Free surfaces with Lattice-Boltzmann method

Nathan Brei, Irving Cabrera, Natalia Saiapova

TU München

July 15, 2016

Output from previous worksheets

- LBM D3Q19;
- Different boundary conditions
  - Non-Slip;
  - Inflow;
  - Free-Slip.
- 2D complex geometries reader.

New values

- New cell types: **GAS** and **INTERFACE**;
- New values for cell: **mass** (double) and **fluid fraction** (double). Fluid fraction is $\epsilon = \frac{m}{\rho}$, where ρ is a density.

Boundary conditions and gravity

- Add gravity to our model;

$$f_i^c(x,t) = (1-\omega) f_i(x,t) + \omega f_i^{eq} + \mathbf{w_i} \rho \mathbf{e_i} \mathbf{g}$$

- Reconstruct distributions from GAS cells to INTERFACE.
  Use INFLOW boundary conditions.

$$f_i(x,t) = f_{inv(i)}^{eq}(\rho_{ref}, \overrightarrow{v}) + f_i^{eq}(\rho_{ref}, \overrightarrow{v}) - f_{inv(i)}(x + c_i \Delta t, t)$$

  Where $\rho_{ref} = 1$ is the atmospheric pressure.

Mass exchange

Calculate new mass for INTERFACE cells.

$$m\big(x, t + \triangle t\big) = m\big(x, t\big) + \sum_{i=1} \triangle m_i \tag{1}$$

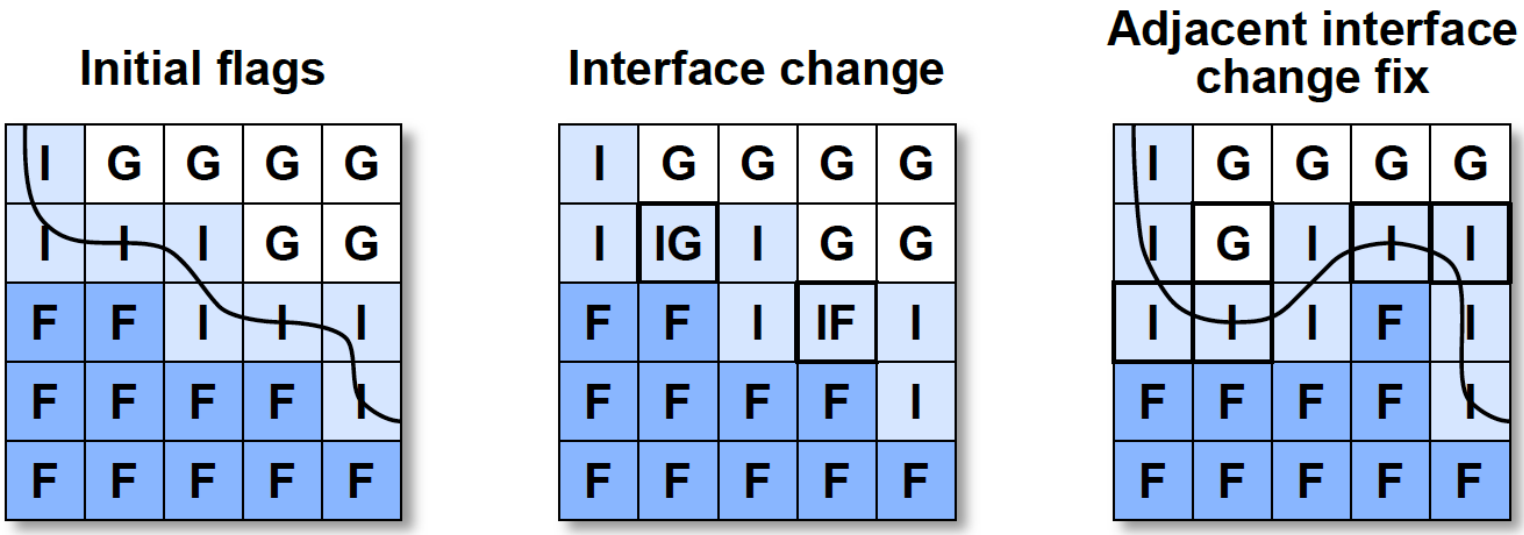
where $\triangle m_i$ is calculated only between INTERFACE-INTERFACE or FLUID-INTERFACE cells in the following way:

$$\triangle m_i = \Big(f_{\bar{i}}\big(x + \triangle t e_i, t\big) - f_i\big(x, t\big)\Big) \frac{\epsilon\big(x + \triangle t e_i, t\big) + \epsilon\big(x, t\big)}{2} \tag{2}$$

For fluid cell mass is equal to its density.

Flag field update

[Schreiber, 2010]:



Update fraction field

Important rule
Between GAS and FLUID cells **always** has to be an INTERFACE cell.

Update flag field

Optimizations

Loops in the functions

- Stream step,
- Collide step,
- Update flags and
- Boundary treatment

were parallelized with OpenMP.
Function to calculate f^{eq} was highly optimized with

- Vectorization
- Redundant calculations omitted
- Semantics

Some numbers

- 1 733 lines of code.
- 38 functions implemented.
- For the biggest example (500x500x200)
  - Each vtk file weights 651 MB
  - It needs 13 GB of memory to make the calculations

Two breaking dams

Inflow and obstacles

High-res breaking dam

References

- Physically based Animation of Free Surface Flows with the Lattice Boltzmann Method, Nils Thürey, 2007.
- GPU based simulation and visualization of fluids with free surfaces, Martin Schreiber, 2010.