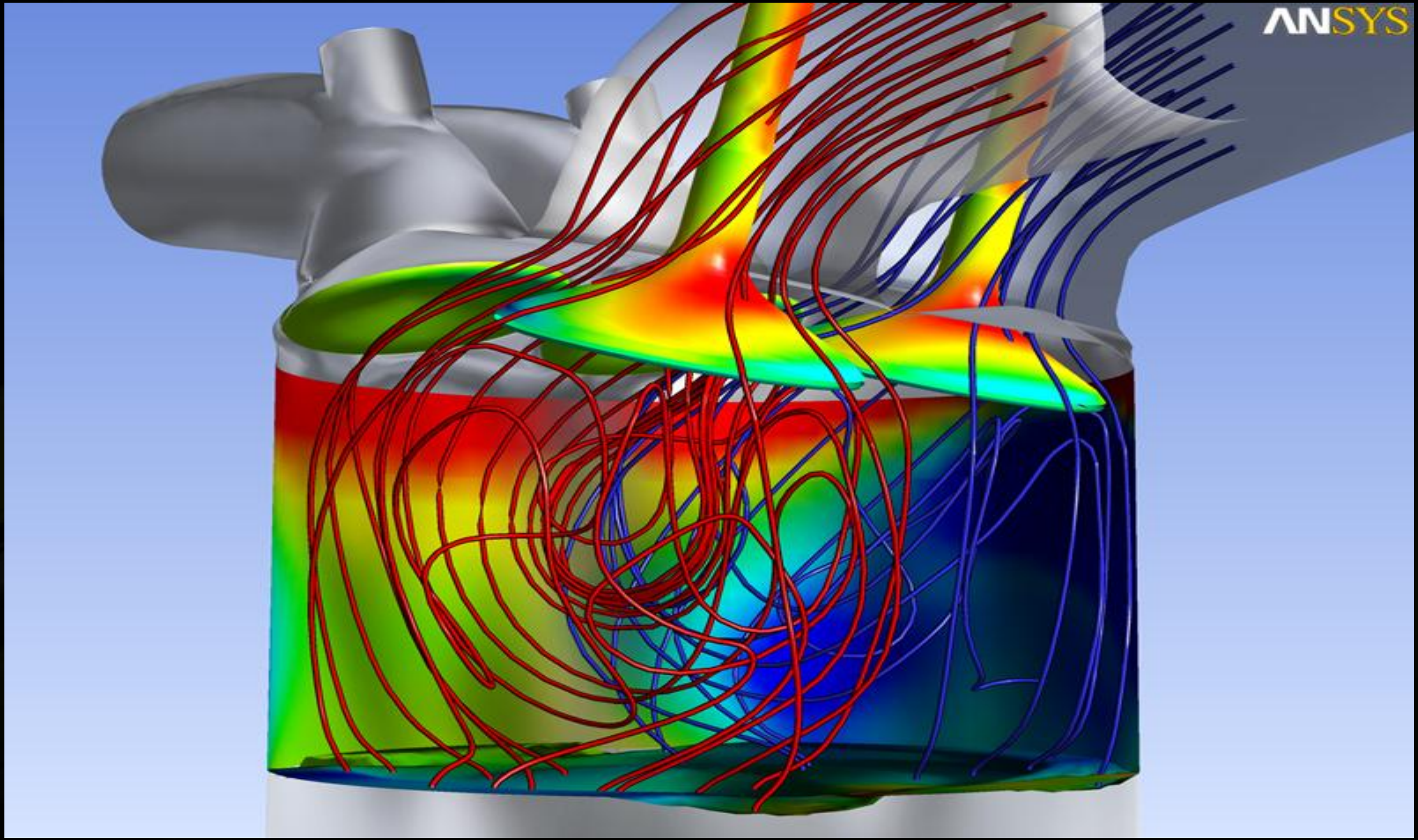
Accelerated ANSYS Fluent: Algebraic Multigrid on a GPU

