Simulating Hair Dynamics

Jamie Snape

The University of North Carolina at Chapel Hill

THE UNIVERSITY
of NORTH CAROLINA
at CHAPEL HILL

- Styling

  Geometry of hair

  Density, distribution, orientation of hair strands

- Simulation

  Dynamic motion of hair

  Collision between hair and other objects

  Mutual hair interactions

- Rendering

  Color, shadows, light scattering effects, transparency, and anti-aliasing

Hair Simulation

- Difficult to provide a realistic model

    Each hair strand has a complex mechanical behaviors

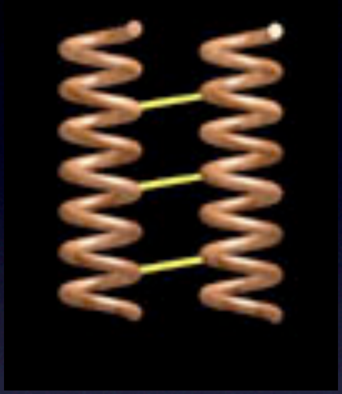
    Little knowledge available of mutual hair interactions

- Problems in terms of computation costs

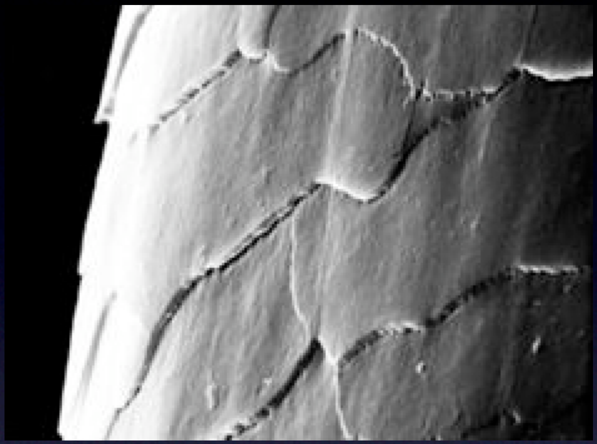
    Existing methods propose compromises between realism and efficiency depending on application

The Mechanics of Hair

- Hair strands are anisotropic deformable objects
  - *Can easily bend and sometimes twist*
  - *Strongly resist shearing and stretching*
- Have some elastic properties
  - *Tend to recover original shape after stress has been removed*

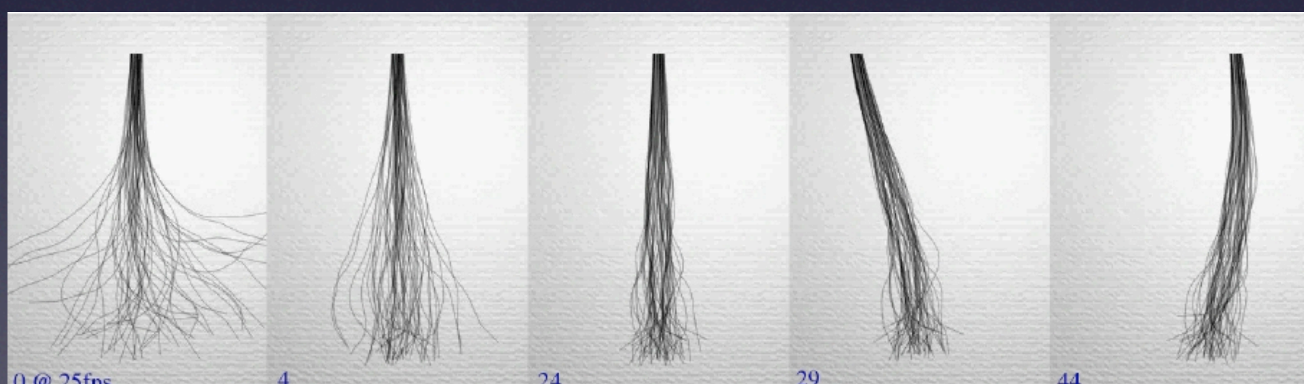


- Complex interactions between hair strands
  - *Surface of individual hair strands consists of irregular tiled scales*
  - *Causes anisotropic friction inside hair with direction depending on orientation of scales and direction of motion*



