Performance–Optimized Lattice Boltzmann

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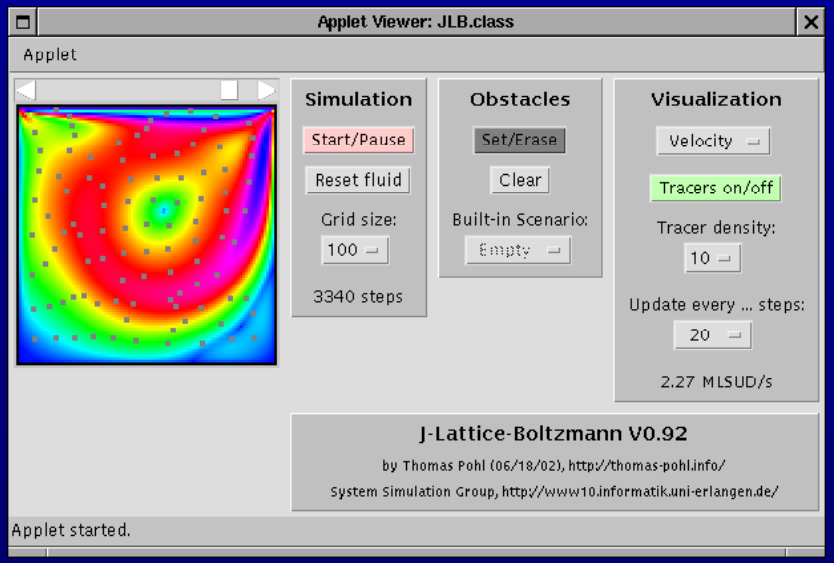
Outline

1. What is Lattice Boltzmann (LB)?
2. LB Implementation in Java
3. Cache Optimizations for LB
4. Applications in Material Science
5. Conclusions & Future Work

A. Grid Computing with LB

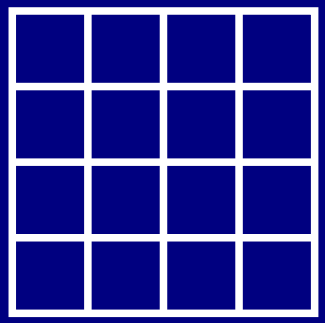
What is Lattice Boltzmann (LB)?

- First introduced by McNamara and Zanetti in 1988
- Another method to do computational fluid dynamics (CFD)
- Weakly compressible approximation of the Navier–Stokes equations
- Good for sufficiently small Mach numbers (< 0.1)
- Very easy to implement

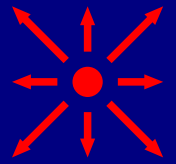


Basic Ingredients of LB

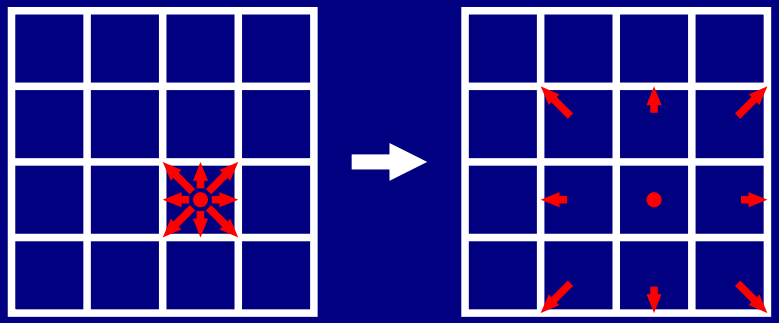
1. Lattice consisting of several cells



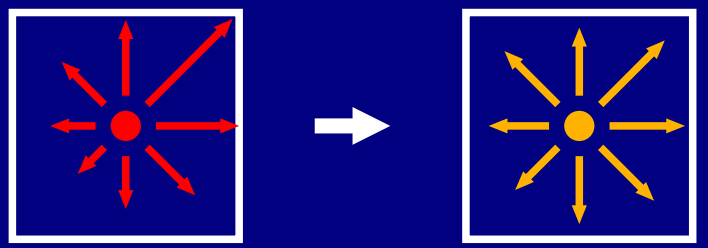
2. Distribution functions $f_i(x, y)$ for each cell



