Ciências ULisboa | Informática

Animação e Ambientes Virtuais 2018/2019

Mestrado

DI- FCUL

Guião das aulas teóricas

Hair Simulation

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Hair Simulation

Summary

Hair modeling involves:

- Hairstyling
- Hair simulation (or hair dynamics)
- Hair rendering

Different approches have been used:

- Explicit hair models
- Cluster hair models
- Volumetric textures models
- Fluid flow model

Modeling and rendering (and animation) are coupled...
– Can't see model without a renderer
– Can't render (or animate) without a model, etc...

Hair Modeling

To produce realistic-looking hair is one of the many challenges in simulating **believable Virtual Humans**. Many of the commercial software applications provide suitable solutions and plug-ins for creating hairy and furry characters.

Modeling hair is difficult:

- On a scalp, human hair strands are typically 100 000 to 150 000 in number.
- Geometrically hair strands are long, thin curved cylinders having varying thickness.

Hair Modeling

Modeling hair is difficult (continued):

- The strands of hair can have any degree of waviness from straight to curly.
- The hair color can change from white to black, red to brown, due to pigmentation.
- The hair has shininess of varying degrees.
- The color, optical and dynamic properties may be altered by a variety of cosmetic products (or just by water..). Most people typically cut and style their hair in various ways through bangs, ponytails, braids, etc.

Hair Modeling

Simulating the motion of hair is even more difficult:

- There are complex interactions of light and shadow among the hair strands.
- Intriguing **hair-to-hair**, **hair-to-body** and **hair-to-air** interaction while in movement.
- When the head moves or the wind blows, each individual hair moves, creating a complex changing of shape and appearance.

Hair Modeling

- **Currently, there is no method that has been accepted as the industry standard for modeling hair.**
- **Hair remains an unsolved problem for which there is currently no standard physically-based model.**

Example: Tangled /Disney (2010)

http://www.youtube.com/watch?v=9K-Gv4XVb10

Hair Modeling

According to Disney's version of the legend, Rapunzel's hair would weigh 60 to 80 pounds (*), and would be 70 feet long (**). Keeping Rapunzel's hair as physically accurate as possible would prove to be a boring movie, so **artistic liberties** were taken in many scenes involving such massive amounts of hair.

Example: Tangled /Disney (2010)

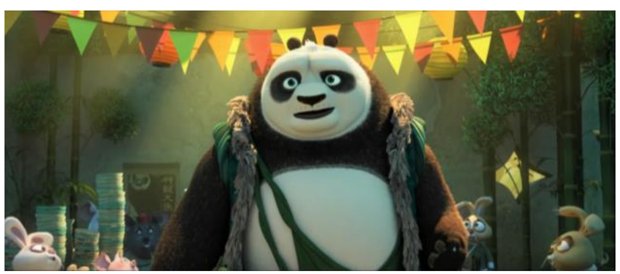
(*) 27 to 32 kg

(**) 21,33 meter

Example: Brave- produced by Pixar Animation Studios and released by Walt Disney Pictures (2012)

https://www.youtube.com/watch?v=7IXKCzko2gM

Example: ***Kung Fu Panda 3***, 2016, produced by DreamWorks Animation
https://www.youtube.com/watch?v=10r9ozshGVE



Example: How to train your dragon: the hidden world

https://www.youtube.com/watch?v=SkcucKDrbOI

DreamWorks Animation, 2019

Hairstyling- **Hair shape modeling**

Hair research began by viewing hair as **individual strands**, or one-dimensional curves in 3-D space.

Hairstyling- **Hair shape modeling**

Hair shape modeling deals with **exact** or **fake** creation of thousands of individual hair- their geometry, density, distribution and orientation.

Explicit hair models

In the explicit hair model, **each hair strand** is considered for the shape and the dynamics of the whole hair. Explicit hair modeling are very intuitive and close to reality. Unfortunately they are tedious to hairstyling.

Typically, explicit hair models take days to model a complex hairstyle; they are also numerically expensive for hair dynamics.

Hairstyling- **Hair shape modeling**

Daldegan et al. 1993 proposed that the user could interactively define a **few characteristic hair strands in 3-D and then populate the hairstyle based on them**.

The user is provided with a flexible graphical user interface to sketch a **curve in 3-D around the scalp**. A few parameters such as **density**, **spread**, **jitter** and **orientation** control the process that duplicates the characteristic hair to form a hairstyle.

