Realtime Hair simulation & rendering

Problem

- Human head has ~150k hair strands
- Physics simulation
- Rendering

Problem

- Scaling problem
- Reduce number of objects
- Reduce computation time
- Exploit problem characteristics
  - Approximations
  - Simulate only a subset of hair strands

Simulation

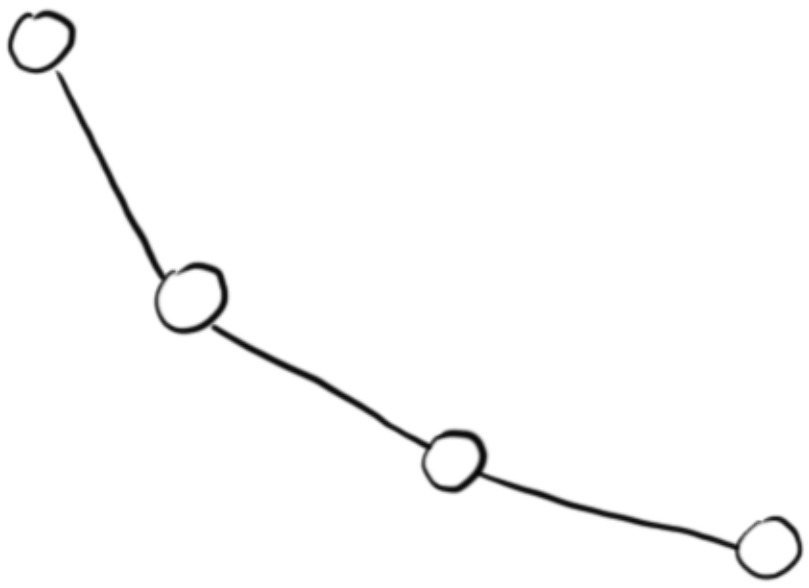
- Simulate forces acting on hair
- Simulate hair-object interactions (collision)
- Simulate hair-hair interactions (collision)

Simulation Modeling

- Each hair strand is a set of linked particles
- Forces acts on particles respecting some constraints
  - A strand is inextensible (can’t change its total length)
  - Hair can not penetrate objects
  - Hair must maintain its volume

Simulation Modeling

- Particles have equal masses
- Root particle is static (infinity mass)
- Forces acting on particles
- Gravity
- Wind
- Shape matching



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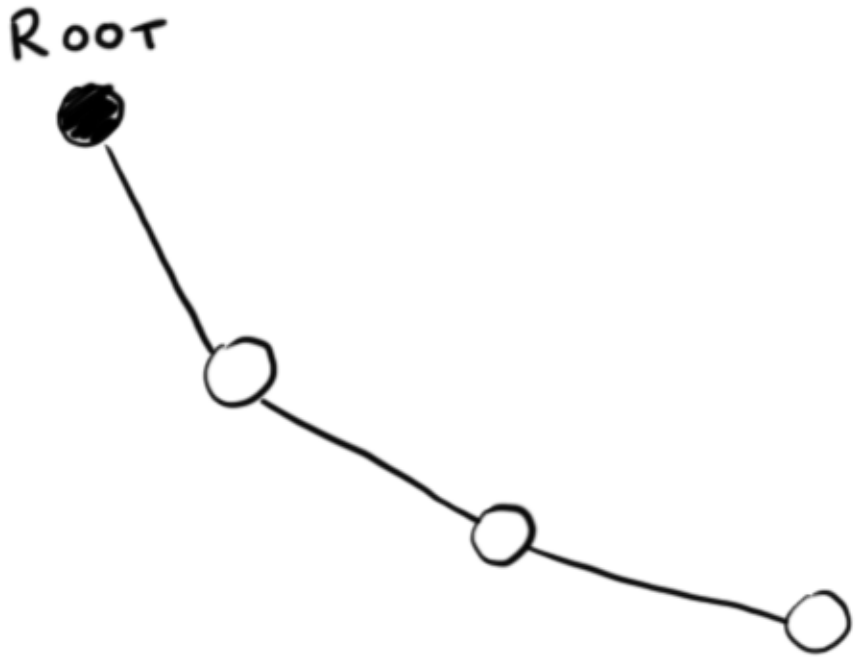

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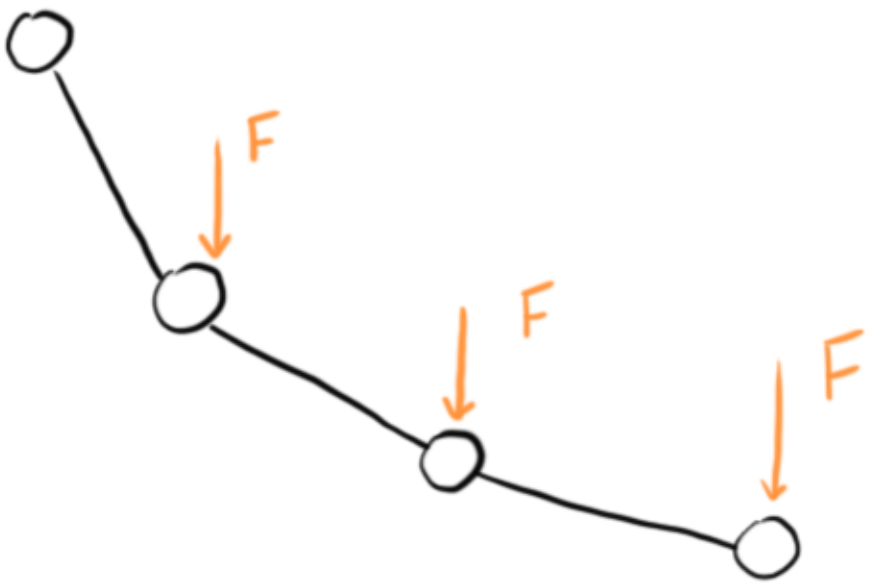

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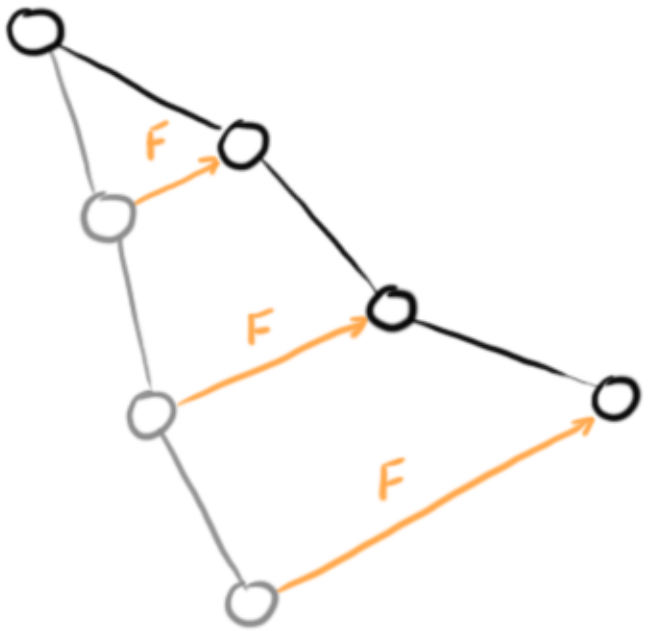
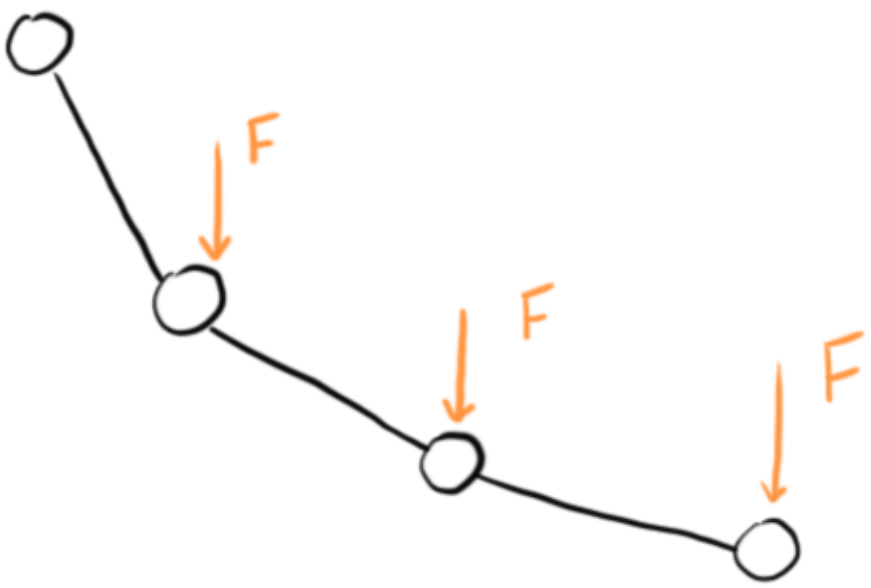