3. Streaming step

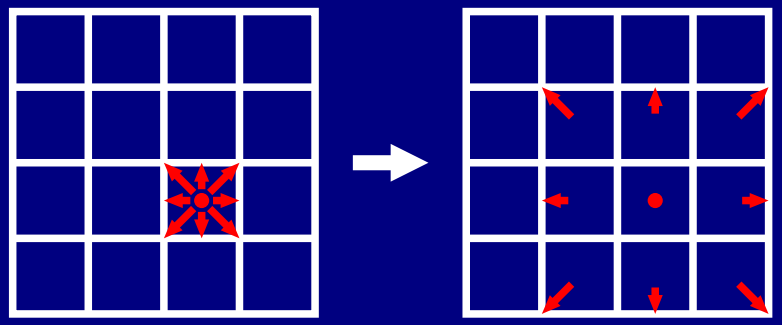


4. Collision step

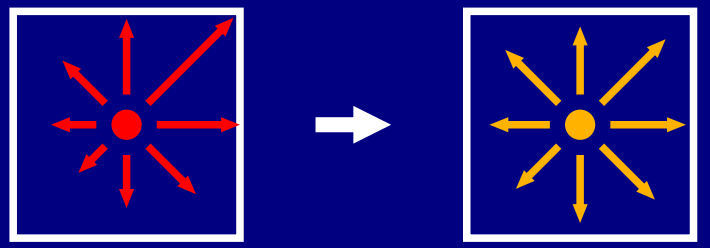


Fused Streaming/Collision Step

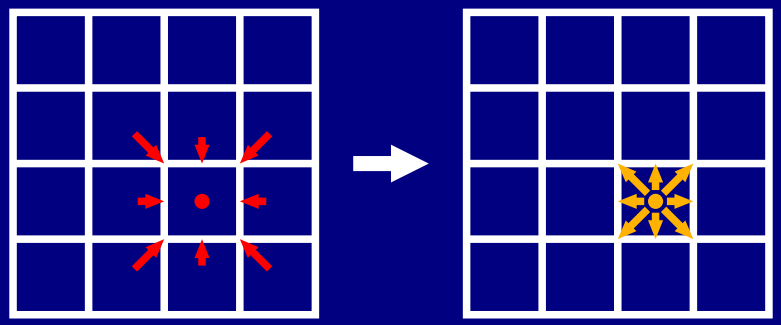
Streaming step



Collision step



Fused streaming/collision step



LB compared to Jacobi Relaxation

Similar:

- Complete sweep over the lattice
- Storage in two separate grids
- Data retrieval for a 9–point stencil

Different:

- Notion: time step $\longleftrightarrow$ iteration
- More data per cell
- More floating–point operations per cell
- Data storage

$\Longrightarrow$ **Optimization techniques for Jacobi should also work for LB**

Cache Optimizations for LB

Optimize performance

⇑

Put cache to work

⇑

Improve spatial and temporal
locality of data access

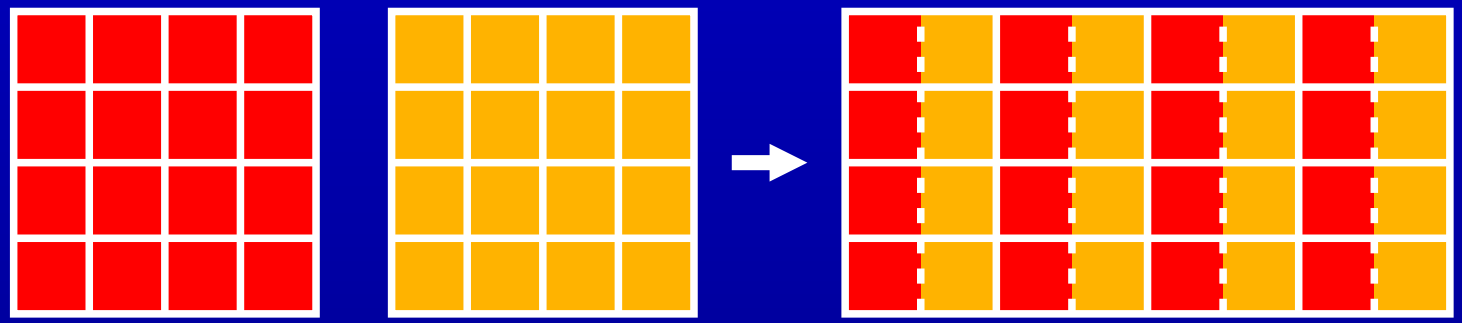
⇑

Techniques:

