# Chocolate Milk: A Fluid Simulation Framework and Implementation

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## Abstract

*In recent years physically based fluid simulations in the computer graphics field have become increasingly realistic both in their visual appearance as well as in their physical characteristics. These methods for realistic fluid simulation are being used throughout both the Animation and Visual Effects industries to create stunning and realistic images of liquids and gases. New methods for modeling fluids such as hybrid particle-grid, FLIP, and particle level set methods have pushed the limits of fluid simulation allowing for even more realistic simulations.*

*The goal of this project is to build a fluid simulation framework using many of these new techniques in physically based animation. Based on recent papers published at SIGGRAPH, the framework will include some of the state of the art methods in fluid simulation and serve as a foundation that is easily extensible for new methods that may become available in the coming years.*

*Project Blog: http://chocolatemilkfluids.wordpress.com*

## 1 Introduction

The Animation and Visual Effects industries today rely heavily on the use of realistic physically based effects in order to create truly dynamic and interesting worlds for the cinema. A large problem within the realm of physically based effects is the topic of fluid simulation that includes smoke, water, etc. SIGGRAPH is constantly accepting papers that deal with new methods of fluid simulation to both increase the efficiency of the simulations and to create more and more realistic models of physical phenomena.

With this in mind, the end goal and the main problem that this project will address is making physically based simulations as realistic and efficient as possible. In computer graphics, the challenge is to develop methods to model the physical world, which is continuous, in a digital form. This has led to a variety of SIGGRAPH papers dealing with many techniques for modeling the complex behavior of fluids. A main issue with the increasing number of methods and systems for fluid simulation is that to some degree the methods seem to diverge between grid based methods and particle based methods. In order to get the best of both worlds, a hybrid method is needed that makes use of ideas in both the grid-based and particle-based simulation techniques.

This problem of realistic fluid simulation is growing more important in the animation and visual effects industries as films continue to push the limits of realism and physical effects. With movies such as *Rango* and *Battleship* , Industrial Light & Magic faced huge challenges with the amount of fluid simulation that was required to bring these environments to life on the big screen. In the future, the need for fluid effects will only increase. This is important because it has led to a lot of research into fluid simulation for computer graphics and the next large step for this field is how to combine the many diverse methods to create the most realistic simulation possible.

This project aims to build a fluid simulation framework that combines many of the cutting edge papers. The framework utilizes a semi-lagrangian MAC-Grid fluid solver, but also uses marker particles to define the fluid and help define smaller details of the fluid simulation. It is the goal of the project to implement a few recent SIGGRAPH papers into this framework and create a system that can produce realistic fluid effects.

Upon the completion of the project, the main contributions of the project will include 1) a complete and well documented fluid simulation framework that can be easily extended and added to at later dates, 2) a hybrid particle-grid method for fluid simulation that uses a semi-lagrangian approach as well as fluid marker particles, and 3) implementations of a variety (at least 2) of recent SIGGRAPH papers dealing with fluid simulation. The possible SIGGRAPH implementations include such topics as mass conservation, rigid body interaction with fluids, the FLIP method, and new fluid grid structures such as octrees and the OpenVDB library.

### 1.1 Design Goals

The target audience for the fluid simulation will at first be the computer graphics community, as the focus early on will be simply implementing the physical effects accurately without focusing on how to integrate these effects into an artistic package such as Autodesk Maya. The main goal of the project is to create a fluid simulation that is as physically accurate as possible by reviewing and implementing a variety of recent SIGGRAPH papers on the topic. The secondary goal is to create a fluid simulation framework that can easily by extended and maintained. The framework will allow for the simple addition of new features and hopefully be able to be a working demonstration of many state of the art techniques in fluid simulation.

Although another goal of the project is to create the framework in such a way that it can easily be rendered out and integrated with a production environment, the emphasis will be places on implementing the physical effects. As such, the framework will support simple OBJ importing and exporting in order to render through systems such as Autodesk Maya. However, if time allows an additional goal of the project would be to create an efficient pipeline between Maya and the fluid simulation to allow artists a streamlined way to create physically based effects in their scenes.

### 1.2 Project Proposed Features and Functionality

The primary functionality that will be implemented within the fluid framework includes:

- Basic MAC-Grid based simulation with PCGSolver
- Viscosity Implementation
- Methods for mass conservation to avoid volume loss
- Fluid interactions with rigid bodies
- Multiphase fluid grid to model liquid/air interactions
- Better support for interactions between multiple fluids and Particle Level Sets

The following features are secondary goals which will be implemented if there is time:

- Efficient pipeline for integration with the Maya environment
- Octree grid data structure for adaptive grids

## 2 Related Work

In terms of related work, recent years have seen a dramatic increase in the quantity and quality of fluid simulations and SIGGRAPH papers pertaining to fluid simulations. Production quality physically based simulations such as Naiad and PhysBam as well as software suites such as Realflow and Houdini are constantly being updated with these newest simulation methods. The basis for my project is to implement a few existing SIGGRAPH papers and integrate these effects into a fluid simulation framework based on the foundation described by Robert Bridson [2008]. The following sections detail some of the new techniques that may be implemented as part of the simulation framework.

