Modeling Plant Life in Computer Graphics

Environmental Response

Siggraph 2016 Course

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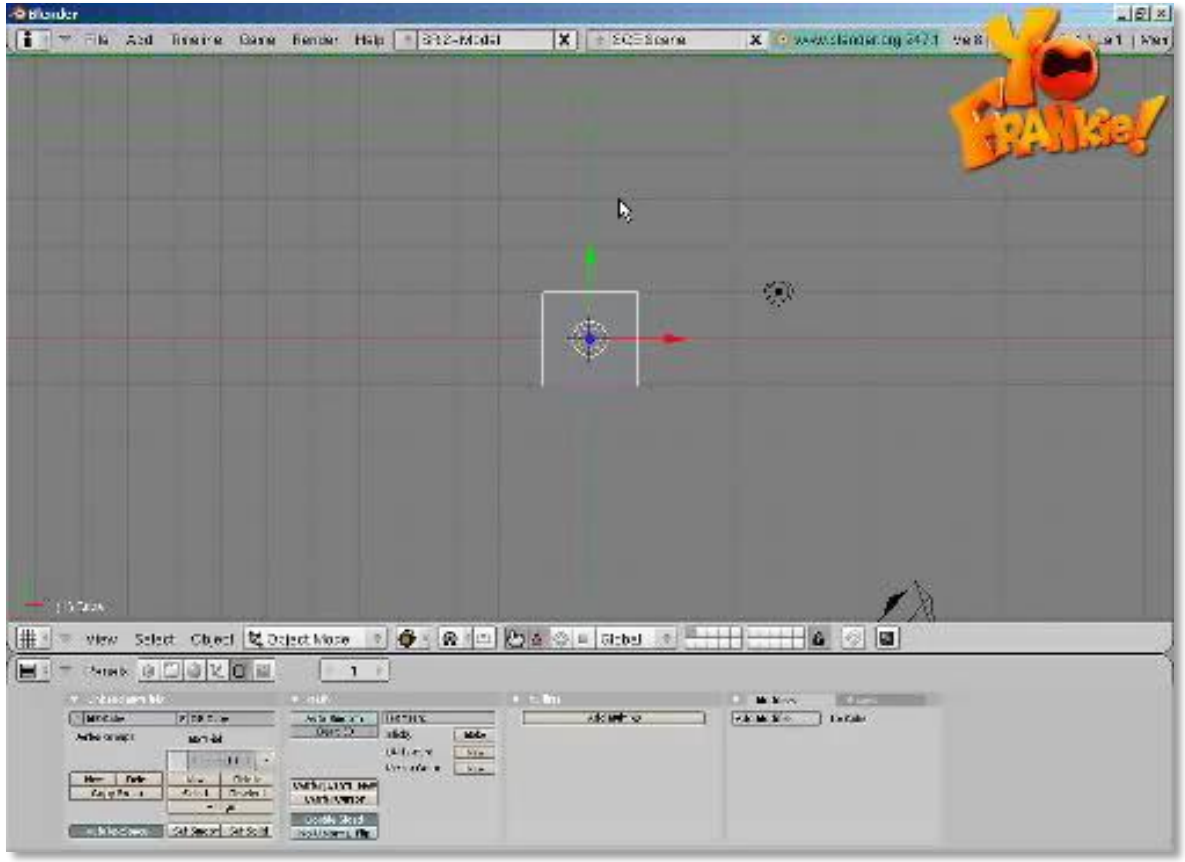
Overview

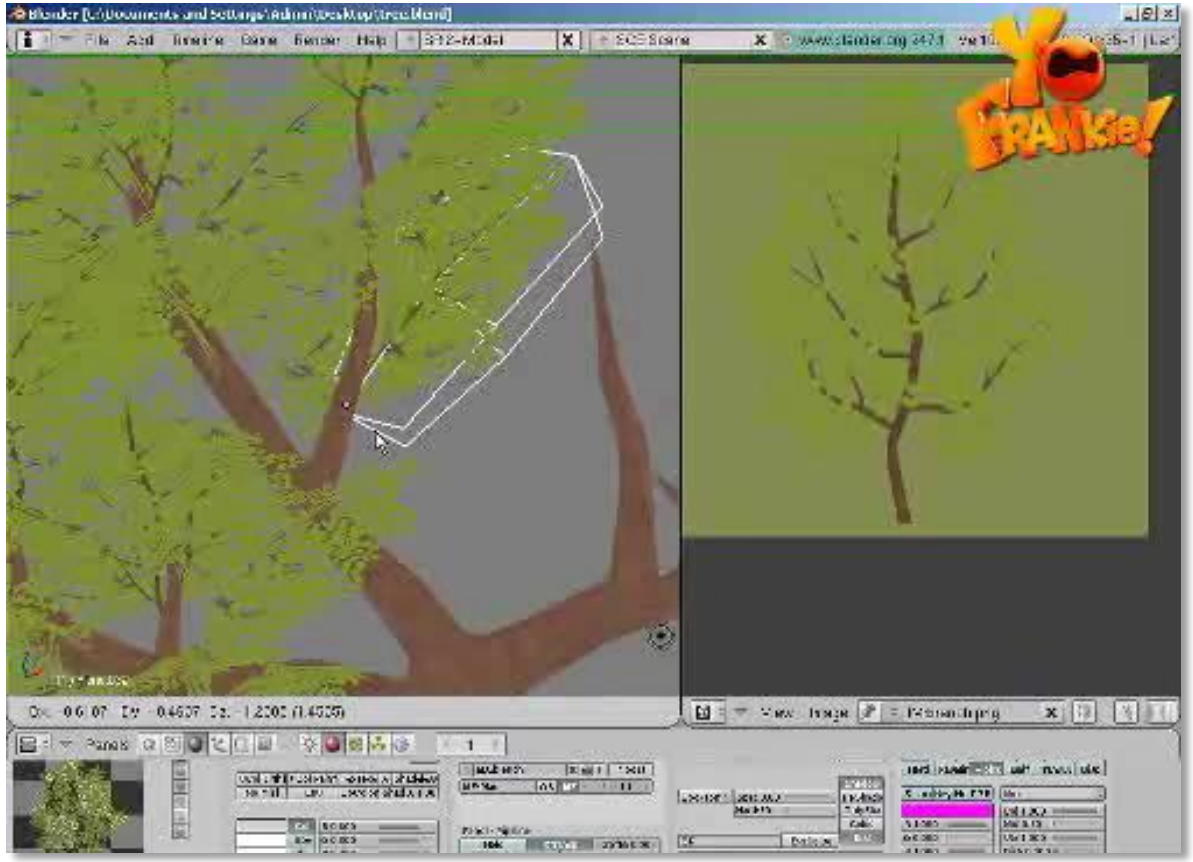
Environmental response [20 minutes]

- Real-time sensitivity of tree models **(Pirk)**
- Capturing growth response **(Pirk)**
- Physics response to wind **(Pirk)**

Tree models are static

3D Tree Modeling





Pablo Vazquez - http://vimeo.com/2956756

Plastic Trees: Interactive Self-Adapting Botanical Tree Models

Pirk, S., Stava, O., Kratt, J., Said, M. A. M., Neubert, B., Mech, R., Benes, B., Deussen, O.
Plastic trees: interactive self-adapting botanical tree models.
ACM Trans. on Graph. 31, 4, 50:1–50:10, 2012.

