  - Should asymptote to a physically reasonable value

Not Changing

Conclusion: Converged

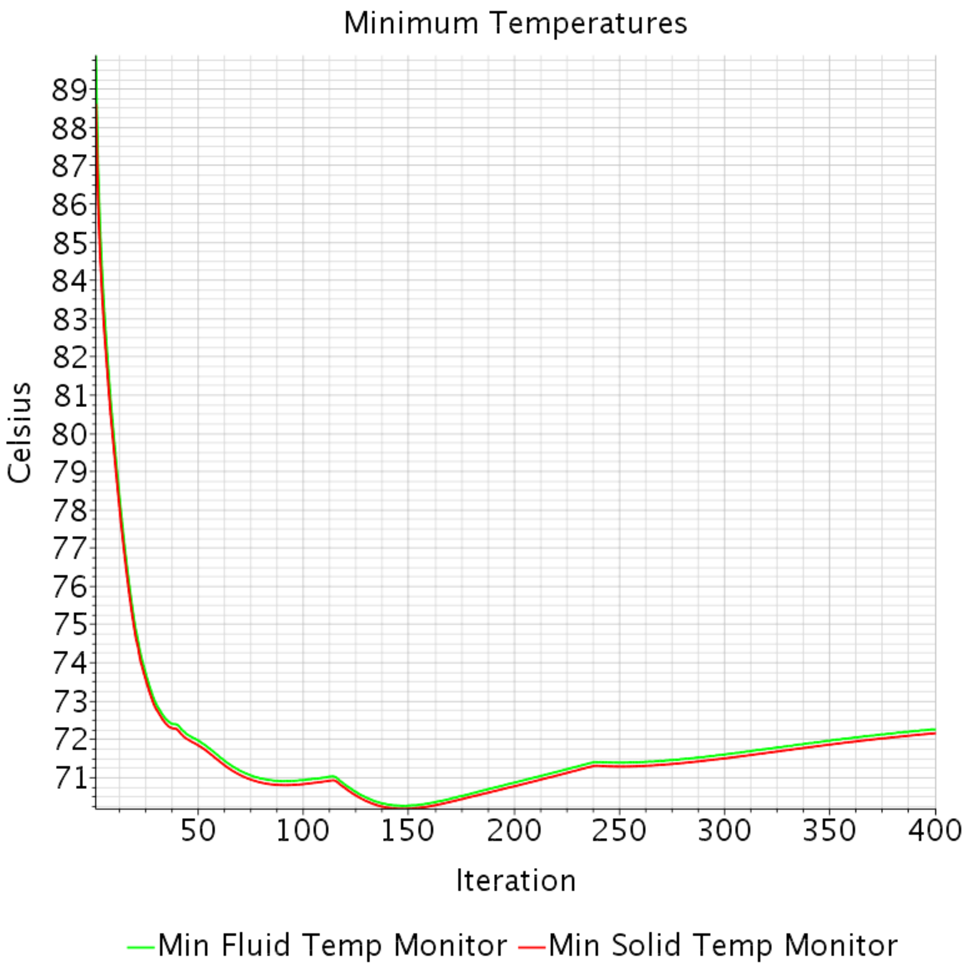


Convergence – Monitoring Convergence

- Minimum Temperatures
  - Use Minimum Report
  - Monitor near locations of interest
  - Should asymptote to a physically reasonable value

