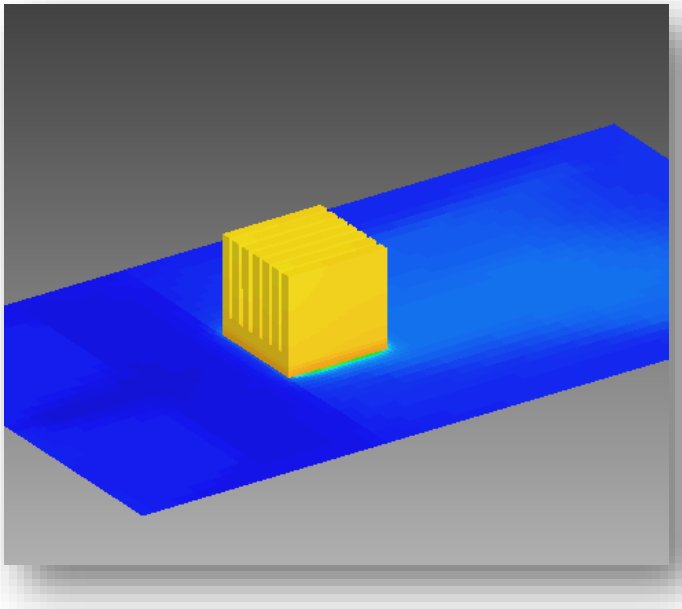
HelyX

Enterprise Open-source CFD

A new region-coupled framework for conjugate heat transfer



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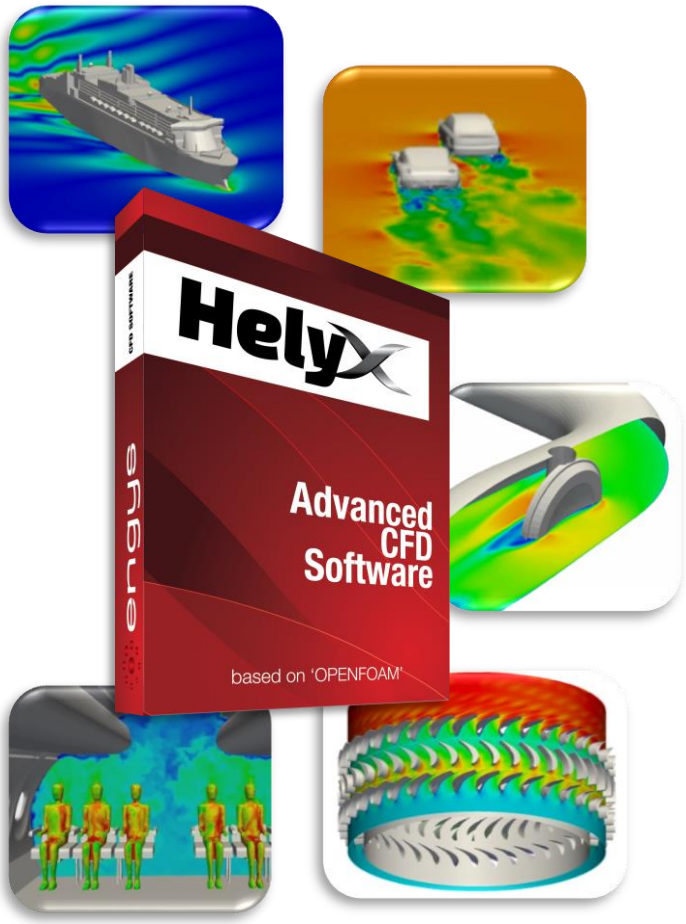
Contents

- Overview
  - Monolithic matrix solver
  - CHT solver
- Verification
- Application: CHT electronics
  - Blade server
  - Mobile phone
- Conclusions



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Overview | Monolithic Matrix Solver

- New machinery for solution of region-coupled equations
- Different mesh regions, different physics
- Traditional multi-region method → Segregated
  - Coupled through boundary conditions
  - Boundary conditions lag solution (Jacobi-coupled)
  - Impaired speed and stability
- New multi-region method in HELYX → Region-coupled
  - Solution of a single 'super-matrix'
  - Coupled through boundary interfaces
  - Fully implicit, robust solution
  - Employs standard, tried-and-tested solver machinery (GAMG, etc.)

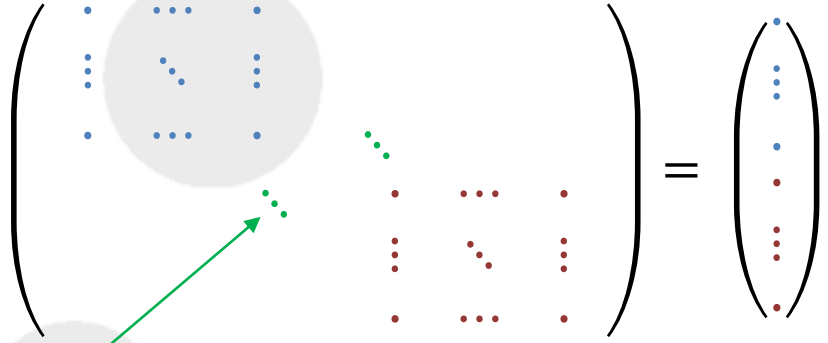
Overview | Monolithic Matrix Solver

Equations

$$\nabla \cdot Uh + \nabla \cdot pU = \nabla \cdot \alpha \nabla h \qquad \nabla \cdot k \nabla T = S$$