Robert Strzodka

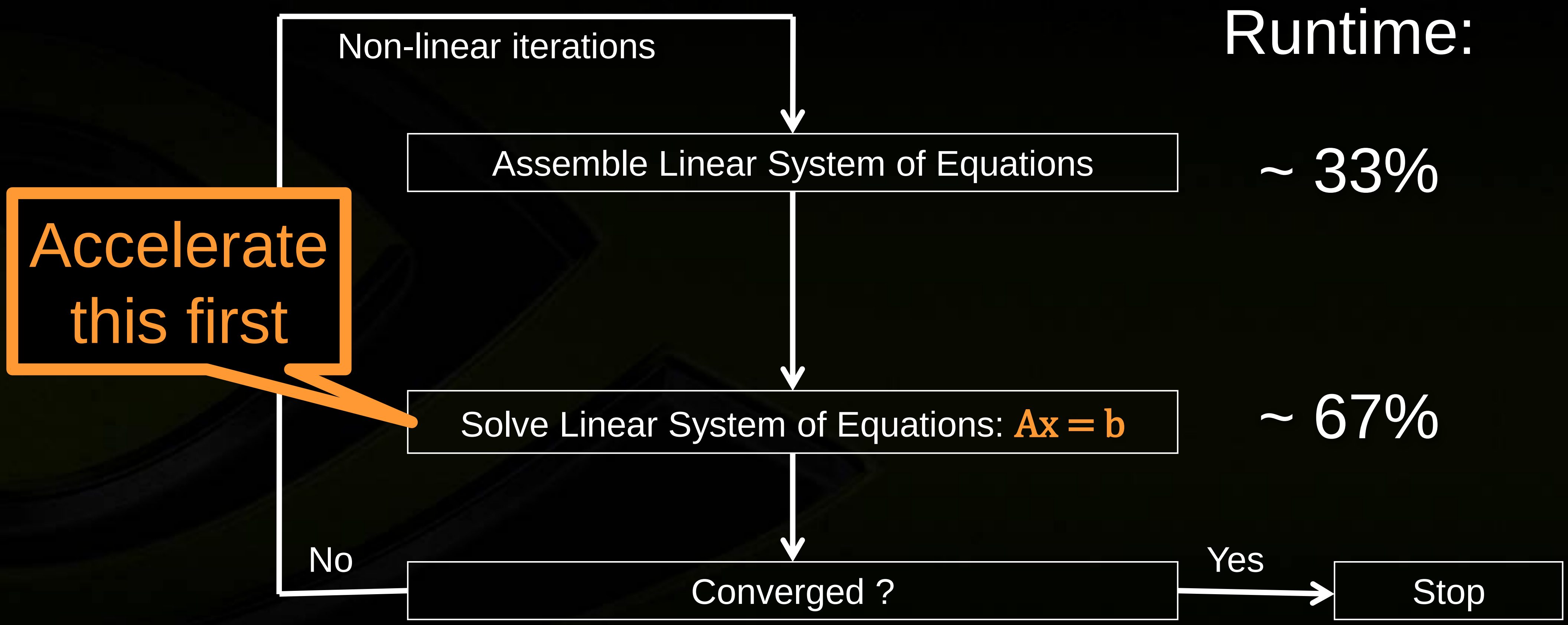
NVAMG Project Lead

A Parallel Success Story in Five Steps

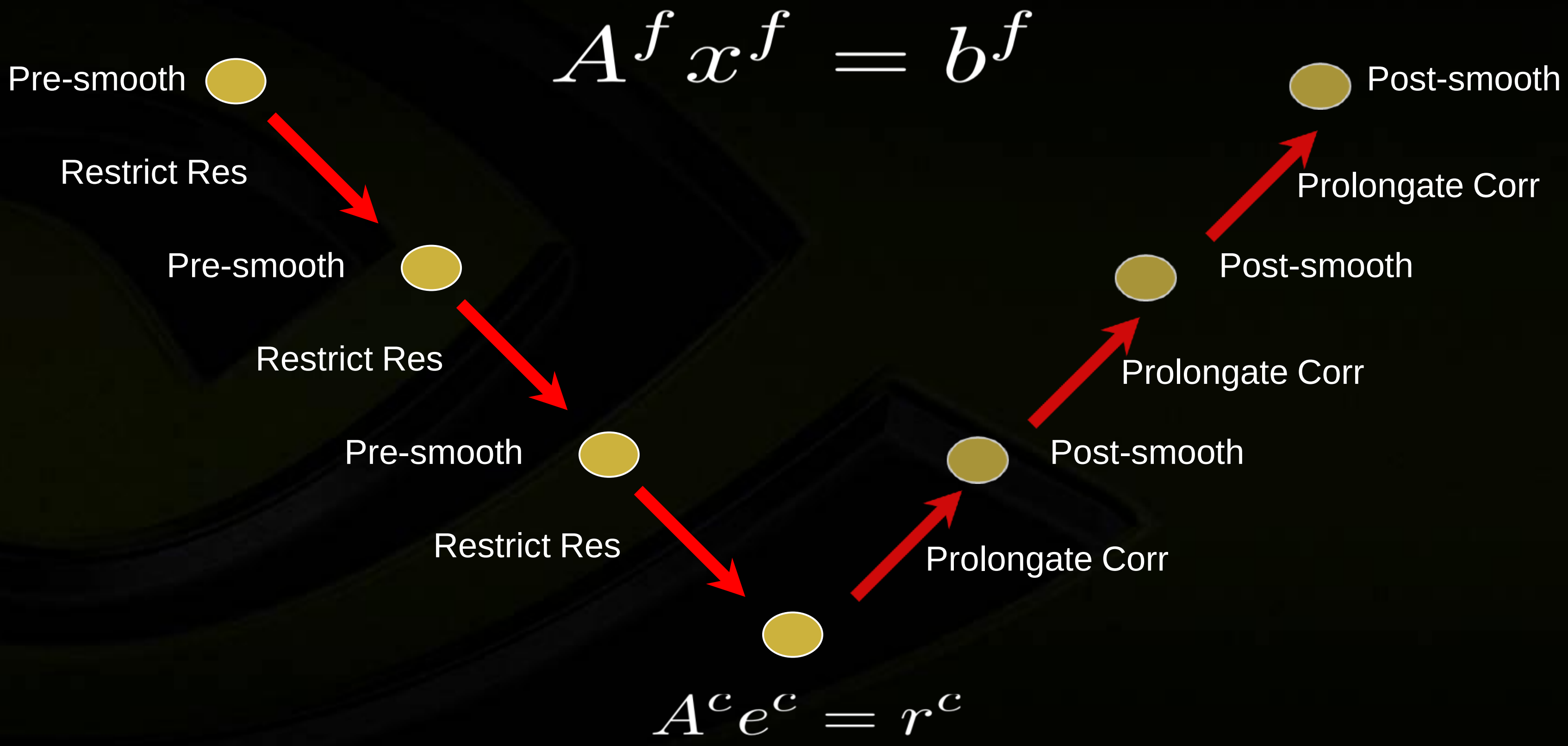
Step 1: Understand Application
ANSYS Fluent Computational Fluid Dynamics

