GPU Accelerated Lattice-Boltzmann Method for Fluid Flows in Nuclear Waste Tanks at Hanford Site

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Introduction

- Nuclear waste stored at Hanford currently resides in tanks as a heterogeneous mixture that is difficult to handle and move.
- Pulsed jet mixers (PJM) will be used to mix this nuclear waste and create a homogenous mixture for easy transportation.
- Computational fluid dynamics (CFD) simulations can be used to predict the behavior of gas bubbles within the tanks and the performance of the PJMs.

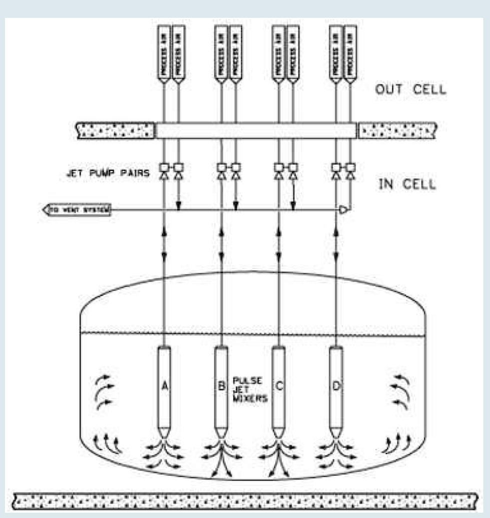

Figure 1. Example of PJM design for mixing waste\. ("Submerged Applications", http://www.transvac.co.uk/nuclear.php)

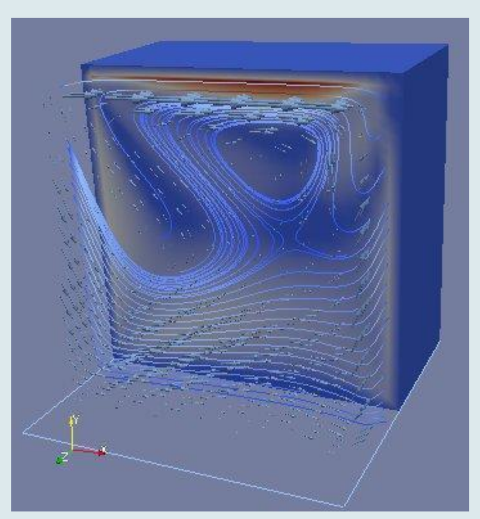

Figure 2. 3-D plot of flow generated with LBM program. ("Lid Driven Cavity Flow", http://sourceforge.net/projects/lbmflow/)

Objective

- Improve effectiveness and speed of existing lattice-Boltzmann method (LBM) computer program by implementing computing power of graphical processing units (GPUs).
- GPUs will allow for the analysis of massive CFD problems while drastically reducing computation time.
- Use GPU adapted code to analyze nuclear waste flows for predicting performance of PJMs.

GPU Programming with CUDA

- GPU programming uses thousands of cores running computations in parallel. A large problem is broken into smaller parts and executed simultaneously.
- NVIDIA's Compute Unified Device Architecture (CUDA) is a general-purpose platform that currently supports C, C++, Fortran, and Python.
- LBM benefits from parallel programming since no memory must be shared between nodes; individual threads perform computations independently
- This reduces the time and resources spent sharing memory; computation time can be increased as much as 50 times faster[1] than CPU processing

