Handling 3D triangle-based geometries in the massively parallel LBM framework waLBerla

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Motivation

- Extend the framework by complex 3D triangle-based geometries, in order to be able to support various applications like aerodynamic simulations, blood flow in vessels and fluid-structure interaction.
- Improve the accuracy of computing the fluid-dynamic forces and moments by using second order boundary conditions.
- Speedup the data processing (dynamic simulation).

Concept

The input triangle meshes describing the surface geometry of a three dimensional object (e.g., STL format) are processed in three main steps:

- Preprocessing the triangle meshes (scaling, shifting, ...).
- Mapping of the surface and setup the boundary conditions of each near-obstacle fluid cell using ray-triangle intersection.
- Fill the inner part of the volume (flood-fill algorithm).

Parallel and Patch concept

Surface mapping algorithm

For each triangle bounding box (TBB), scan through all voxels v(x,y,z) in TBB.

- If intersecting:
  - if Patch (v(x,y,z)) is allocated on the current processor:
    - If v(x,y,z) inside the TBB, change the flag to inside-flag, assign q-value based on distance/direction of the intersection.
    - Else v(x,y,z) outside the TBB, change the flag to border-flag, assign q-value based on distance/direction of the intersection.
  - Else, move to next voxel.

Second order boundary conditions

Representation

<table>
<thead>
<tr>
<th>t</th>
<th>t+1</th>
</tr>
</thead>
<tbody>
<tr>
<td>q&lt;0.5</td>
<td>d</td>
</tr>
<tr>
<td>q&gt;0.5</td>
<td>2d</td>
</tr>
</tbody>
</table>

Formula

\[
P_{\text{t+1}} = \begin{cases} 
(1 - 2q)P_{\text{t}} + 2qP_{\text{t}}' - \frac{6qH_{\text{t}}}{c^2}, & 0 < q < 0.5 \\
\frac{(2q-1)}{2q}P_{\text{t}} + \frac{1}{2q}P_{\text{t}}' - \frac{3qH_{\text{t}}}{c^2}, & 0.5 \leq q \leq 1.
\end{cases}
\]

Experimental results

Voxelization of blood vessels
Simulation of low Reynolds number flow around a car