CUDA Implementation of the Lattice Boltzmann Method

CSE 633 Parallel Algorithms

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Motivation

- The Lattice Boltzmann Method(LBM) solves the Navier-Stokes equation accurately and efficiently.

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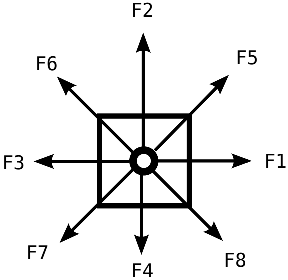
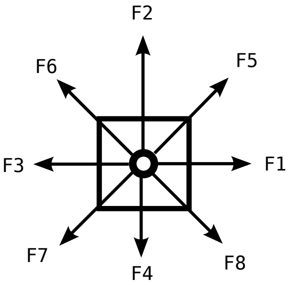
- Uniformity makes it easy to parallelize.
- High volume of simple calculations make it ideal for GPGPU computing.

LBM Degrees of Freedom



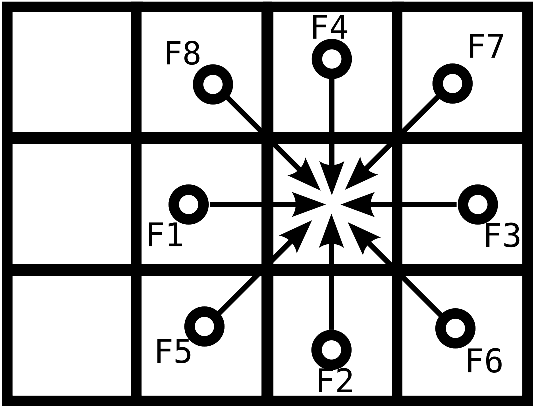
- Each lattice point has an associated mass density

LBM Degrees of Freedom



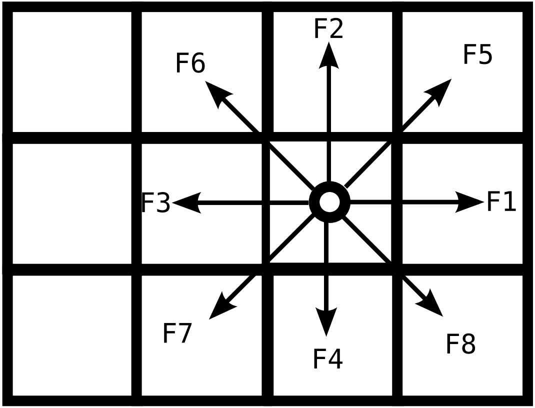
- Each lattice point has an associated mass density
- This mass density is projected in 9 directions

LBM Stream



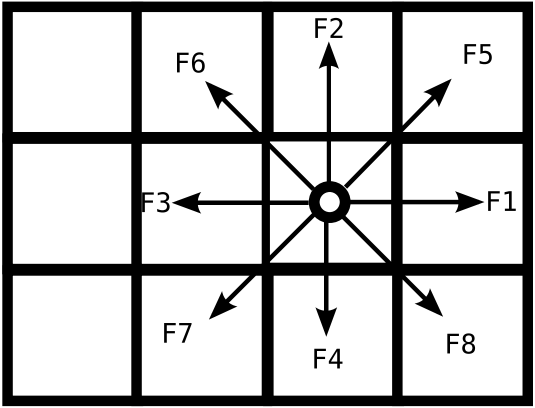
- At each time step, each neighbor passes mass density

LBM Collision



- Collision occurs with the accepted mass densities

LBM Collision



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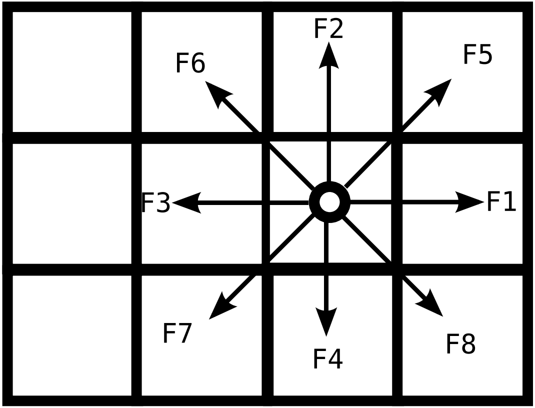
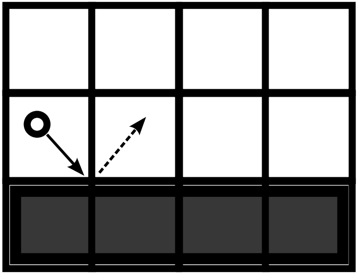


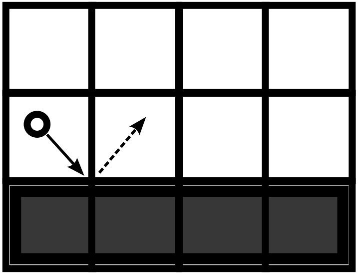
- Collision occurs with the accepted mass densities
- Equillibrium condition is solved
- New projected mass densities are assigned

