Implementing Fast Parallel Linear System Solvers In OpenFOAM based on CUDA

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Objectives

Objective

- To introduce a tool to integrate linear system solvers on the GPU into OpenFOAM

Topics

- Introduction to the GPU and CUDA
- Integrating CUSP into OpenFOAM
- Some preliminary results
- Important considerations when using this tool
- Next steps
- Take home messages

Introduction to The GPU and CUDA

What exactly is CUDA?
Defined as: Compute Unified Device Architecture. I.e. a parallel computing architecture used in graphics processing units (GPU), developed by Nvidia.

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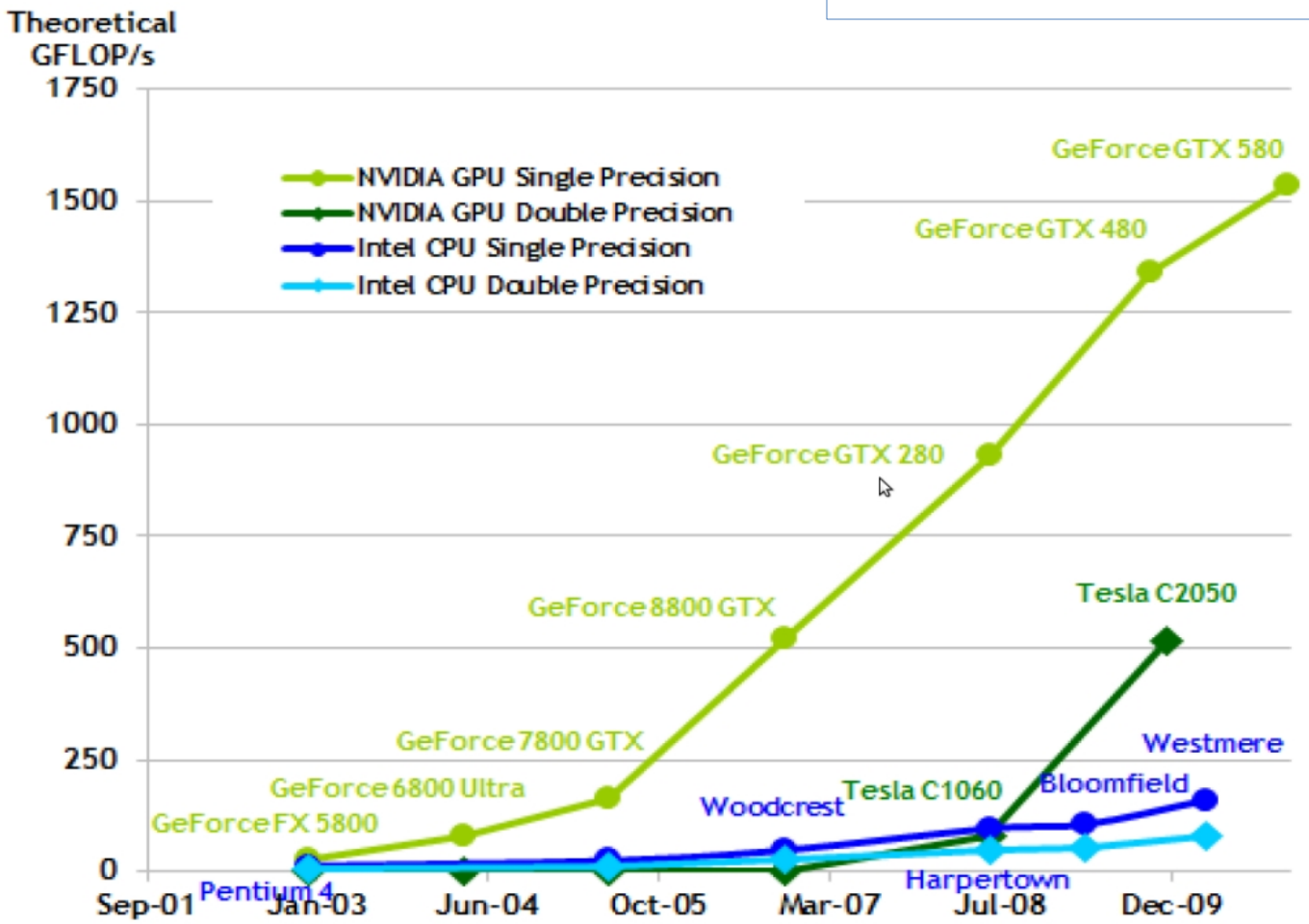
What is CUDA C/C++?
A language that provides an interface so that parallel algorithms can be run on CUDA enabled Nvidia GPUs

Introduction to The GPU and CUDA

GPU v.s CPU Calculations



CPU-GPU Comparison of Floating-point operations per second [1]

Introduction to The GPU and CUDA

Why are we interested?

Larger problems require more computing resources (LES, coupled physics)

GPUs are fast when used properly

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Where can GPUs be applied?

Where parallel algorithms live

- Linear algebra i.e. sparse matrix math

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Why don't we compile everything to work on the GPU?

Only programs written in CUDA language can be parallelized on GPU. **So we cannot just recompile OF.**

Integrating CUSP into OpenFOAM

cusp-Library http://code.google.com/p/cusp-library/

“Cusp is a library for **sparse linear algebra** and **graph** computations on CUDA. Cusp provides a flexible, **high-level** interface for manipulating sparse matrices and solving sparse linear systems.”[2]

Provided Template Solvers:

- (Bi-) Conjugate Gradient (-Stabilized)
- GMRES

Matrix Storage

- CSR, COO, HYB, DIA

Provided Preconditioners

- Jacobi (diagonal) preconditioners
- Sparse Approximate inverse preconditioner
- Smoothed-Aggregation Algebraic Multigrid preconditioner

