CMSE 822: Parallel Computing (Project Proposal)

Saurabh Pargal

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1 Section 1:

1.1 Group members: 1 (Saurabh Pargal)

This project is related to my research work, so I am working on this alone.

1.2 Project title:

Parallelizing fluid flow over a cylinder using Lattice Boltzmann method.

1.3 Abstract:

In this project, fluid flow over a cylinder will be realized on a two-dimensional grid, solving continuity and momentum equations, discretized using Lattice Boltzmann method (LBM) on D2Q9 lattice. The governing equations are the discretized version of Boltzmann equation. Here instead of solving for the Navier stokes equation, the fluid density or probability distribution function of particles is simulated with streaming and collision step.

Both collision and streaming step are counted as 1 time step evolving in time. Here Bhatnagar Gross and Krook (BGK) model is used for relaxation to equilibrium via collisions between the molecules of a fluid. The model assumes that the fluid locally relaxes to equilibrium over a characteristic timescale (τ_f). This timescale determines the kinematic viscosity, the larger it is, the larger is the kinematic viscosity. The macroscopic variables can be calculated from equilibrium and non-equilibrium distributions as shown in Figure 2.

The collision step

$$f_i(\vec{x}, t + \delta_t) = f_i(\vec{x}, t) + \frac{f_i^{eq}(\vec{x}, t) - f_i(\vec{x}, t)}{\tau_f}$$

The streaming step

$$f_i(\vec{x} + \vec{e}_i, t + \delta_t) = f_i(\vec{x}, t)$$

Figure 1: Here 'f' is the probabibility distibution function of particles.

$$
\begin{aligned}
\rho &= \sum_i f_i^{\mathrm{eq}}, \\
\rho \vec{u} &= \sum_i f_i^{\mathrm{eq}} \vec{e}_i, \\
0 &= \sum_i f_i^{(k)} \qquad \text{for } k = 1, 2, \\
0 &= \sum_i f_i^{(k)} \vec{e}_i.
\end{aligned}
$$

Figure 2: Macroscopic variables calculated from distribution function

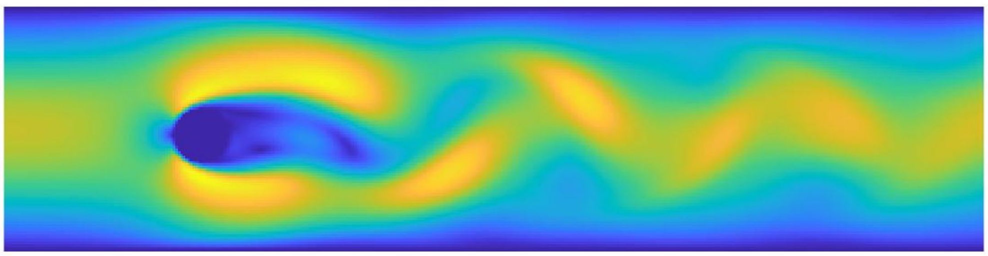

Figure 3: Fluid domain with cylinder

For the boundary conditions, we will have inlet, outlet and no slip boundary conditions at the wall. The wall boundary condition in LBM is simulated using 'bounce back' method.

Figure-3 shows the representation of fluid domain. There is generation of eddies following the obstacle (cylinder).

For more accuracy, large number of "particles" or more accurately large number of distribution functions i.e. several grid nodes are needed. But with more grid nodes, comes, computational time will increase. So, approach is to use OpenMP, to parallelize the domain i.e. grid nodes.

1.4 Benchmark and approach:

Figure-4 shows the collision and streaming step coded in matlab (the code will be reproduced in c++, to use the OpenMP functions learnt in course). Approach is to parallelize the spatial domain, using several threads using OpenMP. So as shown in figure, we have 'feq' and 'fout' terms, which are large matrices with several grid points. So those grid points will be prallelized using '#pragma omp parallel' for the spatial loop. So the sequential code will be the benchmark for the case discussed here. As shown in Fig-5, LBM method, has the potential to being strong scaled. Hence for this case here, I will test the 'strong' scalability of the parallelized code by increasing number of cores with increase in grid points.

```
% COLLISION STEP
for i=1:9
   cu = 3*(cx(i)*ux+cy(i)*uy);
   fEq(i,:,:)  = rho .* t(i) .* ...
                   ( 1 + cu + 1/2*(cu.*cu)  - 3/2*(ux.^2+uy.^2) );
   fOut(i,:,:) = fIn(i,:,:) - omega .* (fIn(i,:,:)-fEq(i,:,:));
end

% OBSTACLE (BOUNCE-BACK)
for i=1:9
     fOut(i,bbRegion) = fIn(opp(i),bbRegion);
end

% STREAMING STEP
for i=1:9
   fIn(i,:,:) = circshift(fOut(i,:,:), [0,cx(i),cy(i)]);
end
```

Figure 4: Collision and streaming step for 1 time step, coded in matlab.

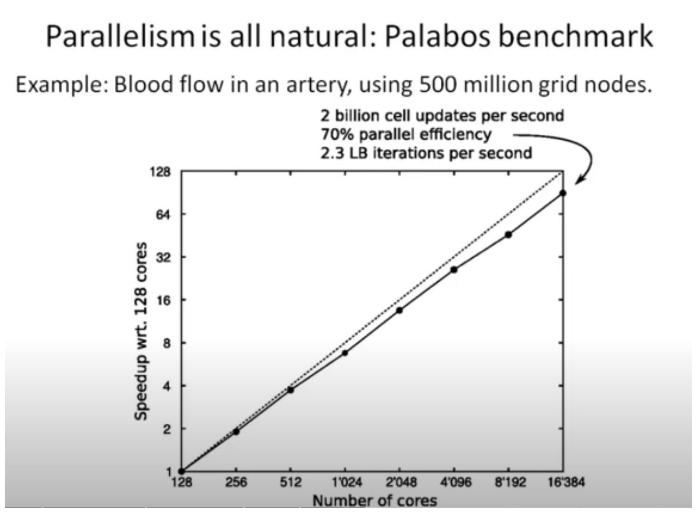

Figure 5: Palabos benchmark: Strong scaling in LBM method (Ref:Introduction to Lattice Boltzmann Method @ Nasa Glenn 2013)

1.5 References:

- Medium: https://medium.com/swlh/create-your-own-lattice-boltzmann-simulation-with-python-8759e8b53b1c
- Wiki: https://en.wikipedia.org/wiki/LatticeBoltzmannmethods
- Youtube: EME 521: Lattice Boltzmann Method; Introduction to Lattice Boltzmann Method @ Nasa Glenn 2013;
- University research groups (Universite de Geneve): PALABOS