LBM Boundary Conditions



- Bounceback is implemented at solid boundaries

LBM Boundary Conditions



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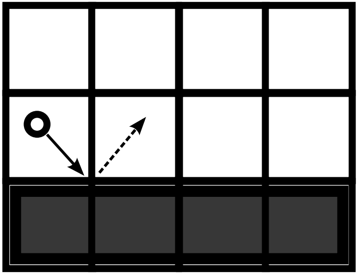
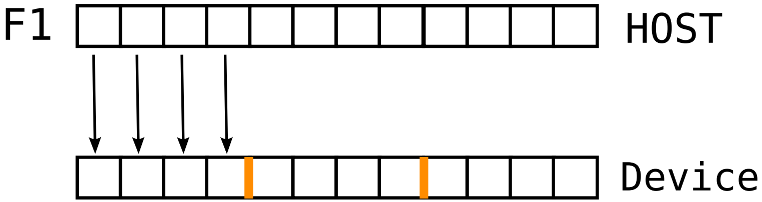


- Bounceback is implemented at solid boundaries
- The inlet has predetermined mass density
- The outlet accepts outward flow

Code: Data Structures



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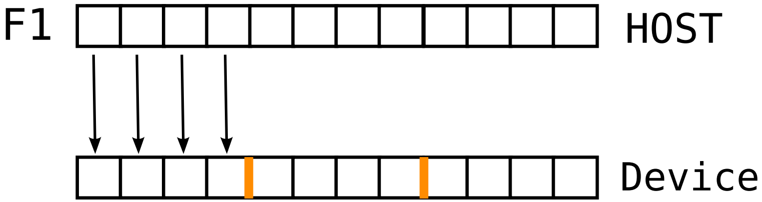

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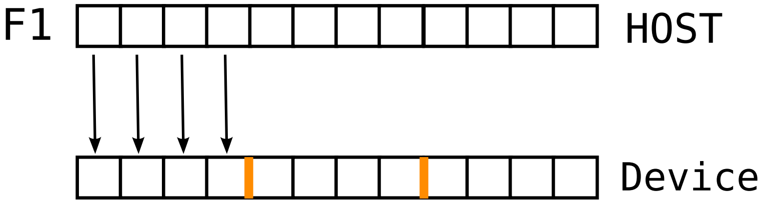

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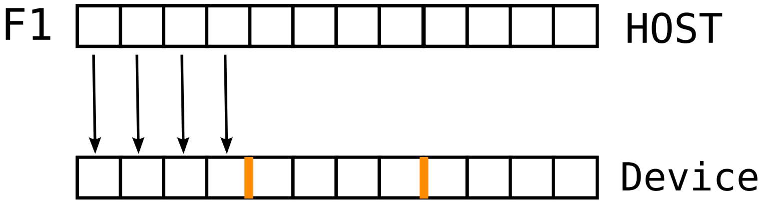

- Data initialized as an array on host
- Pitch stores the width of a row in memory, determined by CudaMallocPitch()
- Memory is allocated on the device linear memory with CudaMallocArray()
- Array copied from host to device with CudaMemcpy2D()

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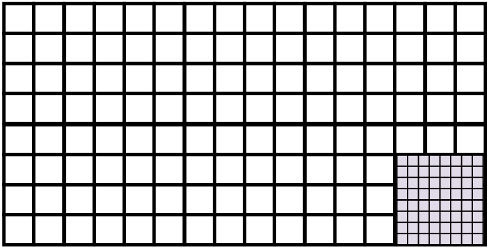
- Use cudaBindTextureToArray() to copy data as a texture

Code: Kernels



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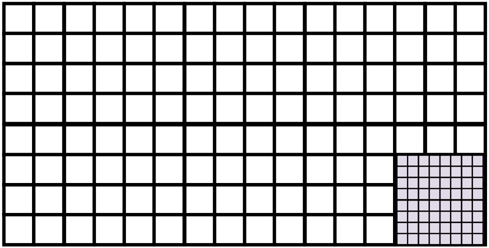
Code: Kernels



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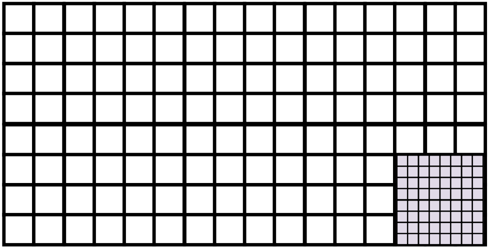


- A kernel is launched on a grid of blocks
- Each block consists of threads which will independently run the kernel(SIMD)
- What follows is the Kernel for the stream() method. This example utilizes a lock-step texture look up.