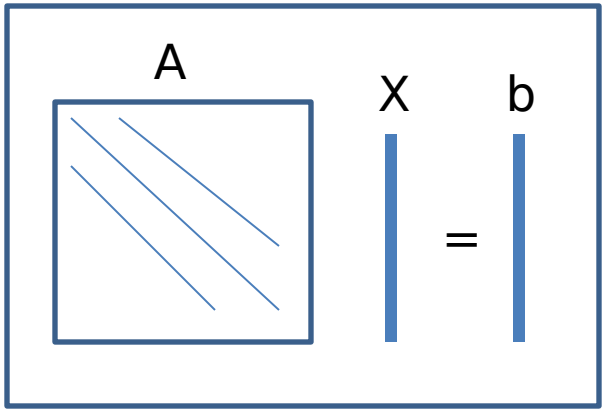
Integrating CUSP into OpenFOAM

http://code.google.com/p/thrust/

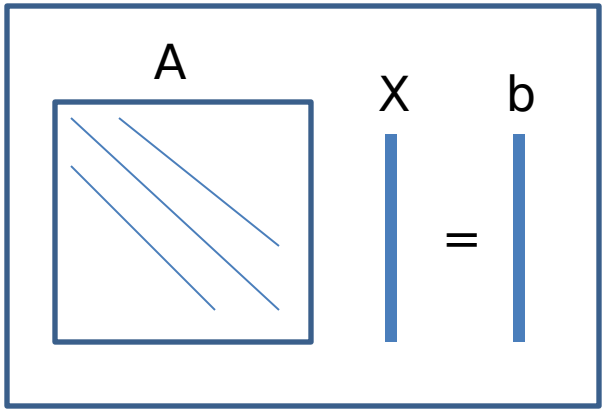
“Thrust is a CUDA library of parallel algorithms with an interface resembling the C++ Standard Template Library (STL). Thrust provides a flexible **high-level**interface for GPU programming that greatly enhances developer **productivity**.
“ [3]

Integrating CUSP into OpenFOAM

OpenFOAM solve(…);



Cusp-based solver on GPU



Thrust Methods

cusp Methods

Integrating CUSP into OpenFOAM

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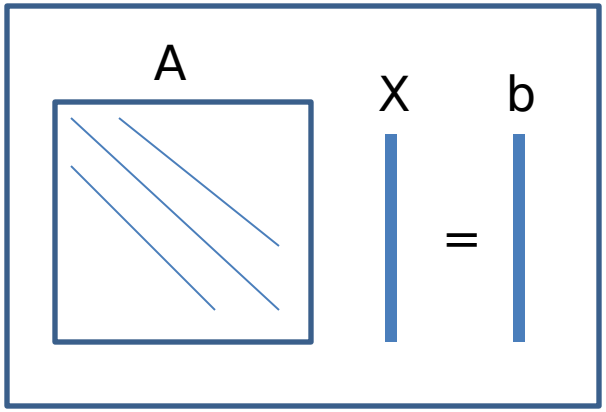

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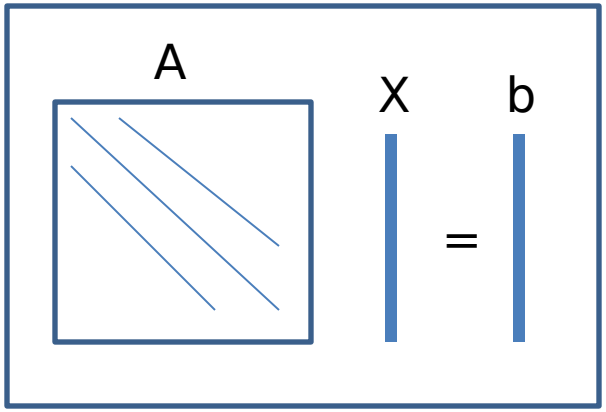


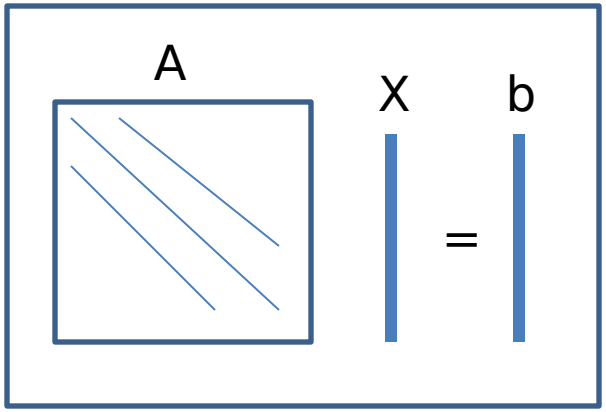
Thrust Methods

lduMatrix is converted to COO Using thrust::copy() in C++

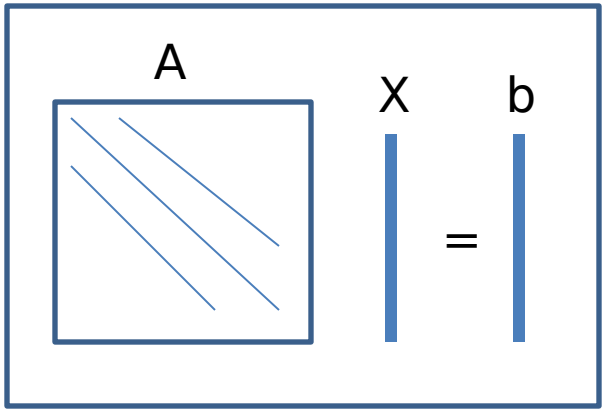
cusp Methods

Integrating CUSP into OpenFOAM

OpenFOAM solve(…);