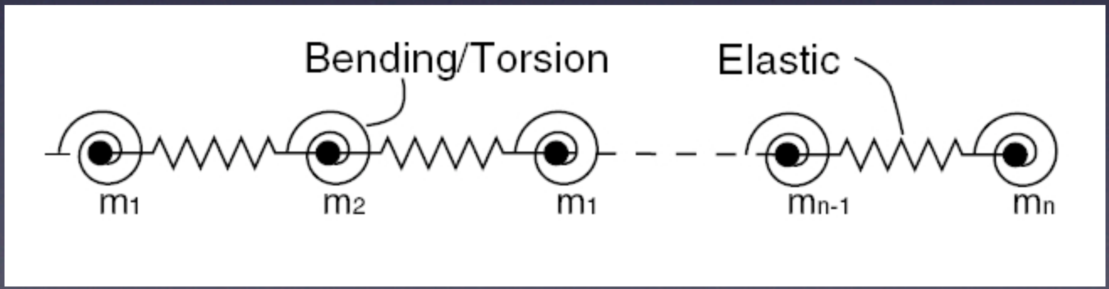
- Geometric shape affects motion of hair
  - *Hair curls can longitudinally stretch during motion*
  - *Clumps more likely to appear in curly hair*
  - *More intricate geometries have less degrees of freedom during motion*

Dynamics of Individual Hair Strands



Mass-spring Systems

- Hair strand modeled as a set of particles connected by stiff springs and hinges
  - *Each particle has one degree of translational and two degrees of rotational freedom*
  - *Bending rigidity ensured by angular springs at each joint*



- Simple and easy to implement

  But does not account for torsional rigidity or non-stretching of each strand

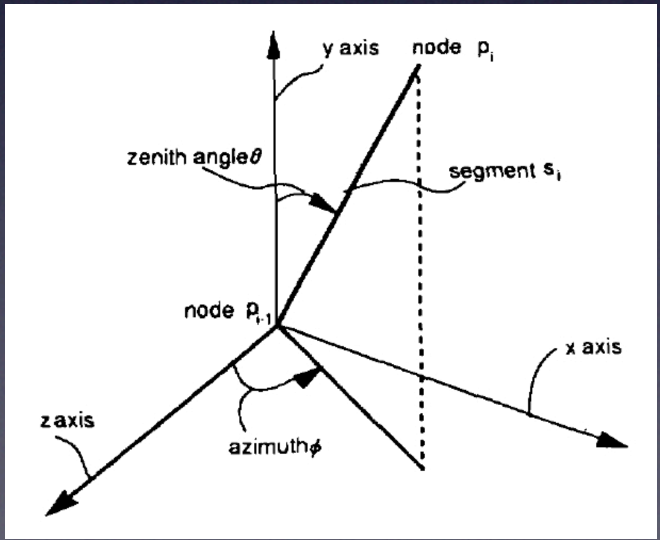
One-dimensional Projective Equations

- Hair strand considered as a chain of rigid sticks

  Sticks parameterized by polar angles ϕ and θ

  External force applied to each stick projected onto two planes defined by ϕ and θ

  Fundamental principles of dynamics applied to each parameter leading to two differential equations at each step



