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# Introduction

## Motivation

Fluids like liquids and gases are ubiquitous parts of the environment we live in. For instance we all know how it looks like when milk gets filled into a drinking glass. In realtime computer graphics, where we traditionally try to reproduce parts of our world as visually realistic as possible, it’s unfortunately hard to simulate such phenomena. Computational fluid dynamics is a relatively old and well known research topic, but most applications (like i.e. in aerodynamics research) aim at results that are as accurate as possible. Therefore the simulations are mostly calculated offline and realtime visualization is mostly used only to render precomputed data sets, if at all.

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| 2.png  3.png  Figure : Example for offline simulation Source: [APK07] | 1.png  Figure : Example for realtime simulation Source: [MCG03] |

Realtime applications that do allow the user to interact with authentically (but not necessarily accurately) simulated and rendered fluids (like i.e. water) are today rare. For all types of virtual realities, like surgical training environments or computer games, there’s always demand to cover more aspects of our world and so realtime simulation and rendering of fluids is an interesting field of study. In 2003 Müller, Charypar and Gross sparked additional interest in realtime fluid simulation, with a paper that proposed a relatively simple, particle based fluid-model, that fits well for realtime applications [MCG03]. Since then many different aspects of realtime particle based fluid simulation where covered in a couple of papers from authors around the world. This thesis gives an overview on the topic, as it discusses my implementation of a particle based fluid simulation and a suitable water renderer.

## How to simulate fluids

In the nineteenth century Claude Navier and George Stokes created the fundamentals of modern fluid dynamics as they formulated the well known Navier-Stokes equations. With these equations, which describe the conservation of momentum, together with two additional equations for mass and energy conservation, it’s possible to simulate the fluid flow. As the formulas tend to get very complicated for less common fluids, they are mostly written for Newtonian fluids which include a variety of common liquids and gases (water, air...).

Simulations apply numerically methods to solve the (in most cases) resulting nonlinear partial differential equations. One common way to do this is to treat the fluid as a continuum, discretize the spatial domain into a grid and use finite differences or the finite volume method. In the literature grid based fluid models are called Eulerian models. For the use within virtual environments grid based methods, as a matter of principle, have the drawback of a bounded simulation space.

Particle based methods (in literature: Lagrangian model, from Lagrangian mechanics) in contrast represent the fluid as a discrete set of particles and simulate the fluid flow through solving the particle dynamics. For realtime applications this brings some advantages over grid based methods:

* simpler calculation (mass conservation can be omitted, convective term can be omitted, see [MCG03])
* no numerical diffusions in the convection terms (diffusion directions are not influenced by the grid layout)
* surface reconstruction is likely to be easier
* fluid can spread freely in space (no boundary through the grid)

For those reasons (especially the last) this thesis focuses on a Lagrangian method based on smoothed particle hydrodynamics (SPH) [Mon05] which became very popular for this kind of applications. The idea behind SPH is that every particle distributes the fluid properties in its neighborhood using radial kernel functions. To evaluate some fluid property at a given point one must simply sum up the properties of the neighboring particles, weighted with the appropriate smoothing function.

## Related work

The first investigations in smoothed particle hydrodynamics where made in 1977 by Gingold and Monaghan (who coined the term) [GM77] and independently by Lucy [Luc77]. Its first usages took place mainly in the astronomy sector to simulate large scale gas dynamics, but later it also has been applied to incompressible flow problems like beach wave simulation, sloshing tanks and bow waves of ships.

While in realtime computer graphics first the Eulerian approach was favored, Müller, Charypar and Gross [MCG03] where one of the first who showed, that a SPH based Lagrange method also suits very well to interactive applications. Later many papers used SPH to simulate fluids (especially liquids) in realtime and brought adaptations and improvements both for the simulation as well as for the rendering of liquids.

Papers on realtime SPH simulation:

* [KC05] proposes to avoid the particle neighborhood problem by sampling the fluid properties from grids witch sum up the weighted properties from all particles
* [KW06] compares the performance of an octree based (linear time for neighbor search, but large costs for the update of the structure) versus a “staggered grid” based solution to the neighbor problem
* in [MST04] Müller et al. show how particle based fluids can interact with deformable solids
* [AIY04] sketches how to use a CPU generated neighbor map so that the property summation for each particle can be handled on the GPU which reaches twice the performance of their CPU only simulation
* [Hei07] uses the Ageia PhysX engine for a SPH based simulation of smoke

Papers with relevance for realtime liquid rendering:

* [MCG03] suggests direct point splatting of the particles or marching cubes rendering [LC87] of the isosurface (which implies that an isovolume must be created for each step)
* [KW03] presents a GPU executed isovolume raycaster; in combination with a efficient method for building the isovolume on the GPU this way the iso surface could be visualized
* [CHJ03] introduces iso-splatting, a point based isosurface visualization technique; same as with [KW03] applies here
* [Ura06] demonstrates a GPU version of the marching tetrahedra algorithm (variation of marching cubes); same as with [KW03]
* [KW06] uses a 2.5D “carped visualization” for the special case of rivers and lakes

## Used techniques

The goal with this thesis was to provide a realtime application that simulates a water-like liquid in a form that is “believable” in terms of behavior and optical appearance. The SPH simulation therefore focuses not on physical accuracy. It’s a straightforward implementation of the lightweight SPH model presented in [MCG03], optimized to run on actual multi-core consumer CPUs. To speed up the neighbor search it stores the particles according to their position in a dynamic grid, with a cell size equivalent to the smoothing length. The particle interactions are evaluated directly on pairs of particles (simultaneous for both particles). Chapter 2 discusses the theoretical foundations and the implementation details of the simulation.

For visualization three techniques are provided: The first directly renders the particles as point sprites, which is mainly useful for debug and tuning of the fluid behavior. The second, which is nearly entirely CPU-based, uses the marching cubes algorithm to construct a triangle mesh representing the isosurface. This technique was implemented to experiment with efficient isovolume construction methods and to test how well a marching cubes / triangle based approach fits for the purpose of liquid visualization. The last and most sophisticated technique uses the GPU to construct an isovolume within a 3D texture and renders the isosurface directly with a raycasting shader. The raycasting enables the visualization of effects like multiple refractions and reflections, which are characteristic for the optical appearance of liquids. Chapter 3 explains each visualization technique in detail.

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| 1.jpg  Figure : Sprite visualization | 2.jpg  Figure : Marching cubes visualization | 3.jpg  Figure : GPU raycasting visualization |

# Fluid simulation

## Smoothed particle hydrodynamics

Smoothed particle hydrodynamics is a technique developed by Gingold and Monaghan [GM77] and independently by Lucy [Luc77] for the simulation of astrophysical gas-dynamics problems. The main idea is to replace the fluid with a set of particles, which carry state parameters that represent the physical properties. The value of each quantity at a given location can then be interpolated over the particles that are near enough to contribute. To do so, the value from each neighboring particle gets weighted with the particles constant mass , the inverse of its density and a smoothing function that depends on the particles relative position, before the contributions are summed up:

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The so called smoothing kernel is radial ...

# Visualization

## Optical characteristics of water

# Conclusion

## Summary

## Improvements and alternatives

# Appendix

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## Glossary

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