Simulating Hair Dynamics

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• 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 $\phi$ and $\theta$

  External force applied to each stick projected onto two planes defined by $\phi$ and $\theta$

  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*
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