**A picture containing clipart

Description automatically generated**

**COMP4910 Senior Design Project 1, Fall 2019**

**Advisor: Gizem Kayar**

**POF: Performance Optimized Fluids**

**High Level Design**

**Design Specifications Document**

**Revision 2.0**

**16.3.2020**

**By:**

**Baran Budak -15070001012**

**Cihanser Çalışkan -16070001020**

**İsmail Mekan -15070001048**

# Revision History

|  |  |  |
| --- | --- | --- |
| **Revision** | **Date** | **Explanation** |
| 1.0 | 12.12.2019 | Initial high-level design. |
| 1.1 | 2.2.2020 | - The introduction part has been revised.  - POF system architecture part has been revised and sentences were made more descriptive. |
| 1.2 | 9.2.2020 | - Sequence, use case, package diagrams have been updated. |
| 1.3 | 15.2.2020 | - Activity diagrams have been updated. |
| 1.4 | 21.2.2020 | - High-level design section elaborated. |
| 1.5 | 26.2.2020 | - Descriptions have updated for the new diagrams. |
| 1.6 | 5.3.2020 | - Table of Contents, list of figures and list of tables updated. |
| 1.7 | 9.3.2020 | - Integration testing of the hash system added. |
| 1.8 | 11.3.2020 | - Integration testing of marching cubes added. |
| 2.0 | 12.3.2020 | - Testing Design section elaborated. |

# Table of Contents

[Revision History 2](#_Toc501993332)

[Table of Contents 3](#_Toc501993333)

[List of Figures](#_Toc501993340) 3

[List of Tables](#_Toc501993340) 3

[1. Introduction 4](#_Toc501993334)

[2. POF System High Level Design 4](#_Toc501993335)

[2.1. POF System Architecture 4](#_Toc501993336)

[2.2. POF System Structure 5](#_Toc501993337)

[2.2.1 Use Case Diagram 5](#_Toc501993337)

[2.2.2 Sequence Diagram 7](#_Toc501993337)

[2.3 POF System Environment 8](#_Toc501993338)

[3. POF System Detailed Design](#_Toc501993339) 9

[3.1 POF System Class Diagram](#_Toc501993339) 9

[3.2 Subclasses of the POF System 1](#_Toc501993339)0

[3.2.1 Activity Diagram of Marching Cubes Scalar Calculator 10](#_Toc501993339)

[3.2.2 Activity Diagram of Surface Recognizer 1](#_Toc501993339)1

[3.2.3 Activity Diagram of Marching Cubes 1](#_Toc501993340)2

3.2.[4 Activity Diagram of Hash System 1](#_Toc501993340)3

[4. Testing Design 1](#_Toc501993340)4

[References 1](#_Toc501993341)7

**List of Figures**

[Fig 1: Use case diagram 5](#_Toc501993332)

[Fig 2: Sequence diagram 7](#_Toc501993333)

[Fig 3: Class diagram](#_Toc501993332) 9

[Fig 4: Activity diagram of Marching Cubes Scalar Calculator 10](#_Toc501993333)

[Fig 5: Activity diagram of Surface Recognizer 11](#_Toc501993332)

[Fig 6: Activity diagram of Marching Cubes 12](#_Toc501993333)

[Fig 7: Activity diagram of Hash System 13](#_Toc501993332)

[Fig 8: Particle and its neighbours in cell. 1](#_Toc501993332)4

[Fig 9: Tracking particle in a cell 1](#_Toc501993332)5

[Fig 10: Tracking particle with neighbours in a cell 1](#_Toc501993332)5

[Fig 11: Marching cubes test scene on arbitrary vertex data. 1](#_Toc501993332)6

**List of Tables**

[Table 1: Description of the use case diagram](#_Toc501993332) 6

[Table 2: POF system environment constraints](#_Toc501993332) 8

[Table 3: System that POF system is operated](#_Toc501993332) 8

# 1. Introduction

The purpose of the Performance Optimized Fluid (POF) system is to research and apply existed methods to simulate fluids and looking for a better way to represent it. Numerous algorithms will be implemented and tested during the research and development of this project. The main goal is to research and discuss the advantages and disadvantages of methods. One of the project objectives is to reach a more efficient and better performance fluid simulation system. However, indicated features are not guaranteed to improve performance. The project goal is visualizing the particle-based fluid system differently by benefiting from specific algorithms. The system expected to work more efficiently as a result of the implementation of the algorithms in the research papers. The project is exceedingly research and development based.