### 2.1 Multiple Interacting Liquids

The starting point for the fluid framework will be the "Chocolate Syrup" multiple fluids simulation developed by Dan Knowlton and Yining Karl Li. This simulation was built based on the paper "Multiple Interacting Liquids" by Losasso et al. The main contribution of the paper was to develop a method for tracking multiple fluids on the same simulation grid. The fluids could have different properties (viscosity, density, etc) and thus would behave differently in the grid. The method utilized multiple level sets to keep track of the surface of each of the fluids and then would have an extra step in which all overlap between the different level sets would be solved for. [Losasso et al. 2006] also deals with methods for dealing with attributes such as viscosity and surface tension within the multiple fluid system.

One area that will need to be revisited in the new fluid framework of this project is the idea of Particle Level Sets to help maintain the boundaries between different types of fluids. While the "Chocolate Syrup" base used particles to track the location of the fluid as a whole, particle level sets were not used to track the surface of each level set and ensure the boundaries between fluids remained intact and the fluids remained distinct. In addition, [Enright et al. 2002] proposes a hybrid particle level set method that can be used in this attempt to track the boundary between different types of fluids.

### 2.2 Mass and Momentum Conservation

Another challenge to be addressed in the fluid simulation framework is the problem of mass conservation as well as momentum conservation. The problem arises due to the fact that through the semi-lagrangian method details of the fluid surface are sometimes lost leading to volume loss and a decrease in mass.

[Lentine et al. 2011a] describes that semi-lagrangian advection as well as the vorticity confinement steps which are very common to fluid simulations do not conserve mass or momentum in their native form. It is important to note that the non-conservative nature of fluid simulations is a result of the need to take discrete time steps and work on a grid rather than a continuous space. Lentine proposes new steps in the advection and vorticity confinement steps of the fluid simulation that ensure that momentum and mass are conserved at each timestep of the simulation. [Lentine et al. 2011b] also proposes a second step to "forward advect" any additional mass that is traditionally missed and unaccounted for in semi-lagrangian simulations. Adding this mass and momentum conservation will be essential to making the fluid framework appear realistic and behave in a physically accurate way.

### 2.3 Fluid Interactions with Solids

One other area that is important to fluid simulation that this project will explore is the interaction between fluid and rigid bodies within the fluid. This interaction is rather complicated and can be very computationally expensive with traditional pressure projection methods. [Batty et al. 2007] presents a method to deal with the interaction of rigid bodies and fluids greatly reduces the cost of the simulation and allows these complex interactions to be simulated efficiently. In their simulation, by thinking of the pressure projection as a minimization of kinetic energy, they are able to draw a connection between rigid body interactions and fluid interactions. This makes it feasible to simulate such complex situations efficiently.

### 2.4 Fluid Grid Data Structures

Another area of interest in modern fluid simulations is the actual data structure and representation of the simulation grid. In a standard simulation, the fluid grid remains a constant, uniform size for the simulation. This results in the loss of details in the fluid that are smaller than the grid dimensions. However, some methods exist to help deal with these problems. [Losasso et al. 2004] presented an octree data structure for fluid simulation which is capable of capturing smaller surface details than traditional grids could. They also presented a method to ensure that the standard preconditioned conjugate gradient method could still be used even with the octree structure.

In addition to the octree technique, other data structures and libraries have become available specifically for the storage of volumetric data. One such method, OpenVDB, which was released last year, is a library that may be worth investigating as an add-on to the fluid simulation framework.

## 3 Project Proposal

The overall goal of the fluid simulation framework is to produce an extensible and well-documented code base capable of simulating a variety of fluids and the interactions between them. At a high level, the simulation will use a semi-lagrangian MAC-Grid approach and contain many modifications and additions based on recent SIGGRAPH papers. The framework will run as an OpenGL app as well as allow the export of the simulation data for more sophisticated rendering.

### 3.1 Anticipated Approach

At its core, the simulation framework will be based off of the "Chocolate Syrup" fluid simulator that Dan Knowlton and Yining Karl Li developed for the final project of CIS563 at the University of Pennsylvania. This base framework consists of a semi-lagrangian MAC-Grid structure with the addition of marker particles to mark the location of the fluid on the grid implemented in C++ and OpenGL. The simulation also makes use of the a Preconditioned Conjugate Gradient solver based on the solver proposed by Bridson [2008]. The "Chocolate Syrup" project is in turn based on a viscosity framework and simulation developed by Christopher Batty. This code base will serve as a reference and starting point for the new simulation framework, but the plan is to rewrite the entire source from the ground up in order to create the most successful and extensible framework as possible.