- Optimize data layout
- Optimize data access

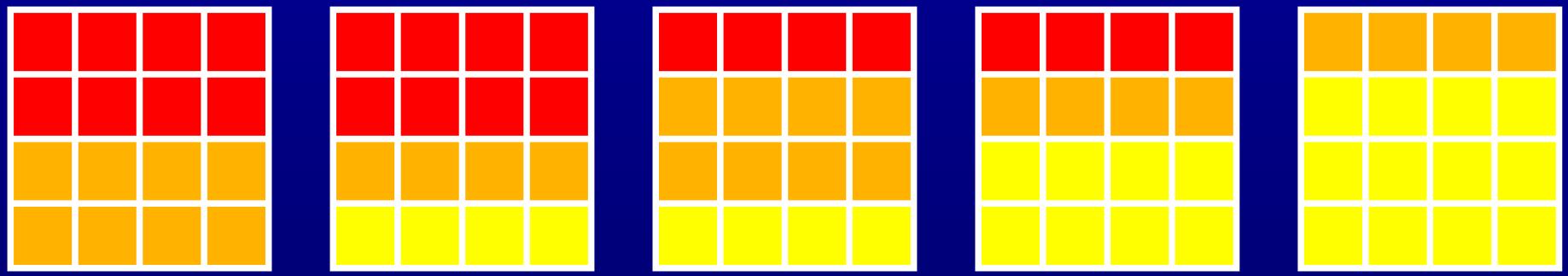
Two Examples for Cache Optimizations

Optimizing data layout: Array Merging



$\Longrightarrow$ **Improved spatial locality**

Optimizing data access: Loop Blocking

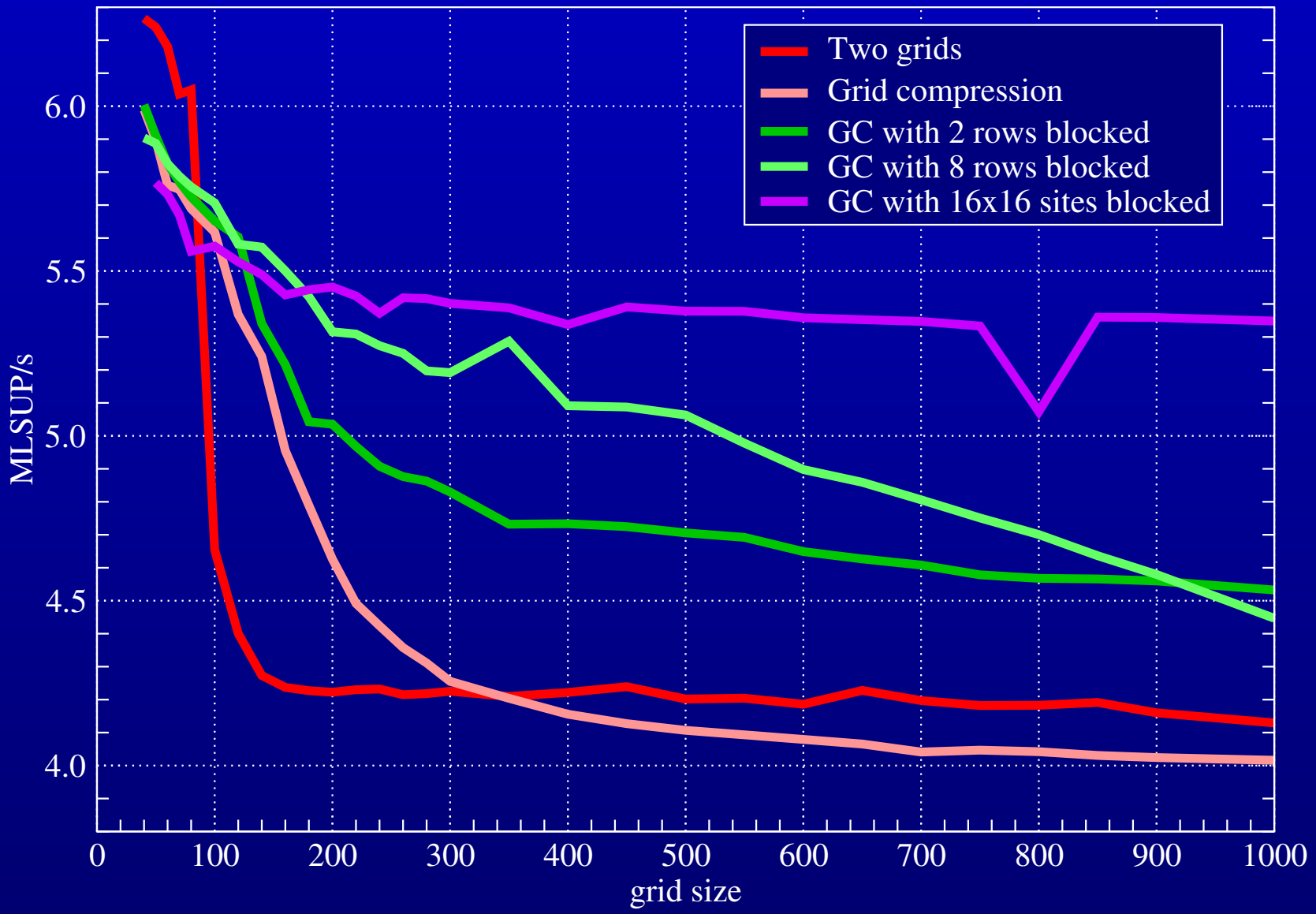


$\Longrightarrow$ **Improved temporal locality**

