Multi-GPU simulations in OpenFOAM with SpeedIT technology.
Attempt I: SpeedIT

- GPU–based library of iterative solvers for Sparse Linear Algebra and CFD.
  - CMRS format for fast SpMV and other storage formats.
  - BiCGSTAB and CG iterative solvers.
  - Preconditioners: Jacobi, AMG.
  - Runs on one or more GPU cards.
  - OpenFOAM compatible.

- Possible Applications:
  - Quantum Chemistry,
  - Semiconductor and Power Network Design
  - CFD (OpenFOAM)
  - etc.
SpeedIT and OpenFOAM

- Provides conversion between CSR and OpenFOAM LDU data formats.
- Easy substitution of CG/BCG with their GPU versions.
- OpenFOAM source code is unchanged due to a plugin concept. No recompilation of OpenFOAM is necessary.

- GPL–based generic Plugin to OpenFOAM.
- Any acceleration toolkit can be integrated now.

1. Edit system/controlDict file and add libSpeedIT.so
2. Edit system/fvSolution and replace CG with CG_accel
3. Compile the Plugin to OpenFOAM (wmake)
SpeedIT vs. CUDA 5.0

Fig. Speedup of our CMRS implementation against scalar, vector (CSR) and HYB kernels as a function of the mean number of nonzero elements per row ($\mu$).

Fig. Speedup of our CMRS implementation against CUDA 5.0 (HYB/CSR formats).

SpMV is a key operation in scientific software.
OpenFOAM & single GPU
Low-cost hardware

GPU cost: $200

Test cases:

- Cavity 3D, 512K cells, icoFoam.
- Human aorta, 500K cells, simpleFoam.
- CPU: Intel Core 2 Duo E8400, 3GHz, 8GB RAM @ 800MHz
  GPU: NVIDIA GTX 460, VRAM 1GB
  Ubuntu 11.04 x64, OpenFOAM 2.0.1, CUDA Toolkit 4.1,
- Pressure solved with CG preconditioned with DIC, GAMG and CG
  preconditioned with AMG.
OpenFOAM & single GPU

Validation

Fig. Velocity and pressure profiles along x axis for aorta (top left) and pressure profile along x axis for cavity3D (top right). Solution for all preconditioners.

Cross-section for velocity in X and Y direction for cavity3D run with OpenFOAM and SpeedIT (lines) and from literature for Re=100 (dotted line) and Re=400 (solid line) without turbulence model (icoFoam).
Fig. Execution times of 50 time steps (up) and acceleration factor for simpleFoam (left) and pisoFoam (right). Performed at Intel E8400@3GHz and GTX460. 1C and 2C stand for one, two cores respectively.
OpenFoam & multi-GPU

- **Motivation**: large geometries (> 8M celss) do not fit to a single GPU card (with max. 6GB RAM).

- OpenFOAM performed the decomposition. MPI was used for communication between GPU cards.

- Tests were performed at **IBM PLX CINECA** with 2 six-cores Intel Westmere 2.40 GHz and 2 Tesla M2070 per node (supported by NVIDIA). One thread manages one GPU card.

- Tests focused on multi-GPU preconditioned CG with AMG to solve pressure equation in steady-state flows.
OpenFoam & multi-GPU

Fig. Time in sec. of first 10 time steps for N GPUs and CPU cores. Motorbike test, simpleFoam with diagonal (blue) and GAMG (green) preconditioners, SpeedIT is marked in red. Geometry is 32 millions cells. Tests were performed at PLX CINECA.
Scaling of OpenFOAM & multi-GPU

- Complex car geometry, external steady state flow, simpleFOAM, 32M cells, pressure: GAMG, velocity: smoothGS.

Fig. Execution times of 2950 time steps (left) and scaling relative to 8 GPU (right).
OpenFOAM & GPU for industries

Figure 1: OpenFOAM performance of 3D cavity case using 4 million cells on a single node.

Authors: Saeed Iqbal and Kevin Tubbs

Full report can be obtained at Dell Tech Center.
OpenFOAM & GPU for industries

Figure 2: Total Power and Power Efficiency of 3D cavity case on 4 million cells on a single node.

Authors: Saeed Iqbal and Kevin Tubbs
OpenFOAM & GPU for industries

Figure 1: OpenFOAM performance of 3D cavity case using 8 million cells on a single node.

Authors: Saeed Iqbal and Kevin Tubbs
OpenFOAM & GPU for industries

![Graph showing power and power efficiency of 3D cavity case on 4 million cells on a single node.]

**Figure 2:** Total Power and Power Efficiency of 3D cavity case on 4 million cells on a single node.

Authors: Saeed Iqbal and Kevin Tubbs
SpeedIT 3.0

What’s new:

- New ILU based preconditioner.
- Support for Keppler NVIDIA cards.
  - much higher bandwidth (300GB/s).
  - 5x faster intra-GPU communication thanks to GPU Direct 2.0.
- Release in the beginning of 2013.
Acknowledgments

- Saeed Iqbal and Kevin Tubbs (DELL)
- Stan Posey, Edmondo Orlotti (NVIDIA)
- CINECA, PRACE

Vratis Ltd.
Muchoborska 18, Wroclaw, Poland
Email: lukasz.miroslaw@vratis.com

More information: speed-it.vratis.com, vratis.com/blog