

Smoothed Particle Hydrodynamics Simulation



Engineering

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ABSTRACT

A parallel and interactive SPH simulation method on the GPU using CUDA has been proposed in this paper which allows for high quality visualization. SPH is easily parallelizable, as the interaction between two particles is independent of the others. However, with a large number of particles there would be a significant amount of computation involved to calculate the interaction between the particles, which is needed to obtain a realistic-looking simulation. A new, efficient rendering pipeline that allows for high quality visualization at very high frame rates is presented. Spatial indexing and searching is based on Z-indexing that eliminates use of buckets and allows determine the neighborhood set of a particle in constant time without wasting space. For visualizing the SPH simulation, a new rendering pipeline is used. The rendering pipeline consists of several steps including the interactive generation of a distance field volume as core step. First, the surface particles have to be extracted from the simulation particle cloud though. The criterion whether a particle is a surface particle is its deviation from the centre of mass of the local neighborhood in combination with the overall number of particles in the local neighborhood. The optimal reuse of the simulation data makes this selection very fast. After the surface particles are extracted, a distance field volume is generated by rasterizing the surface point cloud into a volume with scalar values. Furthermore, it overcomes limitations imposed by shading languages allowing it to be very flexible and approaching the practical limits of modern graphics hardware.

1. Introduction

SPH is a computational method used for simulating fluid flows. It is a Lagrangian approach (where coordinates move with the fluid) for computational fluid dynamics (CFD). It is an interpolation method for particle system and is also known as a meshless or grid-less method. This method was formulated by Lucy (1977), Monaghan and Gingold (1977) and was developed for use in astrophysics areas. The SPH was first tested as numerical solution for gas flow problems for astronomical interest. It has been used in many fields of research such as astrophysics, volcanology, oceanography, ballistics. The state of system is represented by a set of discrete elements that are called as particles, which process individual material properties and move according to the governing conservation equations in SPH method.

With SPH, field quantities that are only defined at discrete particle locations can be evaluated anywhere in space. With this purpose, SPH distributes quantities in a local neighborhood of each particle using radial symmetrical smoothing kernels (Miller, 2003).

1.2 Literature Review

The traditional grid-based numerical method such as finite difference methods (FDM) and finite element methods (FEM) have difficulties in handling some complex phenomena. This motivated researchers to seek options to solve the problems and SPH method has become a very good choice (Liu et. al., 2003). The reason to use SPH over other numerical methods such as Particle in Cell (PIC), FDM and FEM is that SPH does not depend on the boundary conditions meaning girdles. Figure (2) illustrate the SPH equation.

$$A_i(r) = \sum_j m_j \frac{A_j}{r_j} W(r - r_j, h)$$

Eq (1). SPH equations for fluid

A scalar A is interpolated at location r by a weighted sum of contributions from the particles where j iterates over all particles in the scene, m_j is the mass of particle j , r_j the position, ρ_j the density and A_j the field quantity at r_j . The $W(r, h)$ is called smoothing kernel with core radius h . (Horvath et. al., 2007).

Horvath did apply the modified SPH equation based on Miller (et. al.2003). According to Miller (et. al. 2003), using particle-

based simulation should simplify the solution of Navier-Stoke equations. The research showed the implementation of SPH-based fluid simulation engine on a high end 3D animation tool called 'Houdini'. Modification of SPH formula was done by adding the pressure and viscosity value [5]. The study used gravity as their external force. The study simulated 14000 particles using 1 frame per second. Miller presented on number of particles to be used for this study. Fluid animation using 3D applications with 1 frame per seconds seems to be appropriate.

Smoothed particle hydrodynamics (SPH) was invented to simulate nonaxisymmetric phenomena in astrophysics (Lucy 1977, Gingold & Monaghan 1977). An easy to work with and could give reasonable accuracy method requirements are fulfilled with SPH which was rugged, gave sensible answers in difficult situations, and could be extended to complicated physics without much trouble.

The SPH method is a particle method. Unlike the particle in cell method (PIC) (Harlow 1957, 1974, 1988), SPH does not need a grid to calculate spatial derivatives. Instead, they are found by analytical differentiation of interpolation formulae. The equations of momentum and energy become sets of ordinary differential equations which are easy to understand in mechanical and thermodynamical terms. For example, the pressure gradient becomes a force between pairs of particles. The astrophysicist can then use intuition in a way which is difficult with the original partial differential equations. This intuition, coupled with detailed analysis, has allowed SPH to be extended to a wide variety of astrophysical problems. Although very accurate finite-difference methods exist--and these are better than SPH for some problems--they cannot handle complex physics in three dimensions with the same ease [3].

A novel adaptive sampling algorithms for particle-based fluid simulation has been introduced using a sampling condition based on geometric local feature size that allows focusing computational resources in geometrically complex regions, while reducing the number of particles deep inside the fluid or near thick flat surfaces. The further performance gains are also achieved by varying the sampling density according to visual importance [1].