Position Based Simulation

- Update particle position
- Solve constraints
- Derive new velocities



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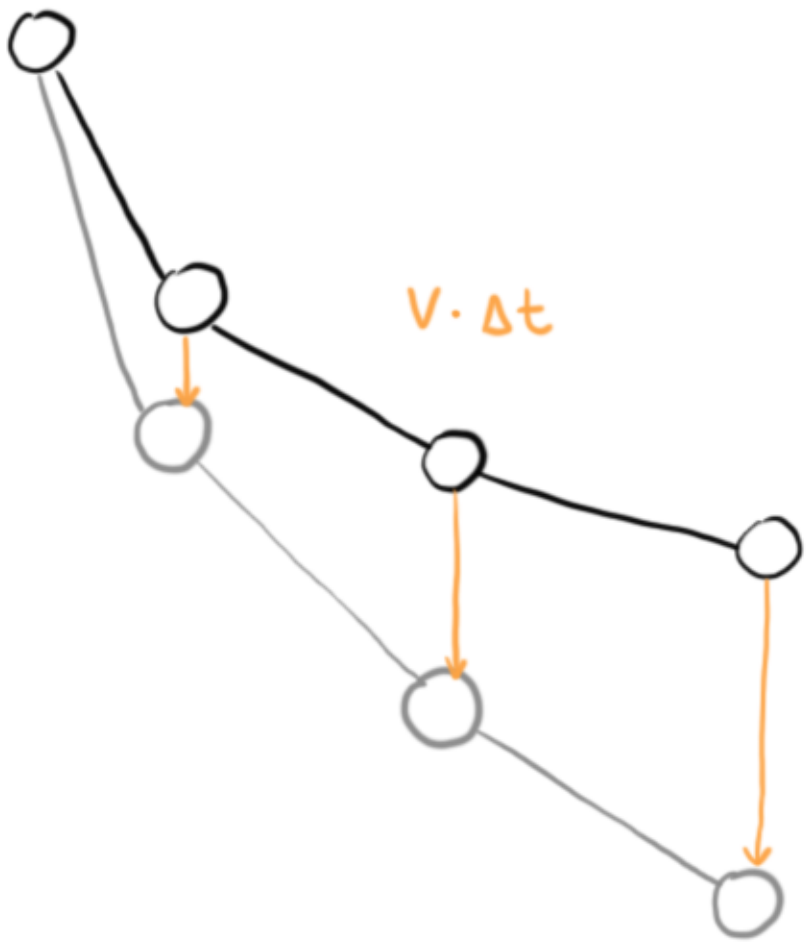

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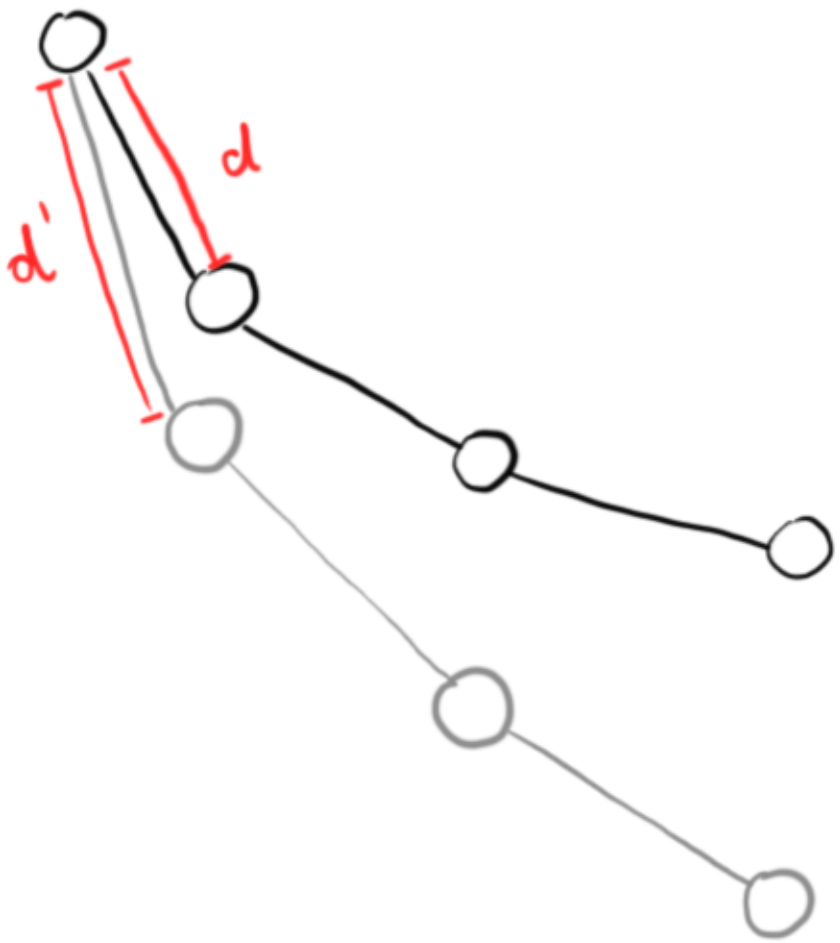

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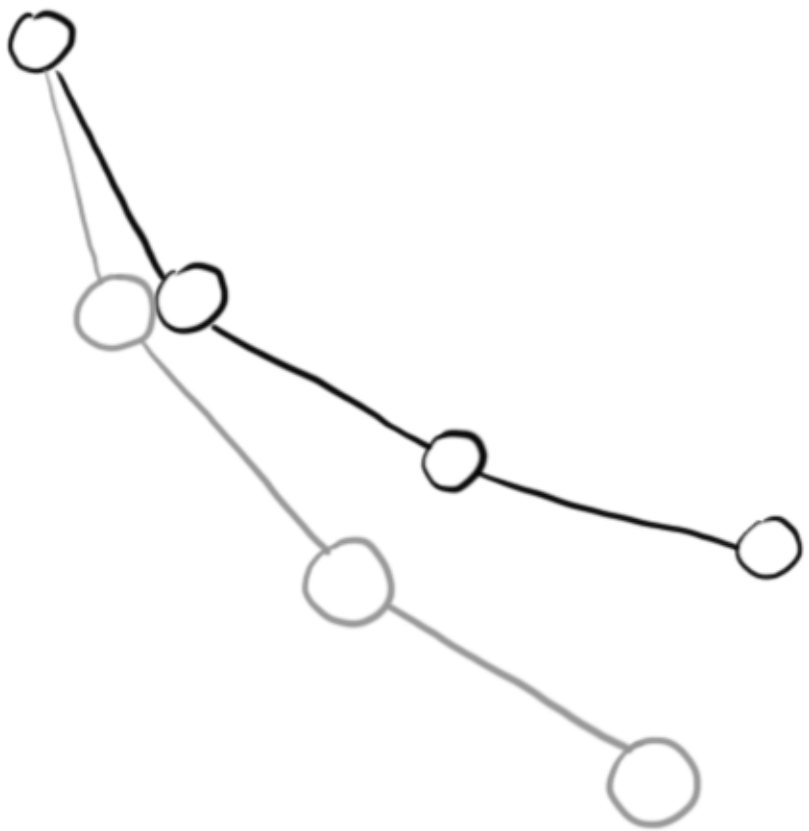