Discretised:
`fvMatrix`

Super-matrix:
`lduMatrix`



Coupling terms provided through boundary `lduInterfaces`

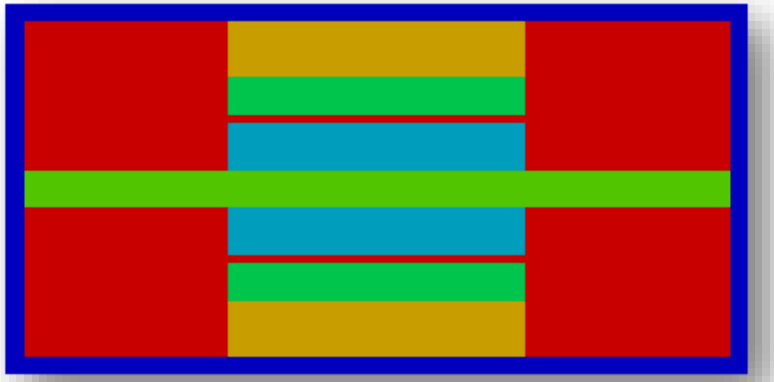
Overview | Region-Coupled CHT Solver

- CHT solver functionally compatible with **chtMultiRegion(Simple)Foam** input deck
- Arbitrary number of fluid/solid regions
- Support for anisotropic conductivity and contact resistance
- Advantages:
  - Coupled solution of thermal equations using super-matrix solver
  - Improved performance & robustness
  - Coupling through AMI interfaces allowing non-conforming region meshes

Region-Coupled CHT Solver | Verification

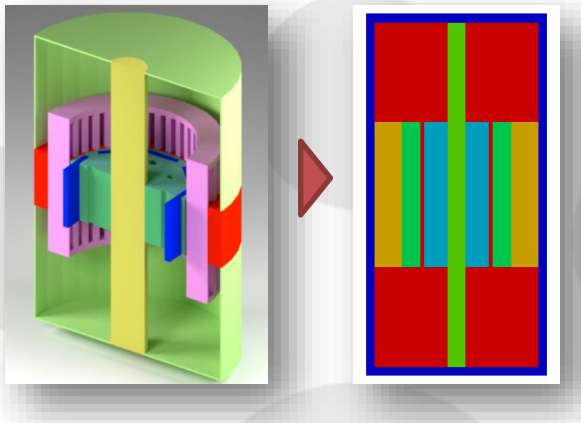
CHT Test Case 1 | Solids Only

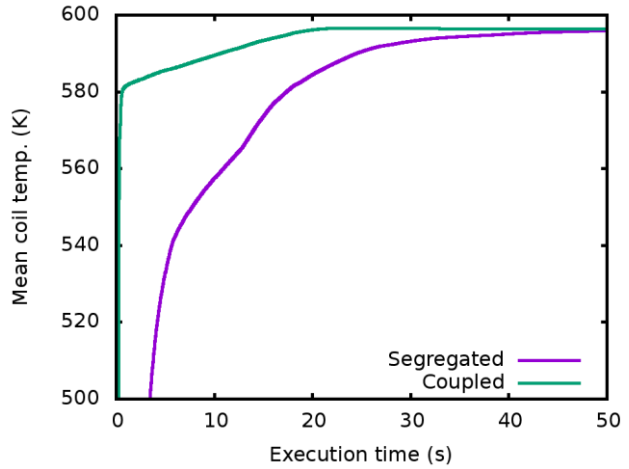
- Verify monolithic solution
- Solids only (linear equations)
- 6 regions (thermal diffusivity range 1 – 380 m^2/s)
- Multiple internal heat sources
- Solution with region-coupled in 1 iteration (10^{-10} residual drop in 86 GAMG iterations)
- Partitioned multi-region solver requires hundreds of iterations



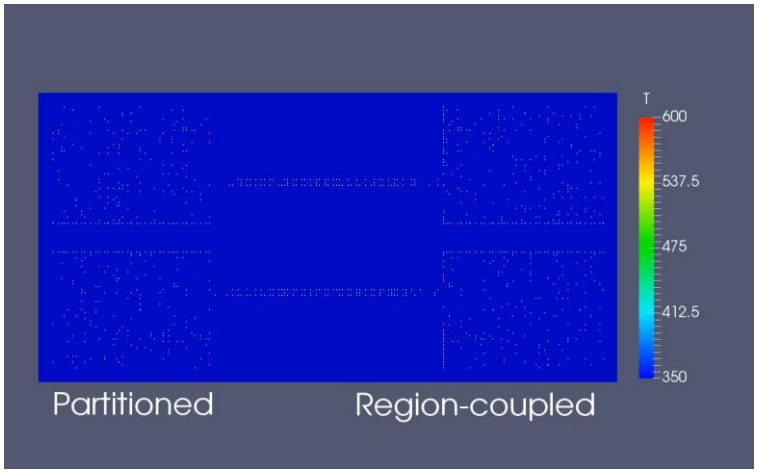
Region-Coupled CHT Solver | Verification

CHT Test Case 2 | Simplified 2D Electrical Motor





- 1 fluid + 5 solids with coil heating source
- Identical result vs. partitioned **chtMultiRegionSimpleFoam**
- Significant speed-up in convergence times



Application | CHT Electronics

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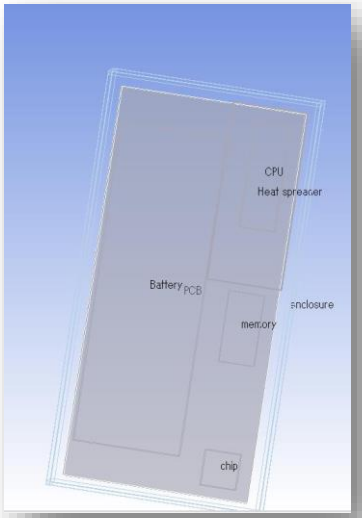
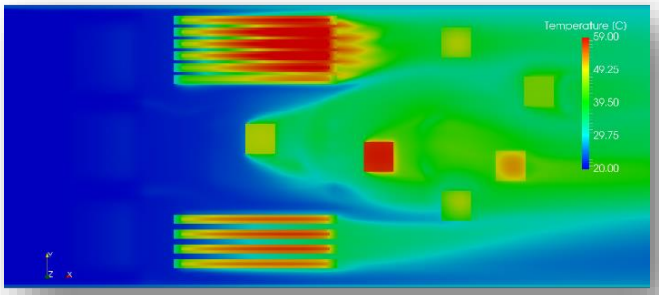
- Standard OPENFOAM orders of magnitude slower than typical commercial codes for industrial CHT
- Two improved CHT methods compared
  - Adaptive projection – adaptive over-relaxation + sub-cycling
  - Super-matrix – region coupled solver
- Test cases provided
  - Blade Server – convection dominated
  - Mobile phone – solid conduction