Environment Aware Trees

Automatic modification of 3D tree models

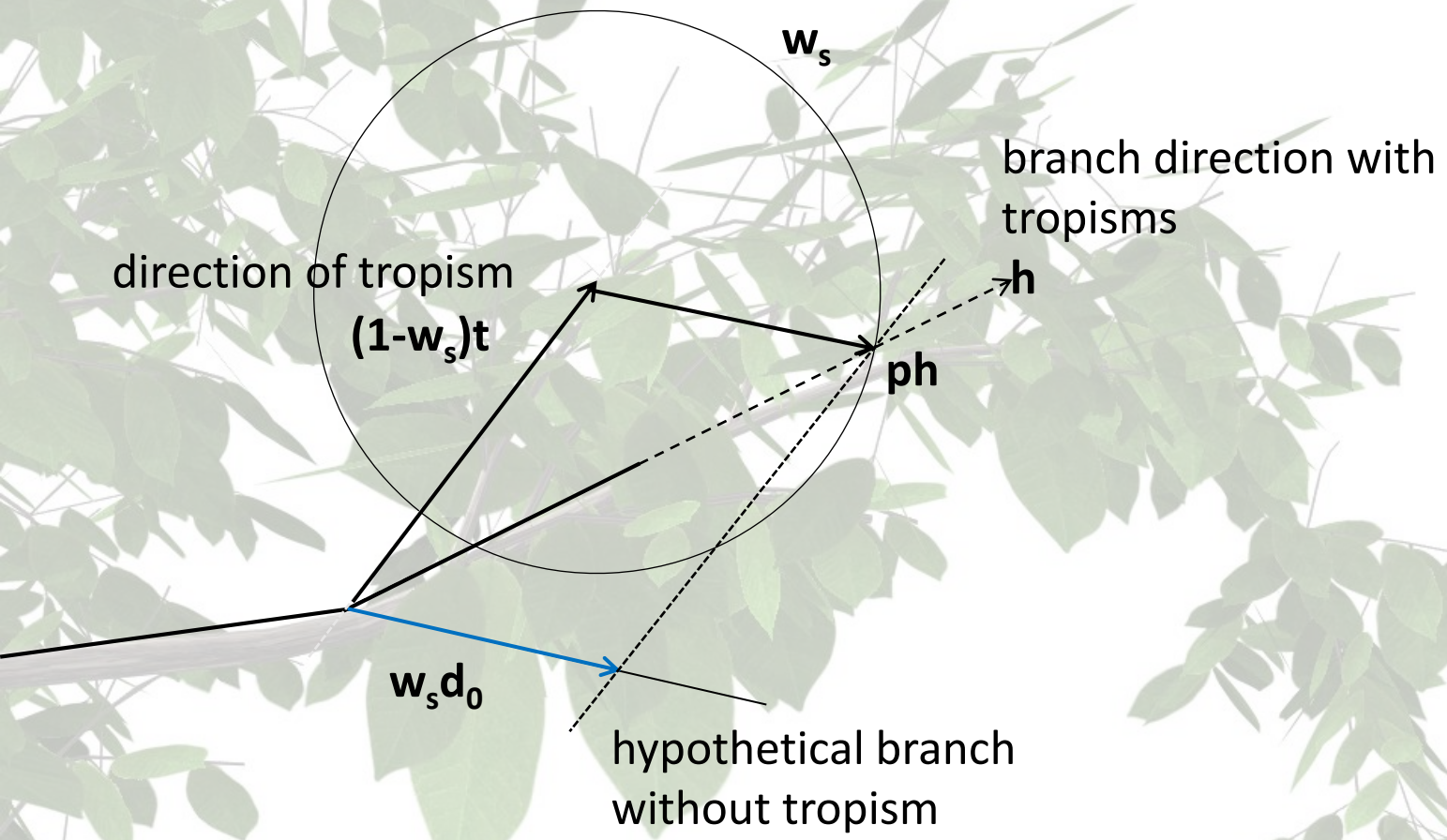
Skeletal Graph

Skeletal Graph

- Branch Age
- Growth Rate

Tree Analysis - Tropisms

Inverse Tropism



Backward modeling to estimate influence of tropisms to the original model

→ allows to apply tropisms triggered by the new environment

Dynamic Interaction - Bending

New Direction

$$\vec{h} = w_s \vec{d}_0 + (1 - w_s) \frac{\sum w_\tau \vec{t}_\tau}{\sum w_\tau}$$

new direction

start weight

normalized direction

weights of tropisms

combination of tropisms

only bending

Transformations represent changes in the tree growth.

Dynamic Interaction - Pruning

Approach similar to **[Palubicki et al. 2009]**

Amount of Light received by the leaf-cluster.

$$\varphi_{t_s} = \sum_{c \in C_s} 2\pi {r_c}^2 i_c$$

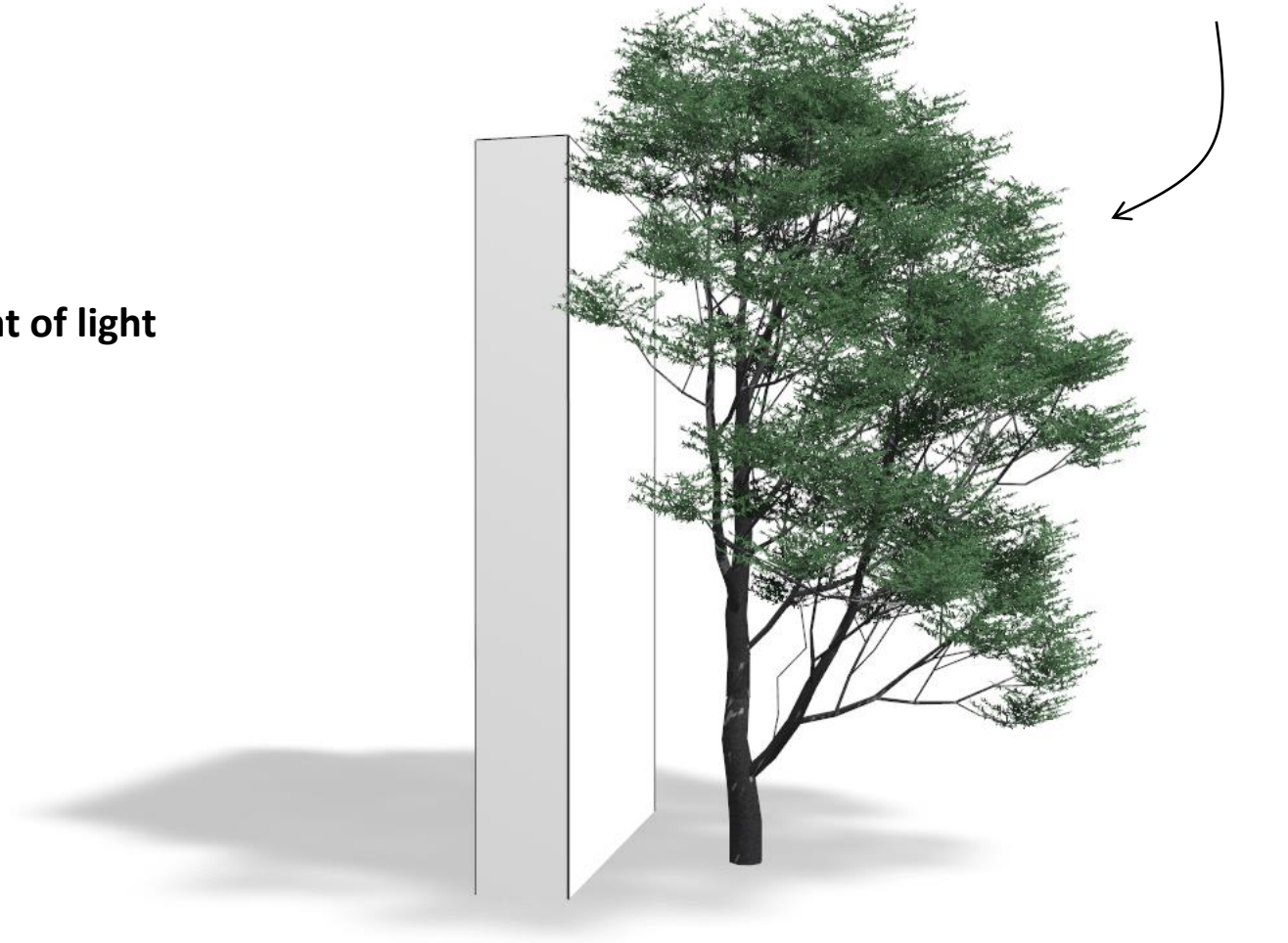
normalized amount of light

amount of resources (light)