Similar approaches for **fur** modelling were proposed by:
Van Gelder and Wilhems, 1993
Bruderlin, 1999

Hairstyling- **Hair shape modeling**

Daldegan et al. 1993

The user is provided with a flexible graphical user interface to sketch a **curve in 3-D** around the scalp.

Few characteristic hair strands are considered for shape. Parameters such as **density**, **spread**, **jitter** and **orientation** control the process that duplicates the characteristic hair to form a hairstyle.

- Intuitive and versatile
- Effective but time consuming
- Can not be effectively used for complex hairstyles involving clips, knots and braid

Hairstyling- **Hair shape modeling**

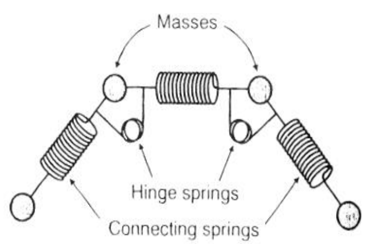
Rosenblum et al. 1991 and **Anjyo et al. 1992** geometrically model each hair strand simply as a linearly connected point set.

- mass-spring-hinge model (Rosenblum et al.)

- cantilever beam model (Anjyo et al.)

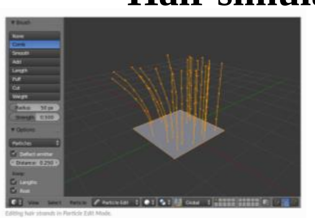
Hairstyling- **Hair shape modeling**

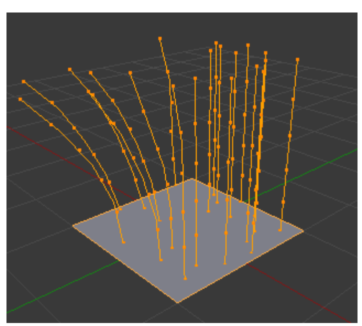
Rosenblum et al. 1991 use a mass-spring-hinge system to control each strand's position and orientation.



Since hair does not stretch very much, springs are stiff.

Hair simulation in Blender





https://docs.blender.org/manual/en/latest/physics/particles/mode.html

Hairstyling- **Hair shape modeling**

Anjyo et al. 1992 developed a hair modeling method that involves a process to bend the hair, which is based on the **numerical simulation** of **cantilever beam deformation**. (**cantilever beam = a beam supported only at one end having a free end and a fixed end**)

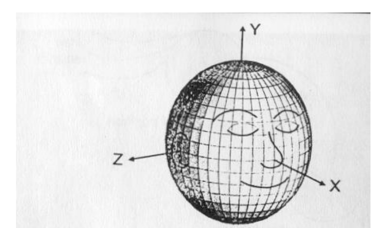
- Anjyo et al. consider that it is a similar case to a human hair strand, where the strand is anchored at the pore, and the other end is free.
- Considering that **gravity** is the main source of bending, the method simulates the simplified statics of a cantilever beam to get the pose of one hair strand at rest. However, due to the use of a linear model, **extra forces** need to be applied to the strand in order to get the proper final shape.

Cantilever = viga (PT)

Hairstyling- **Hair shape modeling**

This approach consists of the following:

- Define an ellipsoide that roughly approximates the desired 3-D head model.

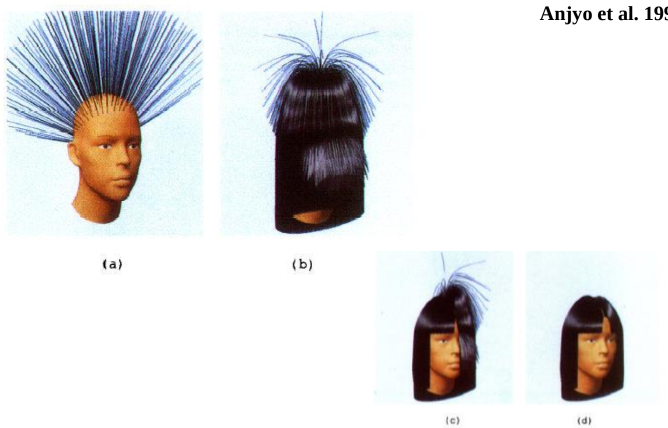


Hairstyling- **Hair shape modeling**

- On this ellipsoid, specify the desired hair follicle regions. One hair strand will originate from each follicle location.
- For each strand, calculate its bent shape based on a simplified cantilever beam simulation. This shape calculation includes **collision detection between each hair and the approximating head ellipsoid**.
- Adjust or cut hair strand lengths for various follicle regions and apply **shaping forces** to achieve the desired overall hair shape.