The design is based on The POF system Requirements Specification Document, Revision 2.0 [1]

This design process conforms to the Requirements Specification Document and its diagrams. Diagrams are describing the project to understand mainly operations of the POF system. Imperceptible parts of the POF system can be changed. However, the general operands of the POF system will remain the same as before. If any change occurs during the development of the POF system, this document and diagrams will be changed.

The system architecture and overall high-level structure of the POF system have given in the second section. Detailed design of all system functions and the user interface in terms of are methods of all classes will be explained later in the third section of this document.

# 2. POF System High Level Design

This section describes the POF system with high-level design. The high-level design section mentions about the POF system architecture and structure in different headings. Besides, the system environment explains the system constraints for the execution of the POF system. In the high-level design, activity diagrams testing design section have elaborated.

# *2.1. POF System Architecture*

The POF system architecture works with NVIDIA Flex which works as an outsource asset. Utilization of NVIDIA flex is mandatory because particle positions and AABB data are necessary to initialize. Initialization of fluid simulation data cannot be randomized. The system has a handler which acts as a communicator between NVIDIA flex and the POF system. Initially, NVIDIA Flex starts the fluid simulation and creates the particles and AABB. The Handler transmits necessary data to relevant classes. We have a hash system section that uses a hash algorithm to reach data quicker which keeps away us from linear search. Surface particle recognizer section determines the particles that are on the surface by calculating colour field quantity. Surface particles and its vertices grouped for a specific radius which is made by group neighbour particle function. Afterwards, grouped neighbour particle data send to the marching cubes algorithm [4]. Marching cubes section determines which vertices must be drawn. Lastly, the Marching cubes section intercommunicates with triangulation section which draws the given vertices.

# *2.2. POF System Structure*

In this section, the POF system structure has described with UML diagrams. Use case and sequence diagrams have drawn in this section.

***2.2.1 Use Case Diagram***

***A close up of a map

Description automatically generated***

**Fig 1:** Use case diagram

|  |  |
| --- | --- |
| **Title** | **Description** |
| **Calculate Scalar Field** | Calculates a constant value of a particle in a given range. |
| **Change grid size** | Interval of grid size of axis-aligned bounding box can change with this function. |
| **Change neighbour area size** | Neighbour particle range of volume can be changed. It affects the visualization of particles and changes the shape. |
| **Change particle appearance** | Particle colour, texture and light settings can be changed with this function. |
| **Change particle number** | Changes the particle number in the scene. |
| **Change particle size** | This function changes the radiusof the particle. Excessively disproportionate sizes compared to the scene can result in bugs and anomalies in physics behaviour of the particles |
| **Change rendering sensitivity** | User can change the rendering sensitivitywith this function. If the sensitivity increase, fluid visualization will be more precise as a result. However, the processing time will increase. |
| **Create Simulation** | NVIDIA Flex simulation initialize when this function called. |
| **Edit particle parameters** | Particle attributes can edit by a user from GUI. Parameters can be maximum particle number, particle size, friction, adhesion etc. |
| **Group Neighbour Particles** | Neighbour particles are grouped by looking at a specific range. |
| **Handler** | Handler transmits data between layers and relevant classes. The Handler manages data transmission. |
| **Hash Model** | Structure class for the Hash System. |
| **Hash System** | This function hashes the particle's position and cell position that particle belongs to. |
| **IMarching** | Interface class for Marching and Marching Cubes classes. |
| **Marching** | Analyze the cube for vertices and convert edges to triangles from the prewritten table. |
| **Marching Cubes** | Applies the Marching cubes algorithm on a single cube. |
| **Marching Cubes Scalar Calculator** | It is an application of Zhu et al. [5]. |
| **Particle** | It represents the particles which used by both NVIDIA Flex and Particle Surface Reconstructor. |
| **Renderer** | Visualize fluid by drawing the given polygons. |
| **Situational Surface Calculator** | This section calculates and returns the value. |
| **Surface Particle Recognizer** | Surface particles marked andprocessed for the necessary calculations in this function. |
| **User** | User can be anyone who has access to the program. |