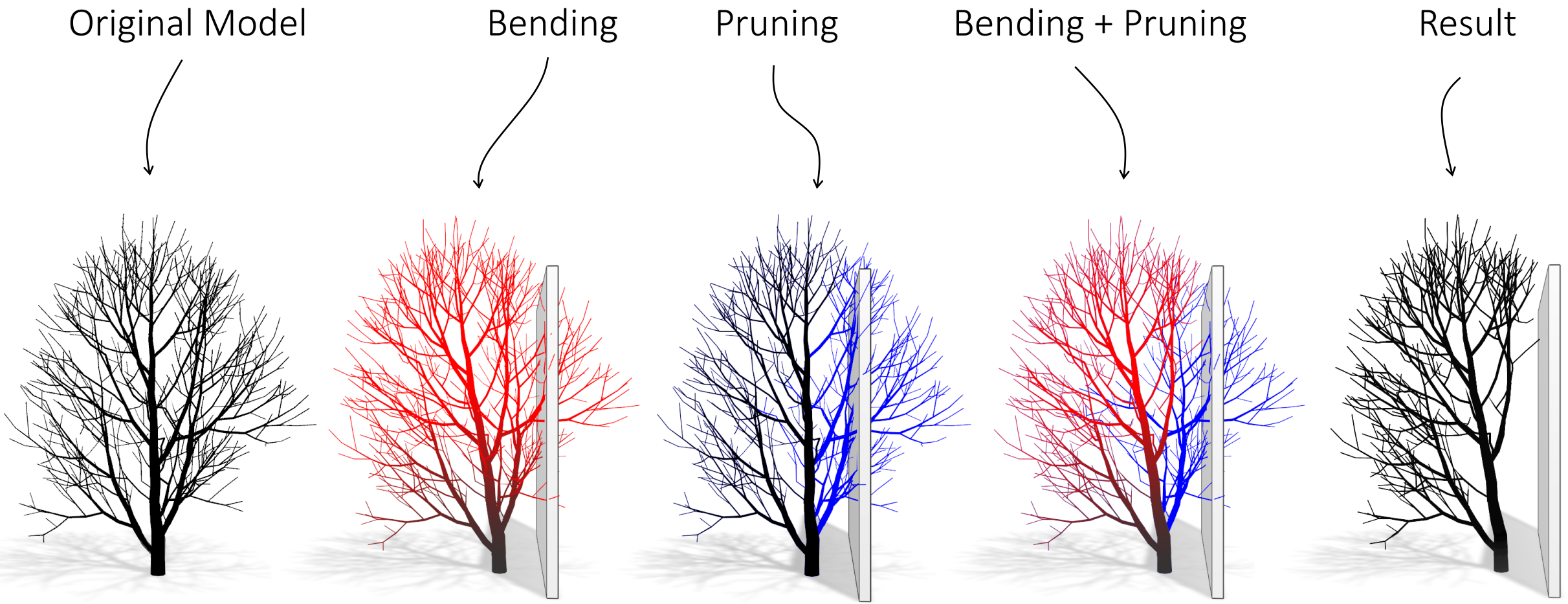
radius of a given cluster

l_t**: sum of distances**

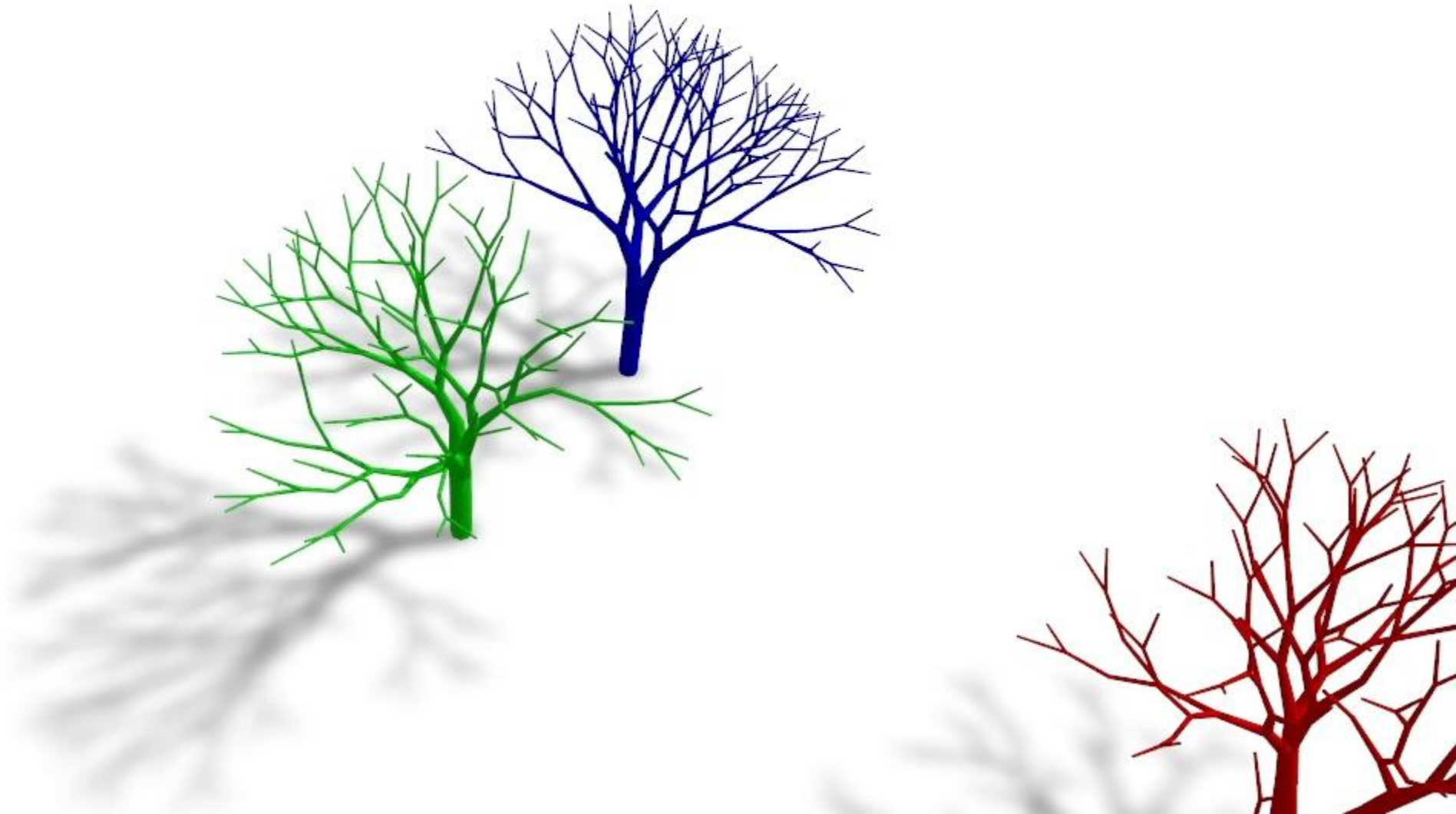
Branch is pruned when ratio $\varphi_{t_s}/l_t < thres$