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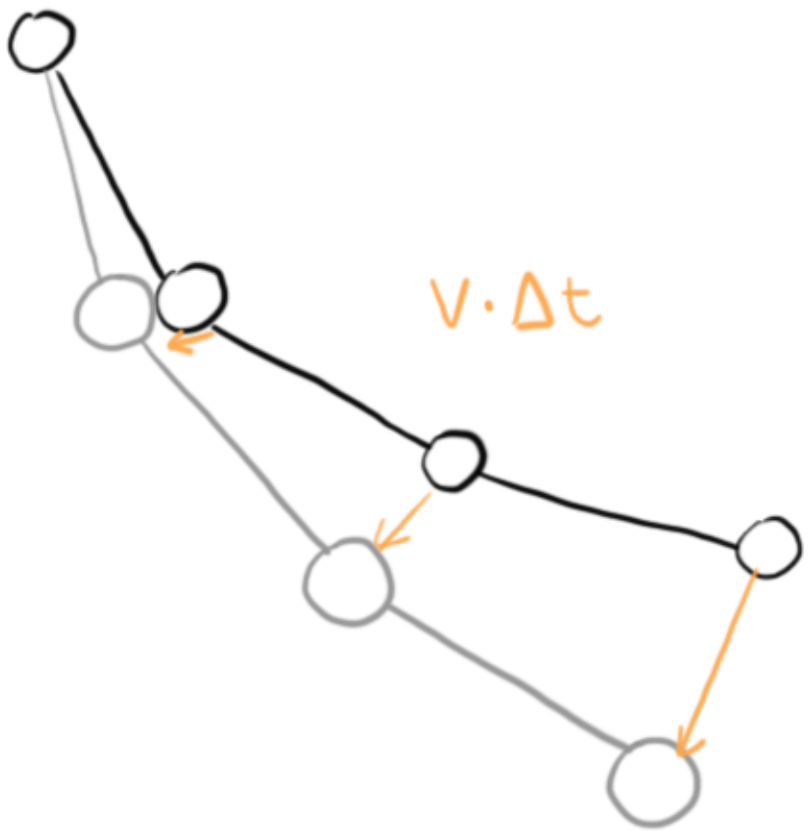

Position Based Simulation

- Strand is a series of mass-spring systems
- Apply newton's law for each particle
  - $v'_{k+1} = v_k \ + a\Delta t$
  - $x'_{k+1} = \ x_k + v'_{k+1}\Delta t$
- Move particles to a valid position
  - $x_{k+1} =$ SolveConstraints(x'_{k+1})
- Derive new velocity
  - $v_{k+1} = (x_{k+1} - x_k)/\Delta t$

Position Based Simulation

- Constraint solver
- Ideal: find a valid configuration which solves all constraints at once
- Reality: Solve each constraint sequentially iteratively

Constraints

- Distance constraints
  - Correct particle distances
  - Must maintain linear and angular momentum
- Constraint Projection
- Follow The Leader (FTL)

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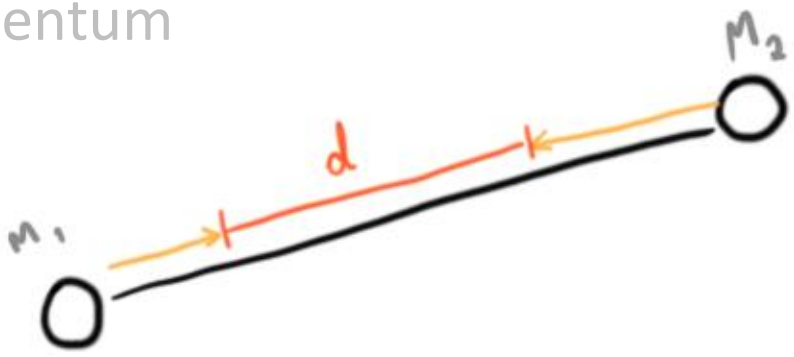

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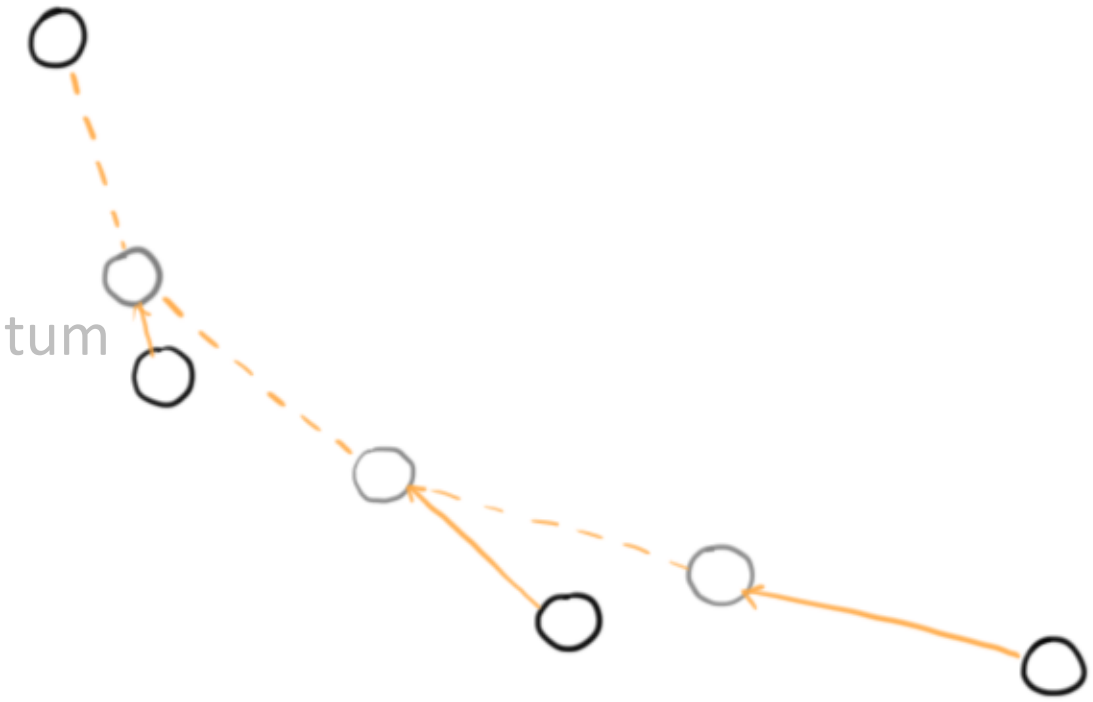

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  - Avoid penetration
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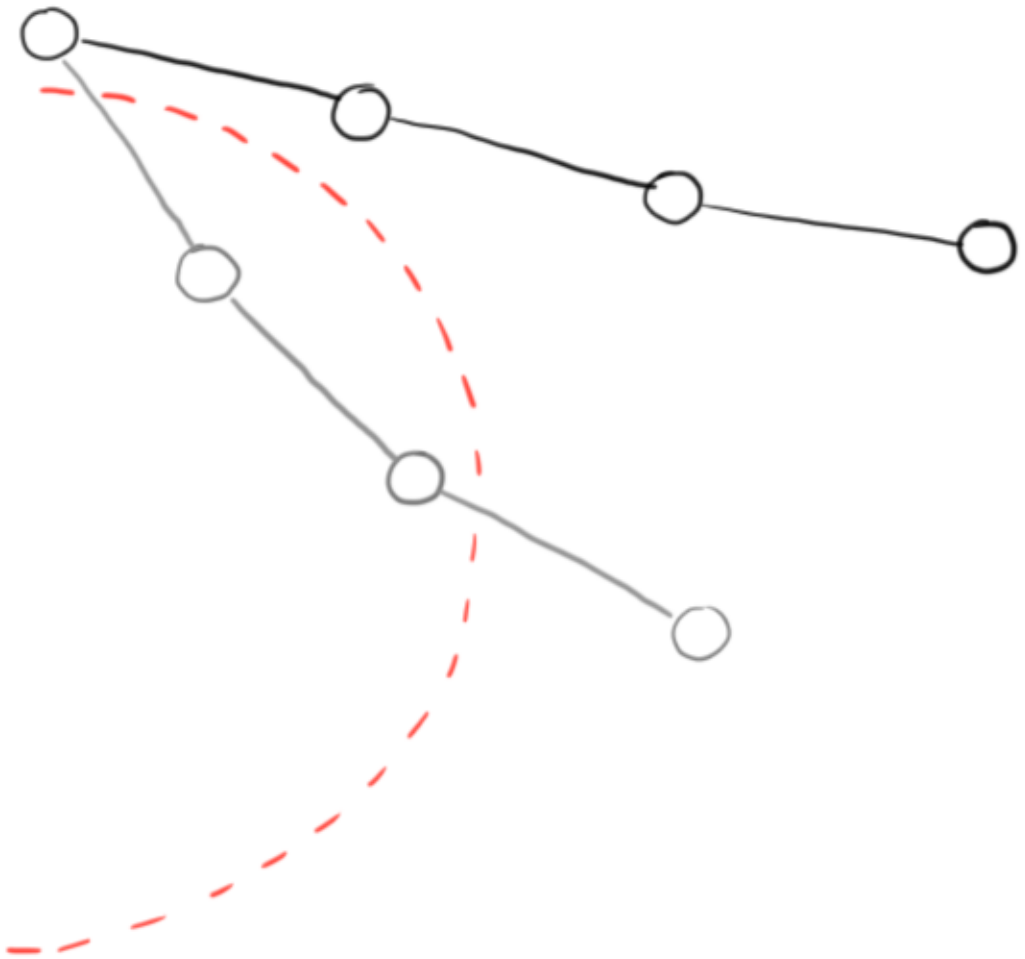