Hairstyling- **Hair shape modeling**

Anjyo et al. 1992



Hairstyling- **Hair shape modeling**

Cluster/Wisp hair models

Due to the effects of adhesive/cohesive forces, hairs tend to form clumps.

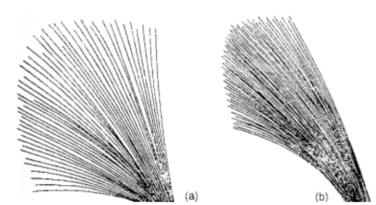
Watanabe and Suenaga 1992 introduced the **wisp model**.

Hairstyling- **Hair shape modeling**

A head of hair contains many wisps, where **wisps** are **groups of individual hair strands**. Hairstyles are not created by controlling individual hairs, but by cutting and forming wisps.

Wisps are used as template units to efficiently create and control the total hair set.

r is the parameter that expresses the randomness in the initial direction vectors

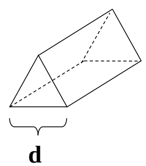


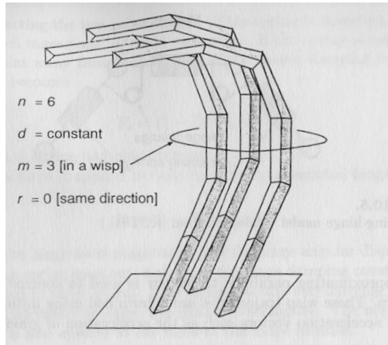
large r small r

Hairstyling- **Hair shape modeling**

The details of each wisp are controlled by its own parameters:

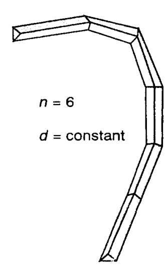
r- randomness in the initial direction vectors
m- density of the strands (typically 100 hairs per wisp)
n- number of trigonal prims for each hair strand





Hairstyling- **Hair shape modeling**

Each hair is defined as a connected sequence of trigonal prisms (instead of cylinders in order to minimize the number of polygons to be rendered).



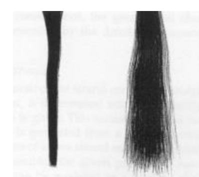
Hairstyling- **Hair shape modeling**

Choe et al. 2005

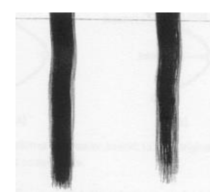
Generating wisps: a whole hair is formed by generating a collection of **wisps**. They determine the geometrical shape of a wisp by <u>manipulating a representative strand</u> and controlling the **statistical properties** of the surrounding member strands.

Solving hair deformation: the hair deformation solver accounts for the effects of **gravity**, hair **elasticity** and **collisions** to determine the deformed shape of the wisps.

Hairstyling- **Hair shape modeling**



Wisps generated by two different deviation radius functions



Wisps generated by two different length distributions

Wisps generated by two different fuzziness values

Show movies

Hairstyling- **Hair shape modeling**

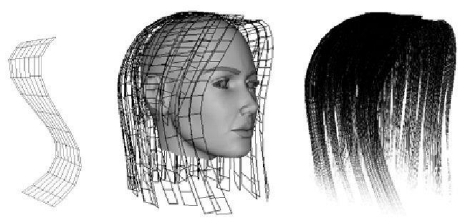
Koh and Huang, 2001
Liang and Huang, 2003
Noble and Tang, 2004

- Use **2D surfaces** to represent groups of strands.
- These methods use a patch of a **parametric surface**, such as a **NURBS(**)** surface (called **hair strips**), to reduce the number of geometric objects used to model a section of hair.
- These hair strips are given a location on the scalp, an orientation, and weighting for knots to define a desired hair shape.
- Texture mapping and alpha mapping (*) are then used to make the strip look more like strands of hair.