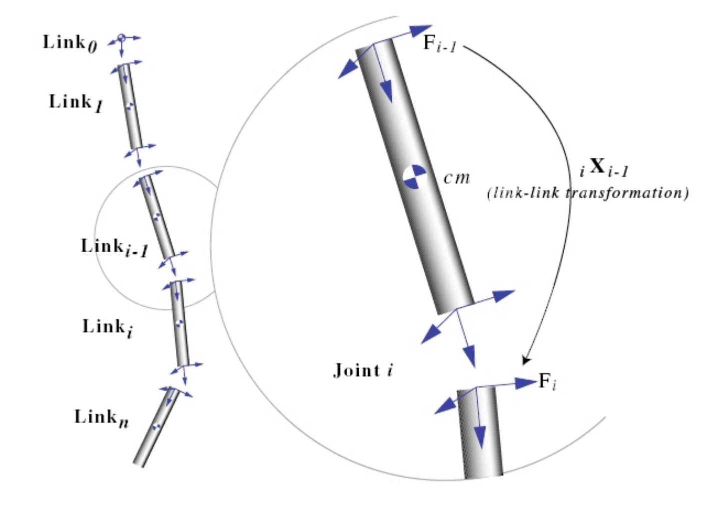
- Hair is prevented from stretching and hair bending is properly recovered

But as torsional hair stiffness cannot be accounted for, three dimensional motion cannot be completely simulated

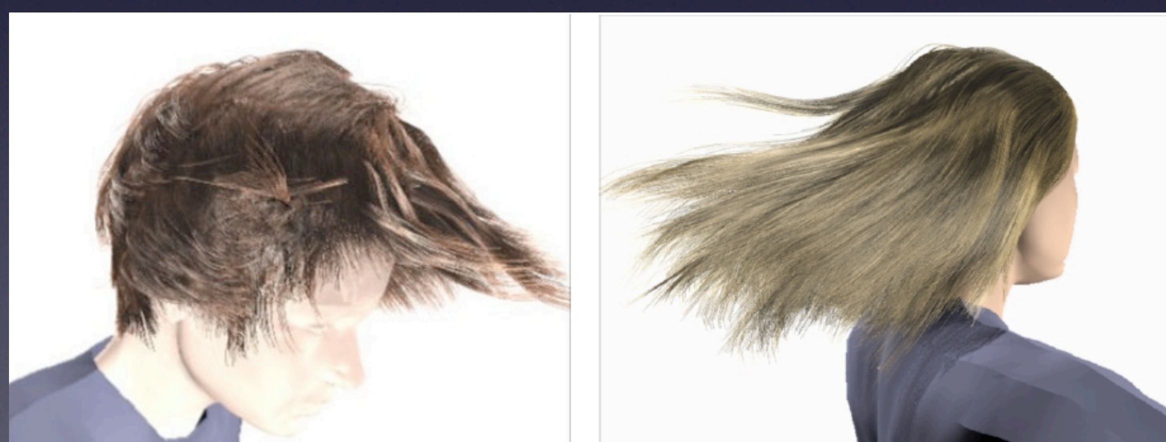
Motion processed from top to bottom, so difficult to handle external punctual forces

Rigid Multi-body Serial Chain

- Hair strand represented as a rigid multi-body open chain
    - *Stretching degrees of freedom removed to ensure only bending or twisting*
    - *Apart from gravity, forces responsible for bending or torsional rigidity are applied to each link*
    - *Motion computed using forward dynamics*



Simulating the Dynamics of a Full Hairstyle



Hair as a Continuous Medium

- A human head of hair normally consists of over 100,000 strands of hair

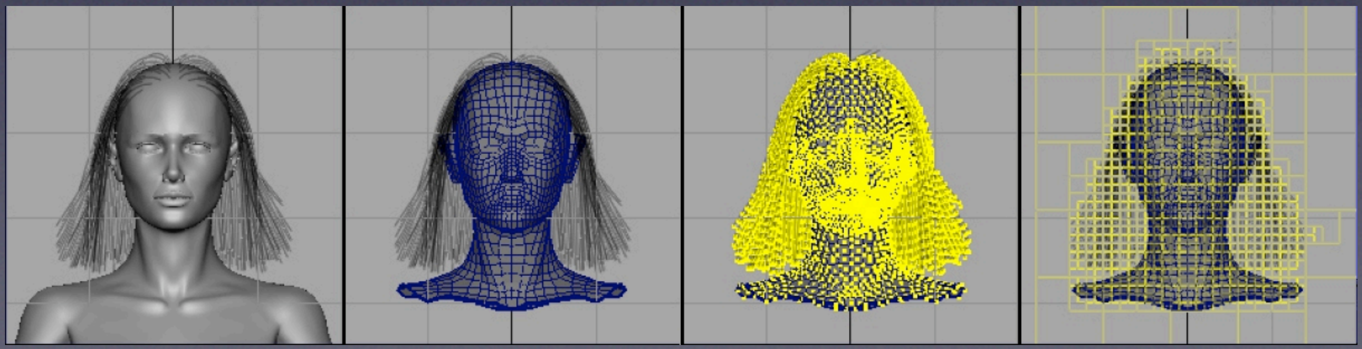
  Simulating each individually is computationally overwhelming