Tree/Obstacle Interaction



Tree/Tree-Interaction



Bending/Pruning Result

Tree/Tree-Interaction

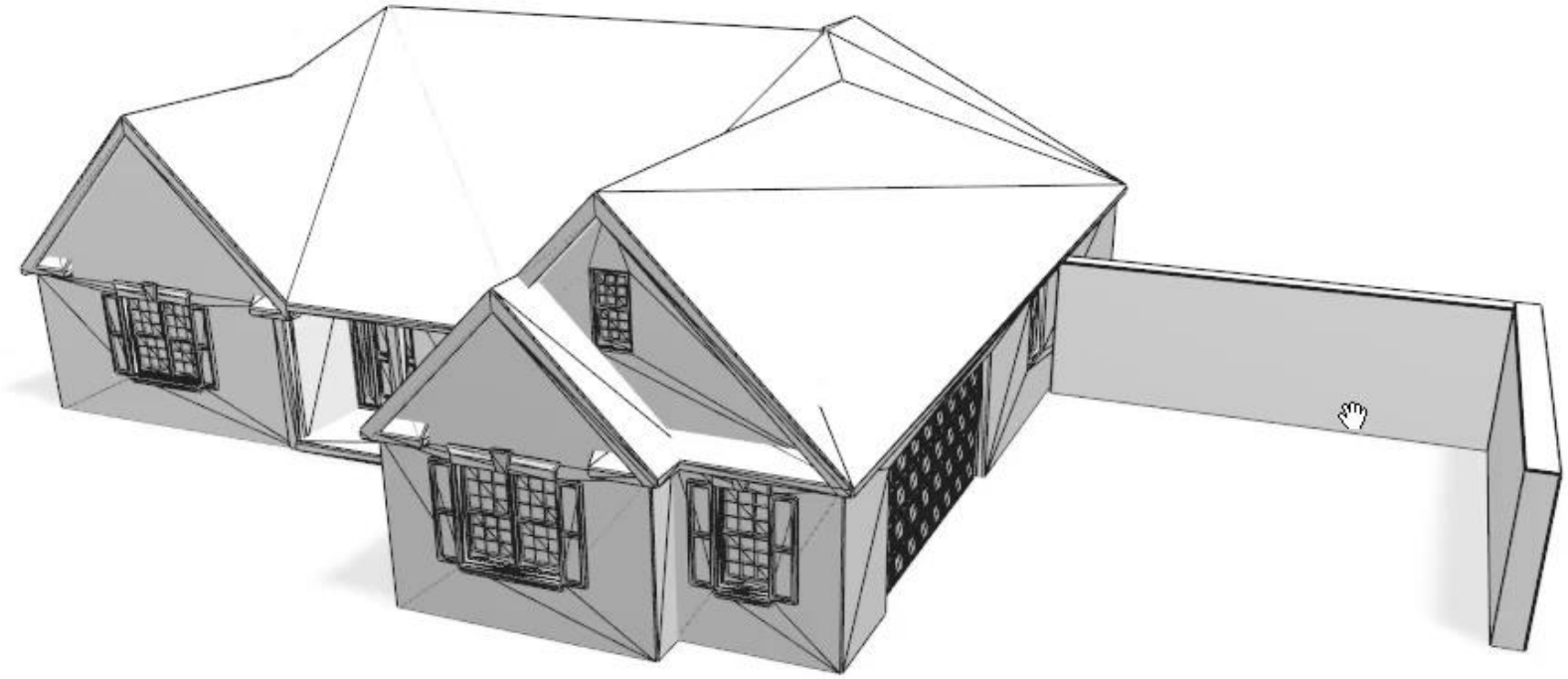
Static Models

Bending and Pruning

Strong Pruning

Exaggerated Bending

Editing

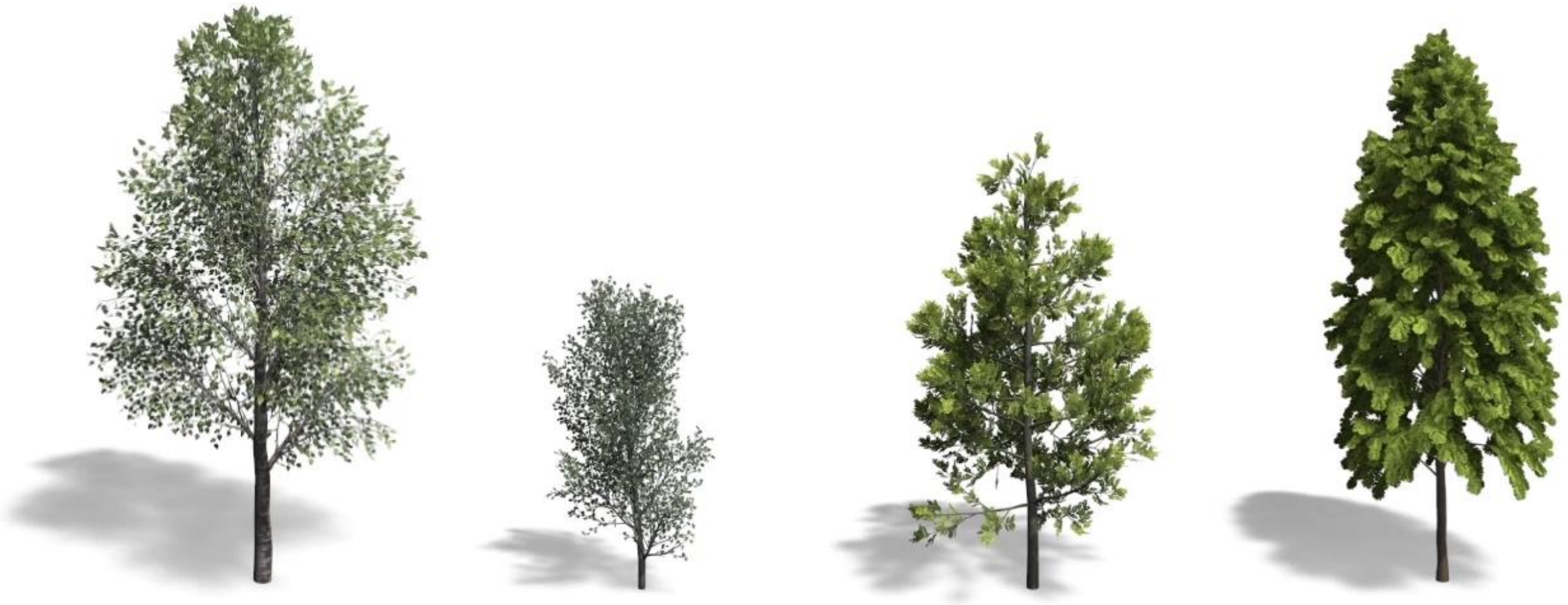


Capturing and Animating the Morphogenesis of Polygonal Tree Models

Pirk, S., Niese, T., Deussen, O., Neubert, B.
Capturing and animating the morphogenesis of polygonal tree models.
ACM Trans. on Graph. 31, 6, 169:1–169:10, 2012.


The Upthink Lab - http://vimeo.com/24487172

Continuous Animations of Growth



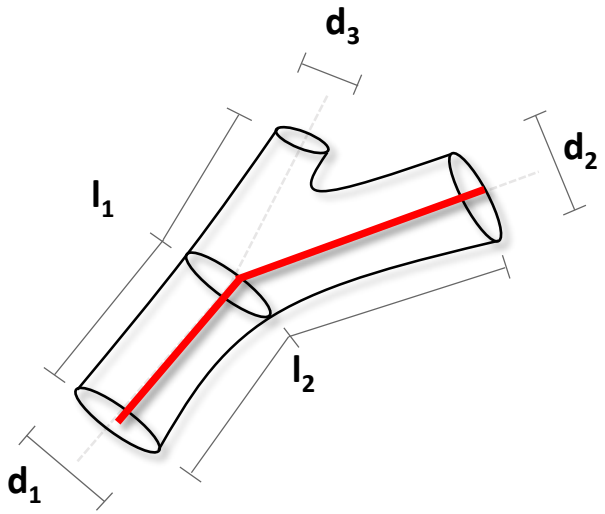
[Pirk et al. 2012b]

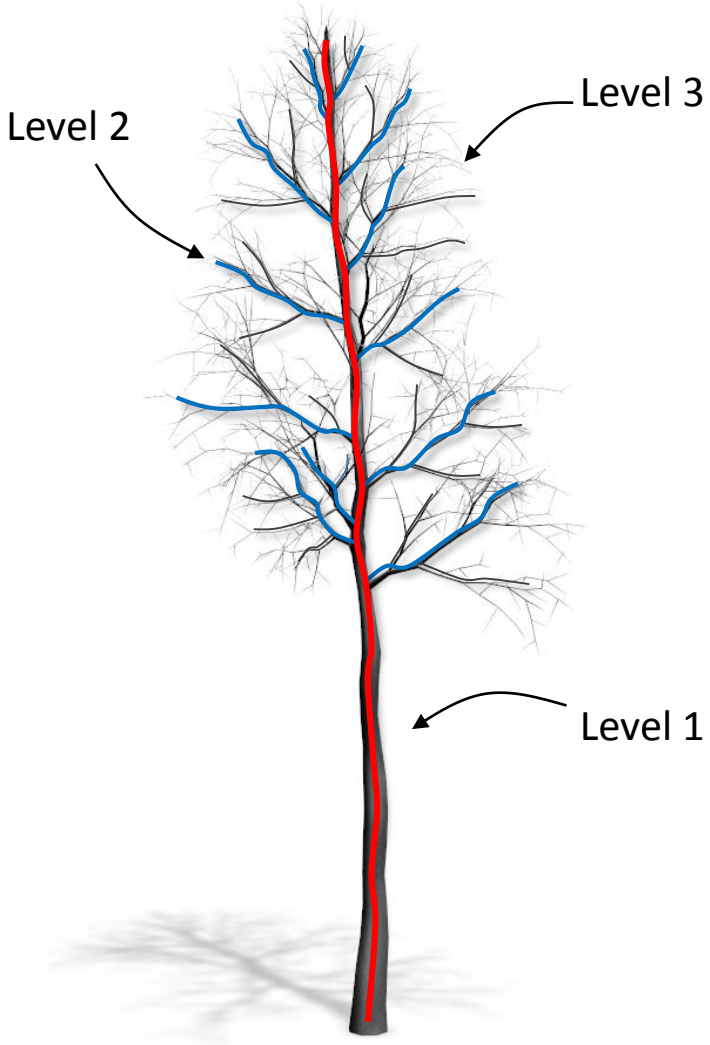
Gravelius Order

Ordering method for identifying hierarchies.

