Simulation of Curly Hair

5th semester Project Laboratory report

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Figure 1. The achieved visual look

Abstract

A self-assessment of the 5th semester Project Laboratory Project is presented in this article. My goal was to achieve hair simulation of acceptable quality both in terms of look and performance. Multiple approaches were considered before arriving at a Position Based Dynamics based solution. The simulation was implemented in C++ with the Open Graphics Library (OpenGL [1]).

[1] http://www.opengl.org

CCS Concepts: • **Computing methodologies** → *Physical simulation.*

Keywords: hair simulation, position based dynamics, OpenGL

1 Introduction

In the 5th semester of their undergrad studies, BSc students from Budapest University of Tehchnology and Economics embark on their first journey of scientific research. I was always interested in and fascinated by computer graphics, it came naturally to choose a subject in this area. As I had

little hands-on experience in this field, a long time had to be dedicated to research and trying out different simulation methods.

The first of this paper reflects this, giving an overview of considered methods, and other possible routes that could have been taken to implement hair simulation.

The implementation and all of the code mentioned is avaiable at http://git.sch.bme.hu/bobarna/brave-2.

2 Overview of considered methods

There were mainly three methods considered, two of them being substantially different:

2.1 Mass Spring System

The whole idea of doing hair simulation as my project laboratory came after reading Iben et al. [1]. They outline a method for the artistic simulation of curly hair for use in their film production. The method was featured in the 2012 movie Brave.

This approach models the hair as a chain of particles with given mass, each connected via springs. This results in a mass-spring system, which is then modelled by considering well-known physics formula's such as Newton's second law of motion ("$F = m * a$", and Hooke's Law, which states that the force (F) needed to extend or compress a spring by some distance (x) scales linearly with respect to that distance. The paper by Iben et al. [1] created an elaborate system of springs, with additional core springs making the simulation stable and resulting in the desired look and feel.

The Iben et al. [1] paper also features great further readings in their citations, which gives a great glimpse into related previous works.

The main characteristic of this approach is that a Mass Spring System deals with forces, and tries to stay true to the laws of physics. It accounts for internal and external forces from which accelerations are computed based on Newton's second law of motion. A time integration method is then used to update the velocities and finally the positions of the particles. This will not be the case with Position Based Dynamics.

2.2 Position Based Dynamics (PBD)

The paper by Müller et al. [2] presents an approach that omits the velocity as well as the force layer of the then-present popular approaches for simulation methods of dynamic systems in computer graphics.

Position Based Dynamics (PBD) – as its name suggests – works with the position of particles. A big advantage of such a system lies in its controllability, and the easy reducability of overshooting problems present in force based systems. Another favorable aspect is that PBD methods are generally easier with the maths and somewhat easier to implement in terms of the needed mathematical and physical background needed to grasp its inner workings. In addition, – as it works directly with the position of particles – collision constraints can be handled easily and penetrations can be resolved completely by projecting points onto the penetrated surface. Although such measures can only be applied on the expanse of physical accuracy, position based dynamics being only a "good enough" approximation of how objects behave in real life.

Chapter 2 of the paper by Umenhoffer et al. [4] builds on the Müller et al. [2] paper and gives a concise overview of the position based dynamics method, and goes on to show the type of constraints that can be applied to control to behaviour of such a system – which is present in both papers.

2.3 Follow-the-Leader (FTL)

The Dynamic Follow-The-Leader (FTL) method outlined in Müller et al. [3] focuses on the fast simulation of hair and fur on animated characters. The sheer number of computation needed for simulating thousands of hair strands, each consisting of numerous particles presents a big challenge. Also, as each strand is inextensible, it is not trivial to come up with an algorithm that does its job in feasible time.

As it will be covered later in this article, the already introduced PBD method needs multiple iterations per frame in order to keep the system from stretching and becoming unstable. The FTL method by Müller et al. [3] presents a method that takes only a single iteration through the particles of each hair strand per frame to achieve the desired results.

As this sounds fascinating, and cuts the computation time needed substantially, in the early stages of my project, I implemented the FTL method alongside PBD. It *works*, and is fast, although due to the iteration count being one, when greater forces are being applied to the system, a substantial amount of stretching was introduced to the system. As it seemed in comparison that the "basic" PBD method yielded the same – or even more accurate – results, and it was feasible to allow myself to use multiple iterations per frame, I did not further investigate if there could have been improvements made to my implementation to eliminate the stretching in the presence of greater forces.