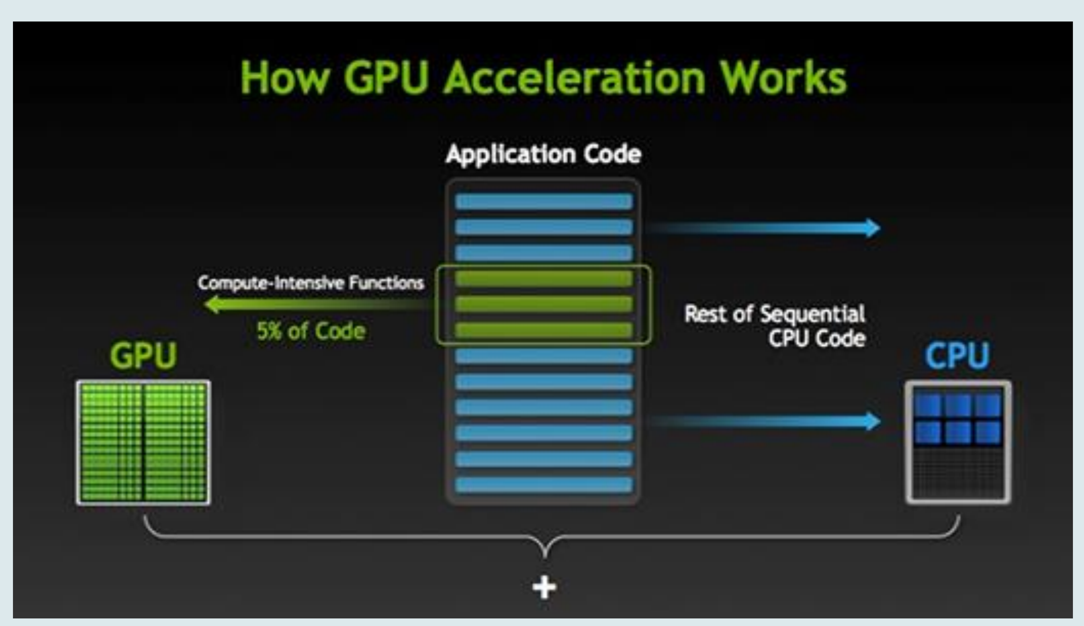

Figure 3. GPU implementation to accelerate computations. ("How GPU Accelerating Works", http://www.nvidia.com/object/what-is-gpu-computing.html)

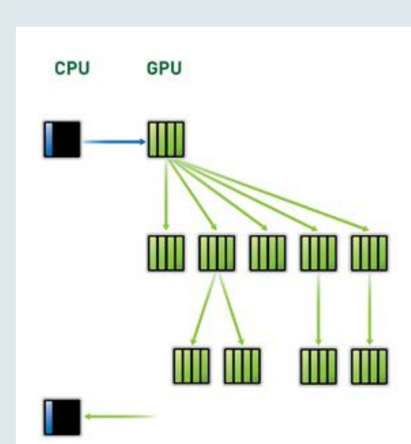

Figure 4. GPU dynamically spawning new threads on it own without returning to the CPU. ("Dynamic Parallelism", http://www.nvidia.com/object/nvidia-kepler.html)

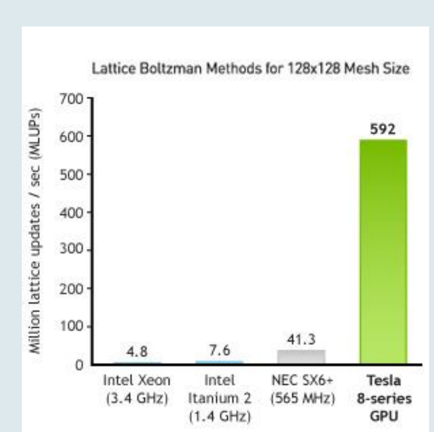

Figure 5. Lattice Boltzmann method computation comparisons. ("Computational Fluid Dynamics", http://www.nvidia.com)

Multiphase LBM for Nuclear Waste

- LBM is broken down into two steps: collision and propagation[2]:

$$|\tilde{f}_\alpha(x, t+\delta t)> = |f_\alpha(x,t)> + \Omega[|f_\alpha(x,t)>]$$

$$f_\alpha(x + \delta t \xi_\alpha, t + \delta t) = \tilde{f}_\alpha(x, t+\delta t)$$

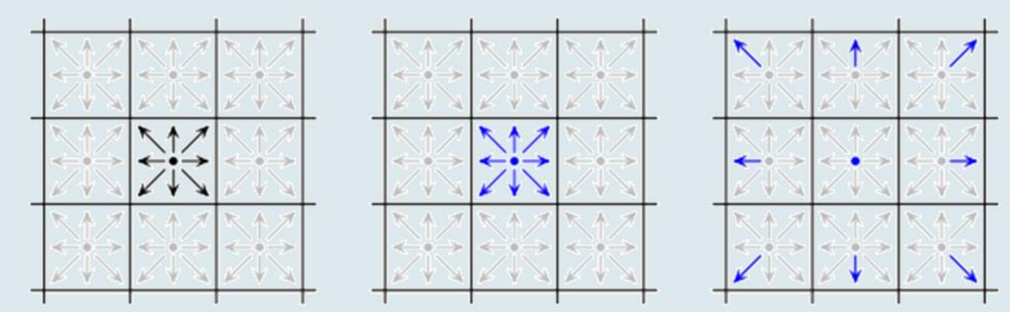

Figure 6. Collision and propagation steps for LBM process. [2]