Still Changing

Conclusion: Not Converged

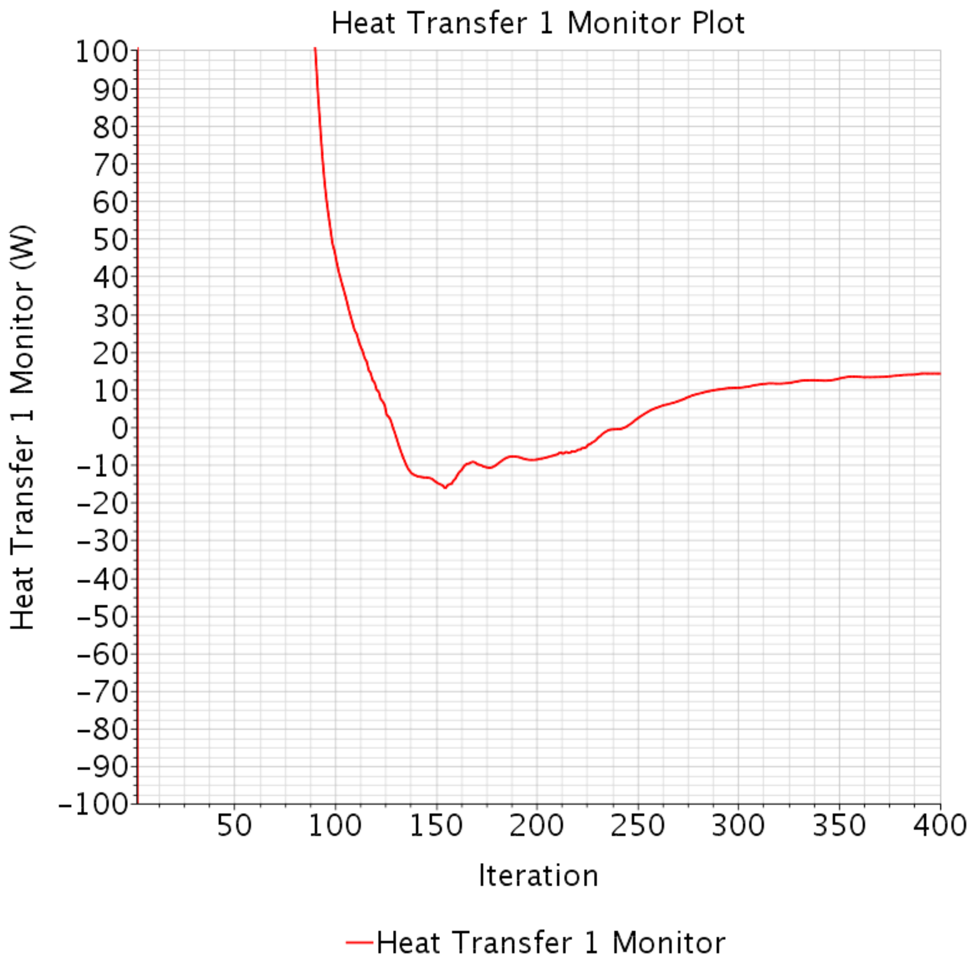


Convergence – Monitoring Convergence

- Heat Transfer
  - Use Heat Transfer Report on all regions/boundaries
  - Should asymptote to 0 if no energy sources present
  - Should asymptote to value of energy source if source is present

Still Changing, not 0

Conclusion: Not Converged



Convergence – Monitoring Convergence Overview

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- Don't just look at residuals!
- Monitor physical engineering quantities
  - Values should asymptote to meaningful values
- Should monitor values from both the flow and energy fields
  - Energy may converge at a different rate than the flow
- Similar method can be used for transient cases
  - Values ***within*** a time step should asymptote

- Note the Sign Convention for heat transfer reports/field functions
  - Heat going out of a boundary/interface = positive (based on outward facing surface normals)

Overview

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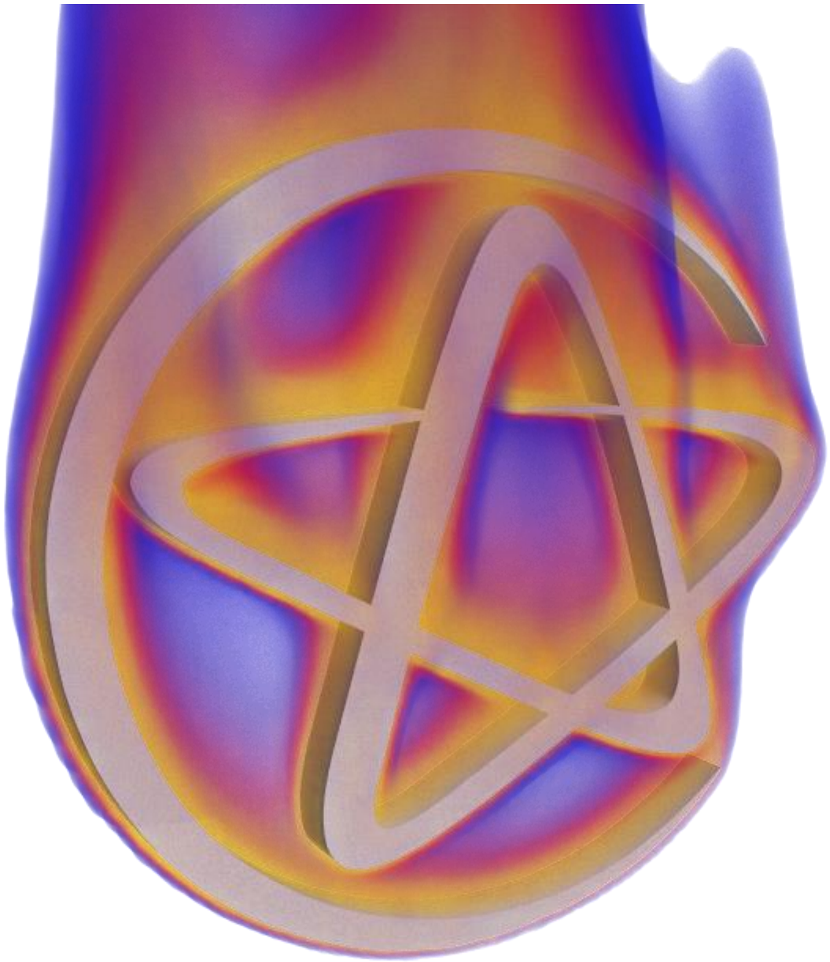