Determine main trunk based on angle between branches.

Also considering length and thickness of a branch.





Pipe Model Theory

[Shinozaki et al. 1964]

Plant forms emerge from vascular systems.

Assembly of leaf units connecting the leaves to the root.

Provides us with branch radii.

Angle/Radii Interpolation

Angle Interpolation

Current Angle

Initial Angle

$$\vartheta_\alpha = \frac{\alpha_i - \alpha_{init}}{\Delta t}$$

Angular Velocity

Duration

Radii Interpolation

Power Law of Branching

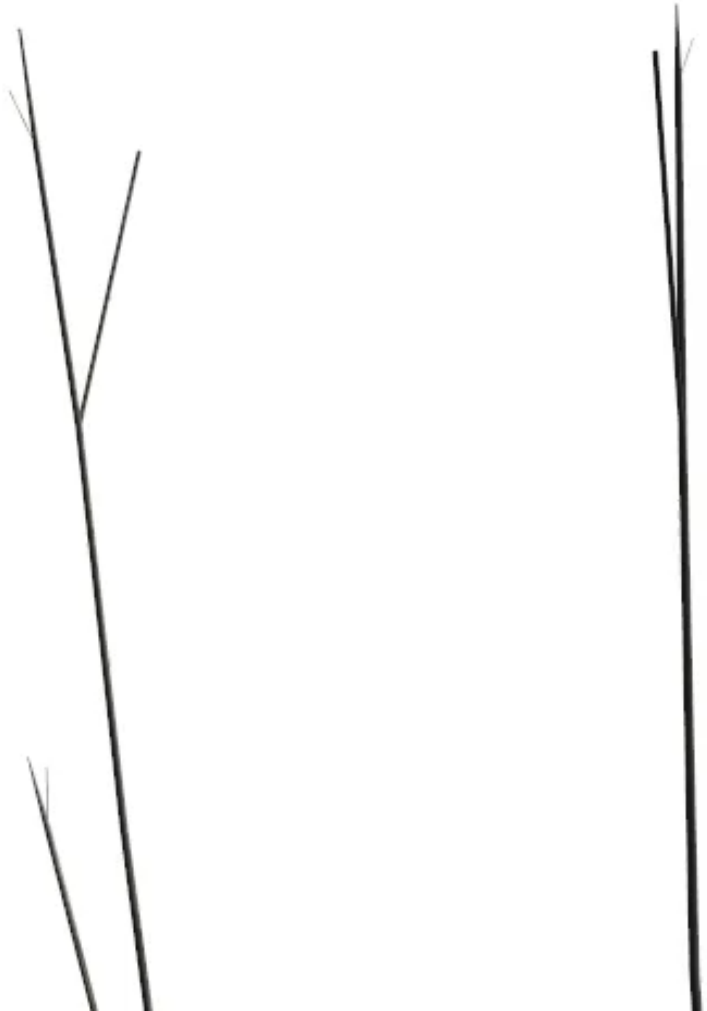
Child Radii

$$r_p = \left(\frac{\sum {r_i}^u}{b^p}\right)^{\frac{1}{u}}$$

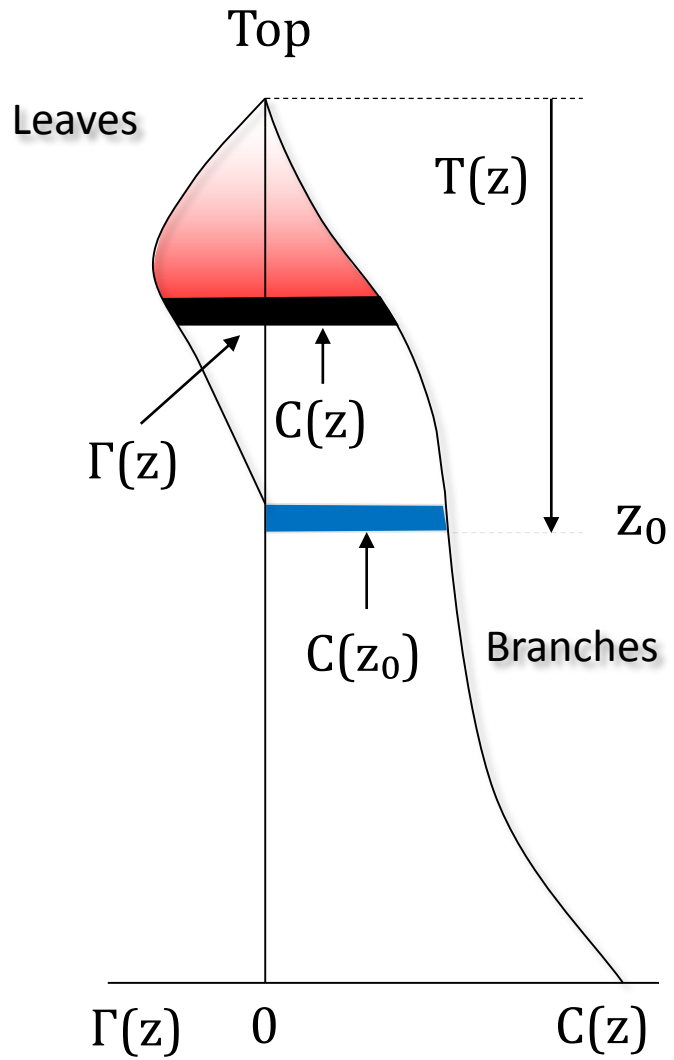
Current Radius

Original Model Coefficient

Angle/Radii Interpolation



Profile Diagram



Similar Among Plant Communities.

Represents vertical distribution of leaves.

Distribution of leaves needs to be consistent.

→ Tells us were geometry is missing.

→ How to measure densities?

[Chiba 1990, Chiba 1991]

Measuring Densities

Stratified Clipping (STC)

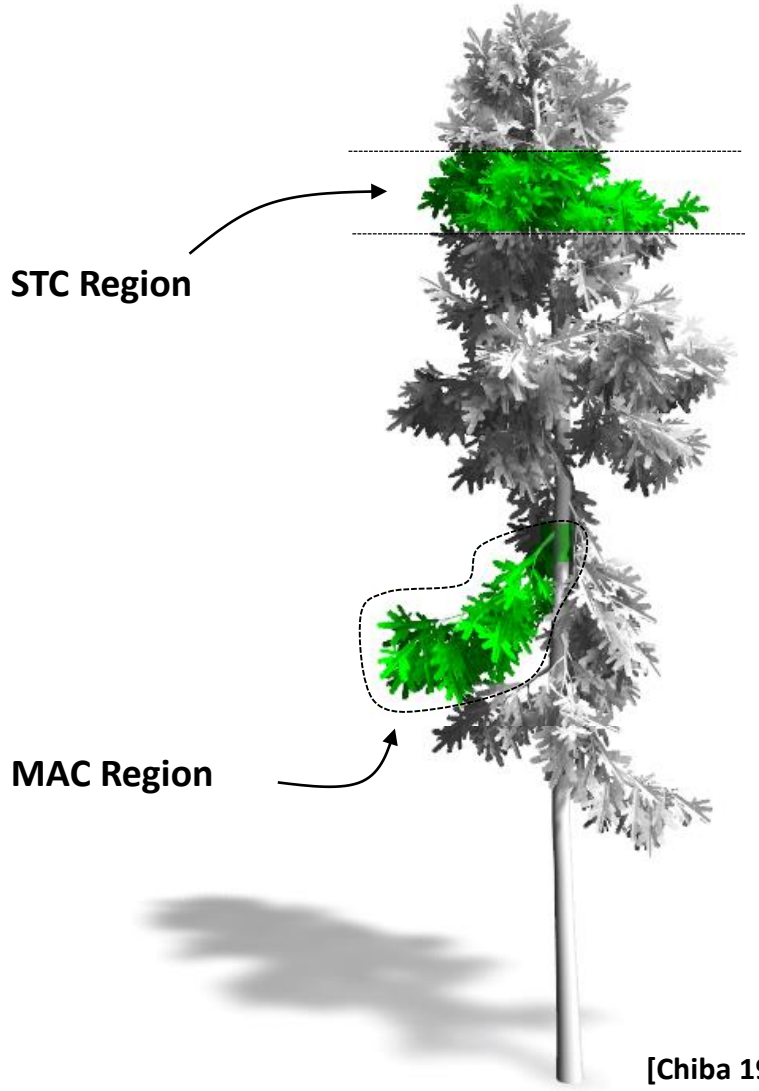
Vertical range of the tree is selected.