Cusp-based solver on GPU



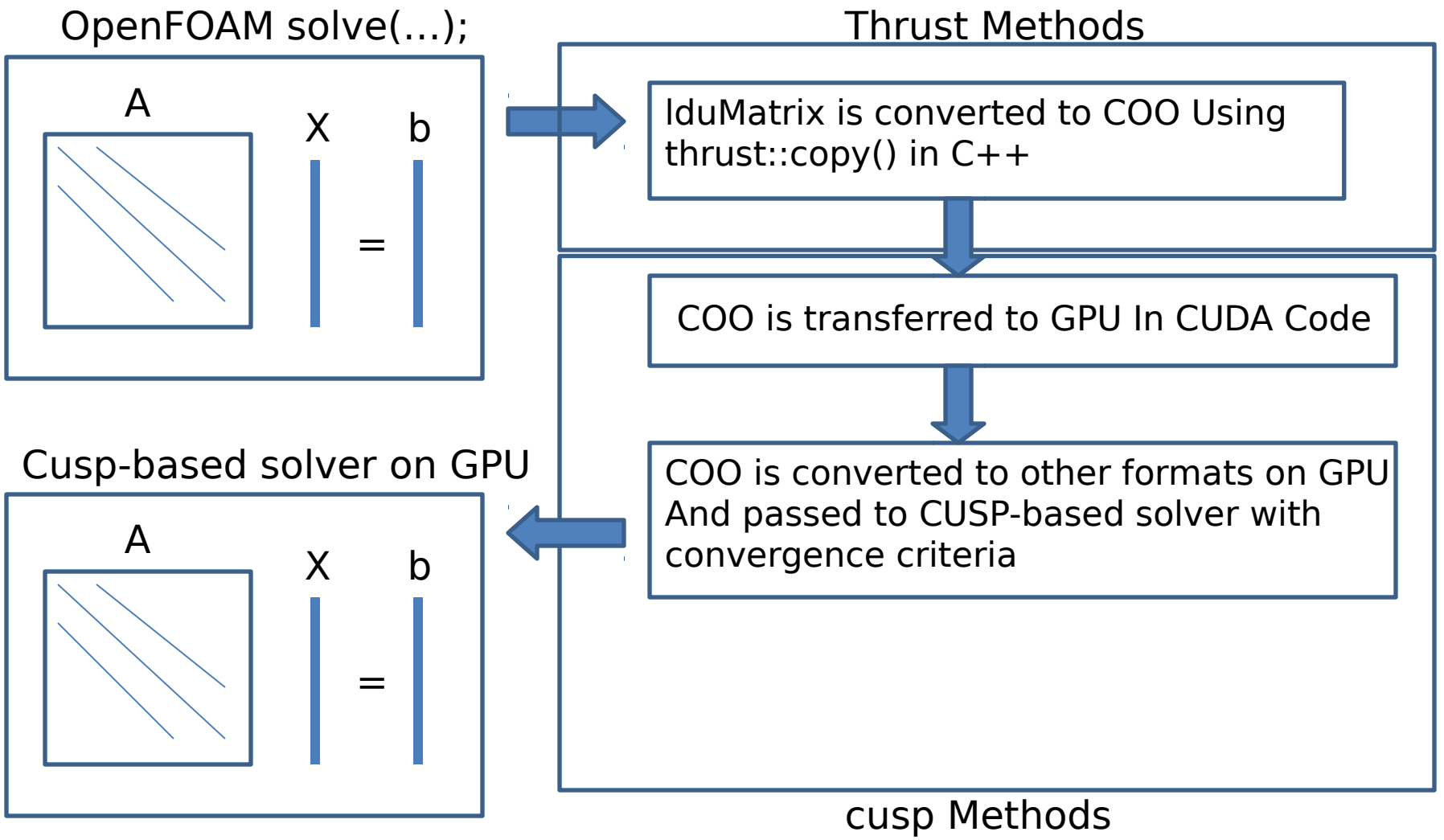
Thrust Methods

lduMatrix is converted to COO Using thrust::copy() in C++

COO is transferred to GPU In CUDA Code

cusp Methods

Integrating CUSP into OpenFOAM



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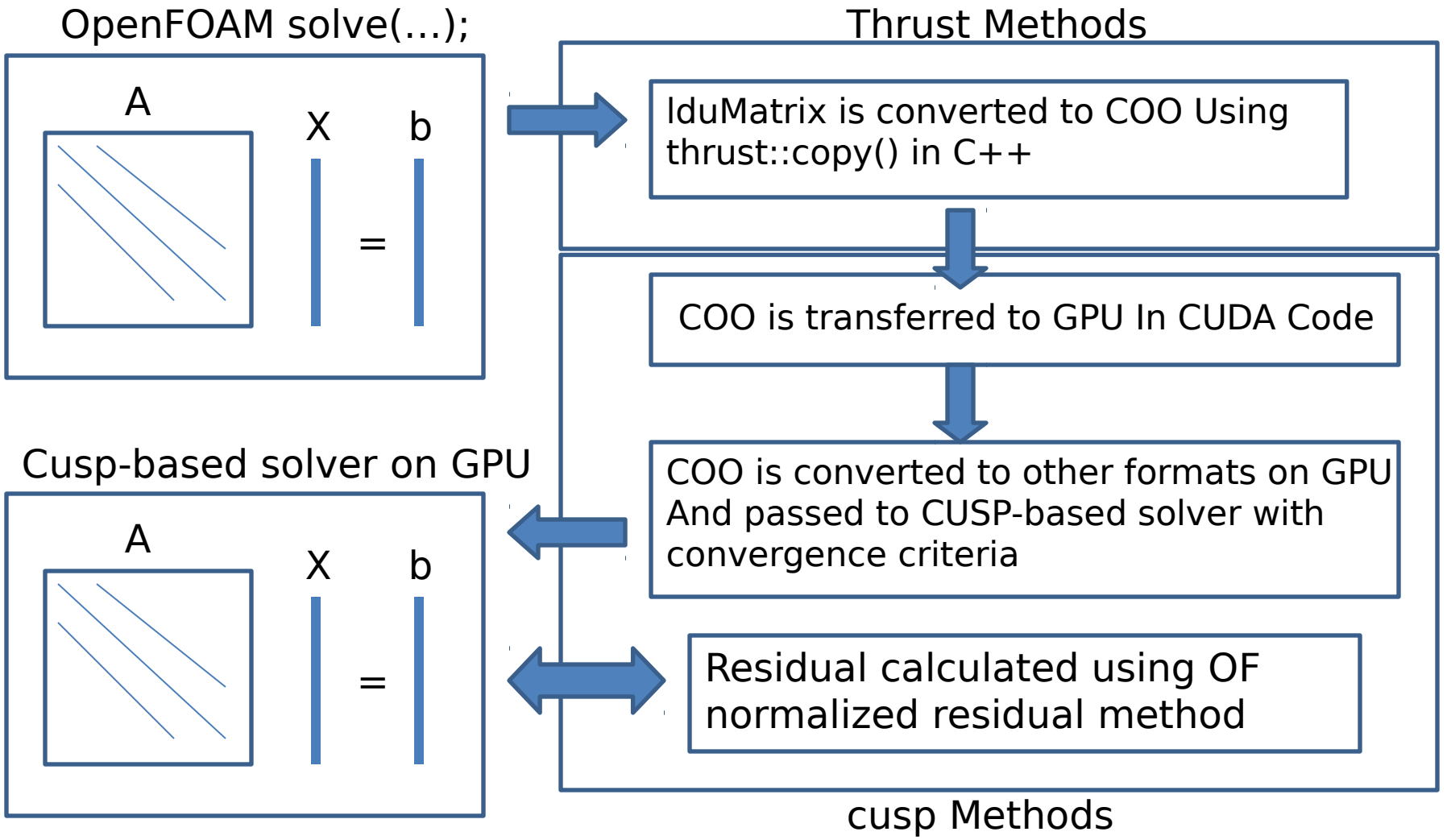