(*) alpha⟶ transparency

(**) Non-Uniform Rational Bezier-Spline

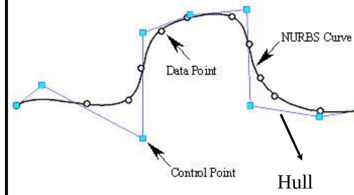
Hairstyling- **Hair shape modeling**



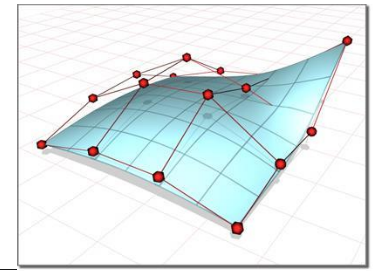
(a) (b) (c)

Figure 5. A Hair Strip (a), Hair Style (b) and Texture and Alpha Mapping (c)

NURBS



http://sabia.tic.udc.es/gc/teoria/Tenicas%20de%20Modelado%203D/nurbs.htm



http://www.3dmax-tutorials.com/CV__Glossary_.html

Hairstyling- **Hair shape modeling**

Kim and Neumann 2000

- Developed a model called **Thin Shell Volume** (TSV) that creates a hairstyle starting from a parameterized surface.
- **Thickness** is added to the hair by offsetting the surface along its normal direction.

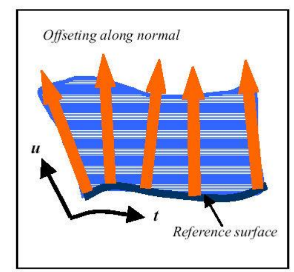
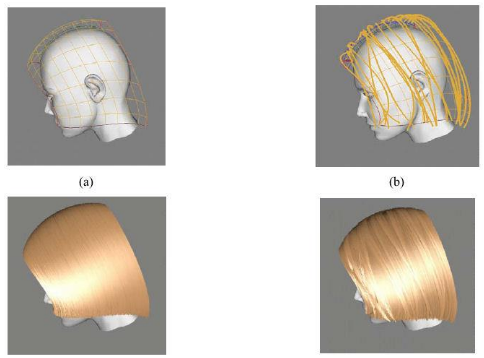


Figure 3. Generation of a thin shell volume

Hairstyling- **Hair shape modeling**

Kim and Neumann 2000



(a) (b) (c) (d)

Plate2. Result of hair combing (a) Hair surface design, (b) Combing function (c) Hair model before combing (d) Combed Hair

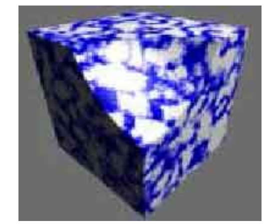
Some authors used Hipertextures to model fur (short hair)

But before, some basic concepts…

Volumetric Textures

Volumetric Textures (or 3D textures)

A volumetric texture is **a texture that is described in three dimensions.** It can be created as a "stack" of 2D bitmapped textures. **When an object with volumetric texture is sliced in half, the texture would still be rendered accurately on the inside.**



http://www.xbitlabs.com/articles/video/display/gforce3-ti500.html

Volumetric Textures

3D texture: a **stack of 2D textures**.

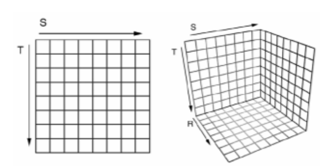
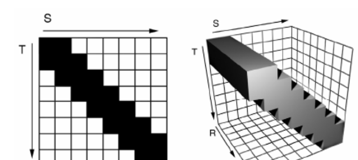
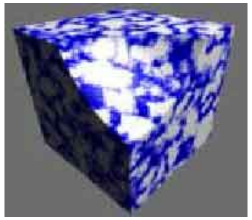


Figure 1 - Relationship between 2D and 3D textures



http://developer.amd.com/media/gpu_assets/ShaderX_3DTextures.pdf

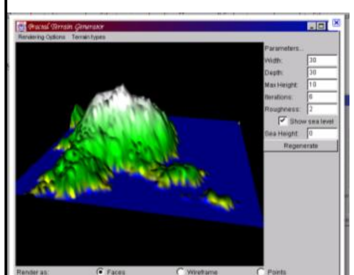
Examples of Volumetric Textures:



http://www.xbitlabs.com/articles/video/display/gforce3-ti500.html

http://www.nullpointer.co.uk/content/?p=396

Procedural Textures



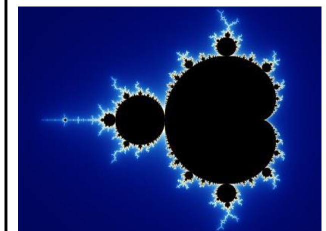
http://code.j3d.org/examples/terrain/index.html