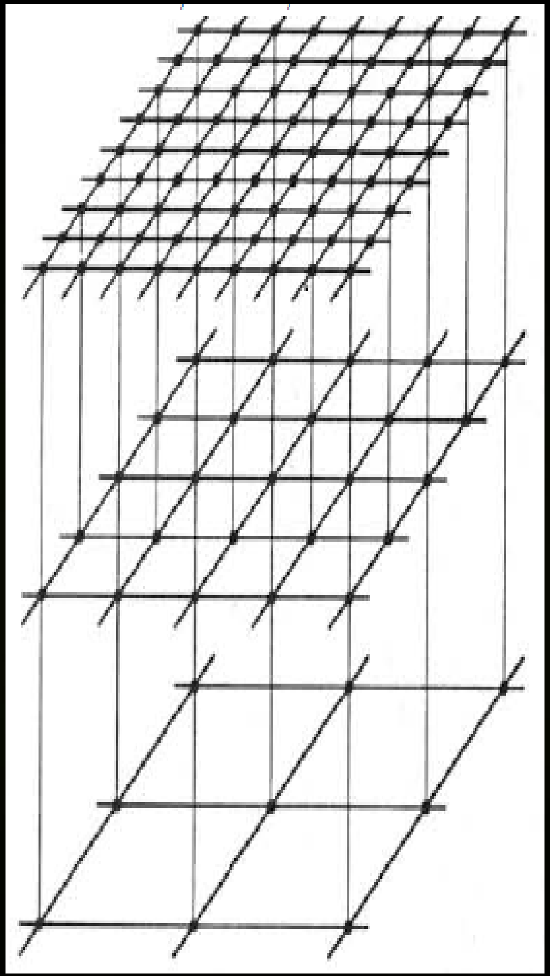


Step 2: Identify Bottleneck in Coupled Solver of Incompressible NS



Step 3: Parallelize Algorithm
Algebraic Multigrid (AMG)