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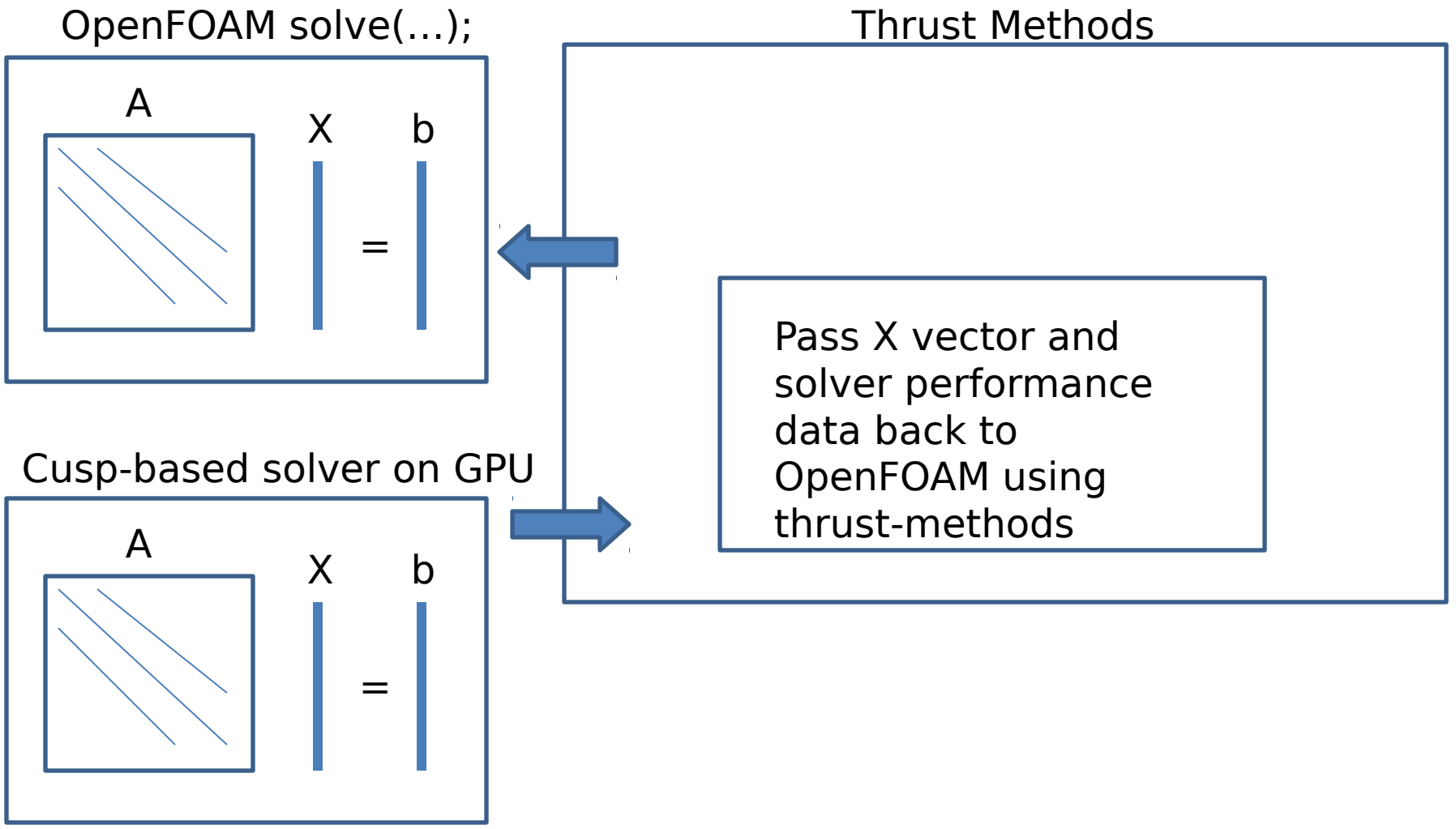