**Table 1:** Description of the use case diagram

***A screenshot of a cell phone

Description automatically generated2.2.2 Sequence Diagram***

**Fig 2:** Sequence diagram

**Description:**Handler manages data transfer between other sections. If any data must transmit to another class, Handler executes this operation. The handler receives the bounds, particles and indices from NVIDIA flex. Handler sends this information to the hash system. Hash systems ask Particle Finder to find the id of the particle and adds to the hash model and acknowledges the handler. Handler sends the hash model to the surface recognizer. Surface recognizer processes the data and asks to the particle finder to find neighbour particles of a specific particle. Surface recognizer sends the data to the situational surface calculator which is responsible to calculate and return weight. The handler receives the neighbour particles and sends it to the marching cubes scalar calculator which finds the surface vertices. Particle finder receives the surface vertices and finds the vertices of the neighbour particles. Marching cubes scalar calculator receives the data from particle finder and sends to the situational surface calculator and it calculates the weight and returns the value. Marching cubes receives the marching cubes constant value which is calculated and send from the marching cubes scalar calculator. Marching cubes mark the vertices to be drawn. The Marching class starts to visualize by triangles.

# *2.3. POF System Environment*

The POF system environment constraints:

|  |
| --- |
| D3D11 capable graphics card |
| NVIDIA: GeForce Game Ready Driver 372.90 or above. |
| AMD: Radeon Software Version 16.9.1 or above. |
| Microsoft Visual Studio 2013 or above. |
| G++ 4.6.3 or higher |
| CUDA 8.0.44 or higher |
| DirectX 11/12 SDK |
| Windows 7 (64-bit) or higher. |
| Unity 3D 2017.3 version or higher |

**Table 2:** POF system environment constraints

The main project made on the system:

|  |  |
| --- | --- |
| Operating System | Windows 10 (64-bit) |
| Processor | Intel Core i7-4700 HQ CPU |
| Memory | 16 GB RAM – DDR3L-1600 MHz |
| GPU | NVIDIA GeForce GTX850M 4GB DDR3 |

**Table 3:** System that POF system is operated

This computer system has satisfying performance on only a small number of particles on this project because it can handle a very small number of particles. The optimal fluid simulation computer system mentioned in the final report [3].

# 3. POF System Detailed Design

This section describes the components of the POF system with activity diagrams. Detailed design has a class diagram for the overall structure. The functionality of these small parts is explained in activity diagrams.

***3.1 POF system class diagram***

***A close up of text on a white background

Description automatically generated***

**Fig 3:** Class diagram

***Description:*** NVIDIA flex is an eternal package which it is accessed by Handler. Handler makes the communication and organizes the data transmission as you can see from the relations. Consecutive actions are described in the sequence diagram. Visualization part is consisting of Marching, Marching cubes and IMarching classes. IMarching is an interface class for the other two class. Marching cubes analyse the cube situation according to the Marching cubes algorithm [4]. Marching class draws the triangles and applies the algorithm for a cube. The situational surface calculator and particle finder is a class that made calculations and returns values for other classes. Marching cubes scalar calculator is an application of Zhu et al. [5]. It calculates and returns a scalar value for being used in the marching cubes algorithm. Surface recognizer receives the calculated valued from other classes and decides the surface particles.

***3.2 Subclasses of the POF system***

This section includes subclasses of activity diagrams.