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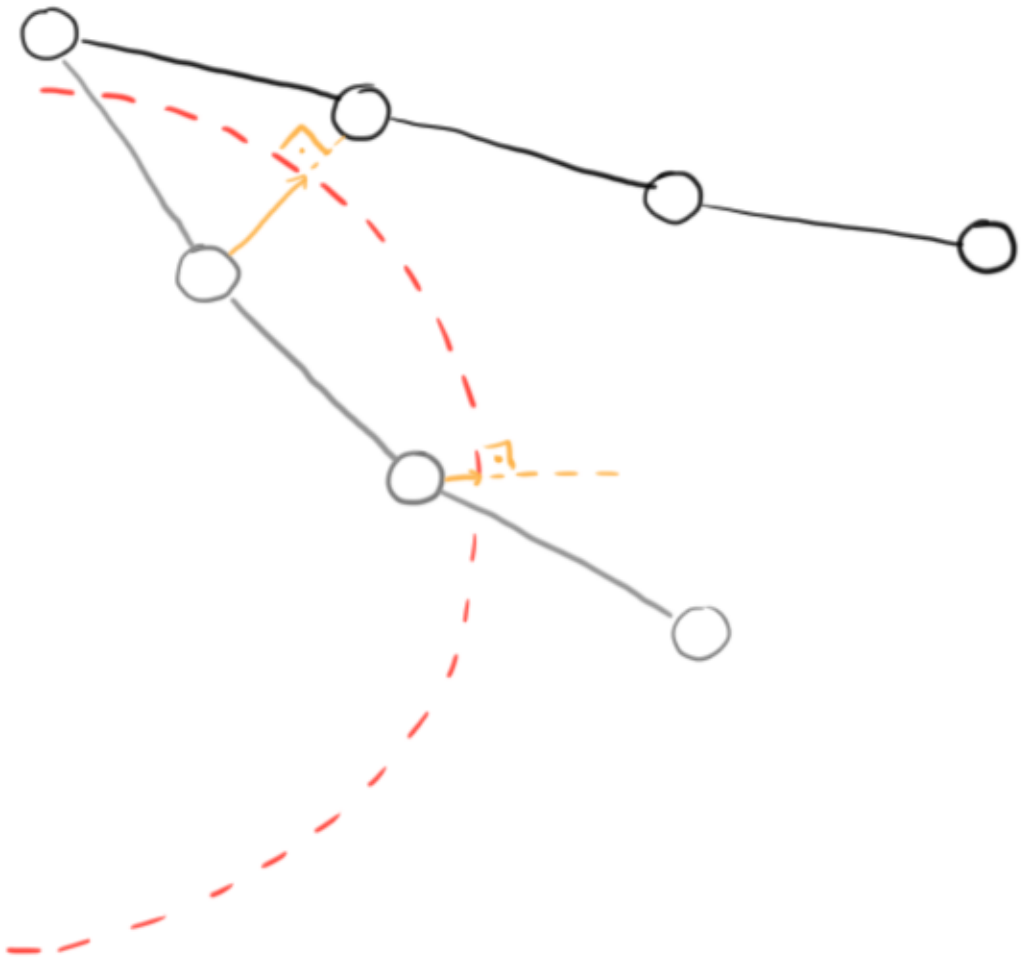

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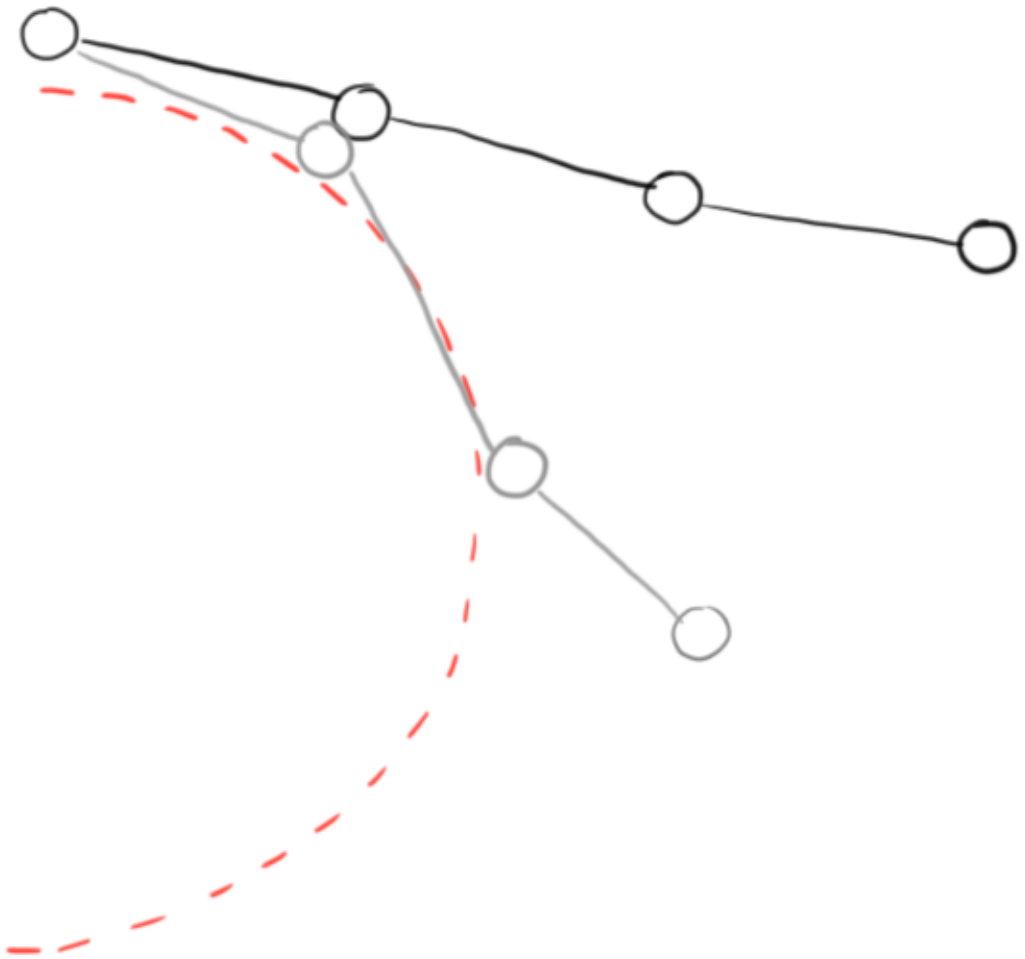

Hair-Hair interaction

- Simulate global behavior
  - Energy diffusion
  - Hair volume
- Brute force $O(n^2)$
  - Collision detection of each strand against all strands
- Volumetric approach
  - Treat particles as fluid
  - Diffuse energy to neighboring particles
  - Apply repulsion to maintain volume

Hair-Hair interaction

- Volumetric approach
- Construct a 3D grid
  - Calculate particle density on grid nodes
  - Average velocities of particles on grid nodes

- $v \quad = (1 - \alpha)v_{particle} + \alpha v_{grid} + v_{repulsion}$

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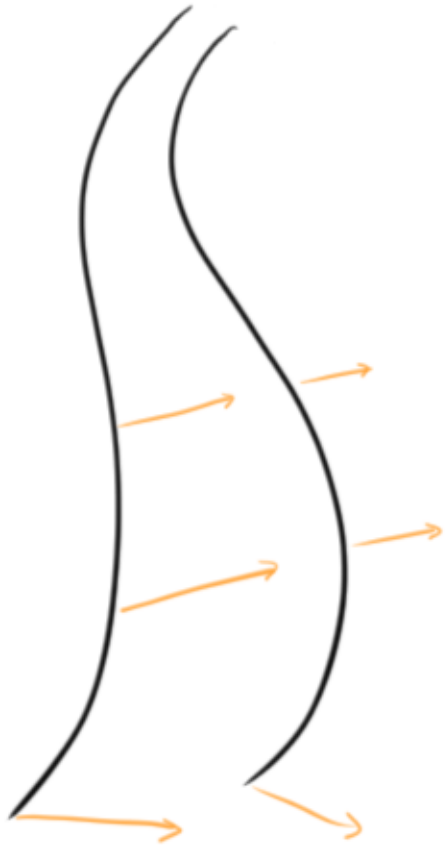