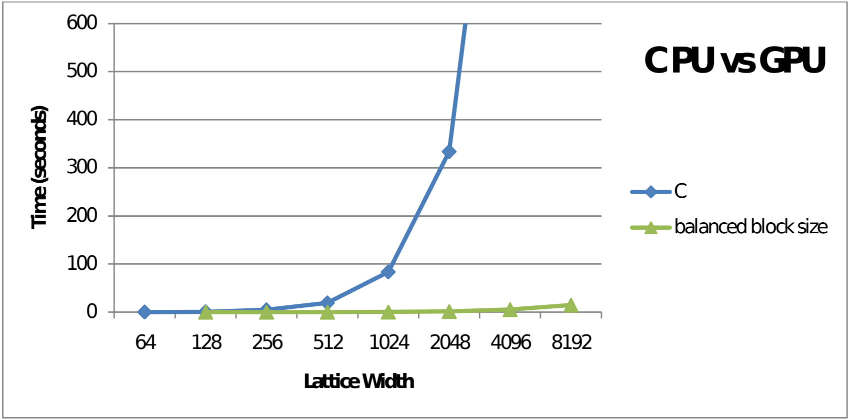
Code: Stream

```
//Define stream kernel//
__global__ void stream_kernel(int pitch, float *f1, float *f2,
            float *f3, float *f4, float *f5, float *f6, float *f7, float *f8){

  int i, j, id;
  i = blockDim.x * blockIdx.x + threadIdx.x;
  j = blockDim.y * blockIdx.y + threadIdx.y;
  id = i + j * (pitch/sizeof(float));

  //Gather adjacent f's for the stream step//
  f1[id] = tex2D(f1_tex, (float) i-1, (float) j);
  f2[id] = tex2D(f2_tex, (float) i, (float) j-1);
  f3[id] = tex2D(f3_tex, (float) i+1, (float) j);
  f4[id] = tex2D(f4_tex, (float) i, (float) j+1);
  f5[id] = tex2D(f5_tex, (float) i-1, (float) j-1);
  f6[id] = tex2D(f6_tex, (float) i+1, (float) j-1);
  f7[id] = tex2D(f7_tex, (float) i+1, (float) j+1);
  f8[id] = tex2D(f8_tex, (float) i-1, (float) j+1);

}
```

Runtime Analysis

The following slides contain graphs comparing run times for the LBM on a laptop with 1.3 GHZ processor running sequential C code and a single Tesla GPU running parallel code in CUDA. The change in performance based on block size is also explored.

Sequential vs Parallel



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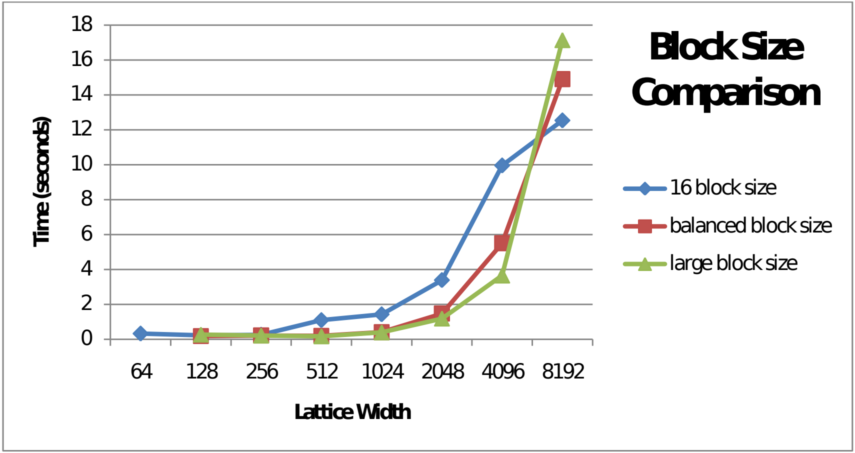
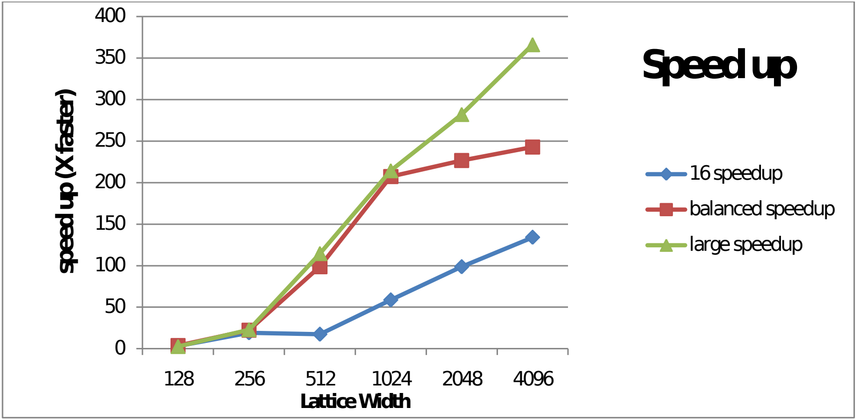


Sequential vs Parallel



Thank You

Thanks to Dr.Graham Pullan from Cambridge University for letting me use and modify his code.

Bibliography

Alexander Wagner, A Practical Introduction to the Lattice Boltzmann Method. North Dakota State University, March 2008.

Graham Pullan, A 2D Lattice Boltzmann Flow Solver Demo. http://www.many-core.group.cam.ac.uk/projects/LBdemo.shtml, University of Cambridge.