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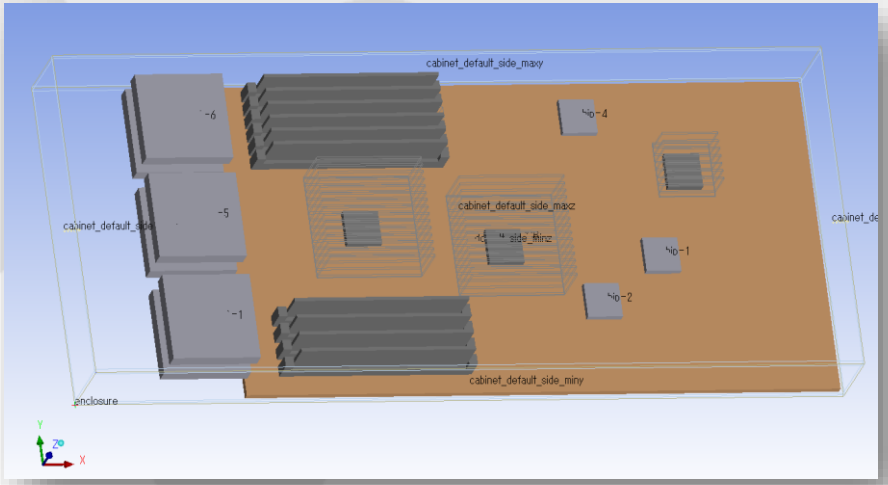
Blade Server

- Forced convection cooling
- Internal flow
- Volumetric thermal heating in CPUs, chips and memory modules
- Comparison between HELYX/OPENFOAM/ANSYS Fluent

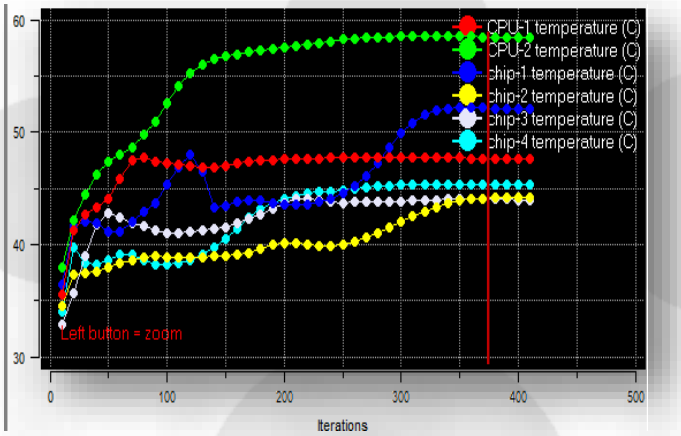
Airflow



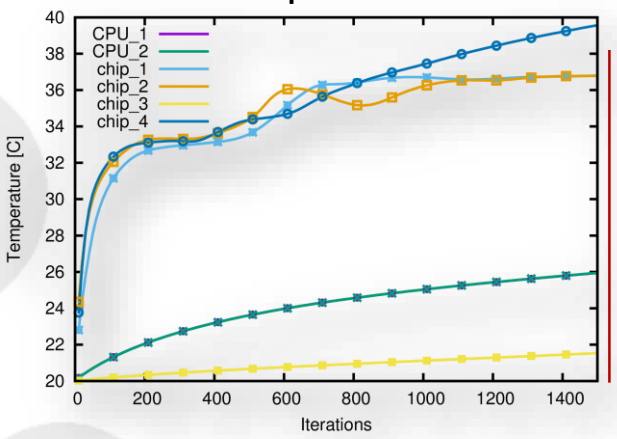
Blade Server | Temperature Probes

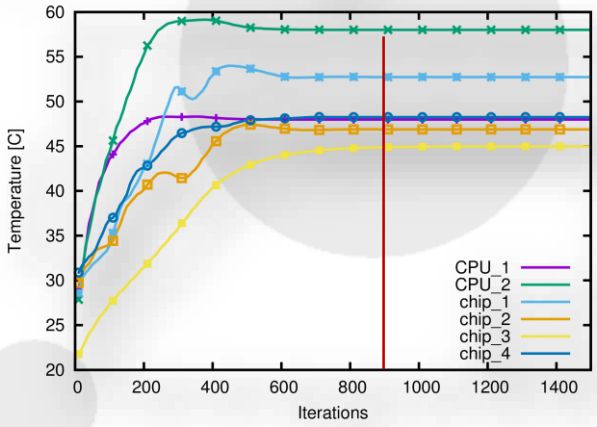
- Forced Convection
- Volumetric heating in IC chips

ANSYS Fluent (courtesy of Fujitsu)

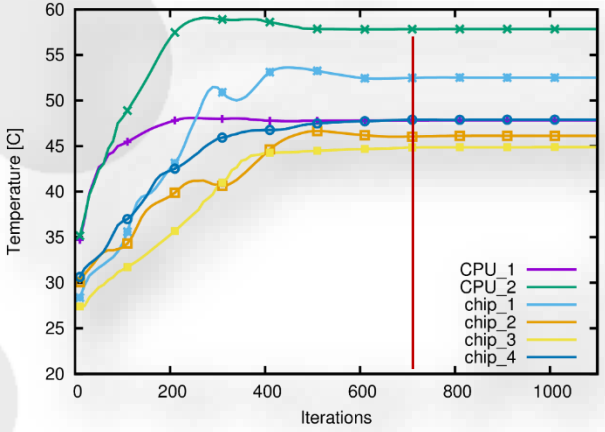


Standard OpenFOAM v2.4.x





HELYX: Adaptive Projection



HELYX: Super-Matrix

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Probe Temperatures | Fluent vs. HELYX (Super-Matrix)