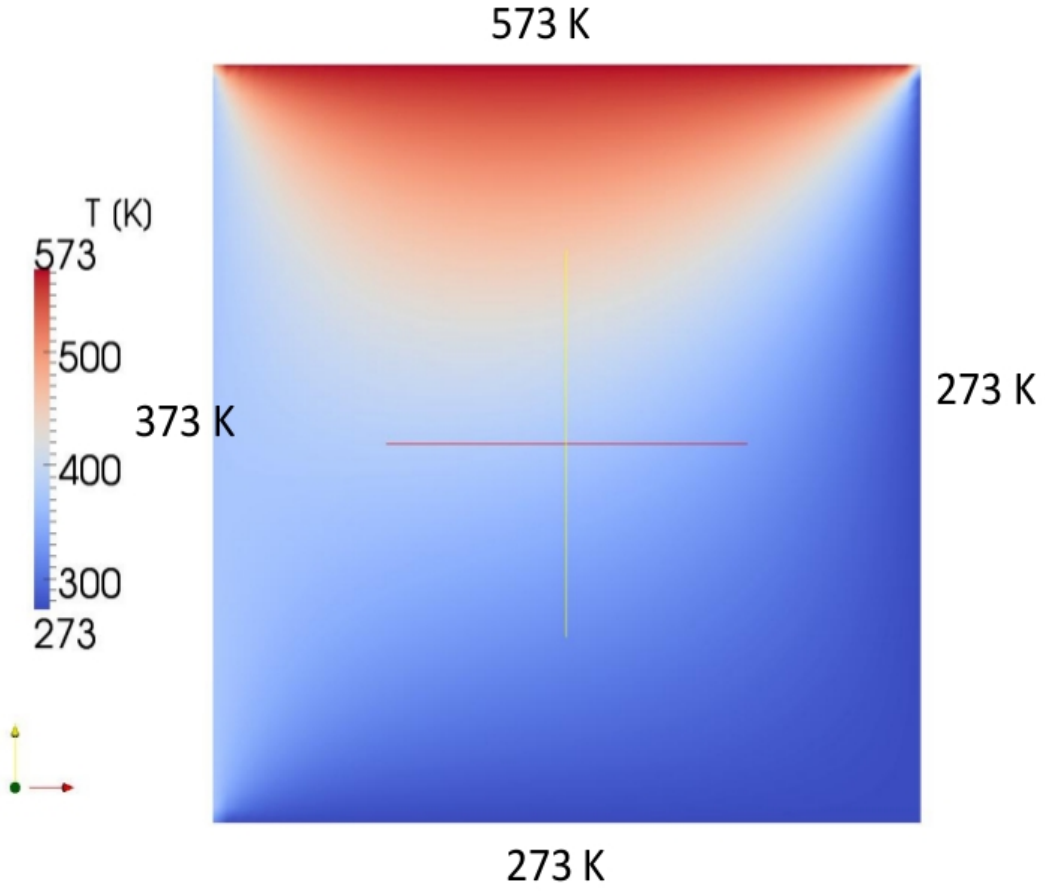
Preliminary Results

A test Problem.

2D Heat Equation

$$\nabla^2 T = 0$$

Vary N from 10-2000
where N^2 = nCells



Preliminary Results

Solver Settings

All CG solvers

Tolerance = 1e-10;
MaxIter 1000;

```
solver          GAMG;
tolerance       1e-10;
smoother        GaussSeidel;
nPreSweeps      0;
nPostSweeps     2;
cacheAgglomeration true;
nCellsInCoarsestLevel sqrt(nCells);
agglomerator    faceAreaPair;
mergeLevels     1;
```

Preliminary Results

Setup

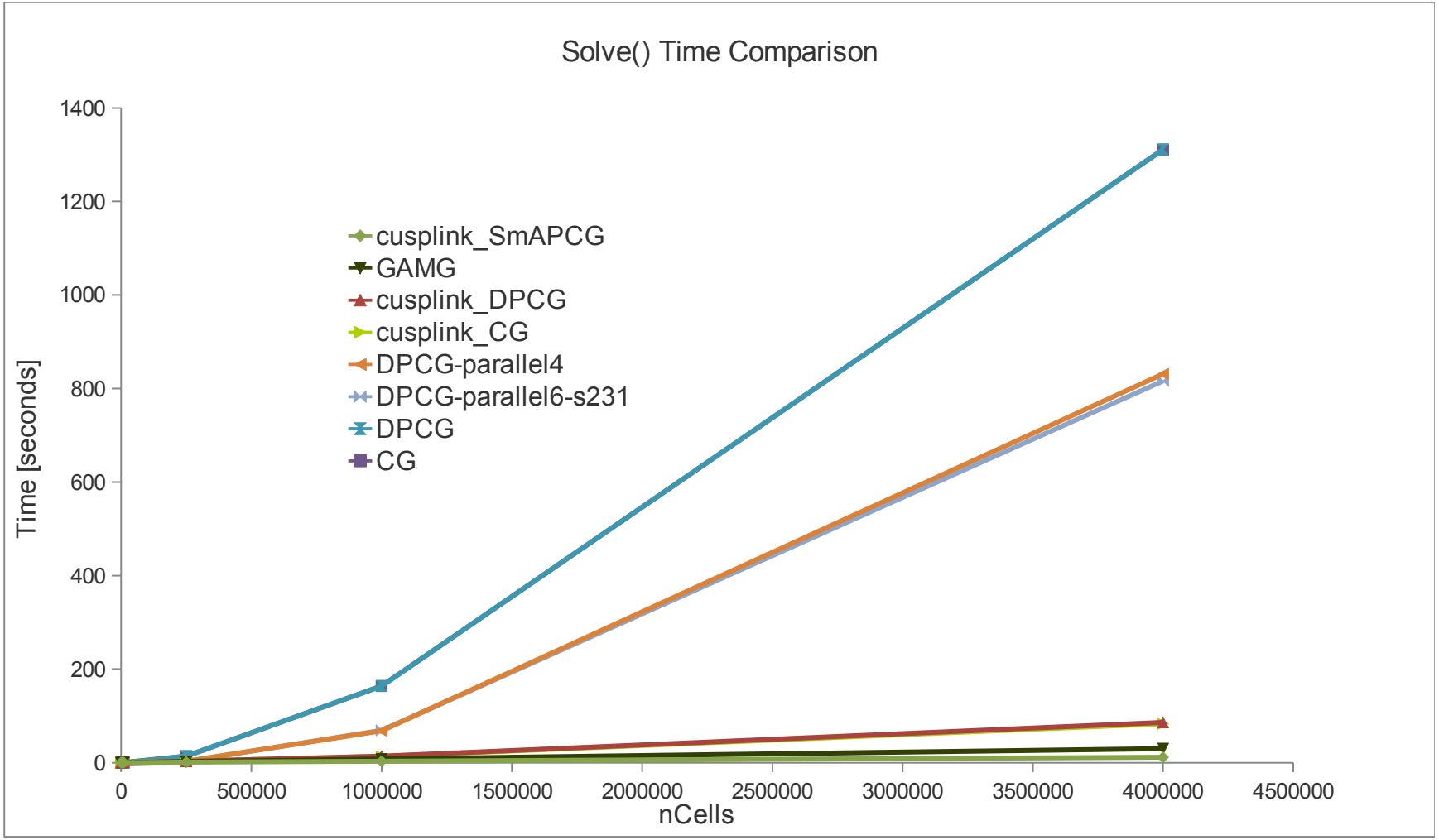
CUDA version 4.0
CUSP version 0.2
Thrust version 1.4
Ubuntu 10.04