The first step in the creation of the fluid framework will be to revisit the base code of the "Chocolate Syrup" project and rewrite this basic functionality. The functionality to be built and rewritten for the base framework includes a semi-lagrangian MAC-Grid structure with marker particles to represent the fluid. The base framework will include basic viscosity solvers but these will need to be updated. The framework will define a scene file format as well as utilities for importing and exporting scene data for use with rendering and scene setup. The base framework also includes an OpenGL environment to view the simulation as it is running as well as tools to screen capture the simulation as it runs. Finally, the basic framework will allow for multiple types of fluids to be simulated on the same grid although there is much additional work required to finish the implementation of "Multiple Interacting Liquids" [Losasso et al. 2006]. The initial framework will also require the implementation of more complete boundary conditions for fluids' interactions with objects and walls.

A part of the implementation of the framework will be a OpenGL viewer and interaction window that has a working camera and tools for creating fluids or different viscosities/properties, importing OBJ meshes as fluids and rigid bodies, as well a tools to visualize the various fluid simulation components including the velocity field, level sets, pressure, temperature, particles, etc. An important aspect of the viewer that will be included with the framework is that the scene should be easy to manipulate and alter from directly within the OpenGL view to allow for making quick changes to a simulation.

The next step of the project will involve beginning to implement some of the SIGGRAPH papers and integrating them with the framework. The first two challenges that I propose to solve are better mass conservation as well as fluid/rigid body interactions. These papers will most likely have to be adapted to function within the context of the fluid simulation framework that was laid out previously. This is the part in which most of the creativity and new ideas will be formed in that there will most likely not be a one to one mapping between the SIGGRAPH implementation and an implementation that will fit within the framework.

A secondary goal of the project will be to integrate the framework with a new grid data structure to both speed up the fluid simulation as well as give more detail to the simulation. Possible new grid methods will include implementing a fluid octree grid structure or possibly integrating the simulation with the OpenVDB grid library.

### 3.2 Target Platforms

The target platform will initially be for Unix based x64 machines using the GLUT OpenGL bindings. All integration with renderers will be through Autodesk Maya 2012. A secondary goal is to build the framework so it is completely cross platform and able to be compiled and run through Visual Studio 2010 on Windows as well as Unix machines.

### 3.3 Evaluation Criteria

The evaluation of the project will involve reviewing the SIGGRAPH papers implemented and visualizing the final simulation results of the fluid simulation. Final results should be as realistic as possible while using the physically based SIGGRAPH papers as guides for implementation and design choices. In addition to the basic fluid framework, the final simulation should include as many new features and physically based algorithms as possible with the minimum standard for implementation being 2 of the SIGGRAPH papers discussed previously. Furthermore the framework for the simulation should be well documented and easily extensible for future projects.

## 4 Research Timeline

The research timeline is broken down into three main components: the preliminary Alpha Version Report, the Final Project Deliverables, and the Future Tasks of the project. (Please consult the GANT Chart on the final page of the proposal.)

### 4.1 Project Milestone Report (Alpha Version - Feb. 15)

- Background Reading ([Bridson 2008] and [Losasso et al. 2006])
- Basic fluid framework built and documented without new SIGGRAPH paper implementations
- Start reading SIGGRAPH papers and decide on 2 that will be tackled first

### 4.2 Project Final Deliverables

- Fluid Framework with at least 2 SIGGRAPH paper implementations
- Demo of fluid functionality in OpenGL environment
- Final renders of fluid simulations
- Documentation and well documented framework code
- Final presentation of work accomplished
- Poster for the final project poster session

### 4.3 Project Future Tasks

- Octree Data Structure/OpenVDB integration
- Better integration with Maya environment

## 5 Method

To be filled out as the semester progresses.

## 6 Results

To be filled out as the semester progresses.

## 7 Conclusions

To be filled out as the semester progresses.

## 8 Future Work

To be filled out as the semester progresses.

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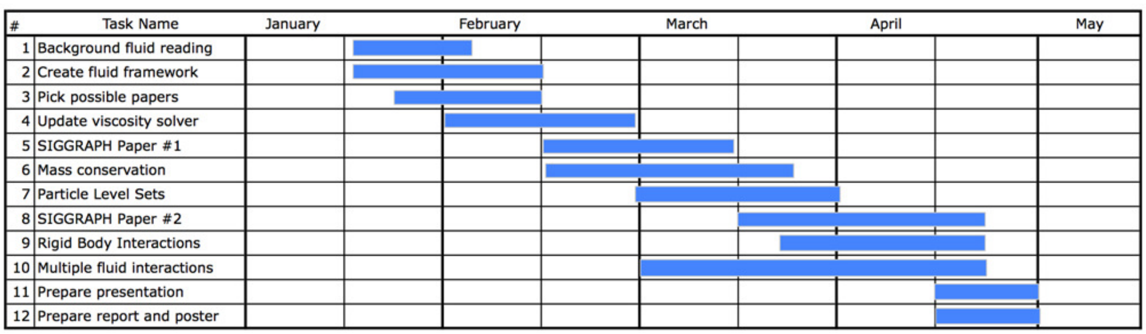


**Figure 1:** *Gant Chart of projected progress throughout semester*