Temperature Probe	Fluent [°C]	HELYX ρ = ideal gas [°C]	HELYX ρ = constant [°C]
CPU 1	47.7	47.8	48.1
CPU 2	58.5	57.8	58.1
Chip 1	52.1	52.5	52.5
Chip 2	44.2	46.1	46.5
Chip 3	44.0	44.9	45.3
Chip 4	45.4	47.9	48.2

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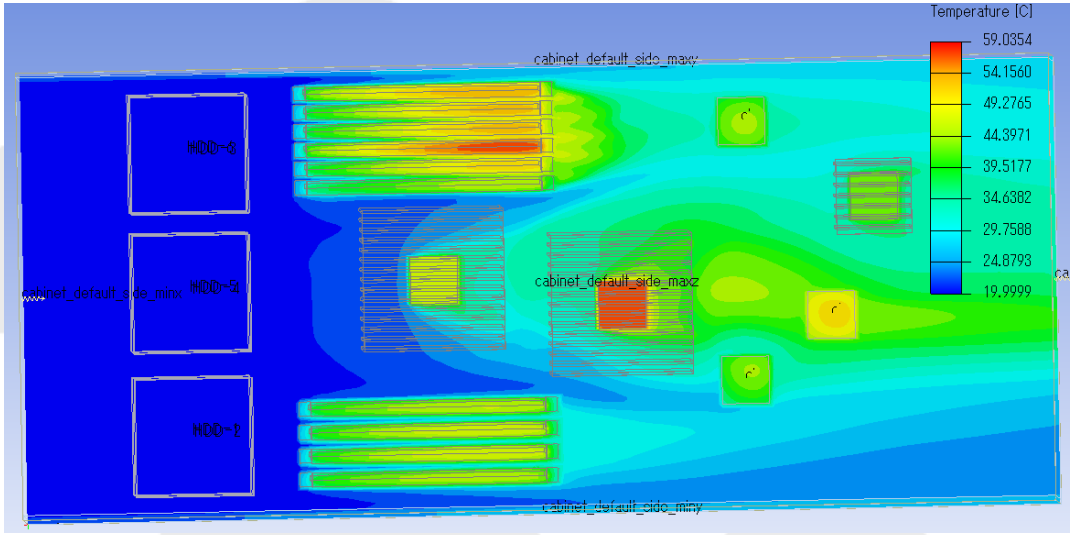
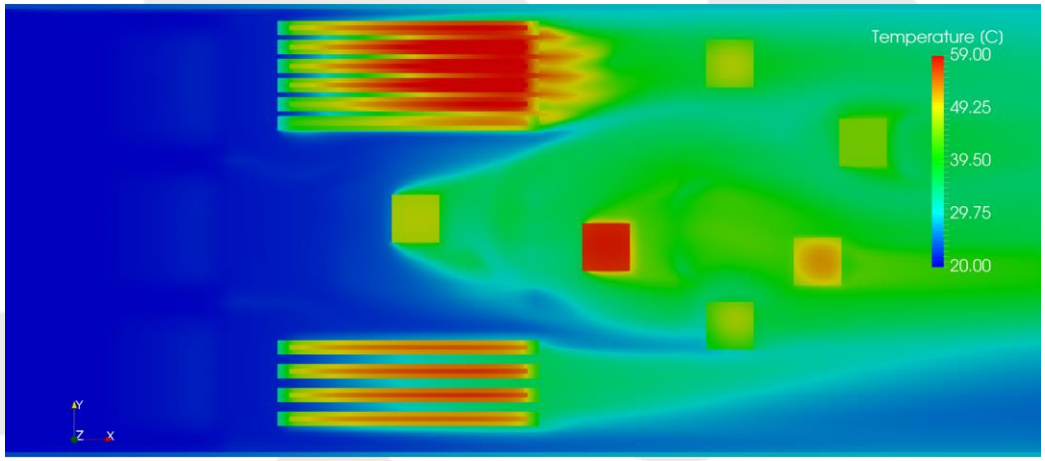
Temperature



ANSYS Fluent



HELYX (Super-Matrix)

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Blade Server | Comments

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- Performance (measured time to probe convergence):
  - ANSYS Fluent: 52min - 4 Intel Xeon 3.2GHz
  - Standard OPENFOAM: 400+min - 3 Intel Core i7 2.60GHz
  - HELYX - Adaptive Projection: 76min - 3 Intel Core i7 2.60GHz
  - HELYX – Super-Matrix: 72min - 3 Intel Core i7 2.60GHz
- Performance comparable to ANSYS Fluent (considering 3 vs 4 cores)
- At least **5x** faster than standard OPENFOAM
- HELYX/Fluent provide similar results