- Heat Transfer in Simcenter STAR-CCM+
- Geometry Preparation
- Meshing
- Parts Based Workflow
- Convergence
- **Heat Transfer Coefficients**
- Summary

Heat Transfer Coefficients

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Heat Transfer Coefficients are calculated using the general form:

$$q''_s = h(T_{surface} - T_{ref})$$

Several different variations are available for post processing Heat Transfer Coefficients

- Local Heat Transfer Coefficient
  - Uses the near wall cell temperature as T_{ref} to compute ΔT
- Heat Transfer Coefficient
  - User Specifies T_{ref} explicitly
- Specified y+ Heat Transfer Coefficient
  - User Specifies y+, fluid properties at this y+ value are used to calculate h, and determine T_{ref}
- Virtual Local Heat Transfer Coefficient
  - Does not need to solve the energy equation
  - User specifies T_{ref} and fluid properties

Heat Transfer Coefficients

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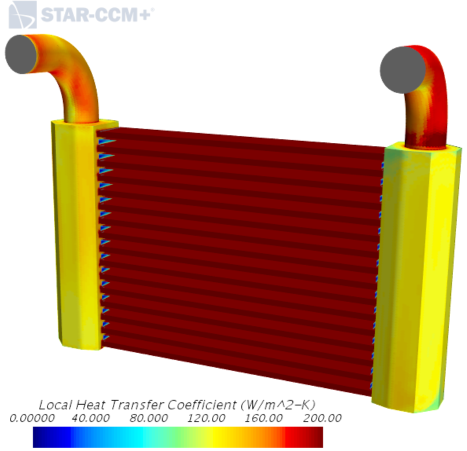
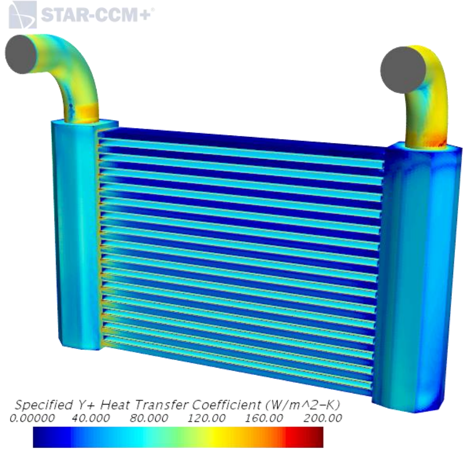
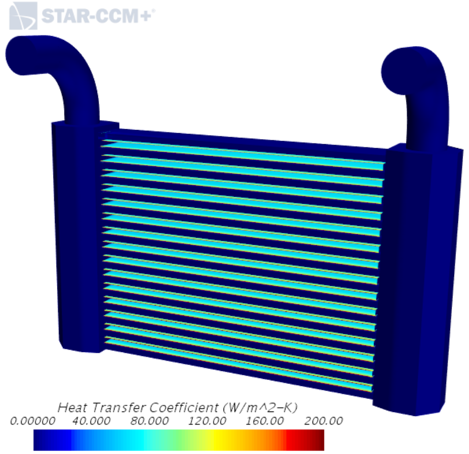
Local HTC

