Particleworks: Particle-based CAE Software fully ported to GPU
“Particleworks”
Why the particle method?

- Existing methods
  - FEM, FVM, FLIP, …
  - Fluid calculation points strictly depends on conservation laws.

- In each time step
- Surface capturing & tracking
- Mesh generation
- Marker creation - annihilation
- Particle based approach
  - The number of fluid calculation points does not decrease
  - In some of our client’s cases, it is difficult to solve with other methods.

- In each time step:
  - Surface capturing & tracking
  - Mesh generation
  - Marker creation - annihilation
Comparison with other software

For pipe flow problems (no free surface), Particleworks may take longer calculation time than other mesh based simulators.

Particleworks (Particle based)
Calculation Points: 28339
Calculation Time: 7728 sec.

FloEFD (Mesh based)
Calculation Points: 27440
Calculation Time: 336 sec.

Inflow: 0.2 m/s
Length: 10 mm
Diameter: 1.4 mm
Time: 0.5 s
Comparison with other software

Particleworks can solve free-surface problems, while most of other mesh based simulators have difficulties. (e.g. Pipe flow with a spray nozzle)

Calculation Points: 42000
Calculation Time: 9000 sec.

FloEFD (Mesh based)
Difficult to simulate

Particleworks (Particle based)

Inflow: 0.2 m/s
Length: 10 mm
Diameter: 1.4 mm
Time: 0.5 s
In Particleworks’ simulation on Hagen-Poiseuille flow of Newtonian fluid, the velocity distribution obtained in the model coincides well with theoretical results.

<table>
<thead>
<tr>
<th>Precondition</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Simulation model</strong></td>
<td>The maximum velocity in the centre of cylinder is coincided well with</td>
</tr>
<tr>
<td>Injecting fluid into circular cylinder with 1.5 mm diameter and 15 mm long</td>
<td>the theoretical results. The decrease trend of velocity towards the</td>
</tr>
<tr>
<td><strong>Theoretical velocity distribution u(r)</strong></td>
<td>edge of cylinder is also well-coincided.</td>
</tr>
<tr>
<td>( u(r) = u_0 \frac{3n + 1}{n + 1} \left( 1 - \left( \frac{r}{R} \right)^{n+1} \right) )</td>
<td>*Particle colour indicates velocity</td>
</tr>
<tr>
<td>Setting ( u_0 = 0.1 \text{ m/s} ) in this model</td>
<td>Red line shows theoretical figures and yellow dots show velocity of</td>
</tr>
<tr>
<td><strong>Particle distance</strong></td>
<td>each particle</td>
</tr>
<tr>
<td>1.0 \times 10^{-4} \text{ m}</td>
<td>*Measures velocity of particles located between 10 – 13 mm from inlet</td>
</tr>
<tr>
<td><strong>Time interval</strong></td>
<td></td>
</tr>
<tr>
<td>5.0 \times 10^{-5} \text{ s}</td>
<td></td>
</tr>
<tr>
<td><strong>Kinematic viscosity coefficient</strong></td>
<td></td>
</tr>
<tr>
<td>1.5 \times 10^{-6} \text{ m}^2 / \text{ s}</td>
<td></td>
</tr>
<tr>
<td><strong>Analysis model image</strong></td>
<td></td>
</tr>
</tbody>
</table>
Particleworks v3.0.2

- Demo
  - Particleworks.cmd
  - 3 min.
### Particleworks Spec. Sheet

#### Computational Fluid Dynamics
- Incompressible fluid
- Weakly compressible gas
- Free surface flow
- Non-Newtonian fluid

#### Applicable Phenomena
- Newtonian and non-Newtonian flow
- Laminar and turbulent flow
- Thermal conduction
- Moving boundary
- Fluid - Rigid coupling
- Fluid - Powder coupling
- Surface tension

#### Physics Models
- Based on MPS
- Pressure calculation (Implicit / Explicit)
- Viscosity calculation (Implicit / Explicit)
- Turbulent model: RANS + LES
- 2D analysis

#### Calculation technique
- SMP and MPP
- GPU

Drain water fall

Tsunami

Back step flow
Next update

- We plan to release ver. 3.1
  - June, 2012

- Features
  - One-way coupling with existing air flow software
  - Pressure boundary condition applied to free surface
  - Python JIT for customizing non-Newtonian solver
  - DEM module ported to GPU
  - And more …
Applications
Automotive industry

Particle simulation is mainly applied to oil and water behavior.

1. Engine crank case
2. Oil jet simulation in cylinder
3. Power-train transmission
4. Mud & water splashing

[Other Application]
Gas tank sloshing
Auto painting
Water immersion
etc.
Chemical industry

Particle simulation is used for highly viscous fluid and powder simulation, especially for material mixing purpose.

Twin extruders

From JAPAN STEEL WORKS, Ltd

Mixer
About our GPU solver
CPU vs GPU

- Particleworks ver. 3.0 (2011)
  - Fully ported to GPU

- CPU: Intel Core i7 920 4 Cores
- GPU: NVIDIA Tesla C2070

- 0.3 M particles
Energy consumption comparison for 1 calculation job

- **Hardware**
  - PC: MAS-i7WS (G-DEP)
  - OS: Windows HPC server 2008r2
  - CPU: Intel Core i7 X990 @3.47GHz
  - GPU: NVIDIA C2075
  - Main memory: 24GB

- **Simulation settings**
  - 1.46 M particles
  - Simulation time: 1.0[s]
CPUs vs GPUs

CPU (Xeon X5637 dual socket) vs. GPU (M2090) comparison results.

**CPU**

- **# of Nodes (with 2 CPUs)**
  - Intel Xeon 6 cores
  - (12 cores)
  - (24 cores)
  - (36 cores)

- **CPU: Intel Xeon X5637 (6 cores) @3.06GHz**

**GPU**

- **# of Cards**
  - Intel Xeon 6 cores
  - (12 cores)
  - (24 cores)
  - (36 cores)

- **GPU: NVIDIA M2090**
Porting resource, schedule & strategy

- Motivation
  - High performance gain reasonably

- Goal
  - Full GPU porting
    - Collision detection, Physics models & Iterative solver.

- Resource
  - 2 persons (Full time) + 2 students (1 day / week)

- Schedule
  - 2010/5 start – 2011/2 release

- Strategy
  - Test driven
  - We needed CPU porting before GPU porting
OpenCL : JIT Customize Function (Prototype & In-house)

- Motivation
  - Marketing sales & Consulting
  - Particle interaction customization

- Goal
  - JIT customization function
    - Using OpenCL

- Resource
  - 1 person (1 week)

- Strategy
  - User can use these Particleworks variables at OpenCL kernel
    - Buffer
    - Function
    - Parameter
Our GPU Cluster
Linux

Spec.

- 4 nodes
- 8 CPUs + 12 GPUs
- 192 GB RAM
- Infiniband QDR dual port
- 5000W PSU
- CentOS
Linux

- Spec. / Compute node
  - CPU x 2
    - Intel Xeon
    - X5685/3.06GHz/6cores
    - 48GB RAM
  - GPU x 3
    - NVIDIA M2090
    - 512cores
    - 6GB DRAM
  - Infiniband x 2
    - QDR
    - 40 Gbps
- Power Supply Unit
  - 1000W
Results: Mixing

- About 10M particles
- 12 GPUs
- Calculation time: 100 hours 30 min.
- Simulation time: 1 sec.
Results: TSUNAMI

- About 5 M particles
- Simulation time: 10 min.
- Calculation time:
  - GPU: 60 hours 2 min.
  - CPU: 82 hours 29 min.
Thank you