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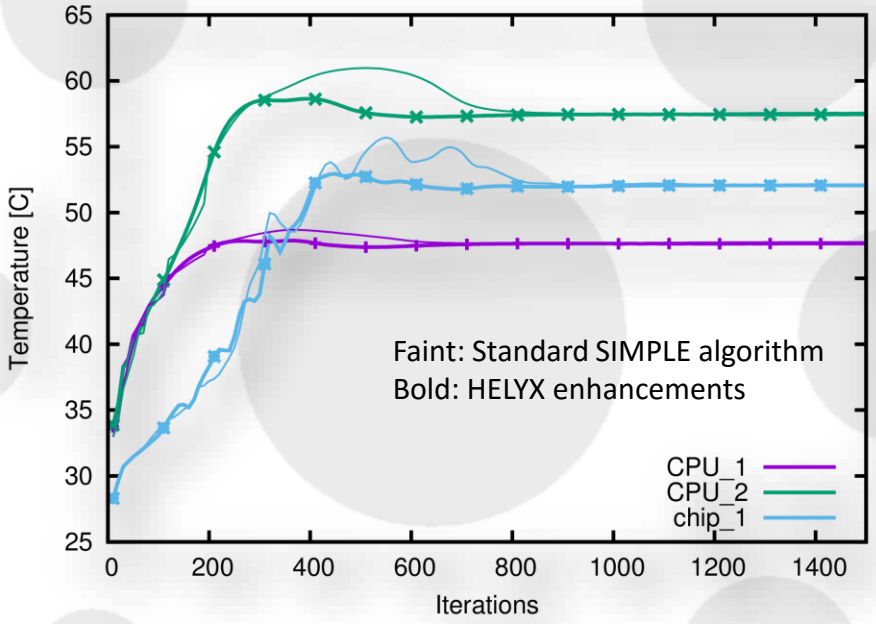
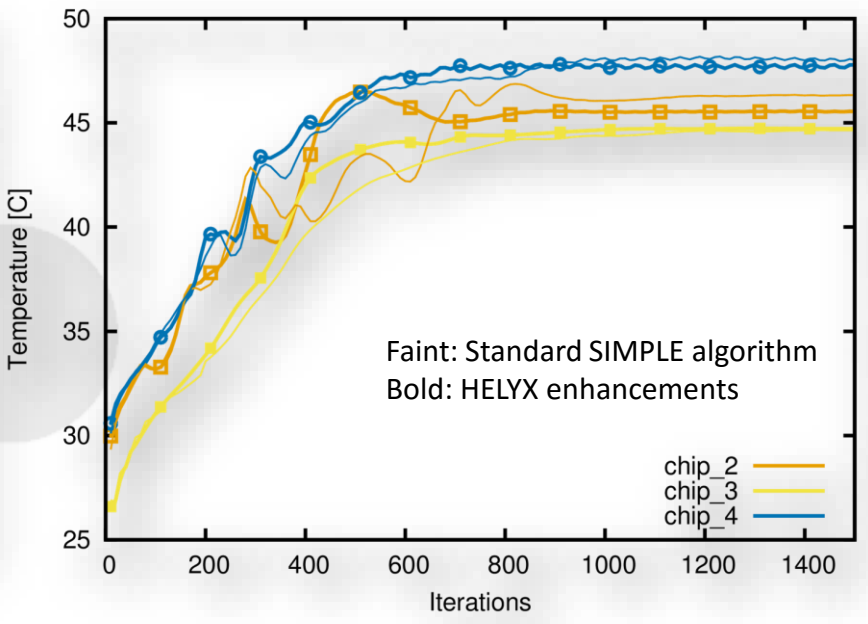
Aside | SIMPLE Enhancements in HELYX

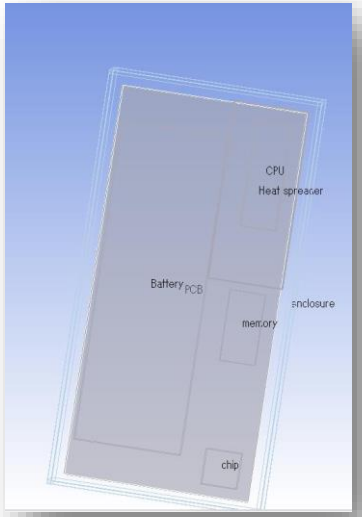
- SIMPLE algorithm in HELYX is enhanced to ensure relaxation factor independence
- Demonstration of improved convergence on Blade Server case, using second-order accurate convection:





Mobile Phone

- Natural convection dominated cooling
- Internal and external flow
- More interconnected solid components
- Volumetric thermal heating in ICs and battery
- Comparison between HELYX/OPENFOAM/ANSYS Fluent