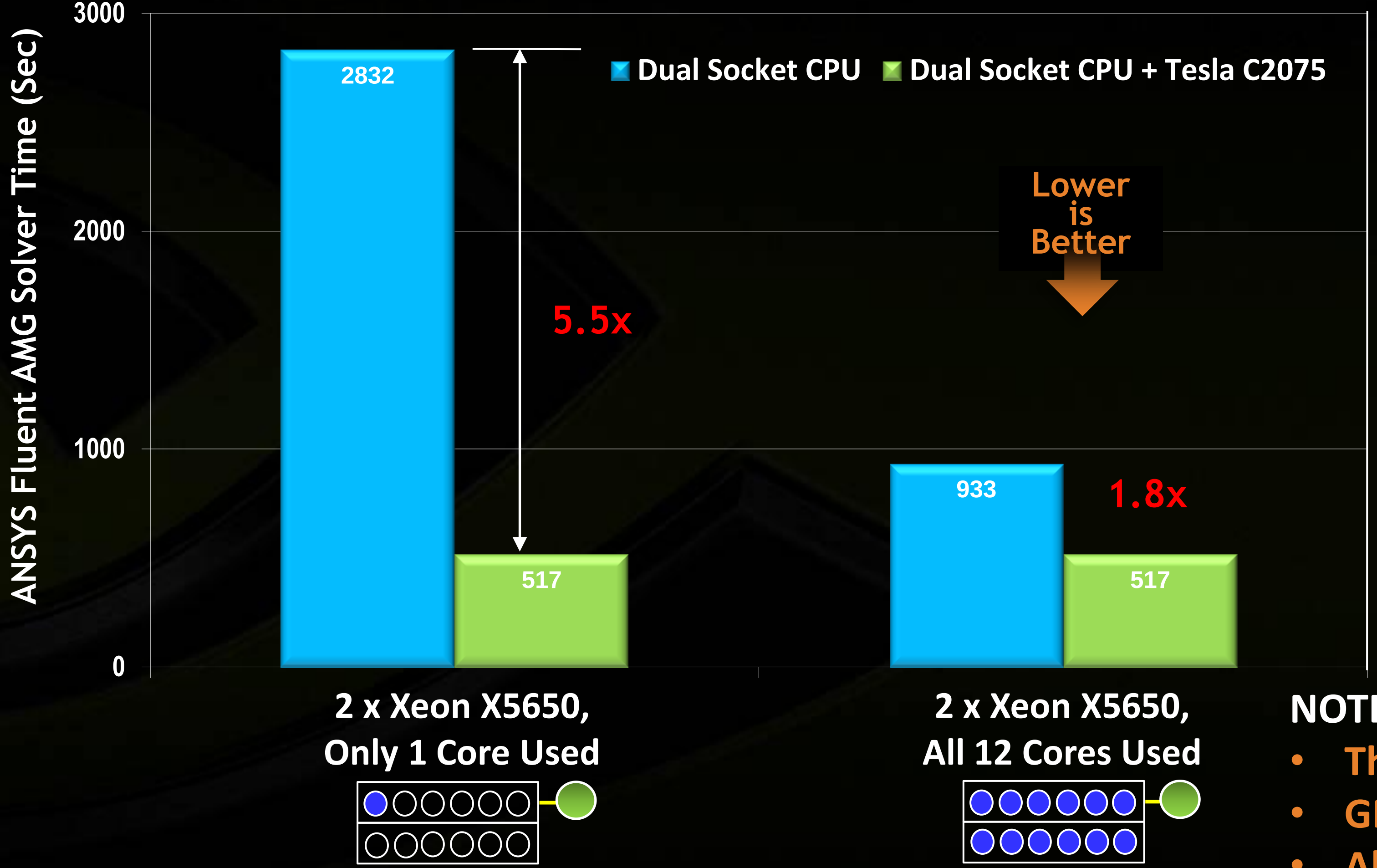


Step 4: Create Library of Production Quality Parallel Iterative Solvers

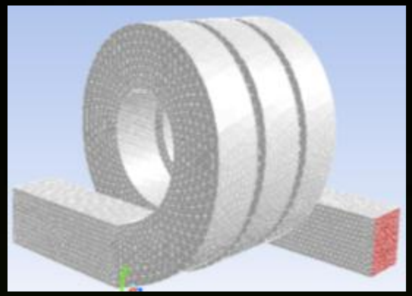
NVIDIA ANSYS

- People (NVIDIA and ANSYS)
  - Assemble a great team
  - Collaborate closely
- Algorithms
  - Innovate with parallelism
  - Understand numerical tradeoffs
- Software
  - Invest in library design and testing
  - Optimize for GPUs

Step 5: Enjoy Acceleration
ANSYS Fluent 14.5 with nvAMG Solver



Helix Model



- Helix geometry
- 1.2M Hex cells
- Unsteady, laminar
- Coupled PBNS, DP
- AMG F-cycle on CPU
- AMG V-cycle on GPU

NOTE:
- This is a performance preview
- GPU support is a beta feature
- All jobs solver time only

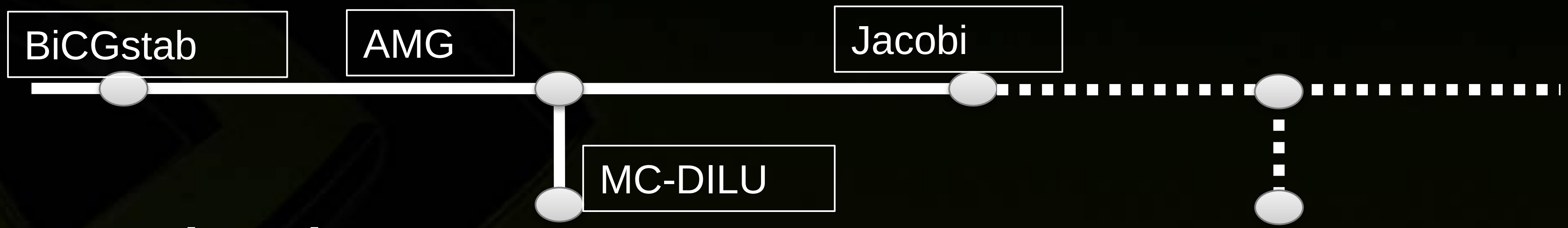
More about nvAMG

nvAMG Library - Interaction

- **Supported matrix formats**
  - Scalar and block CSR
  - Single and double precision
- **Infrastructure**
  - CUDA, Thrust
  - NVIDIA GPUs, tuned for Tesla K20X
- **Integration**
  - Dynamically linkable library
  - Public C interface with flexible text parameters
  - C++ plugin system for low-level extensions

nvAMG Library - Solvers

- Library of nested solvers for large sparse Ax=b
- Nesting creates a solver hierarchy, e.g.



- Example solvers
  - Jacobi, simple local (neighbor) operations, no/little setup
  - BiCGStab, local and global operations, no setup
  - MC-DILU, graph coloring and factorization at setup
  - AMG, multi-level scheme, on each level: graph coarsening and matrix-matrix products at setup