All branches and leaves in this region are used for measuring biomass.

Main Axis Cutting (MAC)

Part of the main axis is selected.

All branches and leaves attached to this part are used for measuring biomass.

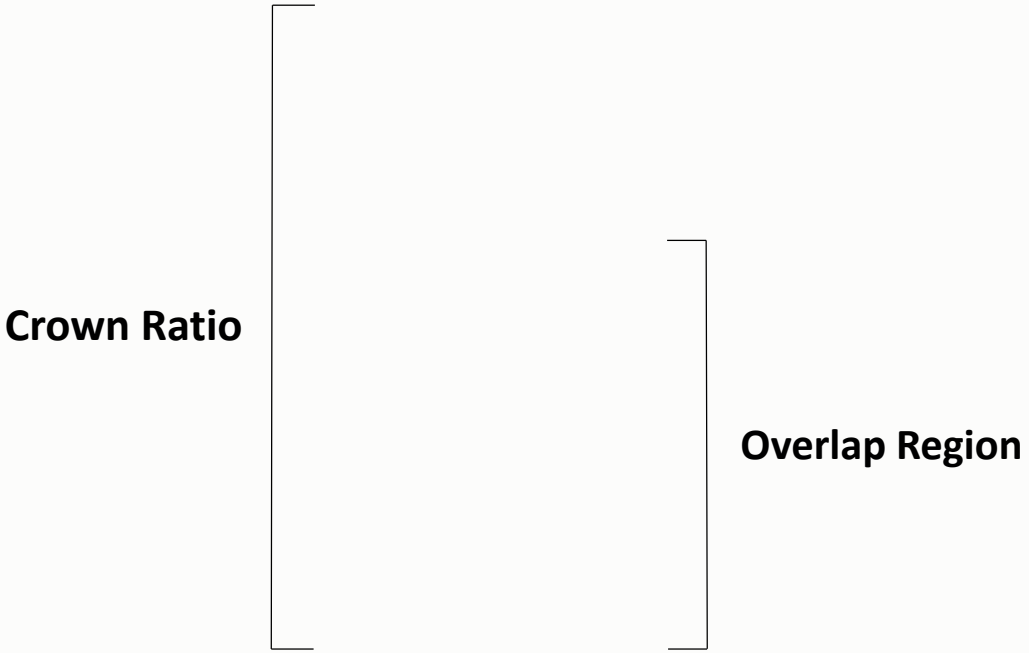


[Chiba 1990, Chiba 1991]

Crown Ratio

Add geometry where no information was available in the original model.

Remove geometry during animation to maintain plausibility and to eventually reach the input.



Growth-based Editing

Individual Growth
of Branches

Windy Trees: Modeling Stress Response for Developmental Tree Models

Pirk, S., Niese, T., Hädrich, T., Benes, B., and Deussen. O.
Windy trees: computing stress response for developmental tree models.
ACM Trans. Graph. 33, 6, Article 204 ,11 pages, 2014.