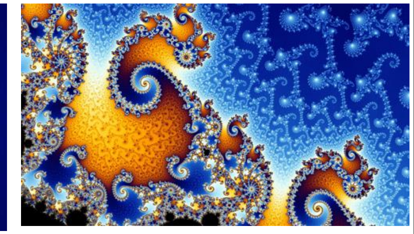
Procedural texture mapping and procedural modeling is the **use of a function or set of functions applied to a set of points in order to generate a texture.** One of the most well known methods of procedural texture mapping is probably the use of **fractal techniques** to generate terrain.

fractals - sets which, when magnified over and over, always resemble the original image.

http://mathforum.org/~sarah/mandelbrot.all.html

Fractals- Mandelbrot set





http://www.sfdm.scad.edu/faculty/mkesson/vsfx319/wip/best_winter2011/ali_jafargholi/project_4.html

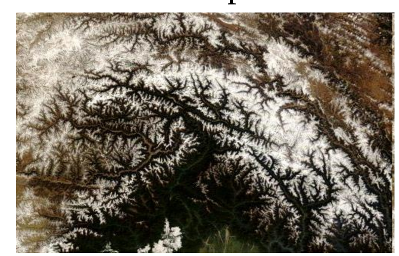
fractals - sets which, when magnified over and over, always resemble the original image.

http://mathforum.org/~sarah/mandelbrot.all.html

Fractals in Nature- examples

Fractal mountains in Tibet

http://www.miqel.com/fractals_math_patterns/visual-math-natural-fractals.html



A simple cauliflower

Hypertextures

It can be a difficult task to model certain types of textures. Especially those that have incredibly **complex boundaries** like **hair** or **fur**, or those that have no real 'fixed' boundaries such as **flames** or **smoke**.

Hypertextures have a <u>density function</u> that describes how the object should behave in the area where it transitions between the outside and inside of the object.

Hypertexture is a method developed in 1989 by Ken Perlin a professor at NYU, **to model and generate complex 3D textures**.

http://web.cs.wpi.edu/~matt/courses/cs563/talks/cbyrd/pres2.html

Hypertextures

An object in Hypertexture is partitioned into **regions**:

- **a hard region-** represents the part of the object where it is completely solid
- **a soft region** - represents a part of the object where the density is variable

The **density function** describes how the object should behave in the area where it **transitions** between the outside and the inside of the object.

Hypertextures

There are **two main functions** that define a hypertexture. Those are the **Density Function** and the **Density Modulation Function**:

The **Density Function**, D(x), describes the density of the object for all points thoughout R^3.
D(x) has a range of 0 to 1.
A value of 1 means the object is completely solid at that point.
A value of 0 means the object has no density at that point.
All values of D(x) such that $0 < D(x) < 1$, represent the objects soft region.

The **Density Modulation Function (DMF)** is the function that **<u>controls the behavior of the density within an object's soft region</u>**. Perlin defines a set of base DMF's that can be used as building blocks to define any hypertexture.

A DMF is applied to an object's Density Function. Multiple DMF's can be applied to the same D(x).

Hairstyling- **Hair shape modeling**

Perlin and Hoffret 1989

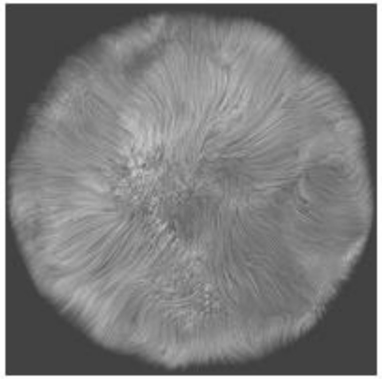
Fur is modeled as **intricate density variations in a 3-D space**, which gives the illusion of the fur like medium <u>without defining the geometry of each and every fiber</u> — **Density Function**

+

3-D vector valued **noise** and **turbulence** to perturb the 3-D texture space. This give a **natural look** to the otherwise even fur defined by the hypertexture. — **Density Modulation Function**

Hairstyling- **Hair shape modeling**

Furry ball (using hypertextures)



Hairstyling- **Hair shape modeling**

- **Kajiya at al 1989** extended this approach to have **hypertextures** tiled on to complex geometry.

  They used a single solid texture tile named **texel** and mapped it repeatedly on the bear’s geometry.

