Fluid Simulation with Smoothed Particle Hydrodynamics(SPH) method accelerated with Compute Shaders

Final project for the practical course in Computergrafik 2016

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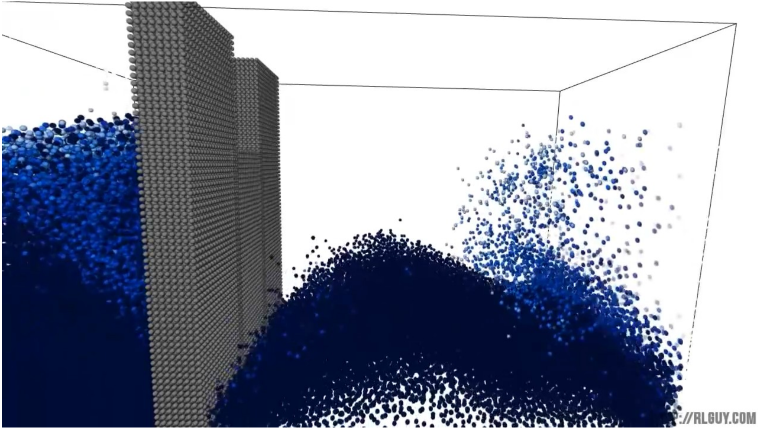
Fluids

- Liquids, e.g. water
- Gasses, e.g. air
- Plasmas

Motivation



source: youtu.be/iHACAIfYeiQ

Navier-Stokes-Equations

Equations which describe the motion of viscous fluids.

We use the Navier-Stokes-Equations for incompressible fluids with constant density:

$$\frac{\partial \boldsymbol{v}}{\partial t} + (\boldsymbol{v} \cdot \nabla)\boldsymbol{v} = \boldsymbol{g} - \nabla \frac{\boldsymbol{p}}{\rho} + \frac{\mu}{\rho} \nabla^2 \boldsymbol{v}$$

where $\boldsymbol{v}$ is the velocity, $\boldsymbol{g}$ is the gravity, $\boldsymbol{p}$ is the pressure and ρ and μ are the material properties density and dynamic viscosity.

Smoothed Particle Hydrodynamics

Physical property Φ_i at position r_i is computed in a sphere with radius h:

$$\Phi_i = \sum_j m_j W(h, \boldsymbol{r_i} - \boldsymbol{r_j})$$

W is the weighting function which sums to 1 over radius h and drops to 0 outside of h.

Smoothed Particle Hydrodynamics

$$\rho_i \approx \sum_j m_j \frac{315}{64\pi h^9}\left(h^2 - \|\boldsymbol{r_i} - \boldsymbol{r_j}\|^2\right)^3$$

$$p_i = \rho_i - \rho_0$$

$$\frac{\nabla \boldsymbol{p_i}}{\rho_i} \approx \sum_j m_j \left(\frac{\boldsymbol{p_i}}{\rho_i^2} + \frac{\boldsymbol{p_j}}{\rho_j^2}\right) \frac{-45}{\pi h^6}\left(h - \|\boldsymbol{r_i} - \boldsymbol{r_j}\|\right) \frac{\boldsymbol{r_i} - \boldsymbol{r_j}}{\|\boldsymbol{r_i} - \boldsymbol{r_j}\|}$$

$$\frac{\mu}{\rho_i}\nabla^2 \boldsymbol{v_i} \approx \frac{\mu}{\rho_i} \sum_j m_j \left(\frac{\boldsymbol{v_j} - \boldsymbol{v_i}}{\rho_j}\right) \frac{45}{\pi h^6}\left(h - \|\boldsymbol{r_i} - \boldsymbol{r_j}\|\right)$$

$$\frac{dv_i}{dt} = \boldsymbol{g} - \frac{\nabla \boldsymbol{p_i}}{\rho_i} + \frac{\mu}{\rho_i}\nabla^2 \boldsymbol{v_i}$$

Compute Shader

- Introduced with OpenGL 4.3
- Written in GLSL
- Can directly interface with other OpenGL buffers contrary to OpenCL, CUDA, etc.
- Run asynchronous per default
- Meant for simpler computational tasks

Compute Shader Example

```
#version 430

layout(local_size_x = 32, local_size_y = 1,
        local_size_z = 1) in;

layout(std430, binding = 0) buffer Elements {
    vec4 eles[];
} elements;

uniform int work_items;
uniform float time;

void main() {
    uint id = gl_GlobalInvocationID.x;
    if ( id <= work_items) {
        elements.eles[id] =
            vec4(id*0.5, sin(time+((3.14/2)*id)), 0.0, 0.0)↩
                ;
    }
}
```

Compute Shader Example

Use:

```
glBindBufferBase(GL_SHADER_STORAGE_BUFFER, 0, buffer_id);
glDispatchCompute(1, 1, 1);
```

Concrete Implementation

- Sort particles in voxel of length h
- Limit interaction with neighbour particles
  - Only interact with n particles
  - Only interact with particles within the interaction radius h
  - Do this while preventing bias

Concrete Implementation

Compute Shaders:

- voxelize

  calculate voxel id for each particle

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- sortPostPass
  rewrite position and velocity data

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  calculate index from voxels to particles

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- findNeighbours

  find the next n neighbours in neighbouring voxels

Concrete Implementation

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- computeDensityPressure

  compute density and pressure values for each particles

Concrete Implementation

Compute Shaders:

- voxelize
  calculate voxel id for each particle
- sort
  sort by voxel id
- sortPostPass
  rewrite position and velocity data
- voxelIndex
  calculate index from voxels to particles
- findNeighbours
  find the next n neighbours in neighbouring voxels
- computeDensityPressure
  compute density and pressure values for each particles
- integrate
  compute pressure gradient, viscosity term, acceleration, integrate velocity and position

Concrete Implementation

A few words about findNeighbours:

- Search in each of the neighbouring voxels until *n* neighbours within the interaction radius are found
- Compute random offset into voxel for each shader invocation then proceed sequentially
- Alternate searching direction by evenness of particle id

Demo

Video/Demo

Main problem

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I am a computer scientist not a physicist.

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I am a computer scientist not a physicist.

The algorithms work(AFAIK) but the numerics are shit.

Lessons learned

- Be sure to know your domain. Otherwise get an expert
- Before trying to accelerate something on the GPU implement it on the CPU
  - Debugging is much easier/possible
  - Easier to get working(more built-ins, more libs, etc.)
  - Verification of performance and correctness
- Be sure to do you research properly. Turns out nobody really uses this method anymore

Appendix

Source code:

github.com/Faerbit/sphfluidsim

Source and implementation ideas:

"Smoothed Particle Hydrodynamics" OpenCL Programming
Webinar Series by AMD (November 29, 2010)
Screencast Slides

Thank you for your attention

Any Questions?
Feedback?