***3.2.1 Activity Diagram of Marching Cubes Scalar Calculator***

***A close up of a device

Description automatically generated***

**Fig 4:** Activity diagram of Marching Cubes Scalar Calculator

**Description:**The handler sends the particles, bounds, groups and radius. Particle finder class receives and set data. Particle finder class is responsible for find neighbours of the particle in a specific radius. Particle finder marks for the surface vertices in every surface particle. Neighbour particles are sent to the situational surface calculator. Weight is calculated and the vertices that will be drawn are marked in according to the algorithm [5]. Surface Particles are added to the list and return to the Handler.

***3.2.2 Activity Diagram of Surface Recognizer***

***A close up of a piece of paper

Description automatically generated***

**Fig 5:** Activity diagram of Surface Recognizer

**Description:** Handlersends data of the particle, bounds, groups and radius to find boundary function. Find boundary searches neighbour boundary cells for every particle and then find neighbour particles process starts. Find weightx function is calculates the weight and return a value. Find weightx section calculates the weight and if weight is smaller than specific constant value ‘q’ [8], Under favour of this calculation, we can decide the surface particles. If weight is bigger than a constant value, the particle is not a surface particle. Marked particles are sent to the Handler.

***3.2.3 Activity Diagram of Marching Cubes***

**A screenshot of a cell phone

Description automatically generated**

**Fig 6:** Activity diagram of Marching Cubes

**Description:**Handler sends a grid cell (Cell is a structure consisting of vertices and iso-level) to polygonise function [4]. Marching analyses the cube situation by looking cases in [4]. There are 256 cases, but it is downgraded to 15 configurations predefined. After that, Marching Cubes finds the surface vertices and marks it. Then, edges that intersected by the surface is found. If the surface does not intersect with the cube, the vertex will not be drawn. Triangles are created by gathering three edges. Finally, the drawing process starts, and triangles are visualized.

***3.2.4 Activity Diagram of Hash System***

***A screenshot of a cell phone

Description automatically generated***

**Fig 7:** Activity diagram of Hash System

**Description:**Handler sends particles, radius and groups to the hash system. Hash system finds the cell id and checks if it is empty. If empty, particle list is created, and the particle list has added. If not empty, checks if particle added. If the particle is not added, the particle is added to the particle list array. Final check occurs for the particles that are on the cell boundary. If the particle is on the boundary, the particle is added to the previous cell. If not, particle remains in the same cell. Hashed cells are sent to the handler and process ends.

# 4. Testing Design

Considering our project is predominantly research and development based, scientific papers and algorithm methods research takes a lot of time. Because of these reasons testing and design changes deferred to the later stages of our project. In this section, we have made the integration test design and prove that our code generally works.

***4.1 Hash System***

The first difficulty of the POF system was to solve the hash system to reach particles faster and increase performance. However, developing on Unity platform has its difficulties. Debugging was a problem in unity game mode. When a bug occurs, unity stops running and close immediately. You cannot test components even for the little bit off the scale values because unity program freezes and terminate the operation. Therefore, we have tried to colouring in scene mode. We have made our test by paint the selected particle to blue colour on gizmos. Neighbour particles painted to red and cell that particle in is drawn as a red wire cube. The other particles are white means neutral and offset the colour of the particles. The outmost yellow wire cube is AABB. Besides, the cell system is an imaginary mathematical structure that does not exist in the POF system. However, it can be computed with position data of a particle by a function immediately.

***A picture containing building

Description automatically generated***

**Fig 8:** Particle and its neighbours in the cell.

In game mode, the particles start to move, and we must track the selected particle and its neighbours including the cell that particle belongs to. From the figure below, you can see that the objective is achieved.

A picture containing sky, stationary, indoor

Description automatically generated

**Fig 9:** Trackingparticle in a cell.

Firstly, we managed to track the particle that we want by changing the particle id which proves that our hash system works correctly. We have made the proof by calculating manually particle order in the AABB afterwards. Tracking the cell boundaries and neighbour particles is as important as tracking the particle itself. Images are taken while unity is playing on game mode.