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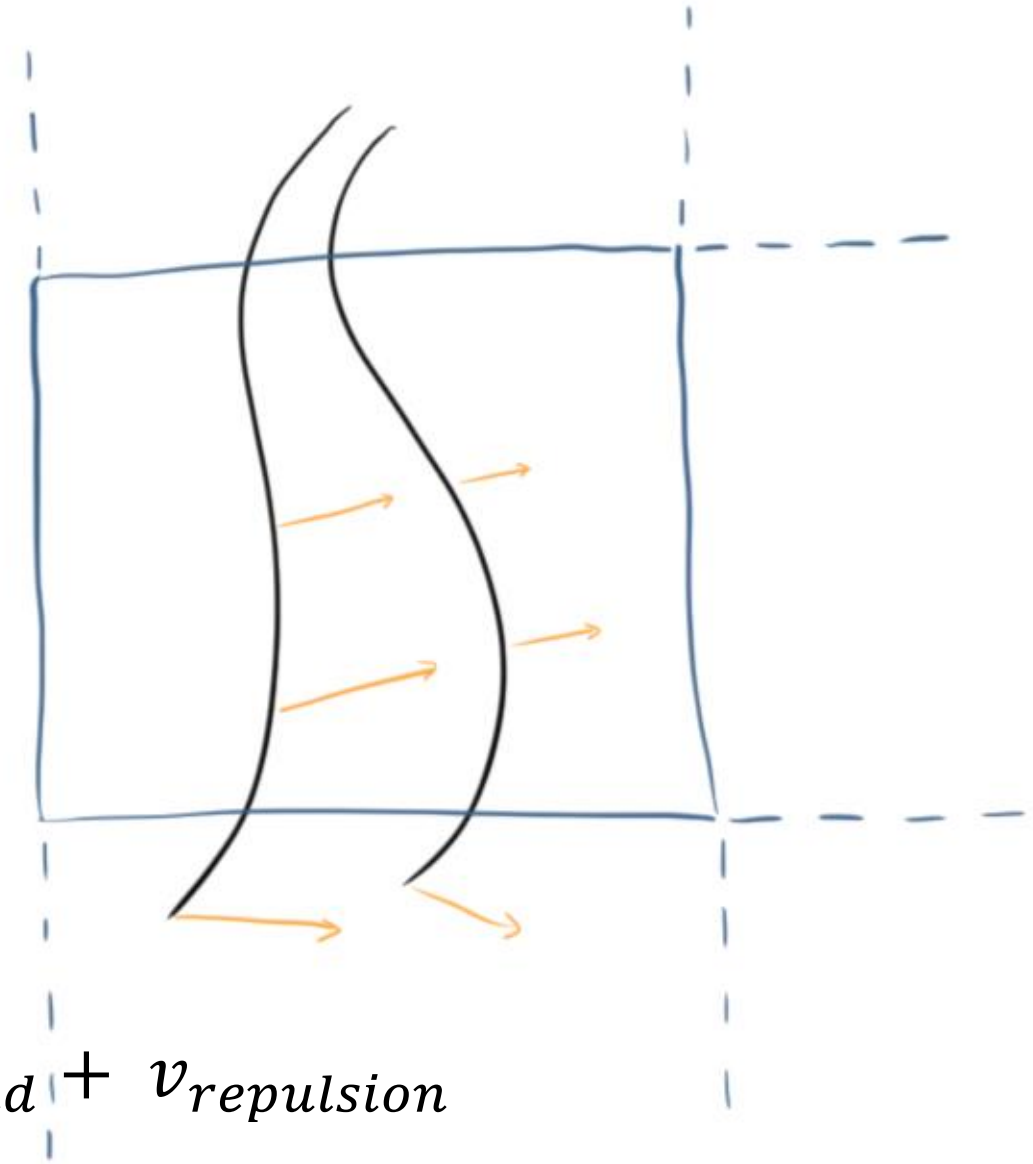

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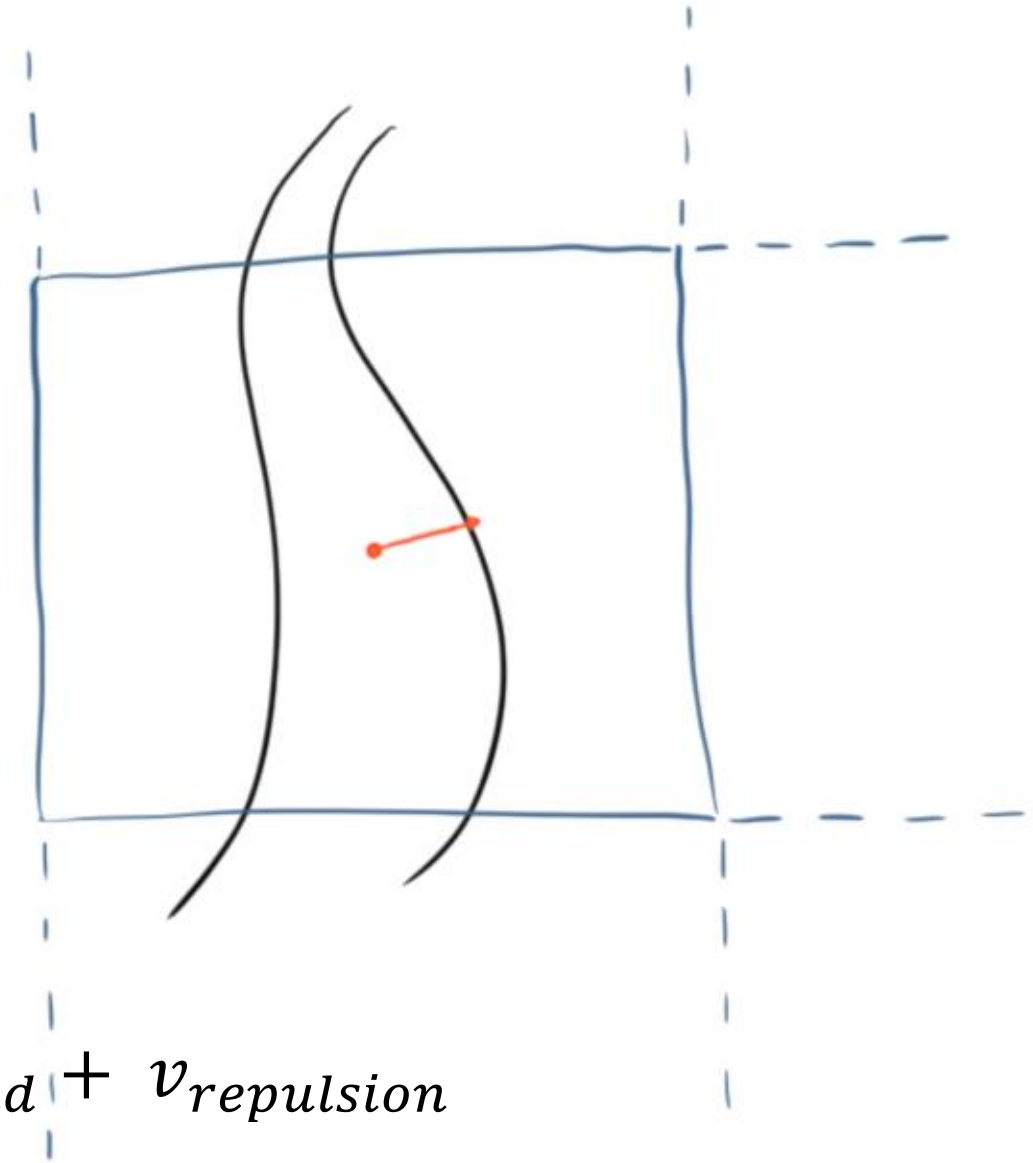