Hairstyling- **Hair shape modeling**

Fluid Flow

Hadap and Magnenat-Thalmann 2000 propose the modeling of hair as streamlines of fluid flow (**the comparison is only limited to static hair shape with a snapshot of a fluid flow rather than its dynamics**).

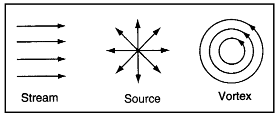
- Though hair is thin in geometry, collectively it has a volume.
- The hair-to-hair collision avoidance is similar to the *continuum property* of fluid: no two streamlines of a fluid flow intersect, however close they may get, with an exception of flow singularities.

Hairstyling- **Hair shape modeling**

- Hair-to-body collision avoidance is the same as a **flow around an obstacle**.
- Hair curls are analogous to **vortices**
- Hair waviness are analogous to the **turbulence** in the flow.
- (…).

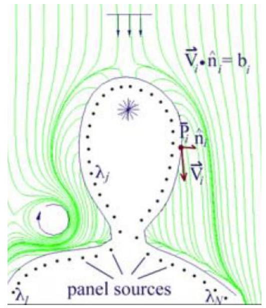
But hair **is not** precisely like a fluid flow. For example, hair tends to form clumps, which is not true in the case of streamlines.

Hairstyling- **Hair shape modeling**



- Stream as gravity
- Source as an obstacle
- Vortex as a curler

… shape the complex flow

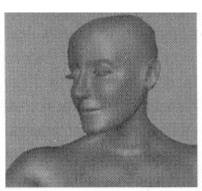


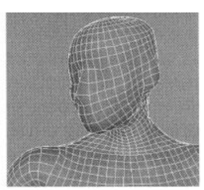
Place a number of "unknown" sources bellow the body

Hairstyling- **Hair shape modeling**

Interactive hair-styler (**Hadap and Magnenat-Thalmann 2000**):

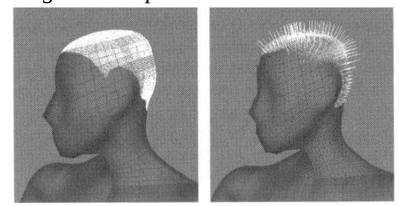
1. The user starts modeling hair on a coarse mesh model





Hairstyling- **Hair shape modeling**

2. Then the user defines the total number of hair and paints the *hair growth map*

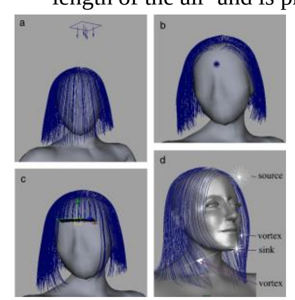


From the probability density function in the form of hair growth map, the placement of individual hair is pre-computed

3. The user paints the *normal velocity map* (normal velocity is zero everywhere except for the regions where the hair originates). The user can control how the hair will stand out from the scalp by varying the magnitude of the normal velocity (the greater the velocity component, the more the streamlines will stand up).

Hairstyling- **Hair shape modeling**

4. The user is provided with a 3-D version of ideal flow elements: streams, sources and vortices and can interactively place them around the model to define the hairstyle. The user defines the length of the air and is provided with a trimming tool.



- Place a stream to give hair a downward direction
- Place a source to repel away unwanted hair on face
- Trim hair
- Place vortices to make curls

Hairstyling- **Hair shape modeling**

http://www.miralab.ch//repository/papers/64.pdf

Hair Dynamics

Hadap and Magnenat-Thalmann 2000 use **fluid dynamics** to simulate hair dynamics, particulary hair-hair and hair-air interactions.

Rosenblum et al. 1991

Each hair strand is modeled as a series of interconnected masses, springs and hinges. Each strand segment is modeled as two masses held a nearly fixed distance apart by a strong spring. A hinge spring is located between segments at the point mass locations. In this implementation, the hair strands do not interact.

Hair Dynamics

Rosenblum et al. 1991

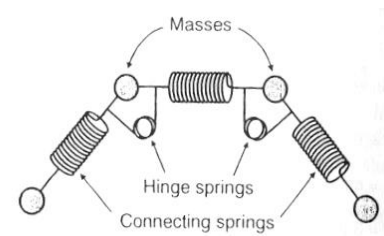
$$F_{sum} = F_s + F_h + F_g + F_d$$

Forces applied to each point mass by the interconnecting springs.

