Understanding Hybrid Fluid Simulation: A Brief Slideshow Overview

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Core components

- **Particles**: These are the fundamental units in the simulation, representing fluid elements. Each particle has properties such as mass, position, velocity, density, and pressure. I followed a Lagrangian approach since fluid properties are associated with individual particles instead of with grid points as in the eulerian approach
- **Grid**: Within the simulation space, a 3D grid of cells divides the environment, facilitating efficient management of particle interactions and neighbor searches, thereby reducing computational complexity.
- **Kernel Functions**: They are mathematical function used to interpolate and smooth quantities (such as density, pressure, and velocity) over a set of discrete particles . The kernel function weights the influence of each particle over a given neighborhood basing on distances and ensures that physical properties are smoothly distributed across the simulation domain.
- **Engine**: At each simulation step, perform physics calculations which to update particles position aiming to maximize the realism of the simulation.

Which kernel functions have been used?

For particles density

$$W_{poly6}(r,h) = \frac{315}{64\pi h^9}\left(h^2 - r^2\right)^3$$

For pressure force

$$\nabla W_{spiky}(r,h) = -\frac{45}{\pi h^6}\frac{(h-r)^2}{r}$$

For viscosity force

$$\nabla^2 W_{visc}(r,h) = \frac{45}{\pi h^6}(h-r)$$

where r is the distance between the two particles under analysis and h is the smoothing length, which determines the radius within which a particle influences other particles.
The smoothing length essentially controls the size of the neighborhood over which the kernel function has a significant effect. Larger values of h lead to smoother approximations but can also increase computational cost, while smaller values provide more localized interactions.

What happens at each simulation step?

1. For each cell, compute the density by considering contributions from particles within the cell and neighboring cells
2. Compute pressure, viscosity and wall forces using kernels defined in the previous slide
3. Update positions by computing the acceleration considering the forces computed in step 2 and external forces (gravity, user interaction).
4. Reflect particles position updates in the particles mesh by modifying its position field.

At any moment, when the mouse moves over particles, it triggers particles to receive a forced velocity, causing them to move in response to the mouse's movement.

Effects of changing fluid properties in the simulation

- **Rest density:** It is the reference density that particles aim to achieve in the simulation. Increasing it results in a denser fluid, which can lead to stronger particle interactions and a heavier, more cohesive fluid. Decreasing the rest density creates a lighter, less cohesive fluid, with particles more easily separating from one another.
- **Gas constant:** Increasing the gas constant k will lead to higher pressure values, given the same density difference from the rest density. So particles will experience stronger repulsive forces, which will make the fluid behave more rigidly. This can result in a more solid-like behavior, where the fluid resists compression more strongly.
- **Viscosity:** It controls the internal friction within the fluid, influencing how easily particles can move past one another. Higher viscosity leads to a thicker, more resistant fluid flow, which slows down movement and creates more drag. Lower viscosity results in a thinner, more fluid motion with faster movement and less resistance.