Solvers

Jacobi Solver – Trivial Parallelism

- **Defect correction with preconditioner M**

$$x^{n+1} = x^n + M^{-1}(b - Ax^n)$$

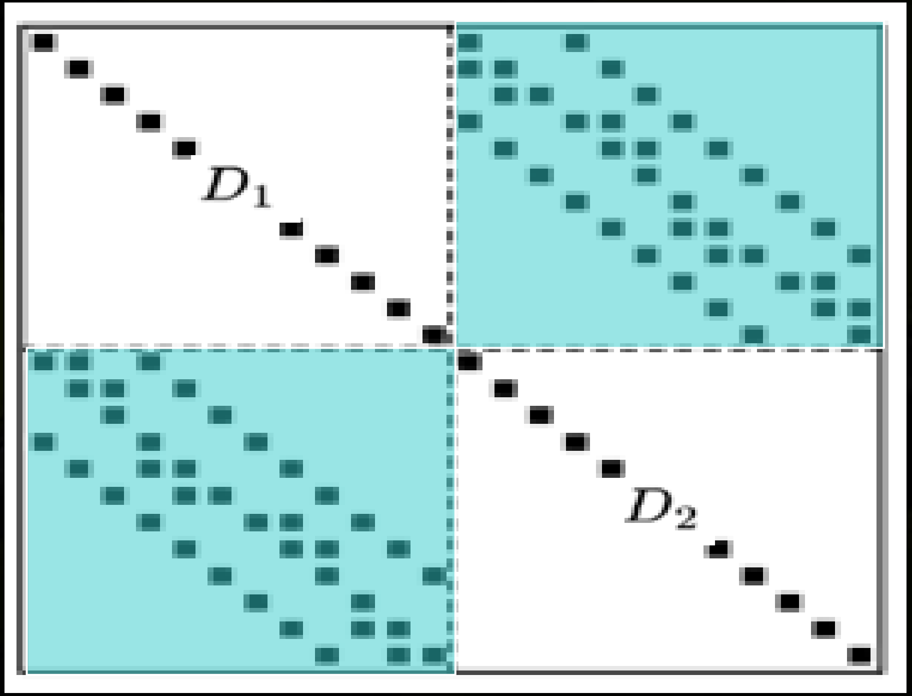
- **In case of Jacobi**

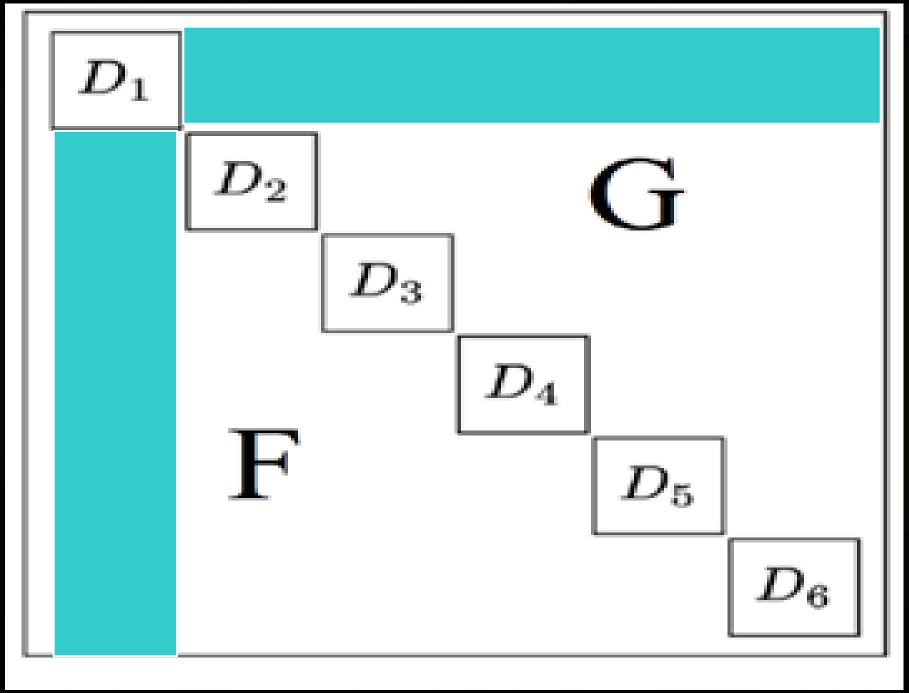
$$M = \begin{bmatrix} D_1 & & & & & \\ & D_2 & & & & \\ & & \ddots & & & \\ & & & \ddots & & \\ & & & & D_{n-1} & \\ & & & & & D_n \end{bmatrix}$$

Ds may be small blocks themselves, e.g. 4x4

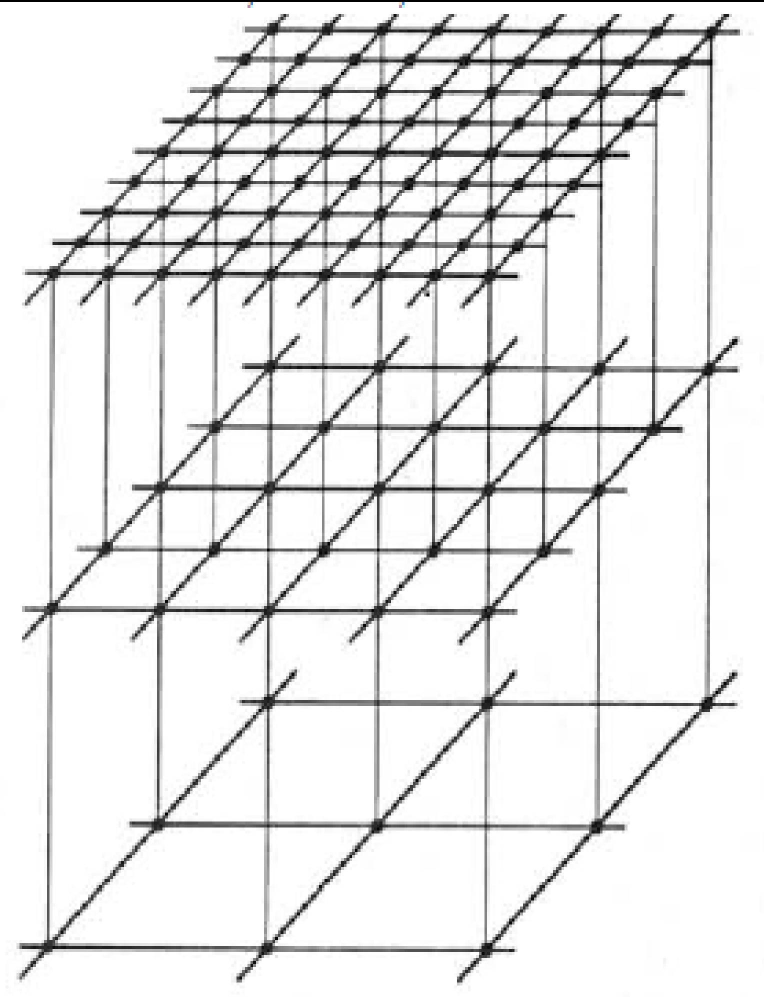
ILU Solvers – Coloring Enables Parallelism