- But strands of hair in close proximity tend to move with similar motions

  Suggests viewing hair as an anisotropic continuous medium

Smooth Particle Hydrodynamics

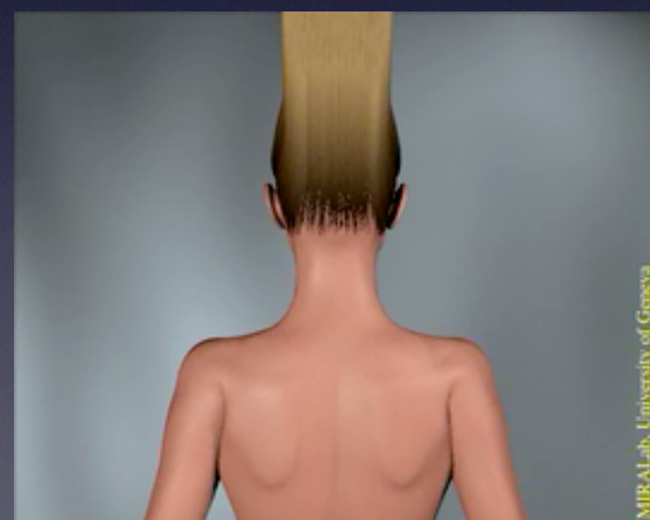
- Model interactions of hair using fluid dynamics
  - *Kinematically link each hair strand to fluid particles in their vicinity*
  - *Density of hair medium defined as mass of hair per unit volume*
  - *Pressure and viscosity represent all the forces due to interactions between hair strands*
  - *Hair-body interactions modeled by creating boundary fluid particles around solid objects*



- Captures the complex interactions of hair strands

    But assumes a continuum of hair, so cannot capture the dynamic clustering effects seen in long and thick hair