A picture containing sky, outdoor, red

Description automatically generated

**Fig 10:** Trackingparticle with neighbours in a cell.

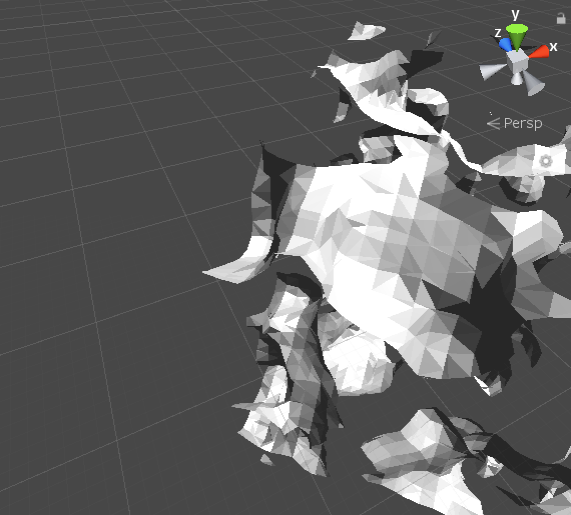
***4.2 Marching Cubes***

Marching cubes [4] is an algorithm for rendering iso-surfaces in volumetric data. It is used for extracting a polygonal mesh of an iso-surface of a surface voxel in our POF system. Marching cubes have various parameters to change the visual output. Some of these factors are linear interpolation and calculating normal.

Linear interpolation is an estimation between two points. The position that it cuts the edge will be linearly interpolated, the ratio of the length between the two vertices will be the same as the ratio of the iso-surface value to the values at the vertices of the grid cell.

A surface normal is basically for each vertex, you can compute an average surface normal at that point by averaging the normal of all triangles sharing that vertex. At each vertex, you can use that normal to compute the lighting at that point. You can interpolate for every point between to determine how bright the surface is at that point. The result is the appearance of edges looks blurry without changing the actual geometry of the object.

We have applied a small test scene to apply marching cubes algorithm. We have created random data values for the marching cubes. The algorithm successfully draws the polygons as you can see in the figure below.



**Fig 11:** Marching cubes test scene on arbitrary vertex data.

Any other test design implementation of new algorithms will be added to this section. The comparison of performance tables with details will be added in the final report.

# References

1. Final Report revision 1.0
2. Requirement Specification Document revision 2.0 (RSD 2.0)
3. Use case and sequence diagrams in RSD 2.0
4. **[WH87]** William E. Lorensen and Harvey E. Cline. (1987). Marching cubes: A high resolution 3D surface construction algorithm. ACM SIGGRAPH Computer Graphics. 21, 163-169.
5. **[ZB05]** Zhu, Y., & Bridson, R. (2005). Animating sand as a fluid. (New York, NY, USA, 2005) ACM Trans. Graph., 24, 965-972.
6. **[BP94]** Paul Bourke 1994, Marching Cubes, viewed 4 March 2020, **<**[**http://paulbourke.net/geometry/polygonise/**](http://paulbourke.net/geometry/polygonise/)**>**
7. **[SSP07]** Solenthaler, Barbara & Schläfli, Jürg & Pajarola, Renato. (2007). A unified particle model for fluid-solid interactions. Journal of Visualization and Computer Animation. 18. 69-82. 10.1002/cav.162.
8. **[AIA12]** Akinci, Gizem & Ihmsen, Markus & Akinci, Nadir & Teschner, Matthias. (2012). Parallel Surface Reconstruction for Particle-Based Fluids. CGF. 31. 1797-1809. 10.1111/j.1467-8659.2012.02096.x.
9. **[TH03]** Teschner, M., Heidelberger, B., Müller, M., Pomerantes, D., and Gross, M.H. (2003). Optimized Spatial Hashing for Collision Detection of Deformable Objects. VMV.