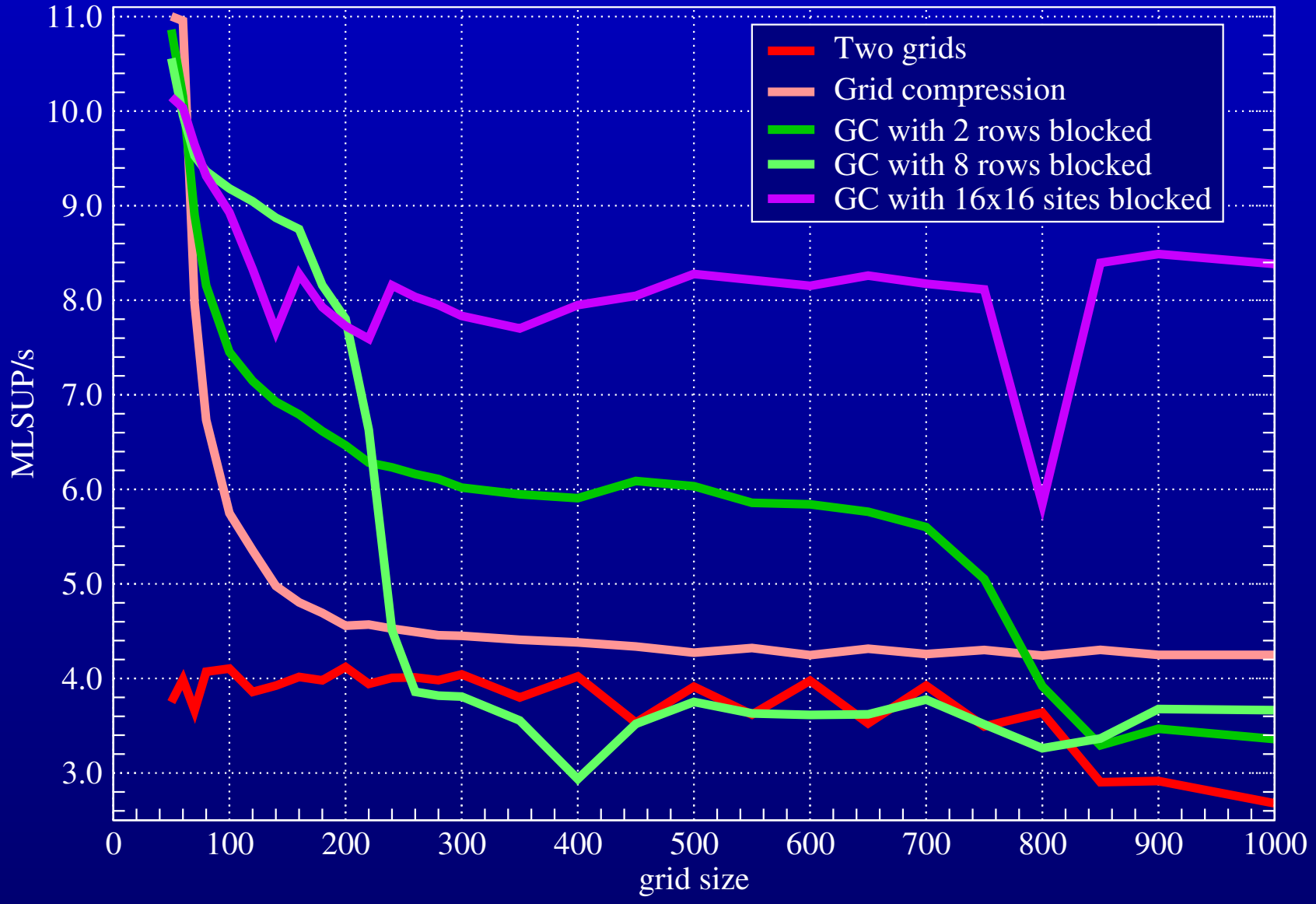
Cache–Optimized LB

- Jens Wilke's undergraduate thesis
- Supervised by Markus Kowarschik and Thomas Pohl
- Research and implementation of another data layout: grid compression (GC)
- Performance tests for 1–way and 2–way loop blocking
- Thesis available (in English) on `http://www10.informatik.uni-erlangen.de/` link "Research"