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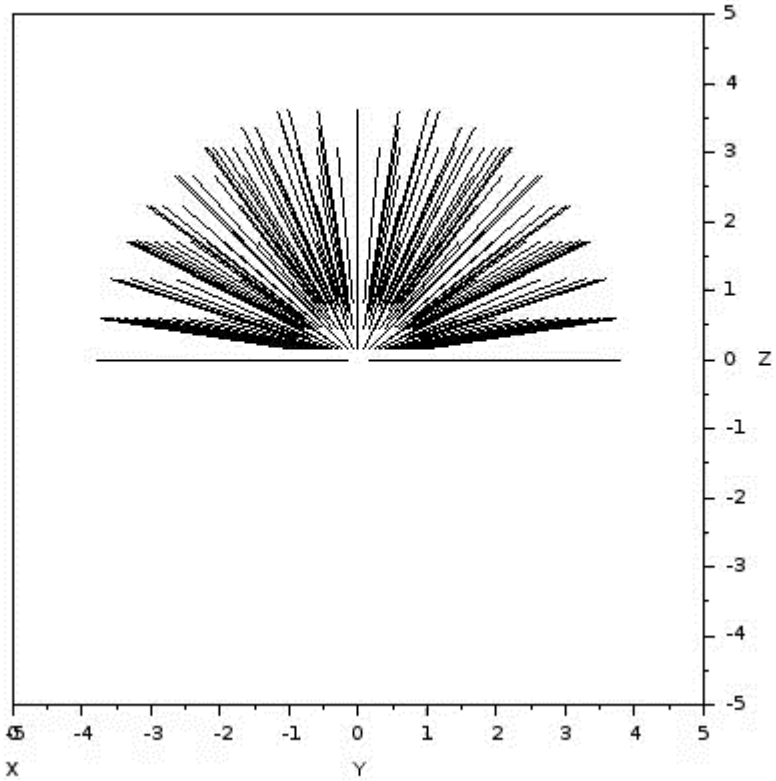
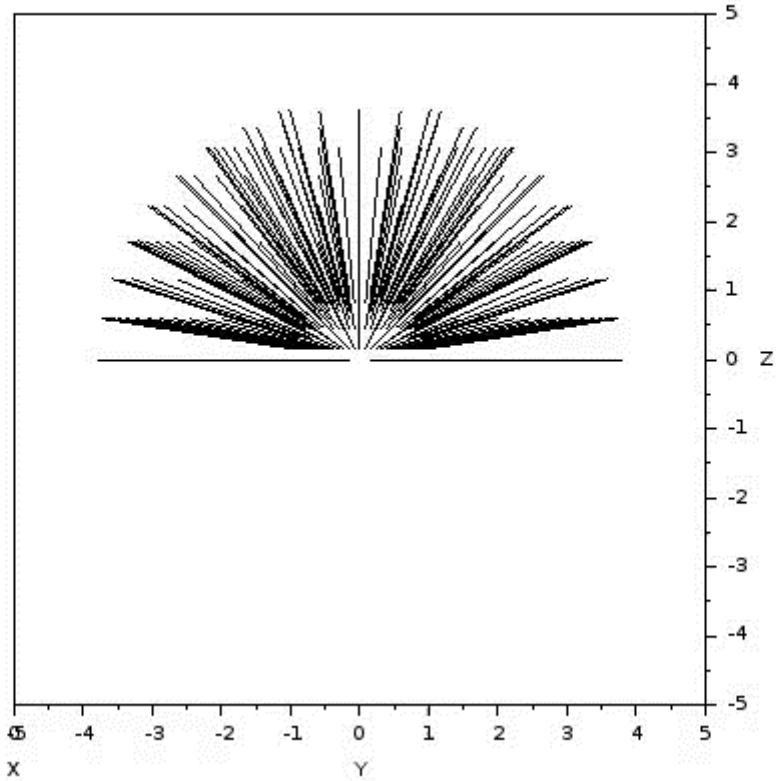
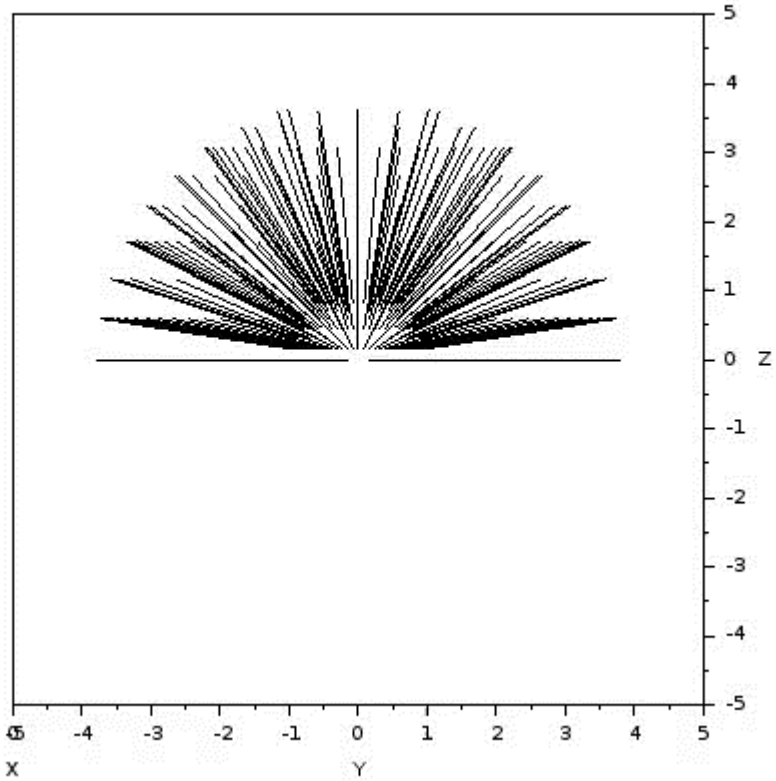
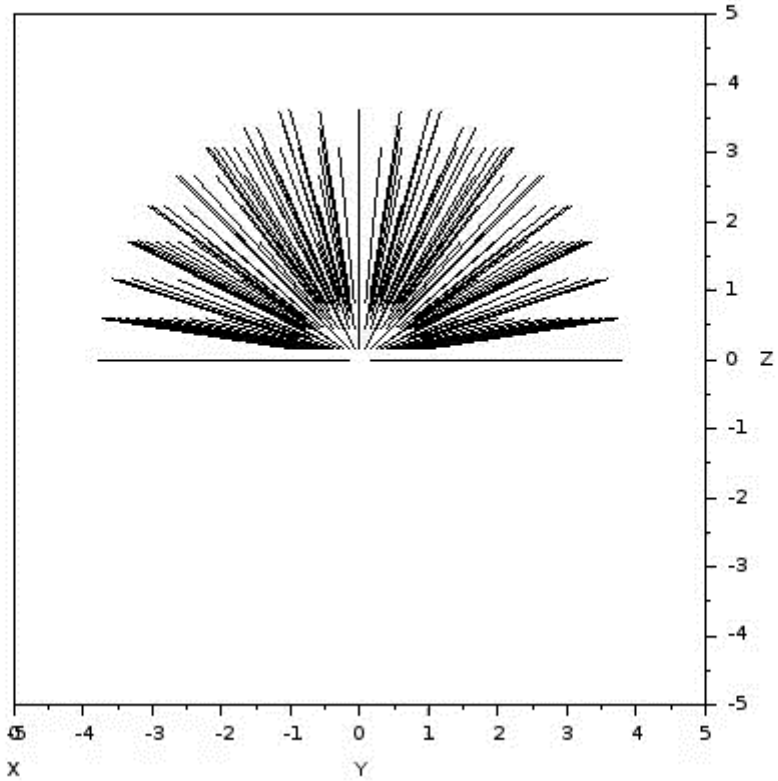