Force applied to each mass by its associated hinge spring

Force of gravity

Aerodynamic drag force



Hair Dynamics

All of the force components are summed and used to compute the acceleration of the mass based on Newton's second law of motion:

The relationship between an object's mass *m*, its acceleration a, and the applied force *F* is *F = ma*.

$$a = F_{sum}/m$$

The acceleration *a* is used to update the mass velocity, which in turn is used to compute the new mass position.

Hair Dynamics

Anjyo et al. 1992 developed a hair modeling method that involves a process to bend the hair, which is based on the **numerical simulation** of cantilever beam deformation.

Each hair strand is represented as a deformed beam composed of linked linear segments.

Fundamental principles of dynamics are applied that lead to two differential equations that are solved at each time step

Heuristic techniques are used in conjunction with the solution of these differential equations to give approximate solutions to **simulate collision** and **interaction** of the hair strands with themselves and with the head.

Hair Rendering

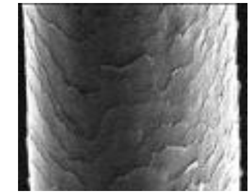
The difficulties of hair rendering arise from various reasons:

- Large number of hair strands
- Detailed geometry of individual hair
- Complex ligth scattering (next slide)
- Complex interactions of light and shadow among the hairs
- Small thickness

Hair Rendering

A hair fiber is composed of **three** structures:

- the **cortex**, which is the core of the fiber and provides its physical strength,
- the **cuticle** (figure), a coating of protective scales that completely covers the cortex several layers thick, and
- the **medula**, a structure of unkown function that sometimes appears near the axis of the fiber.



A hair is composed of amorphous proteins that act as a **transparent** medium with a specific index of **refraction**. The cortex and medulla contain pigments that **absorb light**, often in a wavelength-dependent way; these pigments are the cause of the color of hair.

Hair Rendering

The hair rendering problem has been addressed by several researchs in the last years.

However, most solutions work well in particular conditions and offer limited (or none) capabilities in terms of dynamics and animation of hair.

Much of the work refers to **a more limited problem: rendering fur** (very short hair). It has a lot in commom with rendering natural phenomena such as **grass** and **trees**.

Hair Rendering

Explicit modeling has been widely used for hair rendering. Some approaches are:

- Each hair are modeled as a single triangle laid out on a surface, always facing the camera, and rendered using a Z-buffer algorithm for hidden-surface removal.
- Each hair are modeled as connected segments of triangular prims on a full human head. A hardware Z-buffer renderer is used with Gouraud shading.
- The wisps are modeled as generalized cylinders and volumetric textures + Ray-tracing is used.

Hair Rendering

- Model hair with low primitive count and thus some compromise on realism
- Game Characters have hair modelled as low polygon mesh with texture mapped on it
- Long Hairs mostly modelled as Pony Tail for easier Animation

Hair Rendering

- For realism hair should show real-time modification of appearance based on viewing and lighting conditions
- Using modern powerful graphics engine makes it possible to render complex, high quality hair and fur at very interactive frame rates.

https://en.wikipedia.org/wiki/ZBrush

Brave (hair):
https://www.youtube.com/watch?v=1uYI8T5dvf0

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Edited by N. Magnenat-Thalmann, D. Thalmann, John Wiley & Sons, 2004

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[Ward07] *A Survey on Hair Modeling: Styling, Simulation, and Rendering*, Kelly Ward, Florence Baertails, Tae-Yong Kim, Stephen Marschner, Marie-Paul Cani, and Ming C. Lin; IEEE Transactions on Visualization and Computer Graphics, Vol 13, No. 2, pp 213-234, March/April 2007
Version of 2010::
http://hal.inria.fr/docs/00/17/14/07/PDF/surveyHair.pdf

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http://web.cs.wpi.edu/~matt/courses/cs563/talks/cbyrd/pres2.html

Animation in the old times…

Walt Disney

https://www.youtube.com/watch?v=OebUzEhSLBI (2:21)

Animation in the old times…

https://www.youtube.com/watch?v=B7-QaPlTd-M (5:10)

Alice in wonderland

https://www.youtube.com/watch?v=LWwO-h7ZSlw (0:50)

Recycling...

www.youtube.com/watch?v=hjmaOj3_sKk

https://www.youtube.com/watch?v=FepHIzaXTyg (0:33)

More recently...

https://www.youtube.com/watch?v=W6X9U75Z6AI (1:15)