Intel Itanium2 0.9 GHz



AMD Athlon XP 2.0 GHz



Applications in Material Science

- Cooperation with Michael Thies and Carolin Körner, Material Science and Technology of Metals, University of Erlangen–Nürnberg
- **Goal:** Simulation of the fabrication process of metal foam on the supercomputer Hitachi SR8000–F1 at the Leibniz Computing Center in Munich
- Supported by the Competence Network for Technical, Scientific High Performance Computing in Bavaria **KONWIHR**
- **Results so far:** 3D LB code with free surfaces and surface tension implemented by Nils Thürey
- Ray tracer and animations by Nils Thürey

Conclusions & Future Work

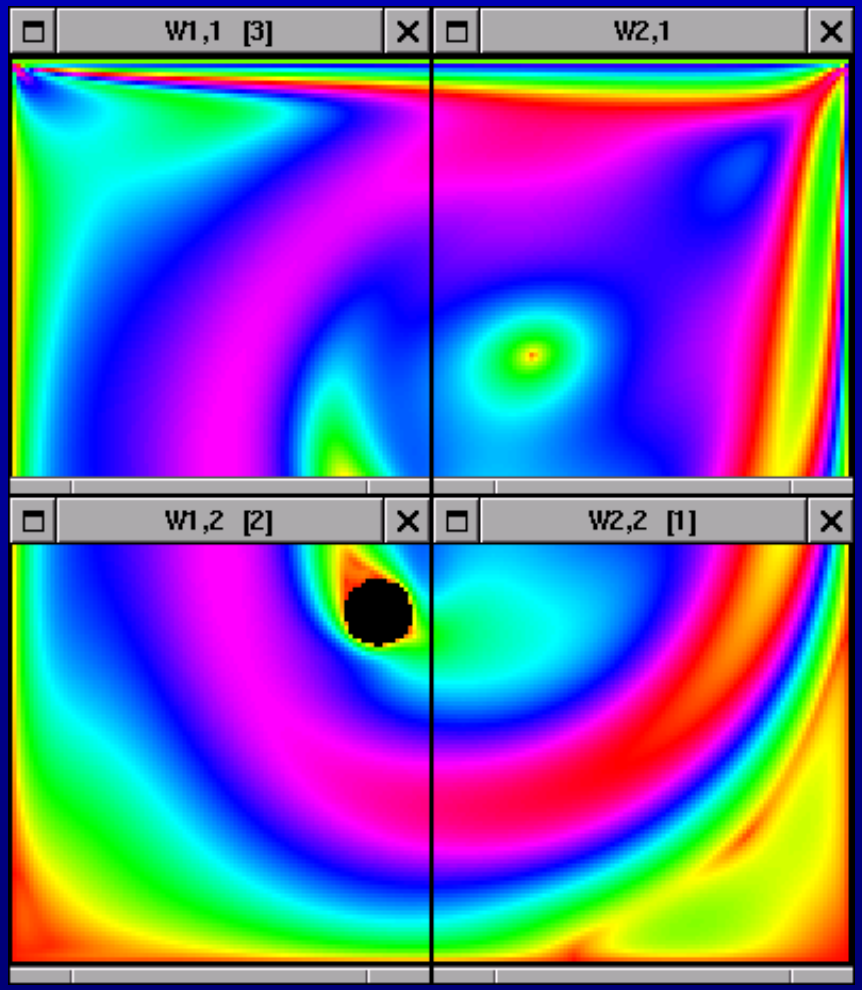
Cache Optimizations:

- Presented techniques do work for LB
- Performance gain strongly depends on the architecture
- Work in progress: extension to 3D

Metal Foam Simulation:

- Lattice Boltzmann with free surface extension is a reasonable choice for this task
- Work in progress: parallelization, more accurate calculation of surface tension, correct handling of bubble segmentation, ...
- Extensions to the model: heat transfer, solidification

Grid Computing with LB



Cooperation with Hans De Sterck and Robert Markel, Department of Applied Mathematics, University of Colorado:

- Implemented in Java
- Simple and small worker tasks
- Upload of the byte code for the simulation to the worker tasks
- Communication is done via bags