Mobile Phone | Temperature Probes

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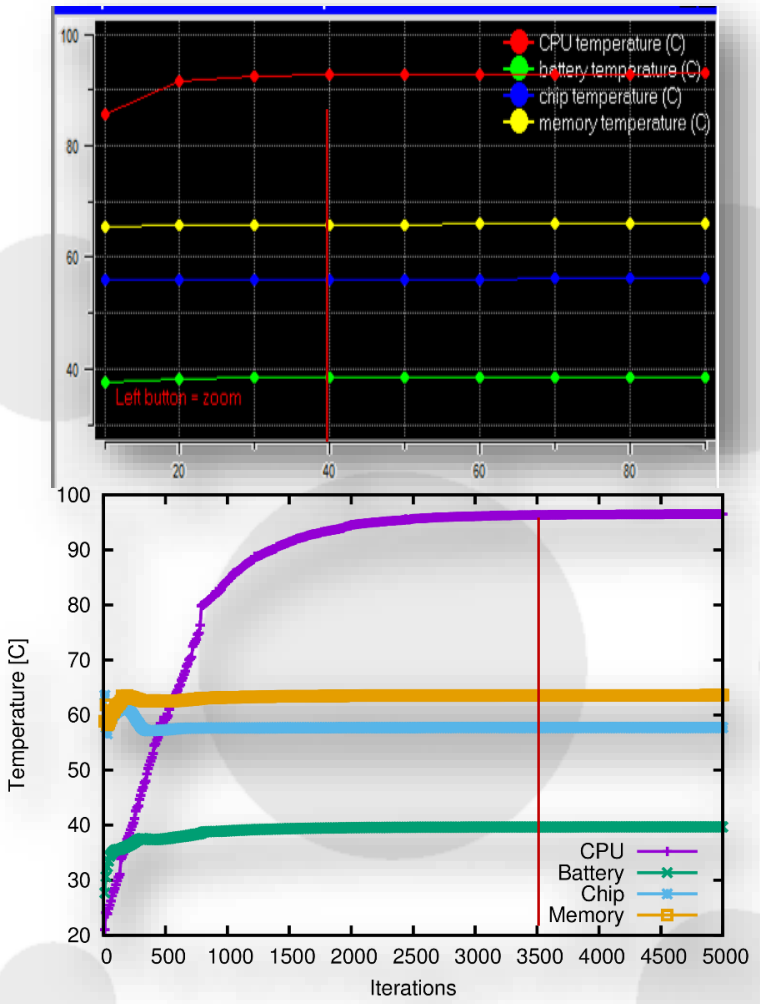
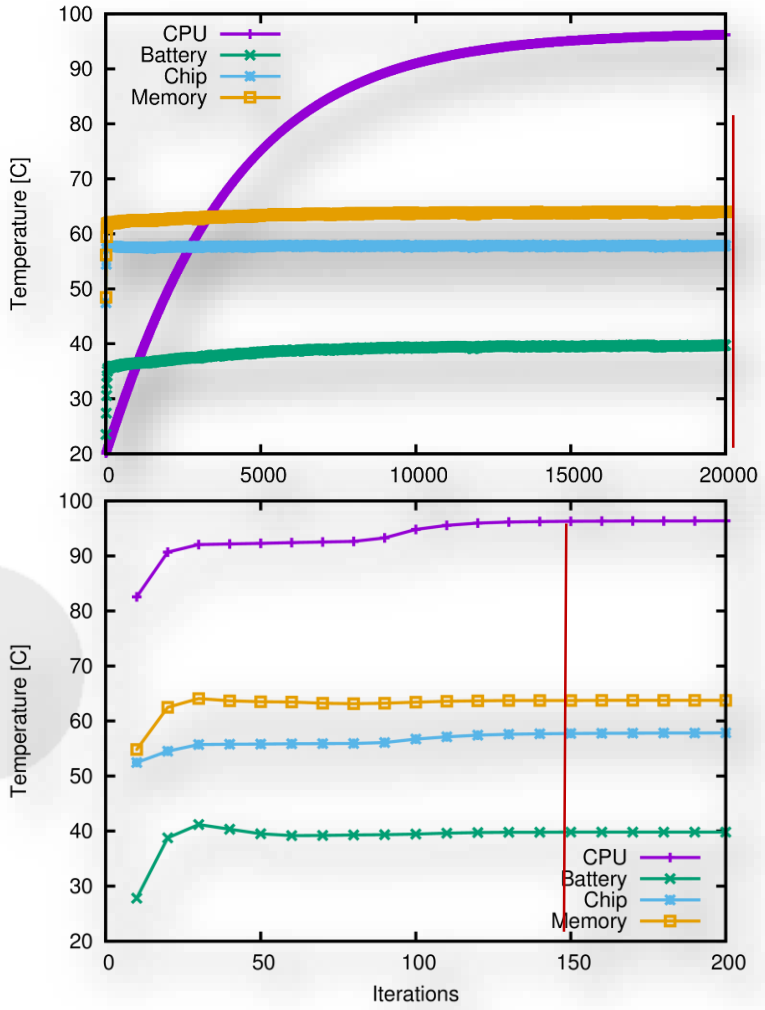
ANSYS Fluent



HELYX: Adaptive Projection

OPENFOAM v3.0



HELYX: Super-Matrix

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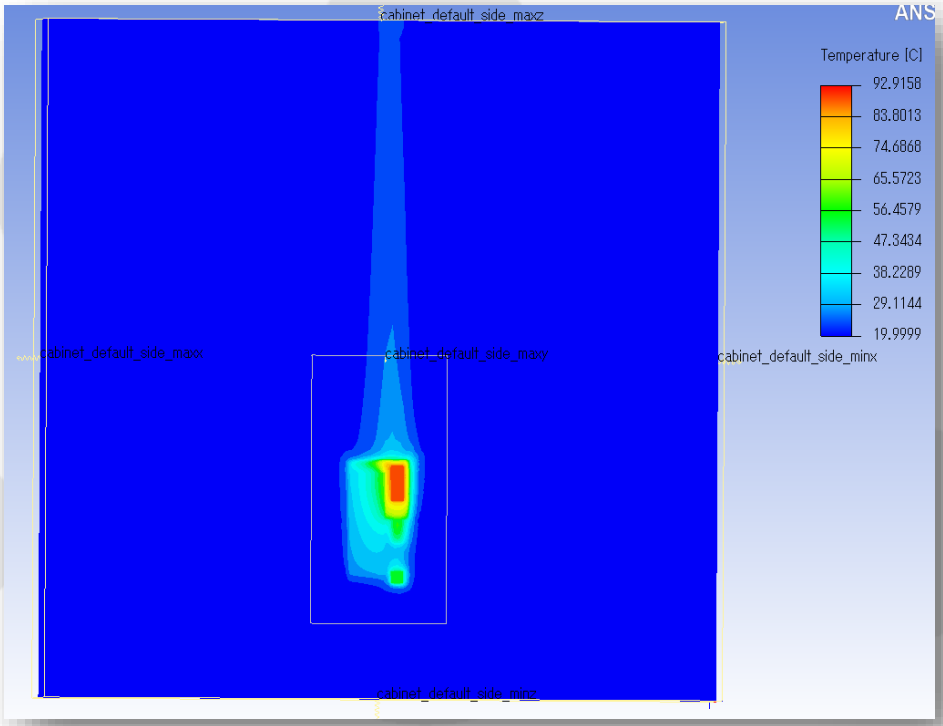
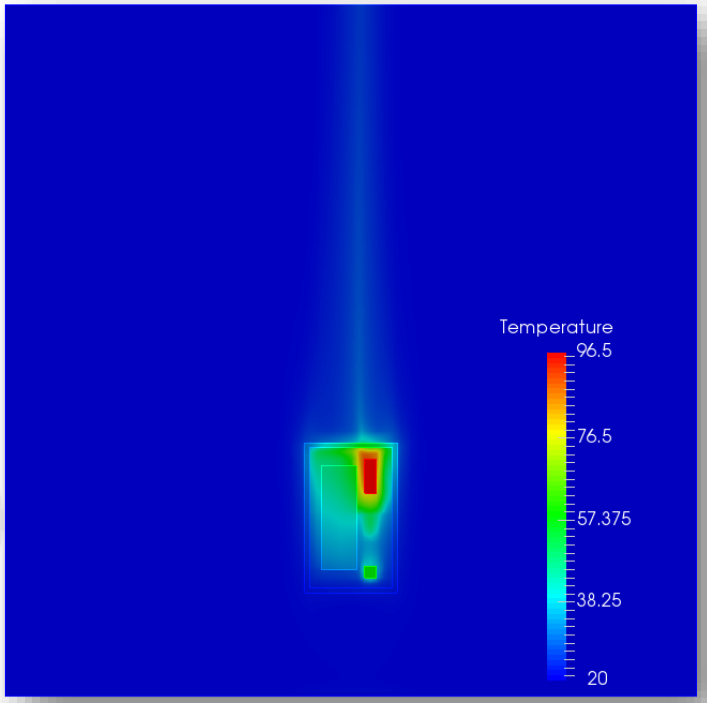
Temperature