    Computationally expensive, slow even using parallelization



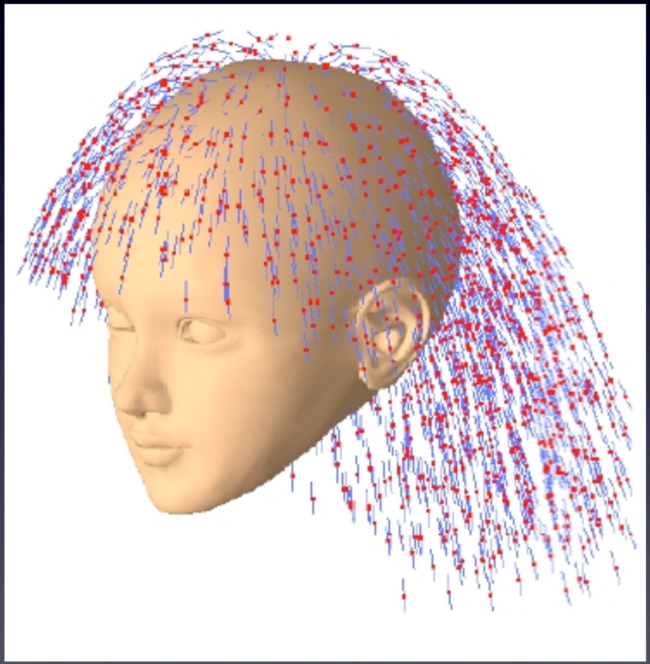
Loosely Connected Particles

- Use a set of SPH particles that interact in an adaptive way

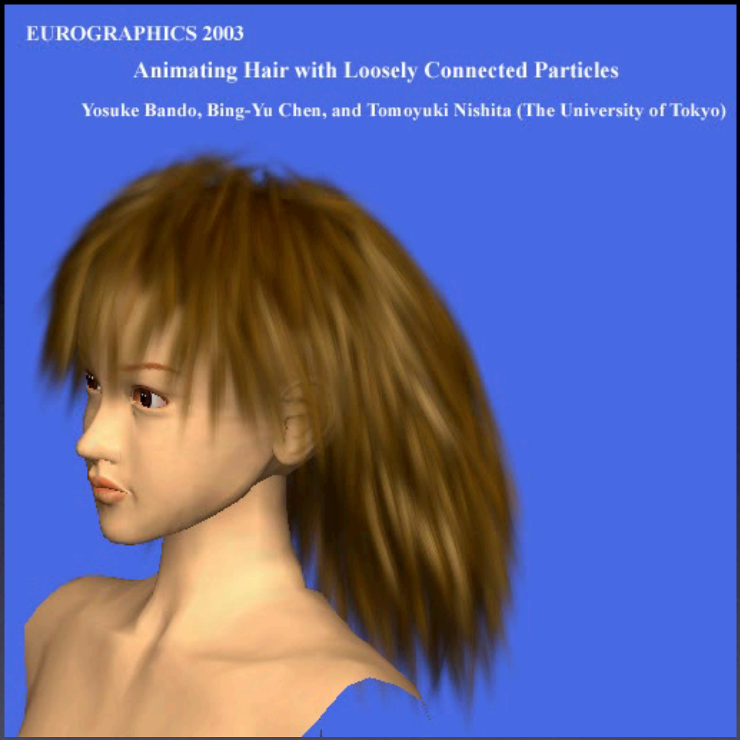
  Each particle represents a certain amount of hair material with a local orientation

- Neighboring particles with similar orientations are linked

  Represents spatial consistency of interactions between particles



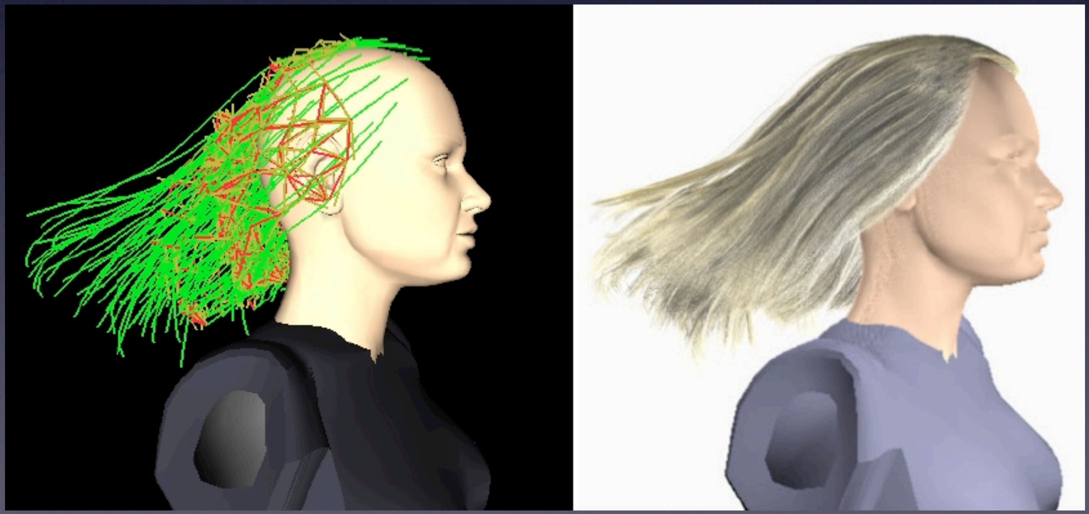
- During motion each particle can interact with other particles in its local neighborhood
  - *Links are breakable and disappear as soon as the particles move a certain distance apart*
  - *Allows separation and grouping while maintaining constant hair length*