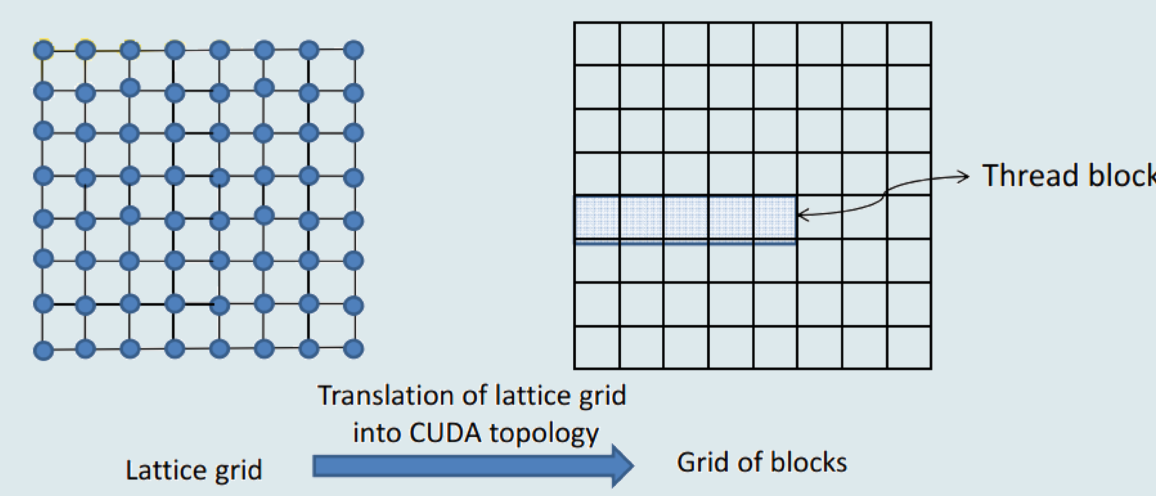

Figure 7. The lattice grid is transferred to the CUDA thread block and executed by kernels. [1]

- Velocity profile of multiphase flows are also being investigated.

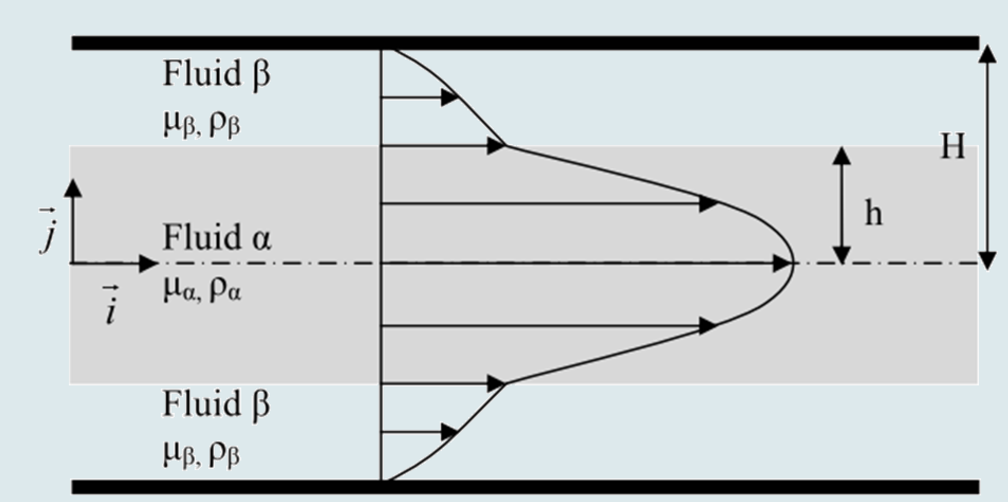

Figure 8. Poiseuille profile for multilayered fluid flow between two plates. Fluid β is the denser fluid. [5]

Conclusion

- Both existing and original codes for LBM are being adapted for GPU parallel programming.
- Multiphase fluid flows analyzed to better predict behavior of nuclear waste in tanks.

Future Work

- Adapt existing LBM code to GPU platform
- Adapt code for cluster that uses several multi-GPU nodes to further accelerate computation.
- Predict performance of PJMs and use data to optimize design mixing of nuclear waste.

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