3 Results

4 Conclusion

After investigating and trying out multiple methods to simulate hair, we arrived at the Position Based Dynamics (PBD) method. An overview of the PBD method, and an introduction to the constraint types used in our implementation was given. An implementation was made in C++ and OpenGL, which easily simulates the hair strands in real time, although the limit of the real-time nature can easily be surpassed when adding thousands of strands with hundreds of particles.

5 Further Work

As this was part only of a semester-long Project Laboratory course, a great deal of time was dedicated in the early stages of the project to investigate and explore the subject area. This left only a sub-optimal time for implementing all desired aspects of the simulation.

- Hair-hair collisions
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- Refinement and proper customizability of the propagation of hair strands on the Head Object.
  – A drawable texture map is considered for the ability to tell the simulation where to put the hair strands on the surface of the hair.
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References

[1] Hayley Iben, Mark Meyer, Lena Petrovic, Olivier Soares, John Anderson, and Andrew Witkin. 2013. Artistic Simulation of Curly Hair. In *Proceedings of the 12th ACM SIGGRAPH/Eurographics Symposium on Computer Animation* (Anaheim, California) *(SCA '13)*. Association for Computing Machinery, New York, NY, USA, 63–71. https://doi.org/10.1145/2485895.2485913 http://graphics.pixar.com/library/CurlyHairB/paper.pdf.

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[3] Matthias Müller, Tae Kim, and Nuttapong Chentanez. 2012. Fast Simulation of Inextensible Hair and Fur. *VRIPHYS 2012 - 9th Workshop on Virtual Reality Interactions and Physical Simulations.* https://doi.org/10.2312/PE/vriphys/vriphys12/039-044

[4] Tamás Umenhoffer, Artúr M. Marschal, and Péter Suti. 2016. Simulation methods for elastic and fluid materials. http://cg.iit.bme.hu/~umitomi/publications/GRAFGEO2016_PhysicsSimulators.pdf.

A Supplementary development

A.1 OBJ Reader

An OBJ reader utility was implemented as part of the project. As the OBJ file format [2] describes a wide range of properties for objects. The present OBJ reader handles only the subset of these describtion options needed for the project. Lines containing other type of object descriptions were ignored, resulting in a successful file read if possible.

- "`v x y z`" defines a vertex with position (x, y, z).[3]

Table 1. Supported OBJ Data Types

Type of data	Format
Comment	`# comment`
Geometric vertex data	`v x y z`
Texture coordinates	`vt u v`
Vertex normals	`vn i j k`
Triangular faces	`f v1/vt1/vn1 v2/vt2/vn2 ... v3/vt3/vn3`

- "`vt u v`" defines a 2D texture coordinate with position (u, v).[4]
- "`vn i j k`" specifies a normal vector with components i, j and k.
- "`f v1/vt1/vn1 v2/vt2/vn2 v3/vt3/vn3`" Specifies a face with the given indices. For the first vertex, the *v1*st previously defined vertex position is used, the *vt1*st texture coordinate and *vn1*st normal vector is used.[5]

A.2 Recording the simulation on-the-fly

A recording utility was made to work in tandem with the application. In essence, the rendered images are written into `bmp` or `png` files if the capturing is on. In the implementation[6], toggling the capturing is mapped to the `C` key.

For handling the export of the rendered image into files, the stb_image_write.h[7] single-file public domain library was used.

The program outputs the image files in the `renders` folder at 24 FPS, with the naming convention renderXXXX[.bmp/.png], where XXXX is the number of the frame with left-padded zeroes.

After the image files are written, the user can start the `make_video.sh` script to assemble the `output.mp4` and delete all the rendered frames. This script uses the free and open-sorce ffmpeg command line utility[8]

[2] http://paulbourke.net/dataformats/obj/

[3] The obj file format allows for a w coordinate (also called the weight) for describing rational curves and surfaces. The default value of *w* is 1.0. My implementation handles only the assignment of *x*, *y* and *z* values.

[4] The obj file format allows for 3D texture coordinates as well, but this implementation handles only 2D texture coordinates.

[5] The obj file format allows for face definitions far beyond only triangles, although this implementation handles only face definitions of the above format.

[6] https://git.sch.bme.hu/bobarna/brave-2

[7] https://github.com/nothings/stb/blob/master/stb_image_write.h

[8] https://ffmpeg.org/