

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.

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

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

Mass exchange

Calculate new mass for INTERFACE cells.

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

where Δm_i is calculated only between INTERFACE-INTERFACE or FLUID-INTERFACE cells in the following way:

$$\Delta m_i = \left(f_i(x + \Delta t e_i, t) - f_i(x, t) \right) \frac{\epsilon(x + \Delta t e_i, t) + \epsilon(x, t)}{2} \quad (2)$$

For fluid cell mass is equal to its density.

Flag field update

[Schreiber, 2010]:

Initial flags

I	G	G	G	G
I	I	I	G	G
F	F	I	I	I
F	F	F	F	I
F	F	F	F	F

Interface change

I	G	G	G	G
I	IG	I	G	G
F	F	I	IF	I
F	F	F	F	I
F	F	F	F	F

Adjacent interface change fix

I	G	G	G	G
I	G	I	I	I
I	I	I	F	I
F	F	F	F	I
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.