Free surfaces with Lattice-Boltzmann method

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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.

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

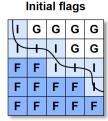
where $\triangle m_i$ is calculated only between INTERFACE-INTERFACE or FLUID-INTERFACE cells in the following way:

$$\triangle m_i = \left(f_i(x + \triangle te_i, t) - f_i(x, t)\right) \frac{\epsilon(x + \triangle te_i, t) + \epsilon(x, t)}{2}$$
(2)

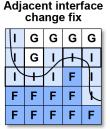
For fluid cell mass is equal to its density.

Flag field update

[Schreiber, 2010]:



Interface change G G G G IG G G F F IF F F F F F F F F



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.