LBM for the Cell Processor and Fluid Particle Interaction

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Outline

• LBM on the Cell Processor
  – Problem description
  – The Cell Processor
  – Results
  – How to make it fast

• Large Scale Particle Simulation using LBM
  – The problem
  – Implementation
  – Results
LBM on the Cell Processor

• Use case: Blood flow simulation
  – To help understanding the development of cardiovascular diseases and to support therapy planning
  – Long runtimes on standard PCs for huge datasets

• Why the Cell processor?
  – The Cell processor offers a revolutionary design and massive compute power
  – Low budged „HPC“ (Playstation 3)

• Challenges
  – Getting the performance from the Cell
  – Programming the Cell processor
LBM on the Cell Processor

- **Element Interconnect Bus**
  - up to 204.8 GB/s

- **Power Processor Unit**
  - simplified PowerPC
  - 3.2GHz

- **Memory Interface Controller**
  - Rambus eXtreme Data Rate
  - 25.6 GB/s bandwidth

- **Synergistic Processor Unit**
  - "main memory" of SPE
  - 256 kB only

- **Synergistic Processor Element**
  - SIMD vector processor
  - 128 SIMD registers (128 bit)
  - 204.8 GFlop/s max. for 8 SPEs

- **Broadband Engine Interface**
  - connection to 2nd CPU
  - IO devices
LBM on the Cell Processor

Patient → Angiography → 3D data → Simulation → Interpretation
LBM on the Cell Processor

- Domain partitioning
  - Divide whole domain into equally sized patches (8x8x8) and only allocate and calculate patches including fluid cells
LBM on the Cell Processor

• Performance Results
  – Single precision performance and memory for a real vessel geometry with size 250x250x220

<table>
<thead>
<tr>
<th></th>
<th>Core 2 Duo (3.0 GHz, both cores)</th>
<th>Cell (3.2 GHz, 8 SPUs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 CPU</td>
<td>11.7 MFLUPS</td>
<td>49.1 MFLUPS</td>
</tr>
<tr>
<td>2 CPU</td>
<td>21 MFLUPS</td>
<td>90 MFLUPS</td>
</tr>
<tr>
<td>memory</td>
<td>128 MB</td>
<td>106 MB</td>
</tr>
</tbody>
</table>

Measurements on Core 2 Duo (Woodcrest) done by Thomas Zeiser (RRZE) with the code from the Lattice Boltzmann Development Consortium
LBM on the Cell Processor

• Performance Results
  – Comparison of the single precision performance for a straight-forward LBM implementation in C against the optimized version

<table>
<thead>
<tr>
<th></th>
<th>Straight-forward C</th>
<th>Optimized</th>
</tr>
</thead>
<tbody>
<tr>
<td>CPU</td>
<td>Core 2 Duo</td>
<td>SPU</td>
</tr>
<tr>
<td>MFLUPS</td>
<td>10.2</td>
<td>2.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>49.0</td>
</tr>
</tbody>
</table>
LBM on the Cell Processor

How to make it fast

1. Memory Layout
   - Key to all optimizations
   - Save memory
   - Use large transfers and correct alignment

2. Parallelism
   - Instruction level parallelism very important
     • Use SIMD instructions (scalars are slow, branches even slower)
     • Scheduling and register blocking
   - Real parallelism
     • Low synchronization overhead
Large Scale Particle Simulation

• The **physics engine** pe
  – Framework for accurate and games rigid body simulation
  – Both primitive and compound geometries
  – Calculation of contact forces and torque
  – Accurate friction calculation during collision
  – Coupling to different simulation frameworks
Large Scale Particle Simulation

**Example**

1. Set boundary conditions
2. LBM stream collide
3. Add forces from fluid to obstacles
4. Move and collide obstacles
   - send to instance
   - move and collide locally
5. Move and collide obstacles on instance
6. Send values back
7. Receive and update values from instance
8. If obstacle getting near border, then send to neighbor
Large Scale Particle Simulation

- Performance compared to simulation without obstacles

Size per process: 75x75x200 lattice cells
Obstacles: spheres
Diameter: 10 lattice cells
Large Scale Particle Simulation

- Performance compared to simulation without obstacles

Size per process:
75x75x200 lattice cells

Obstacles: spheres
Diameter: 10 lattice cells
Large Scale Particle Simulation

- Number of obstacles treated by pe instance

![Graph: Number of obstacles treated by instance vs. Number of obstacles]

- Size per process: 75x75x200 lattice cells
- Obstacles: spheres
- Diameter: 10 lattice cells
Large Scale Particle Simulation

- Performance compared to simulation without obstacles

Size per process:
180x180x180 lattice cells

Obstacles: spheres
Diameter: 6 lattice cells
Acknowledgements

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Thank you for your attention