- Incomplete LU factorization: $M = LU \approx A$
- Graph coloring allows parallel setup and solve
- With *m* unknowns and *p* colors, *m/p* unknowns run in parallel





From Geometric to Algebraic Multigrid



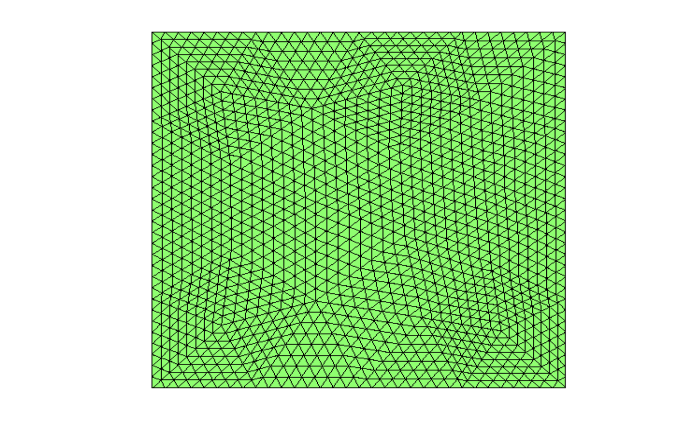
$$A_h x_h = b_h$$

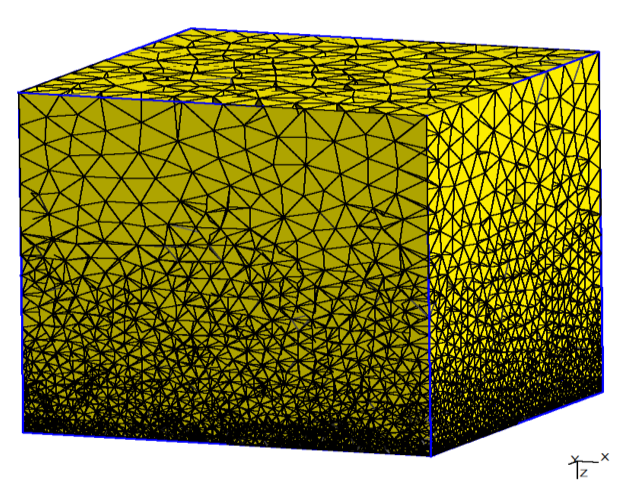
R_{2h} ↓ P_{2h} ↑

$$A_{2h} x_{2h} = b_{2h}$$

R_{4h} ↓ P_{4h} ↑

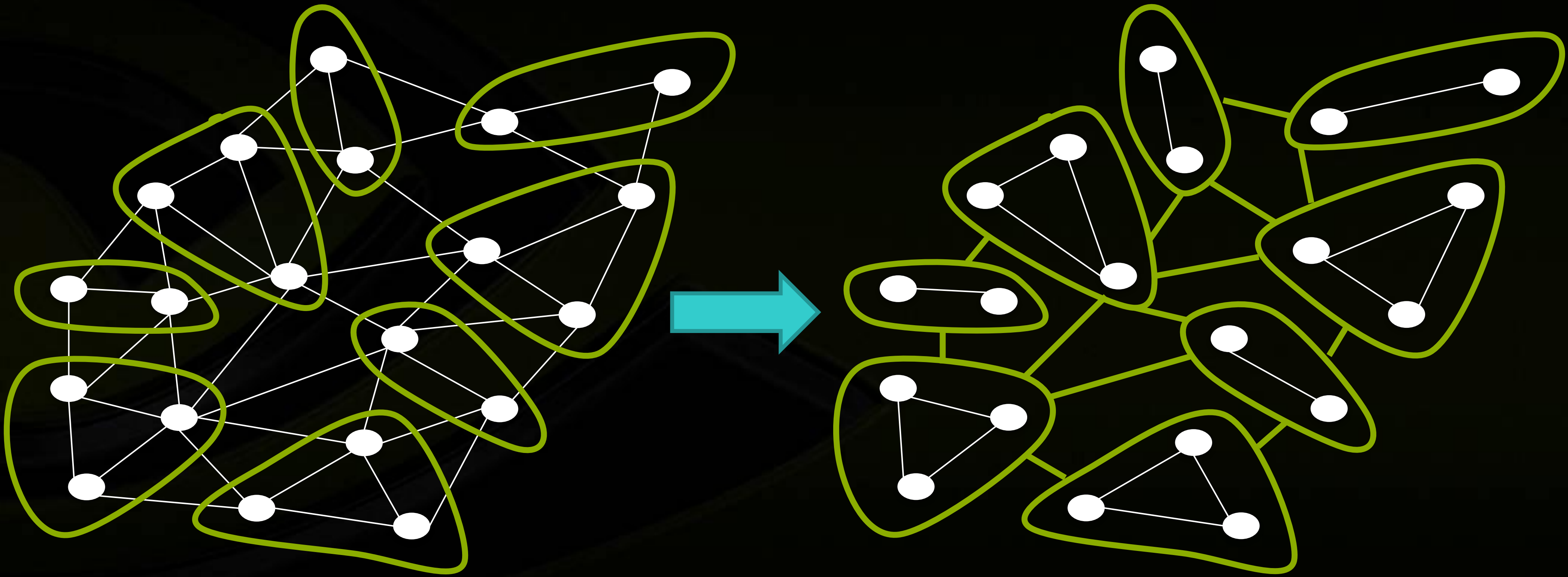
$$A_{4h} x_{4h} = b_{4h}$$





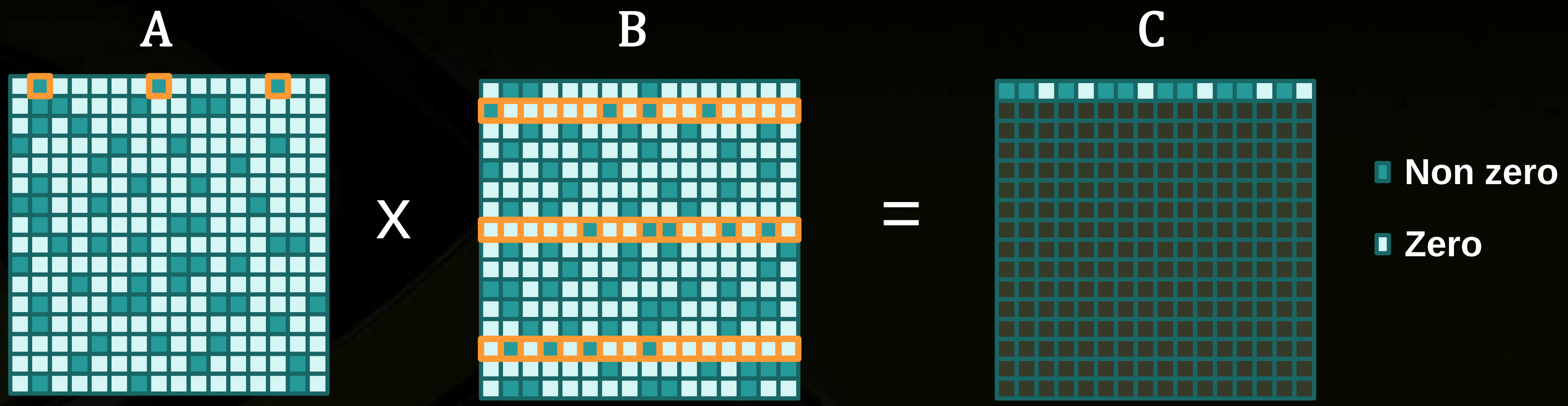
From Fine to Coarse Matrix

Aggregation **Sparse matrix-matrix product**