CPU: Dual Intel Xeon Quad Core E5430 2.66GHz
Motherboard: Tyan S5396
RAM: 24 gig

GPU: Tesla C2050 3GB DDR5
515 Gflops peak double precision
1.03 Tflops Peak single precision
14 MP * 32 cores/MP = 448 cores
Host-device memory bw = 1566 MB/sec (Motherboard specific)

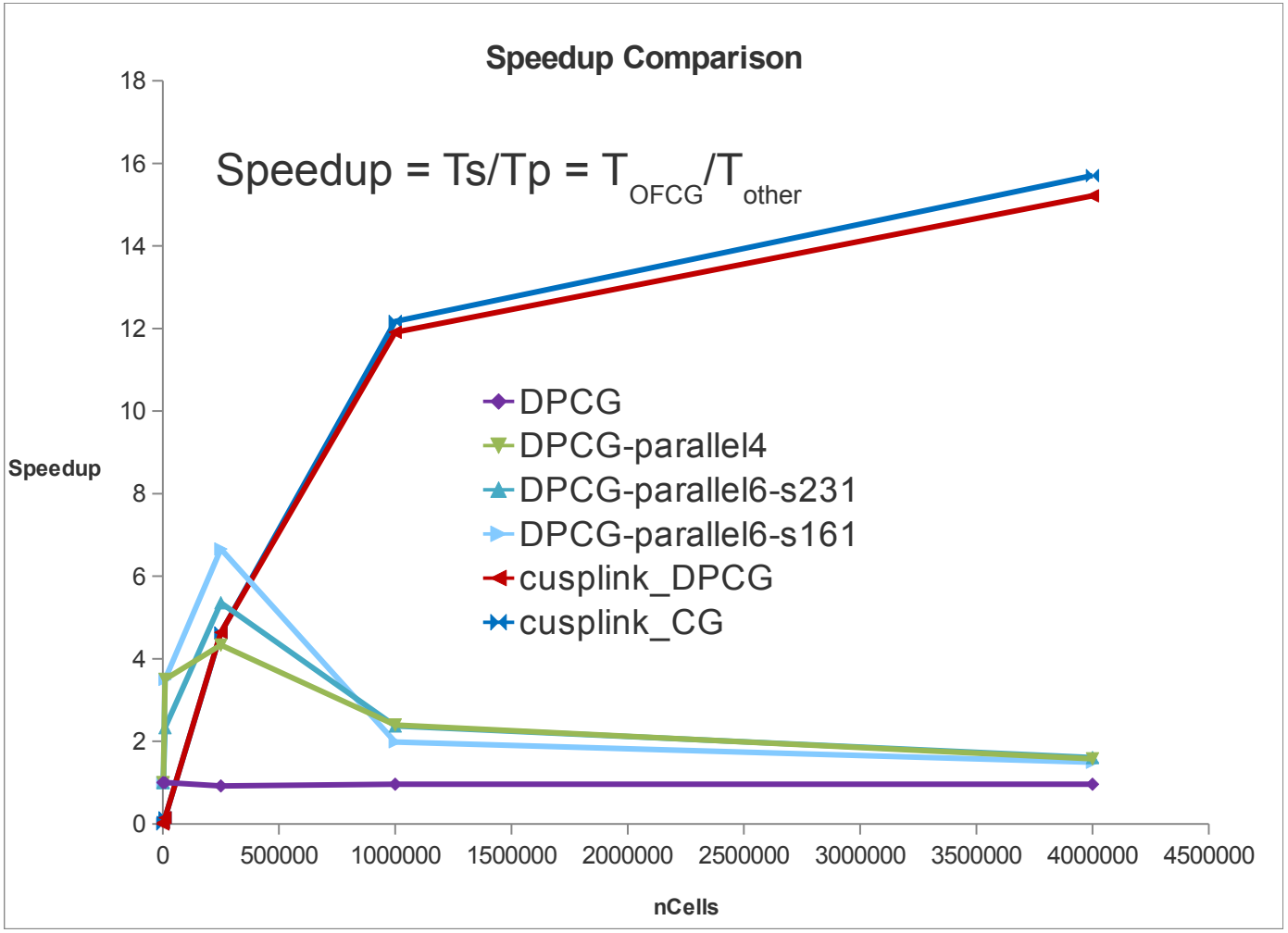
Preliminary Results

Solve Time



Preliminary Results

Solution Speedup



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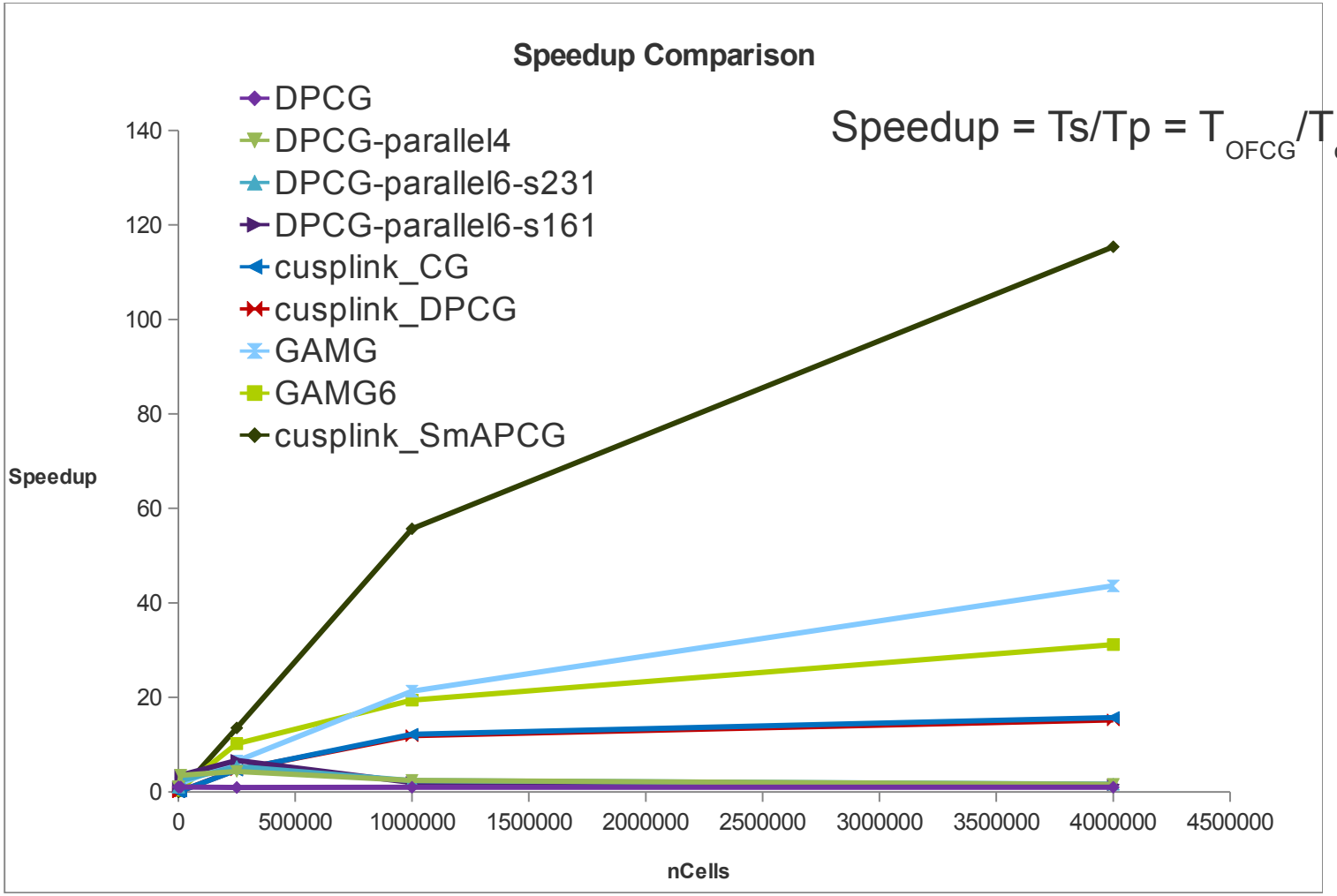