ANSYS Fluent



HELYX: Super-Matrix

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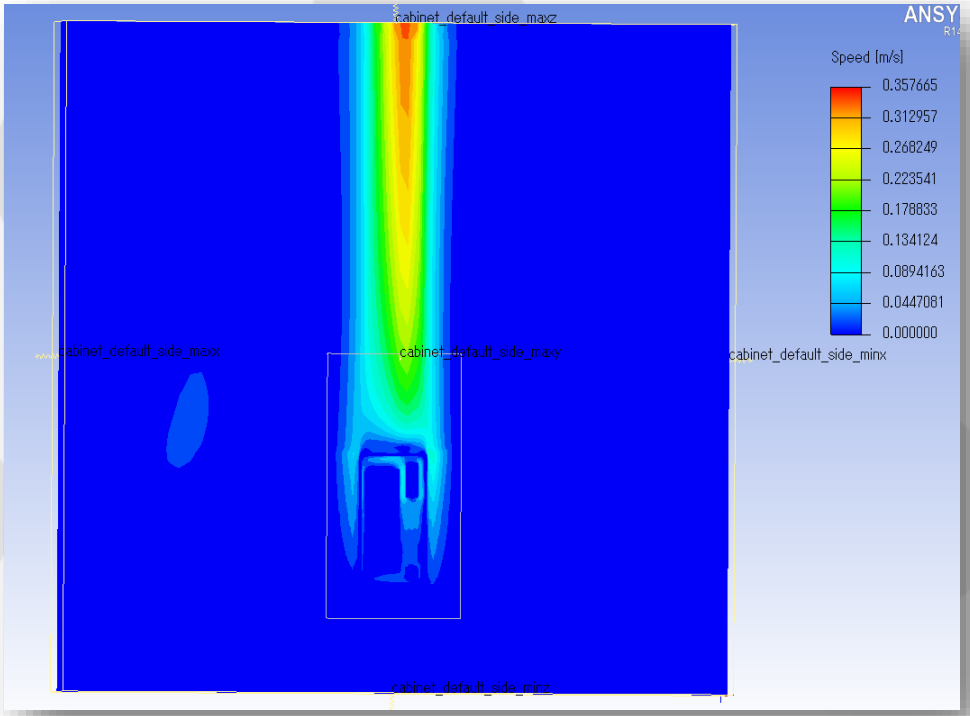
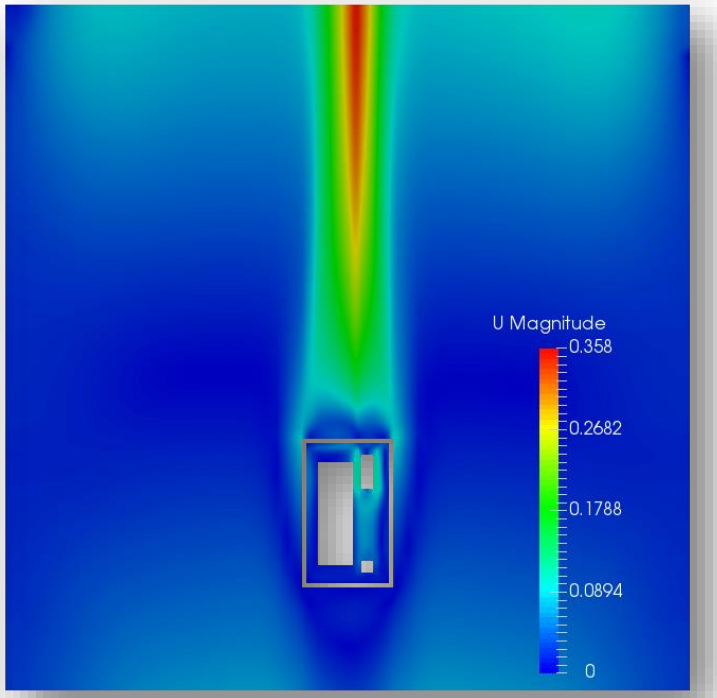
Mobile Phone | Results