Parallel Sparse Matrix-Matrix Product

- Galerkin product in AMG: $A_{2h} = R_{2h} A_h P_{2h}$
- In general: $A \times B = C$



- Two parallel steps
  - Find the number of non-zeroes per row of C
  - Compute the columns indices and values per row of C

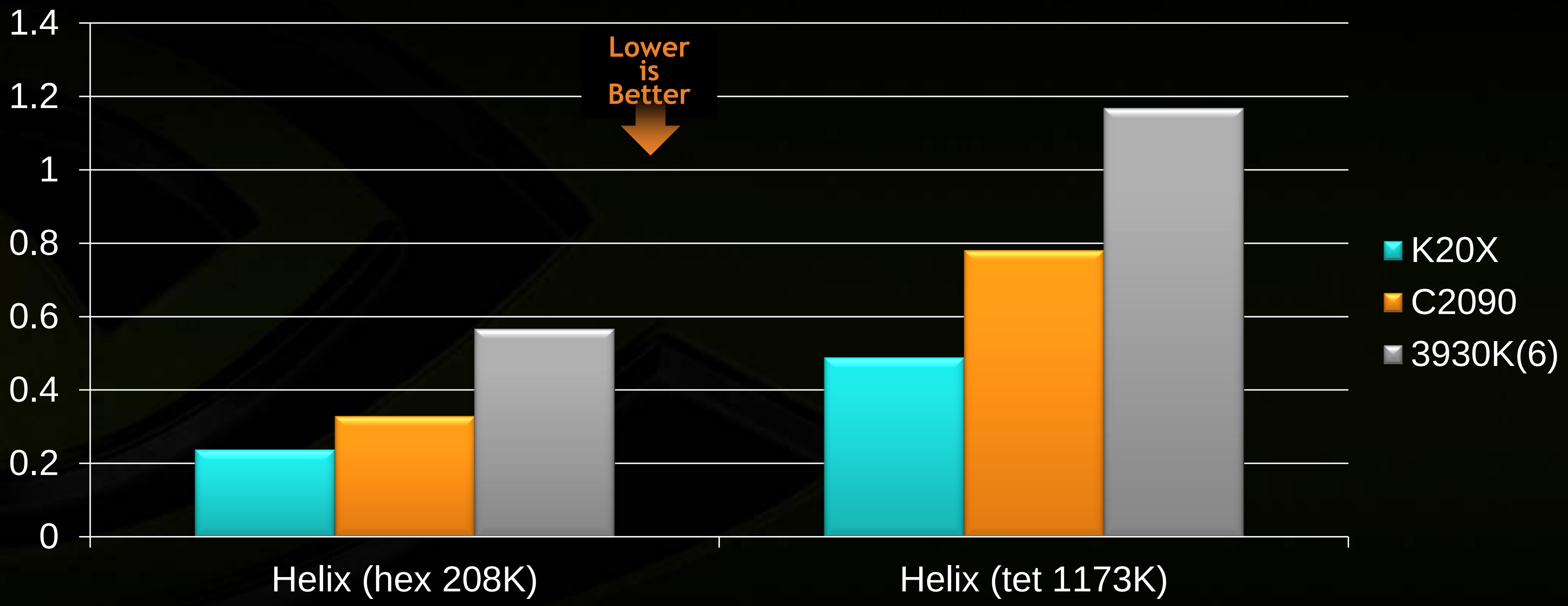
nvAMG results
for different Ax=b

Hardware

- K20X
  - Kepler architecture, Tesla K20X GPU Accelerator
- C2090
  - Fermi architecture, Tesla C2090 GPU Accelerator
- 3930K(6)
  - Sandy Bridge architecture, Core i7-3930K, 6 cores