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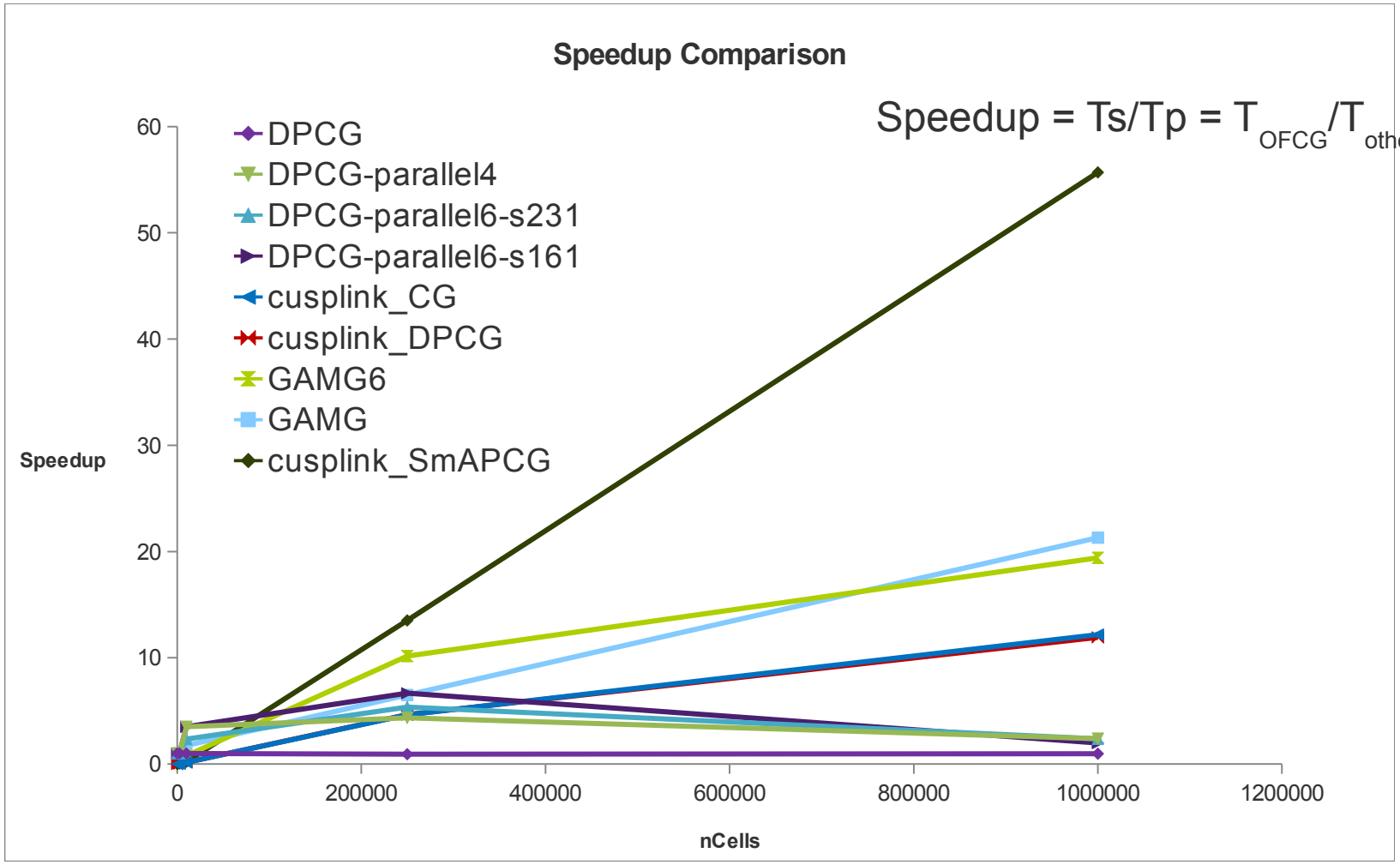

Preliminary Results

Notes on Comparison

- GPU Tesla C2050
- All are double precision results in CSR
- Low precision timers used
- Parallel CPU results a little skewed, i.e. other processes occurring on cpu
- Residuals are scaled in the same manner as OF
- GPU Results include data transfer time
- The GPU smoothed aggregate preconditioner was 115x faster than CG

Important Considerations

Before you jump….