Velocity smoothing: off vs on

Hair-Hair interaction





Grid filtering ($\alpha = 0.9$): off vs on

Rendering

- Geometry
- Appearance

Rendering

- Geometry
  - Coarse geometry
  - Strands rendered as texture

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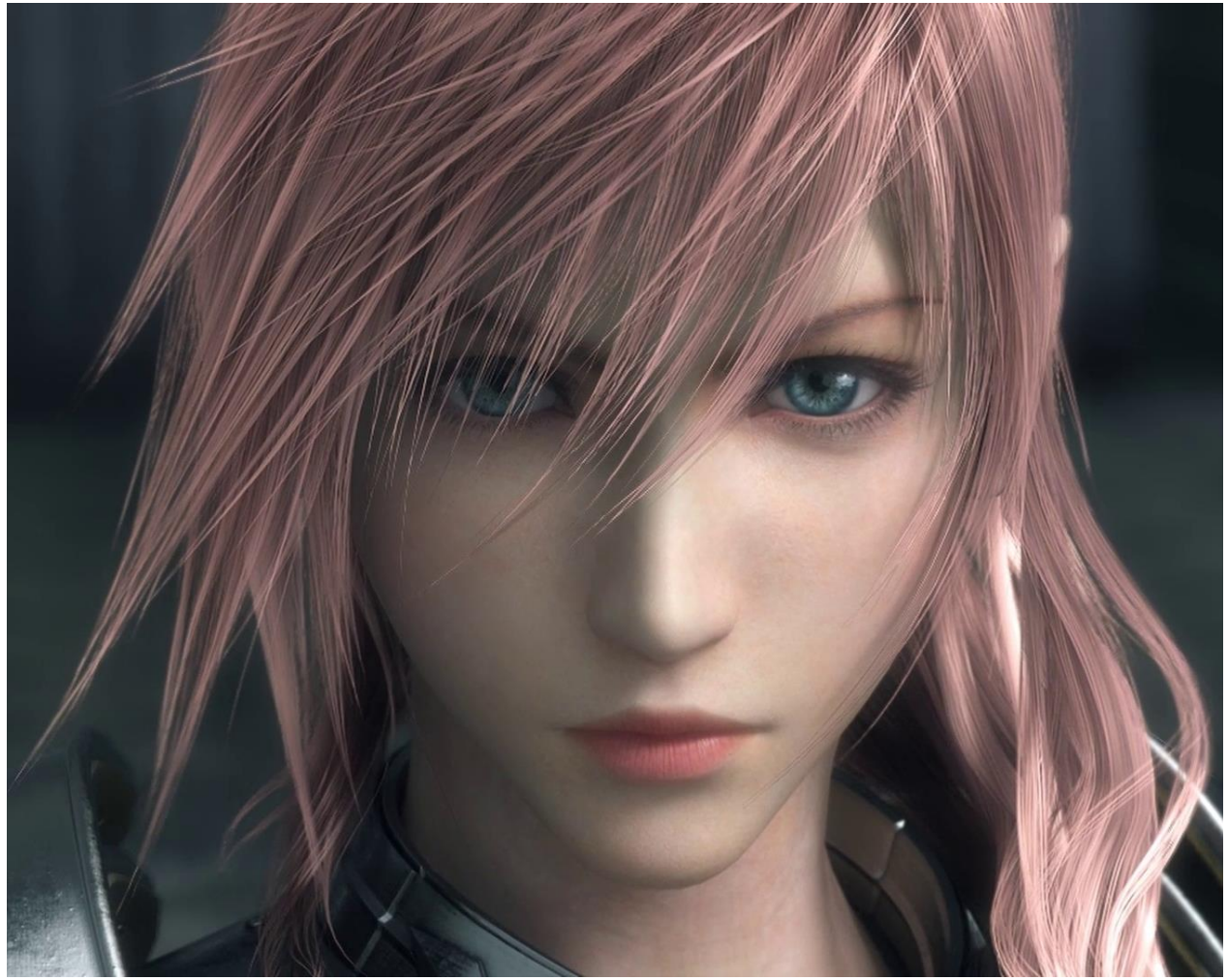
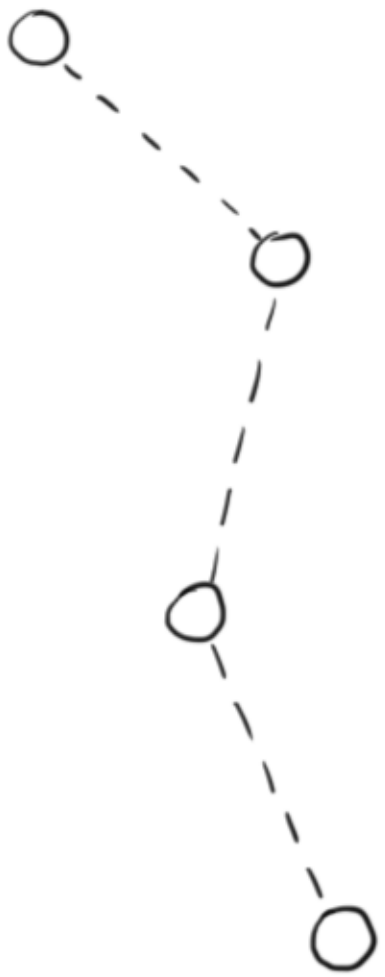


Rendering

- Geometry (refined)
  - Spline interpolate strand particles
  - Generate polygon strip
  - Generate follow strands



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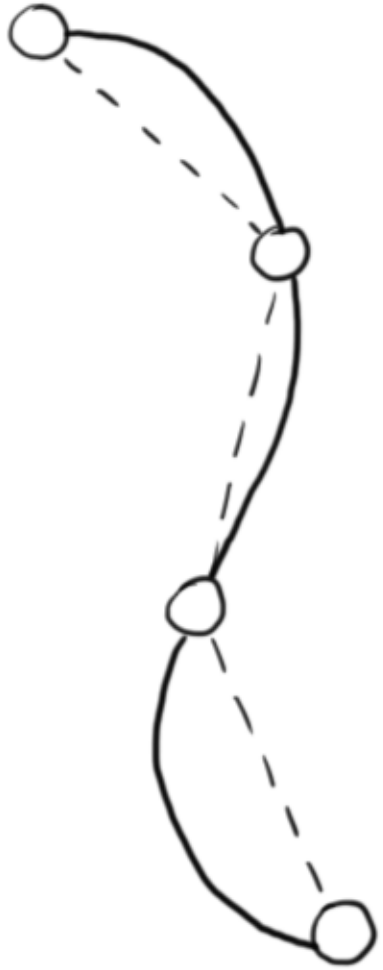

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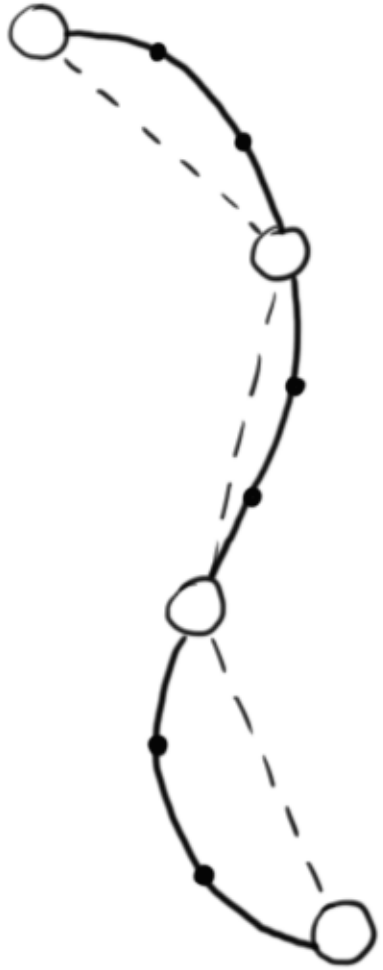

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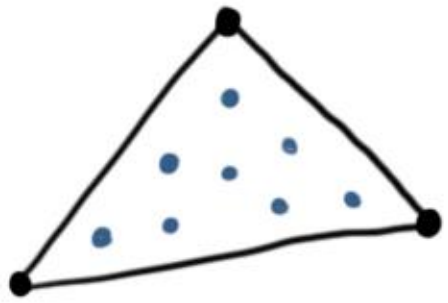
    - Barycentric interpolation