Interpolation between Guide Hair Strands

- Simulate a sparse set of hair strands

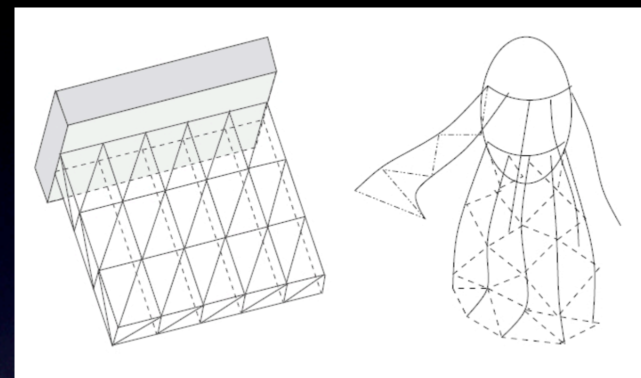
  Create a dense model by interpolating the position of the remaining strands from the guide strands



- Use the guide strands to detect and handle hair interactions

    Only using strands inefficient so build an auxiliary triangle strip between corresponding vertices

    Check for interactions between hair segments and a hair segment and triangular face



Free Form Deformation

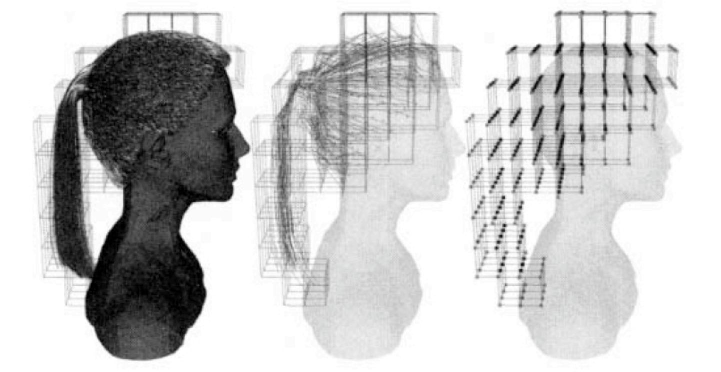
- Define a mechanical model for a lattice surrounding the head

  Lattice is deformed as a particle system and hair strands follow by interpolation

  Collisions between hair and body handled by approximating the body as a set of metaballs

- Good for simulating complex hairstyles when head motion has low magnitude

  Cannot reproduce discontinuities in hair



Hair as Disjoint Groups

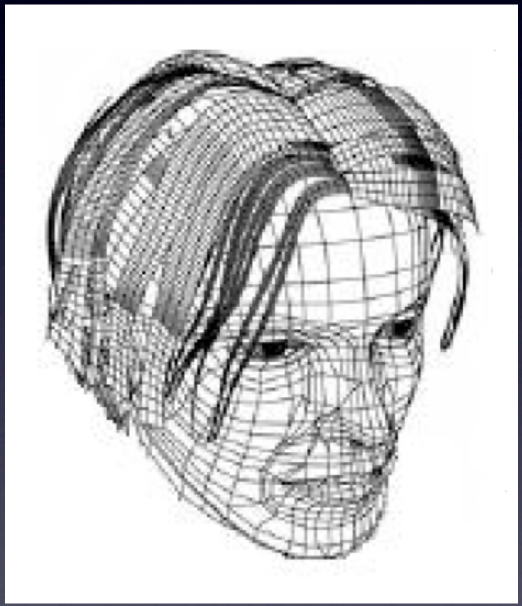
- Group nearby hair strands and simulate groups as independent, interacting entities

  Saves computation time compared to simulating individual strands

  Able to account for local discontinuities seen inside long hair during fast motion