Velocity



ANSYS Fluent



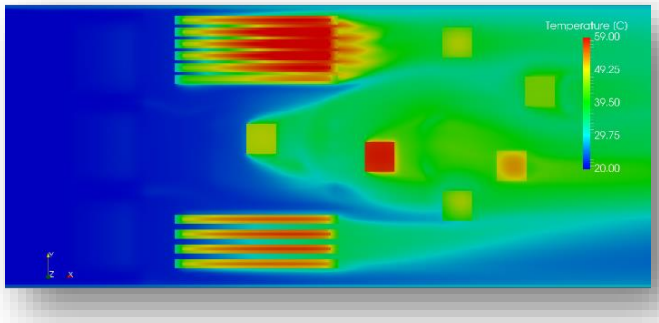
HELYX: Super-Matrix

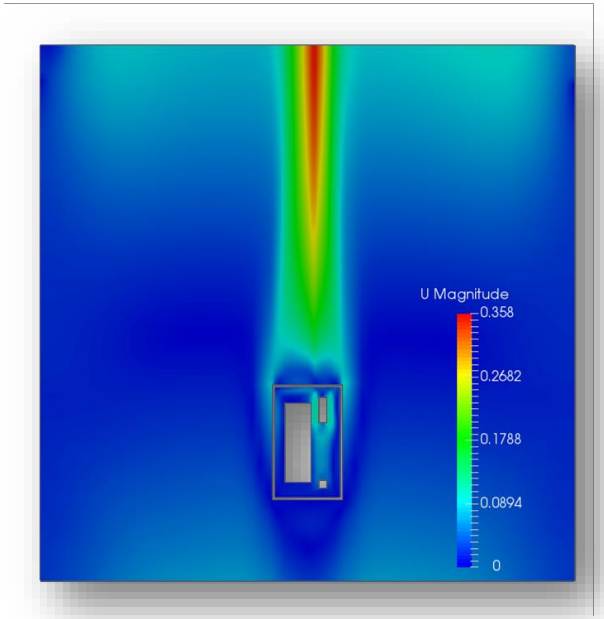
Mobile Phone | Comments

- Results between Fluent and HELYX generally similar
  - Some discrepancies due to difference in radiation model
- Performance (measured time to probe convergence):
  - ANSYS Fluent: cf. **11** min - 4 Intel Xeon 3.2GHz
  - OPENFOAM v3.0: **1000+** min - 4 Intel Core i7 2.60GHz
  - HELYX – Adaptive Projection: **79** min - 4 Intel Core i7 2.60GHz
  - HELYX – Super-Matrix: **10** min - 4 Intel Core i7 2.60GHz
- HELYX Super-Matrix provides a viable alternative to traditional proprietary CHT solvers

Comments

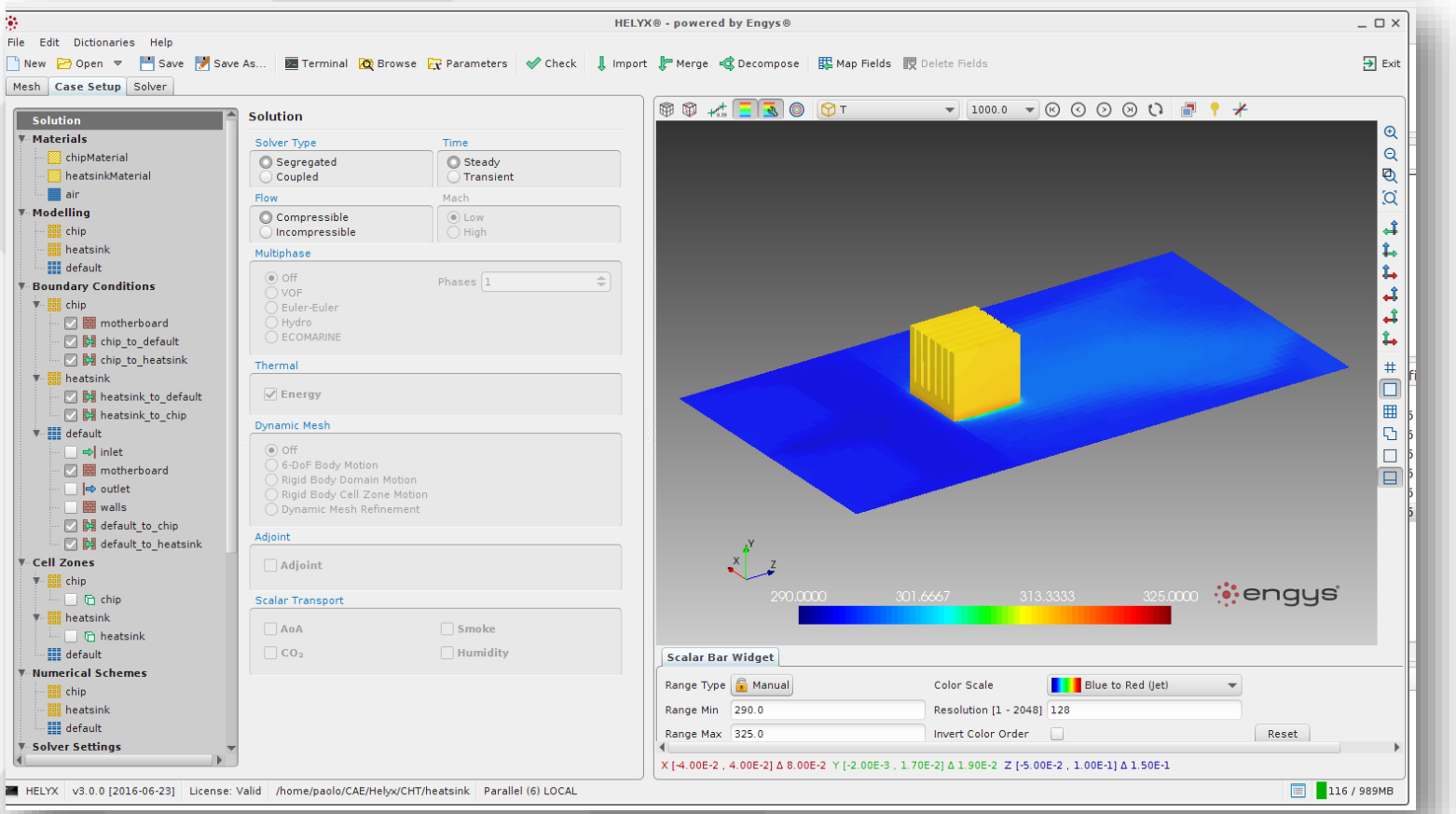
- Super-matrix provides implicit coupling between solution regions
- HELYX solution shows improved convergence properties w.r.t. standard OpenFOAM
- Greatest improvements where problem is thermally driven or contains multiple serially connected solid regions
- Wall-clock time to convergence for HELYX CHT solvers similar to ANSYS FLUENT solvers based on previous benchmarks





Comments

- Super-matrix based CHT supported in HELYX v3



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