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Rendering

- Appearance
  - Shading
  - Self-Shadowing
  - Transparency

Rendering

- Shading
  - Kajiya-Kay model
  - Marschner model
  - Photograph

Rendering

- Self-Shadowing
  - Opacity maps
  - Voxel based

Rendering

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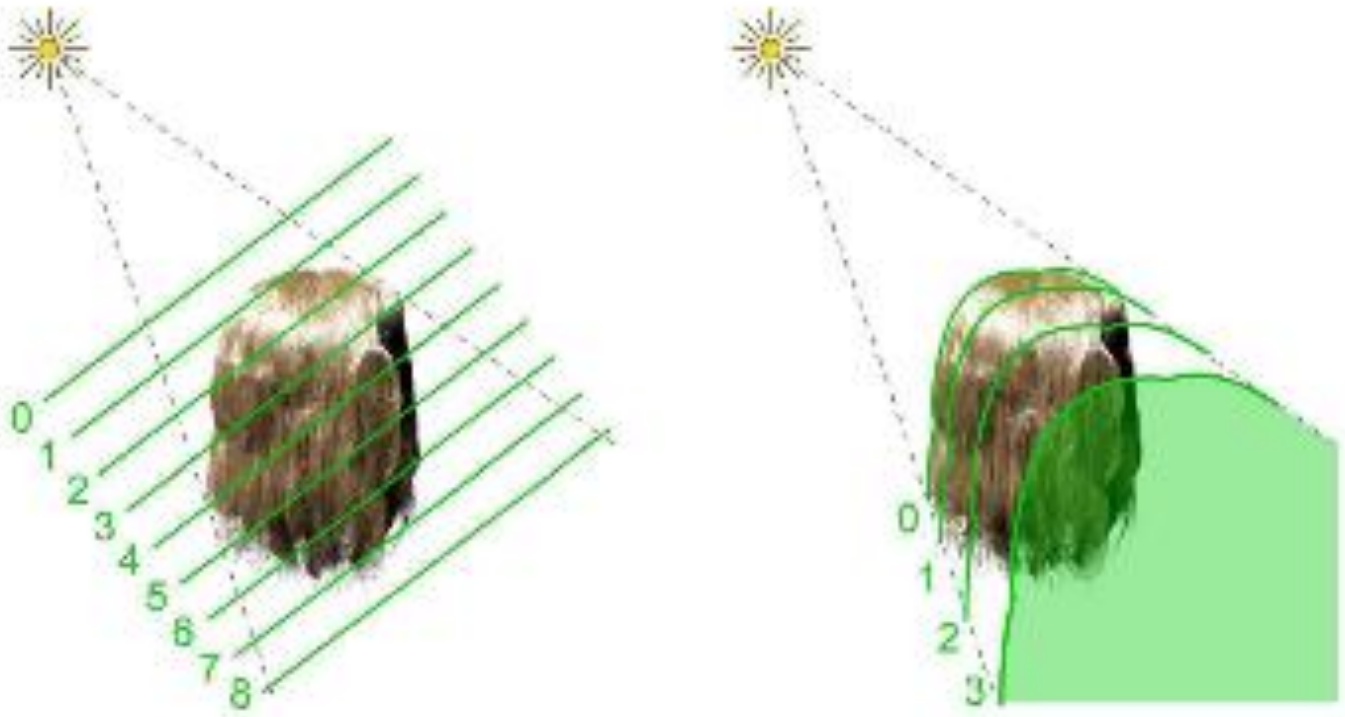

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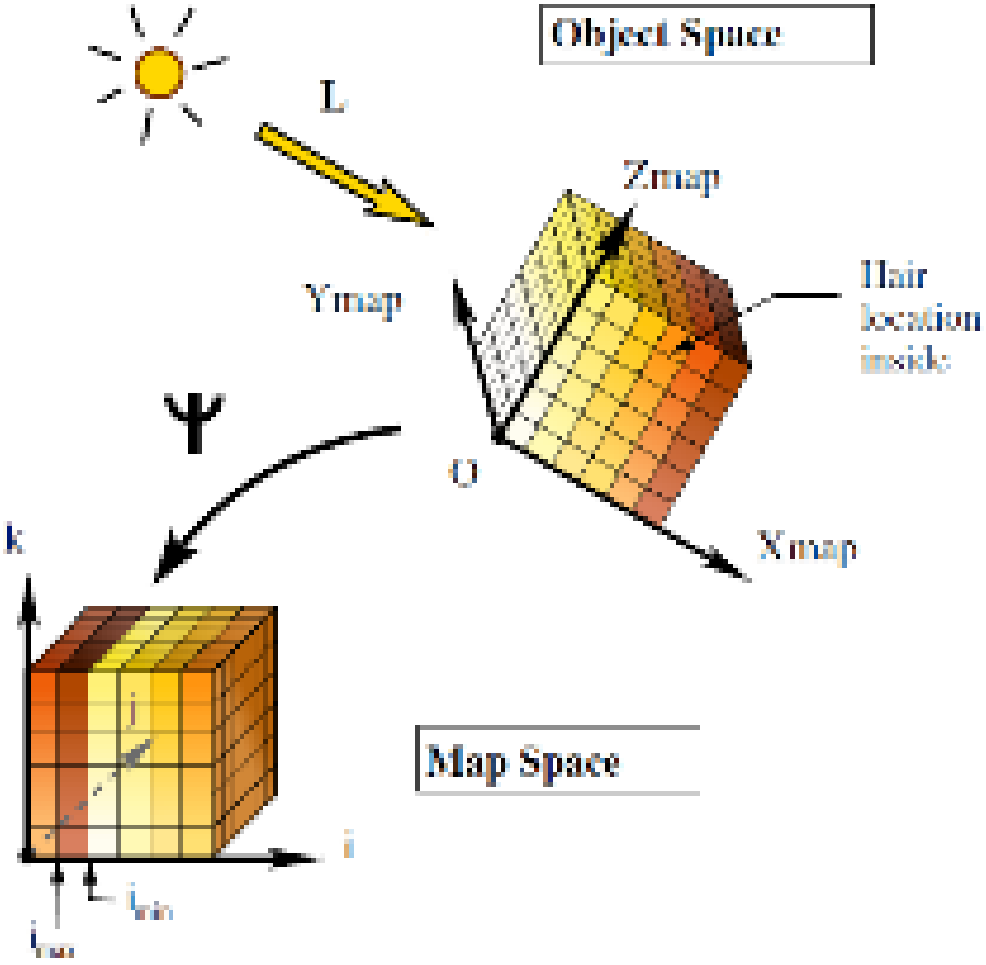
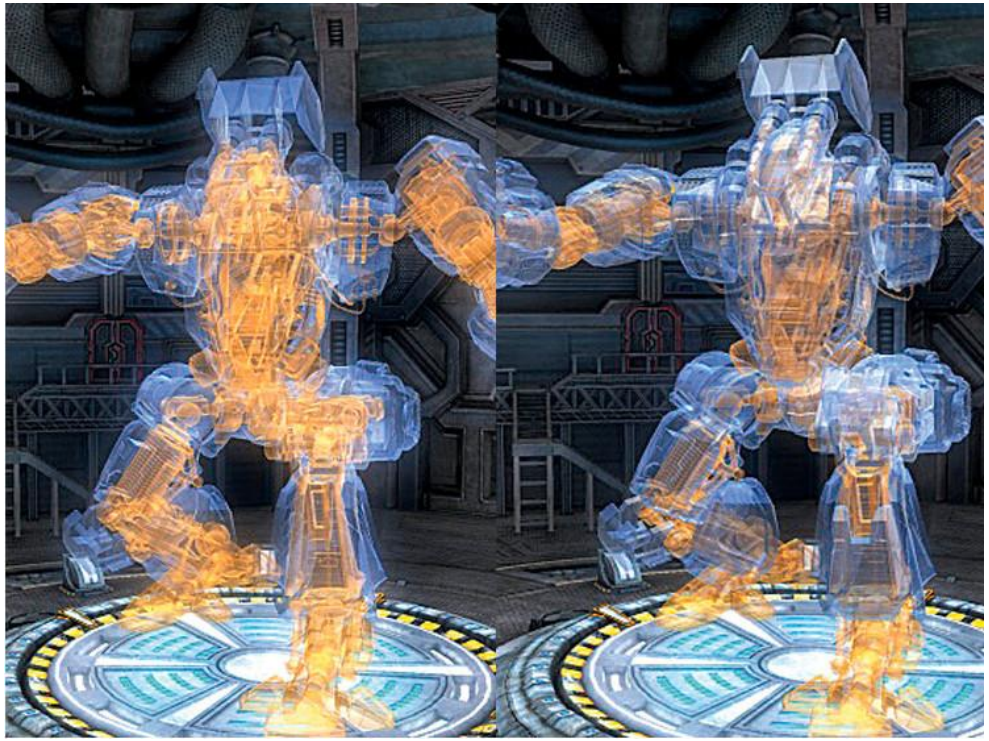


Rendering

- Transparency
  - Blending operation does not commute
  - Must render back to front



Rendering

- Order independent Transparency
  - Store multiples fragments (color, alpha and depth) per pixel
  - Sort and blend

Rendering

- Stochastic Transparency
  - Use multiple samples per pixel
  - Randomly paint samples according to fragment alpha
  - Guarantee correct color on average

Rendering

- Commutative blending op
  - Approximate blending
  - Low error only on specific cases

Rendering summary

- Complex light interaction
  - Anisotropic specular
  - Refraction
  - Reflection
  - Self-Shadowning
  - Transparency

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