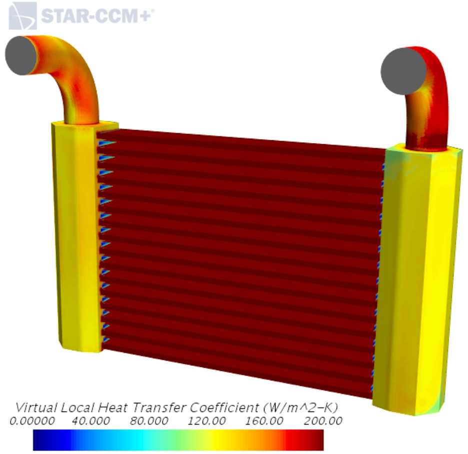


Specified y+ HTC





Heat Transfer Coefficient



Virtual Local HTC

Heat Transfer Coefficients

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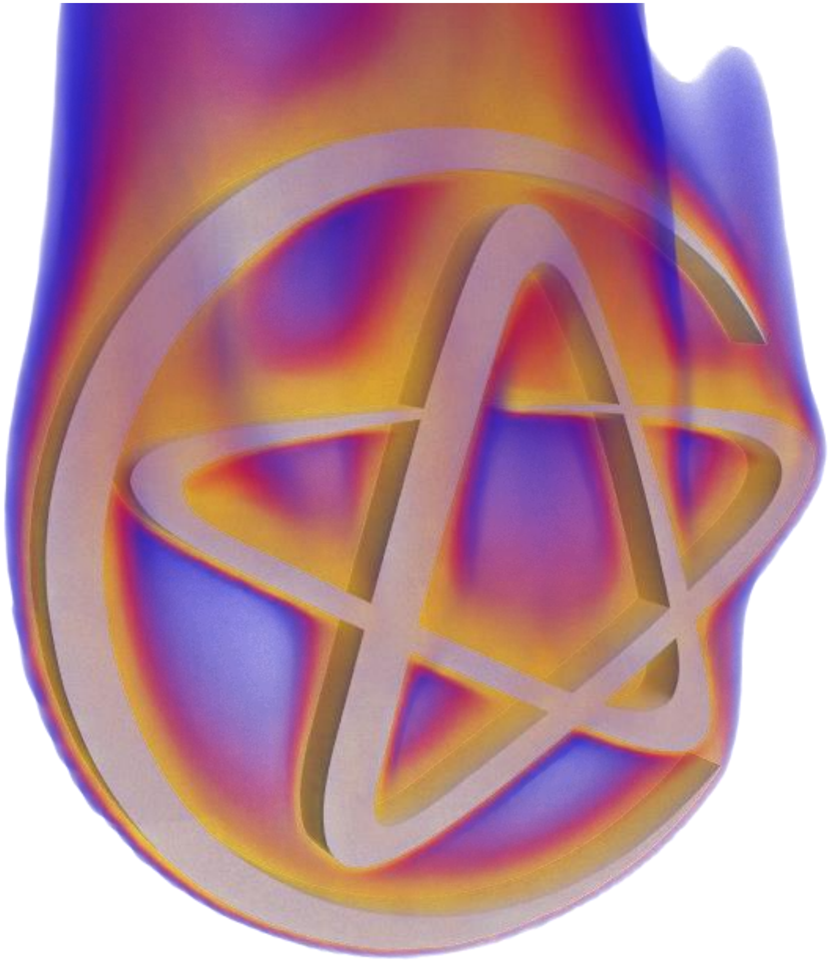
- So which Heat Transfer Coefficient should I use?
  - Choice of HTC is a post processing choice only and does not affect the solution results computed internally when solving CHT in Simcenter STAR-CCM+
  - Should match HTC definition to what was used for comparison

- When coupling to other codes to solve for temperatures, generally Specified y+ HTC is recommended
  - Less dependent on mesh than Local HTC
  - Gives better conditioned system at solve time
  - Generally recommended to use y+ value of 100

Overview



- Heat Transfer in Simcenter STAR-CCM+
- Geometry Preparation
- Meshing
- Parts Based Workflow
- Convergence
- Heat Transfer Coefficients
- **Summary**

Summary

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- Three main workflows for geometry prep/meshing depending on model needs
  - Conformal/Imprinted
  - Non-Conformal/Imprinted
  - Non-Conformal/Weak Contacts
- Parts Based Workflows
  - Improve scalability
  - Reduce complexity in simulation setup
- URF’s can be modified to help speed convergence
  - Set Solid Energy URF to 0.9999 or 1.0
- Engineering quantities of interest should be monitored for convergence
  - Min/Max temperatures
  - Energy Balance via Heat Transfer Report
- Choice of HTC is a purely post-processing choice
  - When coupling to external codes, use Specified y+ HTC

Thank you

Relevant Knowledge Base Articles

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Heat Transfer Coefficients
Wall Functions in Heat Transfer Applications
Natural Convection Best Practices
Surface to Surface Radiation Best Practices
Tips for Meshing Thin Solids
Best Practices for Full Vehicle Thermal Setup
Best Practices for Modeling Heat Exchangers
Multi-Part Solid and Parts Based Profiles
Benefits of Contact Mode Interfaces
Imprinting Tips and Tricks