- Tool is not multi GPU yet.
- Proper motherboard and power source
- CUDA Enabled hardware
- Amount of System Ram >= GPU RAM
- Working install of CUDA, CUSP, and OF-ext

Next Steps

Where to Start?

- Finish asymmetric solvers
- Clean up current version and release code

- Multi GPU support
- Improve the solvers as CUSP improves

Take Home Messages

- The GPU only solves the Ax=b system
- We have double precision
- GPUs have been integrated into OpenFOAM using Thrust and CUSP
- As cusp and thrust improve, nothing needs to be changed in this code, only to update cusp and thrust.
- They have been shown to be faster in the cases provided, because it is mostly solving Ax = b.
- Residuals are calculated the same as in OpenFOAM
- Multi-GPU still needs attention.
- The results show that memory bandwidth still is an issue with this particular setup and results could be faster with other setup.

Acknowledgements

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OpenFOAM Developers Community

Advisors

Dr. Ramachandran

Dr. Dudukovic

Sources

1. Nvidia CUDA Programming Guide, Version 4.0, 2011. Nvidia Corporation.
2. Nathan Bell and Michael Garland, Cusp: Generic Parallel Algorithms for Sparse Matrix and Graph Computations, 2010, http://cusp-library.googlecode.com,Version 0.1.0
3. Jared Hoberock and Nathan Bell, Thrust: A Parallel Template Library, 2010, http://www.meganewtons.com/,Version 1.3.0

Thanks for your attention!

Questions?

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Preliminary Results

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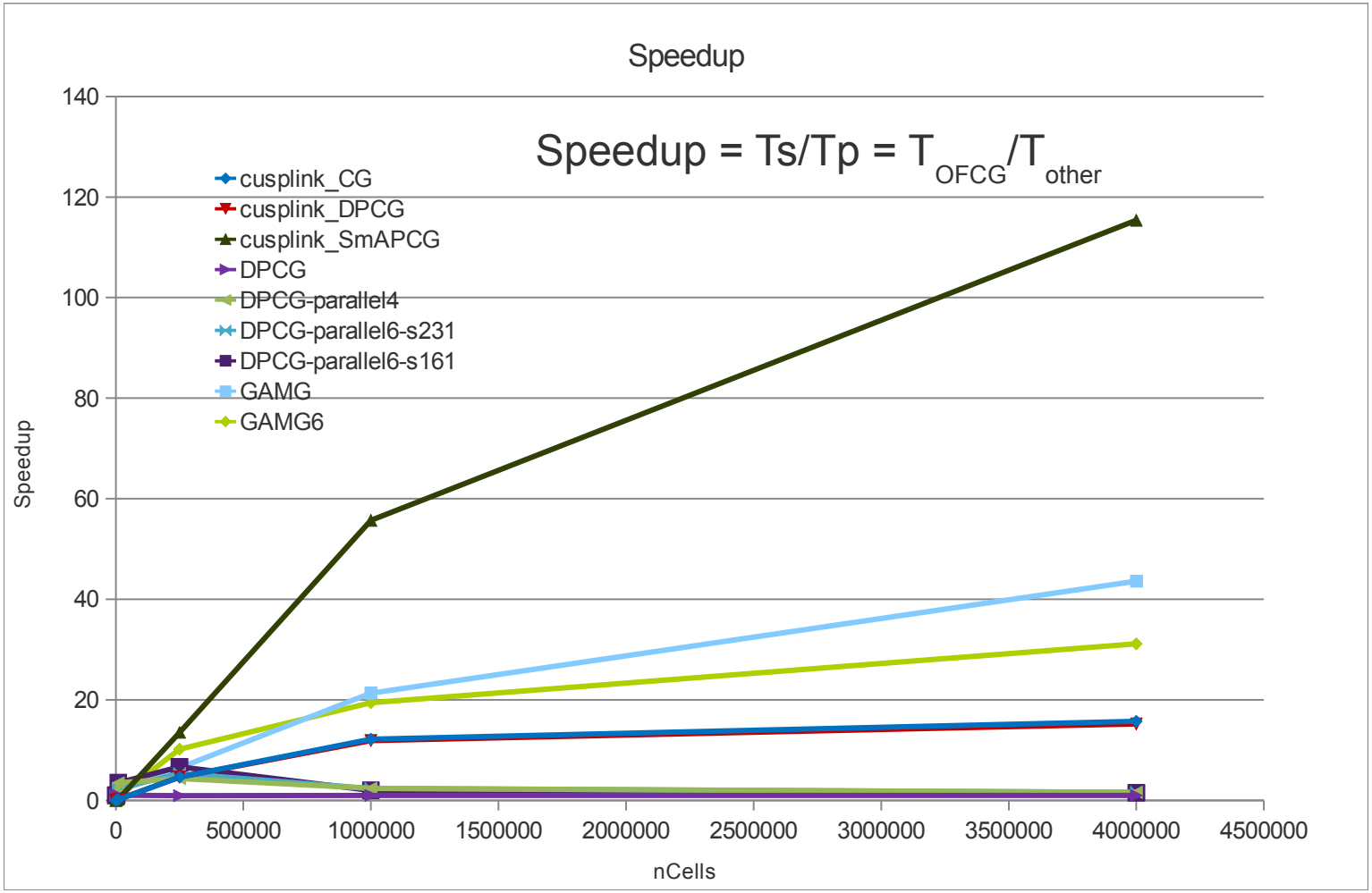

Residual Scaling

For matrix A x = b,

residual is defined as

res = b - Ax

We then apply residual scaling with the following normalisation factor procedure:

Type xRef = gAverage(x);

wA = A x;
pA = A xRef;

NormFactor = gSum(cmptMag(wA - pA) + cmptMag(source - pA)) + matrix.small_;

and the scaled residual is:

residual = gSum(cmptMag(source - wA))/normFactor;

I will save you from complications with vectors and tensors in my block solver. :-)

Enjoy,

Hrv

Source: http://www.cfd-online.com/Forums/openfoam-solving/57903-residuals-convergence-segregated-solvers.html