A sliced data structure that is effective for use in neighboring

particle search for particle-based simulations in which a grid is dynamically constructed to fit to a particle distribution. Rather than computing the grid to fit perfectly to the particle distribution, it compute a grid with some margin to the distribution. This lowers the computation cost of constructing the data structure. Before storing particle indices on a grid, key values which are used to compute the index of a voxel are calculated. These data structures are introduced into particle-based simulations that run entirely on the Graphics Processing Unit (GPU) because the construction of this data structure and access to storing values can also be also performed entirely on the GPU particle-based simulations and its quantitative evaluations [2].

1.3 Problem Specification

An interactive SPH simulation that supports large number of particles is specific goal of this system. The greatest performance will be beneficial to required work ratio. We cannot parallelize the particles by using one thread for each of them, for instance. For simulation, there are two main forces are considered- the gravity force and pressure. First and most simply is the gravity force. This force acts uniformly on all particles. Another type of force is the pressure. In ordinary cases, fluids are incompressible. This force works pair wise to ensure that the density particles do not move too closes together, enforcing the incompressibility condition. Over the difference in density the force is determined by the gradient. These two forces make up the entire simulation.

1.4 Proposed Methodology

In this paper, the issue of SPH simulation is addressed, i.e., how to generate the blocks using CUDA and hoe to apply CUDA thread to them. SPH is easily parallelizable, as the interaction between two particles is independent of the others. However, with a large number of particles there would be a significant amount of computation involved to calculate the interaction between the particles, which is needed to obtain a realistic-looking simulation. Although the computation is highly independent, the number of particles involved are huge. A new, efficient rendering pipeline that allows for high quality visualization at very high frame rates is presented. The state of each particle for each frame based on its interaction with all other particles need to be computed. This is a large amount of computation. Fortunately, SPH is easily parallelizable because the interaction between two particles is independent of others and it works on particles. So in this way applying parallelism to SPH fluid simulation can effectively speedup the computation.

2. Architecture

The Smoothed-particle hydrodynamics method works by dividing the fluid into a set of discrete elements that are referred to as particles. These particles have a spatial distance that is known as the “smoothing length”, over which their properties are “smoothed” by a kernel function. Means the physical quantity of any particle can be obtained by summing the relevant properties of all the particles which lie within the range of the kernel or the block.

Mainly, there are 4 phases in SPH simulation that need to be performed for each particle:

Finding all neighbors within the smoothing length H

Density Phase: Update the density and pressure for each particle based on these neighbors

Force Phase: using updated density and pressure value, update pressure and viscosity force, detect collision, apply external force, and calculate acceleration. (depends on result from step 2)

Physics Phase: Step the particle to new position and velocity

within time step t. (depends on result from step 3)

(GPU) Copy data from GPU to CPU

All these steps play vital role in SPH simulation. These are supposed to be carried out for this implementation.

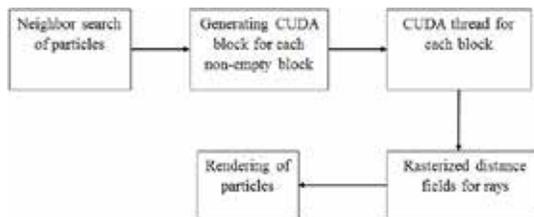


Figure 1: System Architecture for SPH

Initially all particle data copied to the GPU, performed the physics computations, then copied all data back to main memory, and was then immediately displayed (which sent the data back to the GPU). Then the empty and non-empty blocks generation of CUDA block which store an index to the first particle to the Z-index array, along with the particle count in each block is carried out. Then removal of the empty blocks is done by applying CUDA thread to each block that is generated from previous stage.

After the splitting process for the blocks with more than a certain number of particles based on the threads per CUDA block, physics computation process is performed. It is based on physics computation that includes force, density, surface tension and collisions. Then rendering of particles is carried based on positions and resulted pointers applied to them.

3. Application

Smoothed Particle Hydrodynamics, SPH, is a method developed as an attempt to model continuum physics avoiding the limitations of finite difference methods. It has been used in a wide variety of astrophysical applications and hydrodynamic problems. In coastal engineering, the problems are associated with propagating waves across the nearshore region, through the breaker line, and up the beach face. The SPH method is capable of dealing with problems with free surface, deformable boundary, moving interface, especially wave propagation and solid simulation.

SPH simulation can be applicable in wide areas such as astrophysics, magneto-hydrodynamics, solid mechanics, fluid dynamics, long waves, quasi-incompressible fluid flow, viscous fluid flow, high velocity impact of solid, desiccation induced cracks in soils, Slope stability analysis and slope failure simulation, Reinforcing retaining wall modelling, simulating damp cracking problems. It can be also used to solve complex applications, such as complex topologies and geometries, complex physics involving fluid structure interactions, complex free surface problems,

4. Conclusion

Real-time fluid simulation on the GPU can be performed and gained, but fine-tuning it to be as optimized as possible proved to be quite challenge. Using this paper, the particles sorting and rendering is method is applied. A technique is presented to track particles in fluids and simulating them.

SPH simulation is at interactive speed as this study discovered, the SPH method requires too much computation to provide the sort of speed necessary for an interactive simulation. This can be useful in fluid dynamics.

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