Tree/Wind Interaction

Wind as Developmental Factor

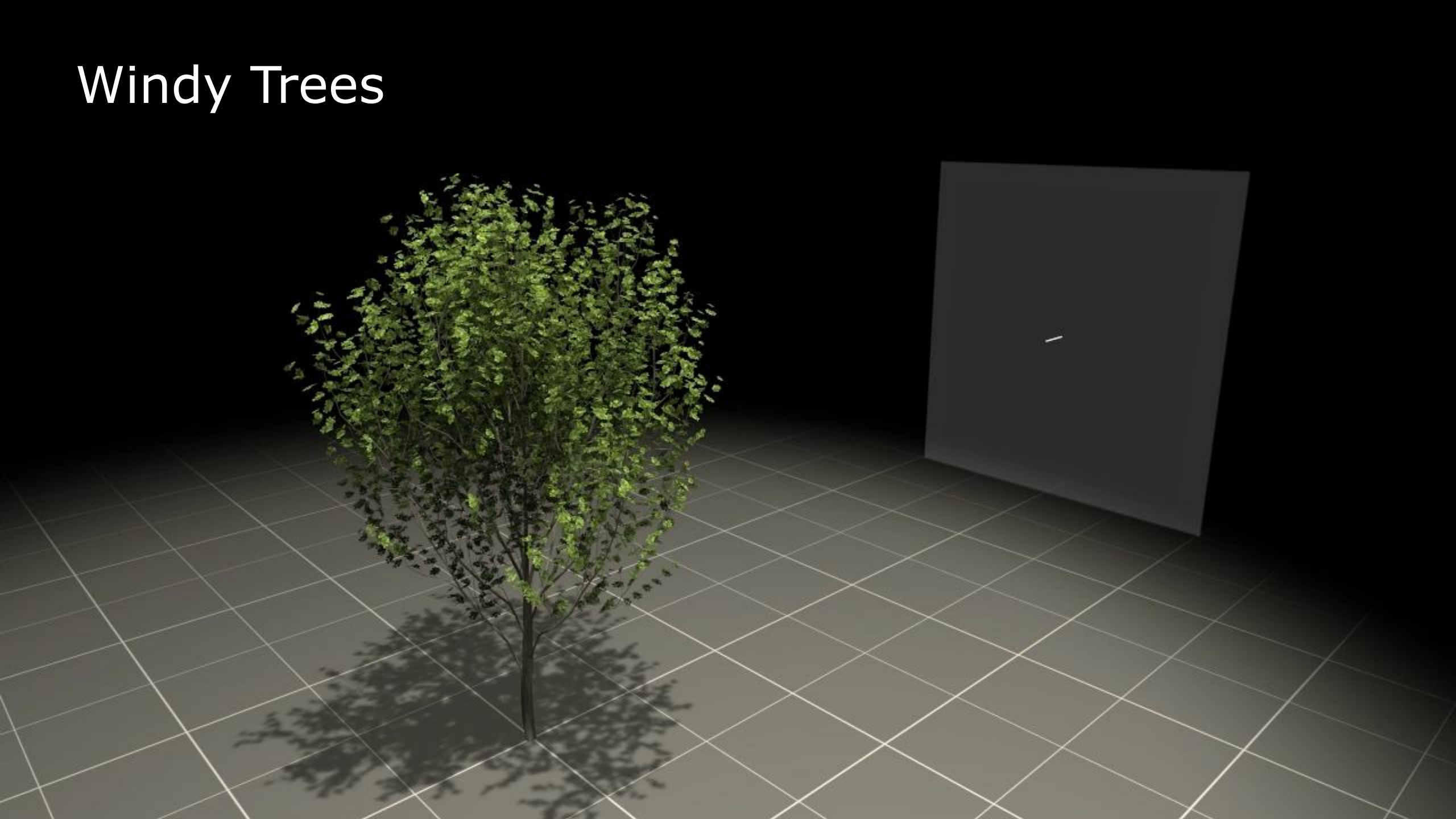
Alex Bamford

Rich Price

Walberth Mascarenha

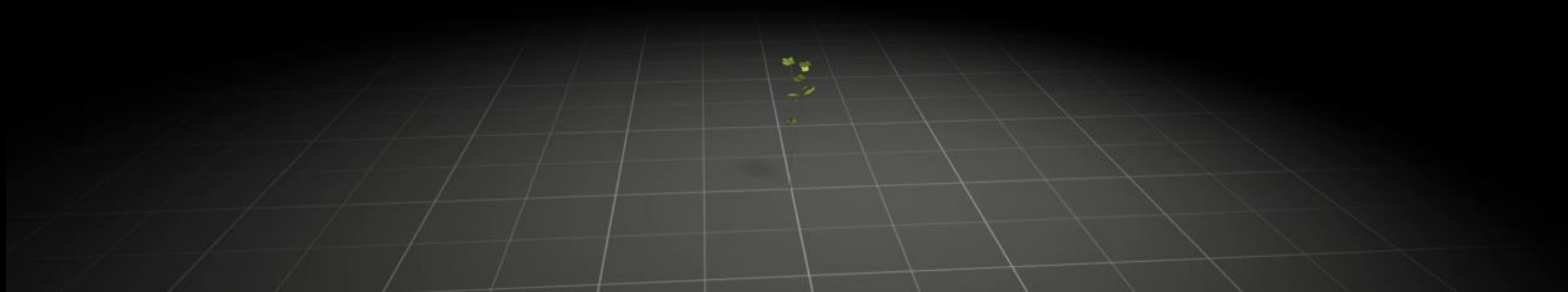
Fedderica Gentile

Windy Trees

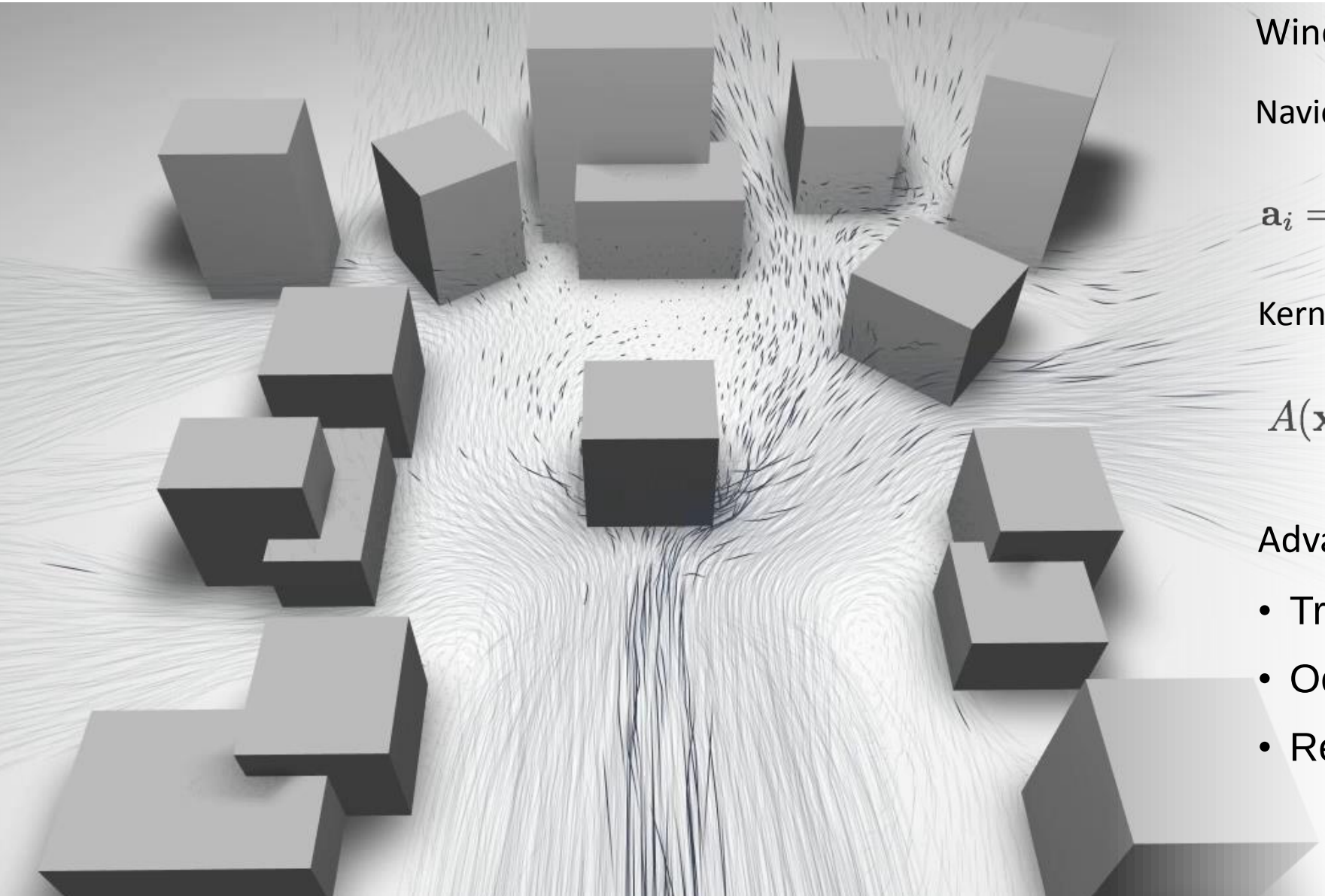


Growth Model

- Pipe Model Theory
- Gravelius Order
- Branching Angles
- Branch Radii
- Growth Rate



Smoothed Particle Hydrodynamics (SPH)



Wind Simulation

Navier Stokes - Acceleration

$$\mathbf{a}_i = \frac{d\mathbf{v}_i}{dt} = \frac{-\nabla p + \mu \nabla^2 \mathbf{v} + \rho \mathbf{g}}{\rho_i}$$

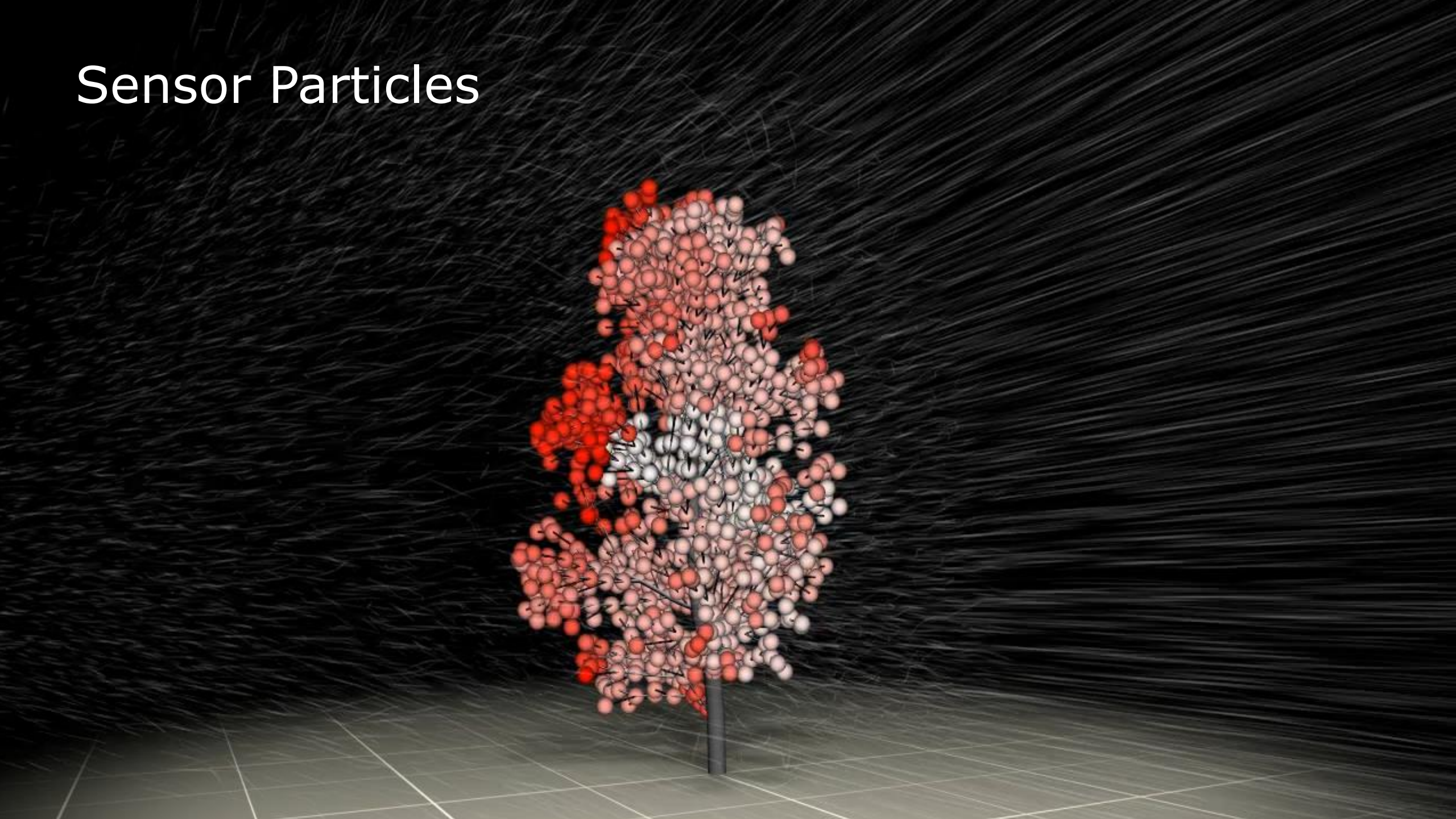
Kernel Smoothing Function

$$A(\mathbf{x}) = \sum_{j=1}^{N} \frac{m_j}{\rho_j} A_j \; W(\mathbf{x} - \mathbf{x}_j, h)$$