Real-time Simulation of Hair Strips

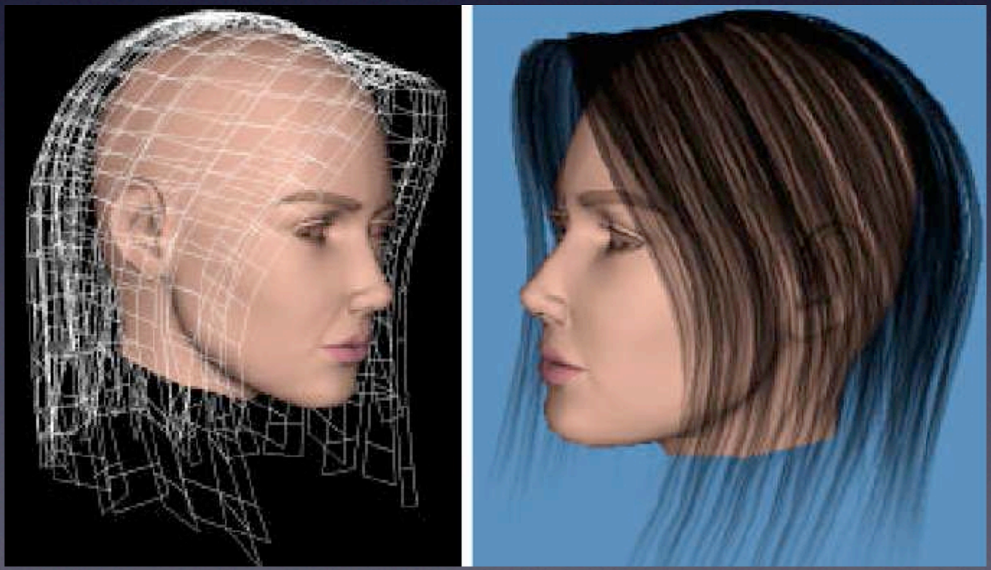
- Model groups of strands using a thin flat patch
  - *Place springs between neighboring strips to prevent collisions*
  - *Also prevents strips from moving too close or far apart*
  - *Use ellipsoids to represent the head and body and a reaction constraint method to move a strip back to the boundary if it intersects*



- Using a strip to represent tens or hundreds of hairs allows real time simulation

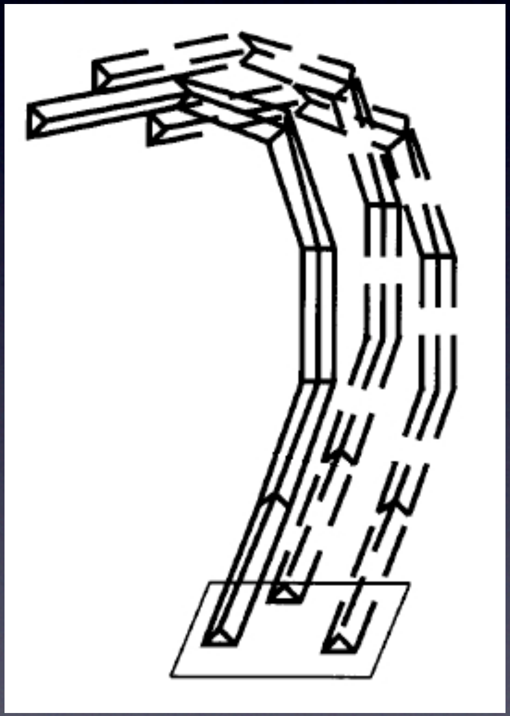
    But process limited in the types of hairstyle and motion it can represent

    Flat shape of strips most suited to long straight hair



Simulation of Wisps

- Group neighboring strands together into wisps
  - *Approximate the shape of a wisp during motion using parabolic trajectories of particles initially located at the base of each wisp*
  - *Alternatively simulate the motion of a typical strand and generate additional strands by adding random displacements*
  - *Interactions between individual strands or wisps not considered*