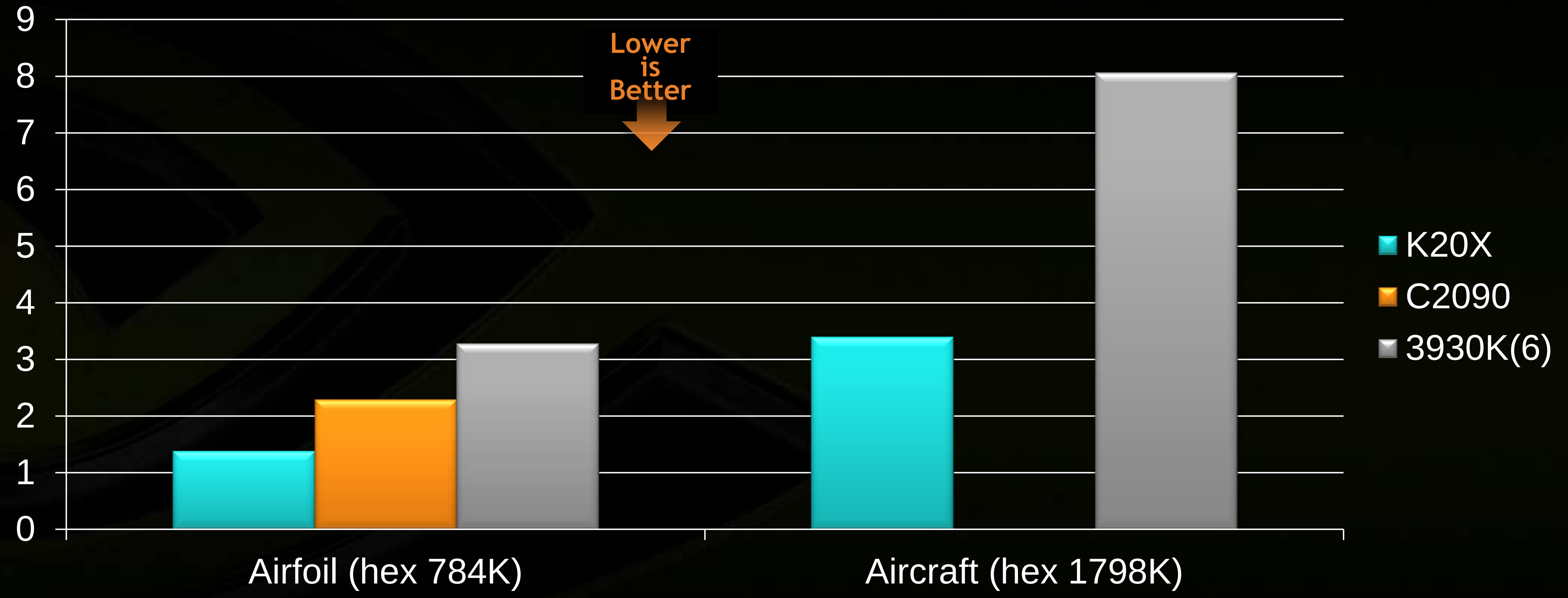
AMG Timings on Regular Discretizations

- CPU Fluent solver: AMG(F-cycle, agg8, DILU, 0pre, 3post)
- GPU nvAMG solver: AMG(V-cycle, agg8, MC-DILU, 0pre, 3post)

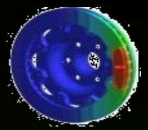


AMG Timings on Irregular Discretizations

- CPU Fluent solver: AMG(F-cycle, agg8, DILU, 0pre, 3post)
- GPU nvAMG solver: AMG(V-cycle, agg2, MC-DILU, 0pre, 3post)



ANSYS and NVIDIA Collaboration Roadmap

Release	ANSYS Mechanical 	ANSYS Fluent 
13.0 Dec 2010	SMP, Single GPU, Sparse and PCG/JCG Solvers	
14.0 Dec 2011	+ Distributed ANSYS; + Multi-node Support	Radiation Heat Transfer (beta)
14.5 Oct 2012	+ Multi-GPU Support; + Hybrid PCG; + Kepler GPU Support	+ Radiation HT; + GPU AMG Solver (beta), Single GPU
15.0 Mid-2013	CUDA 5 + Kepler Tuning	Multi-GPU AMG Solver

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- Step 1: Understand Application
- Step 2: Identify Bottlenecks
- Step 3: Parallelize Algorithms
- Step 4: Create Library
  - People (Team + Collaboration)
  - Algorithms (Innovation + Mathematics)
  - Software (Design + Optimization)
- Step 5: Enjoy Acceleration

Big praise for nvAMG and ANSYS team

Welcome to ANSYS Fluent with nvAMG

Starting with single GPU support as a beta feature in 14.5

Questions?

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