Multi-resolution Methods

Level-of-detail Representations

- Three levels of detail to accelerate simulation while maintaining high visual quality
    - *Individual strands represented by subdivision curves*
    - *Clusters represented by subdivision swept volumes*
    - *Strips represented by subdivision patches*
- Create a hair hierarchy using these LODs and collision detection using swept sphere volumes

- Hair hierarchy traversed during simulation to choose appropriate representation and resolution of a given section of hair

    Transition automatically to a higher LOD for sections that are most significant based on visibility, viewing distance, or motion

    If a section is occluded or out of field-of-view, simulate with the coarsest LOD

    As distance decreases or hair moves more drastically, there is more observable detail and need for more detailed simulation

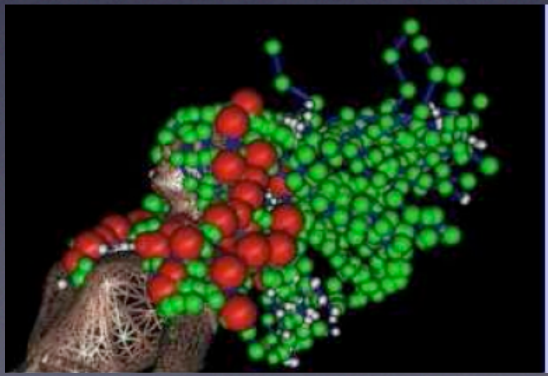
Adaptive Clustering

- Continuously adjust the amount of computation according to local complexity

  An adaptive wisp tree represents at each time step the wisp segments of the hierarchy that are simulated

  Hair should be more refined near the tips than roots, so AWT dynamically splits or groups wisps while preserving tree-like structure

  Implicitly models hair interactions so that neighboring wisps with similar motions merge



Summary

- Hair modeling
- The mechanics of hair
- Dynamics of individual hair strands
  - *Mass-spring systems*
  - *One-dimensional projective equations*
  - *Rigid multi-body serial chain*

- Simulating the dynamics of a full hairstyle
    - *Smooth particle hydrodynamics*
    - *Loosely connected particles*
    - *Interpolation between guide hair strands*
    - *Free form deformation*
    - *Real-time simulation of hair strips*
    - *Simulation of wisps*
- Multi-resolution methods
    - *Level-of-detail-representations*
    - *Adaptive clustering*

References

Anjyo, Usami & Kurihara (1992): A simple method for extracting the natural beauty of hair

Bertails, Kim, Cani & Neumann (2003): Adaptive wisp tree - a multiresolution control structure for simulating dynamic clustering in hair motion

Chang, Jin & Yu (2002): A practical model for hair mutual interactions

Hadap & Magnenat-Thalmann (2001): Modeling dynamic hair as a continuum

Koh & Huang (2000): Real-time animation of human hair modeled in strips

Kurihara, Anjyo & Thalmann (1993): Hair animation with collision detection

L'Oréal (2005): Hair Science www.hair-science.com

Magnenat-Thalmann & Hadap (2000): State of the art in hair simulation

Petrovic, Henne & Anderson (2007): Volumetric methods for simulation and rendering of hair

Pixar Animation Studios (2001): Monsters, Inc. www.pixar.com

Plante, Cani & Poulin (2001): A layered wisp model for simulating interactions inside long hair

Rosenblum, Carlson & Tripp (1991): Simulating the structure and dynamics of human hair: Modeling, rendering, and animation

Ryu (2007): 500 million and counting: Hair rendering on Ratatouille

Volino & Magnenat-Thalmann (1999): Animating complex hairstyles in real-time

Watanbe & Suenaga (1992): A trigonal prism-based method for hair image generation

Ward, Bertails, Kim, Marschner, Cani & Lin (2007): A survey on hair modeling: styling, simulation and rendering

Ward & Lin (2003): Adaptive grouping and subdivision for simulating hair dynamics

Ward, Lin, Lee, Fisher & Macri (2003): Modeling hair using level-of-detail representations