Advantages

- Tracking of individual collisions
- Occlusion handling (wind shadow)
- Real-time simulation

Sensor Particles



Two-Way Coupling

Force Model for Branches

Torque

$$N = I\frac{d\omega}{dt}$$

Moment of Inertia (rod)

$$I = \frac{mr^2}{3}$$

$$F_W = S_b\sigma\nu$$

Wind Force

$$D = -(\hat{\omega} \times \hat{e})\mu\omega|\omega|$$

Damping Force

$$\boldsymbol{F = F_w + R + D + P + L}$$

Restoration Force

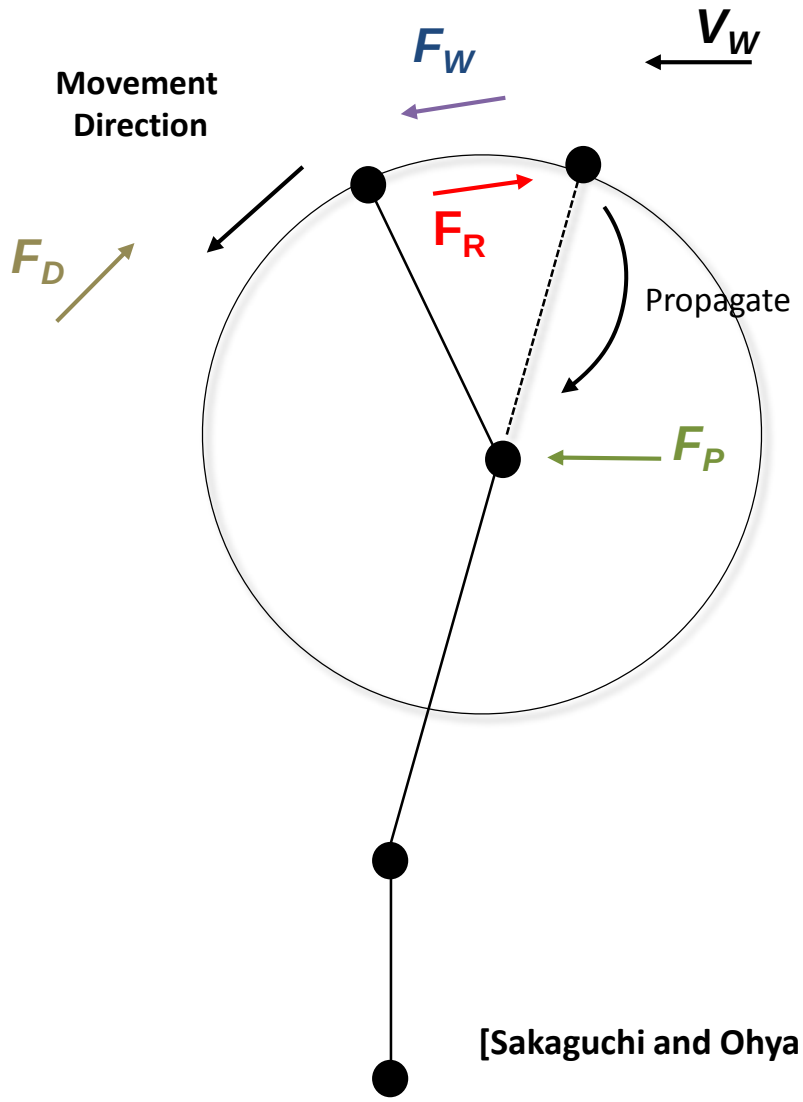
$$R = d_r k\alpha$$

Propagation Force

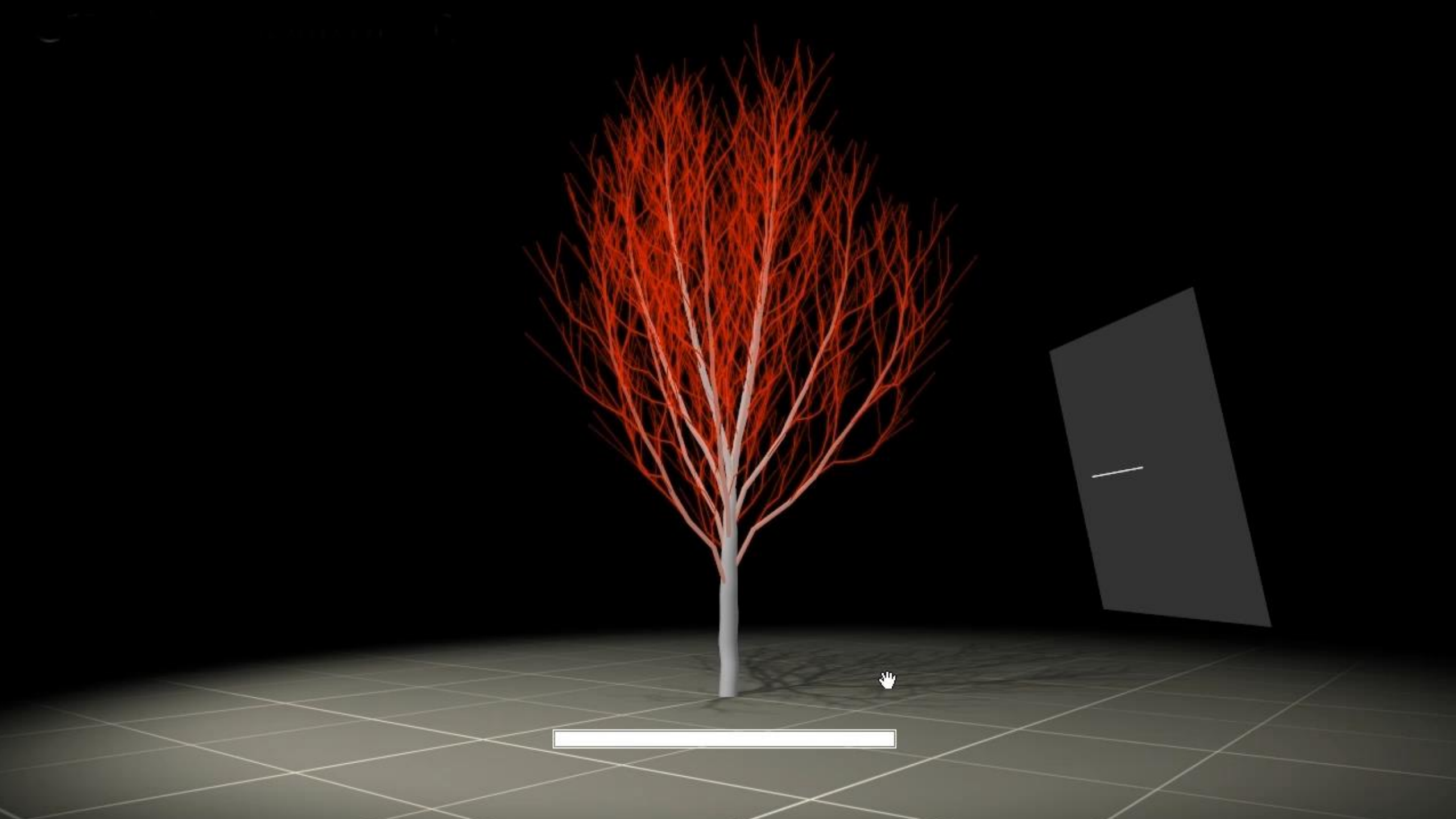
$$P_{i-1} = -\sum k_i F_{Ri}$$

Leaf Force

$$L = S_l\sigma\nu c$$



[Sakaguchi and Ohya 1999]



Breaking of Branches

- Branch breaks when the acting forces exceed a certain level of stress
- Wood is a highly inhomogeneous material
- Approximating Young's Modulus and Hook's law

Young's Modulus Coefficient

Bending Moment

Stress

$$\sigma = \frac{4cM}{3\pi r^2}$$

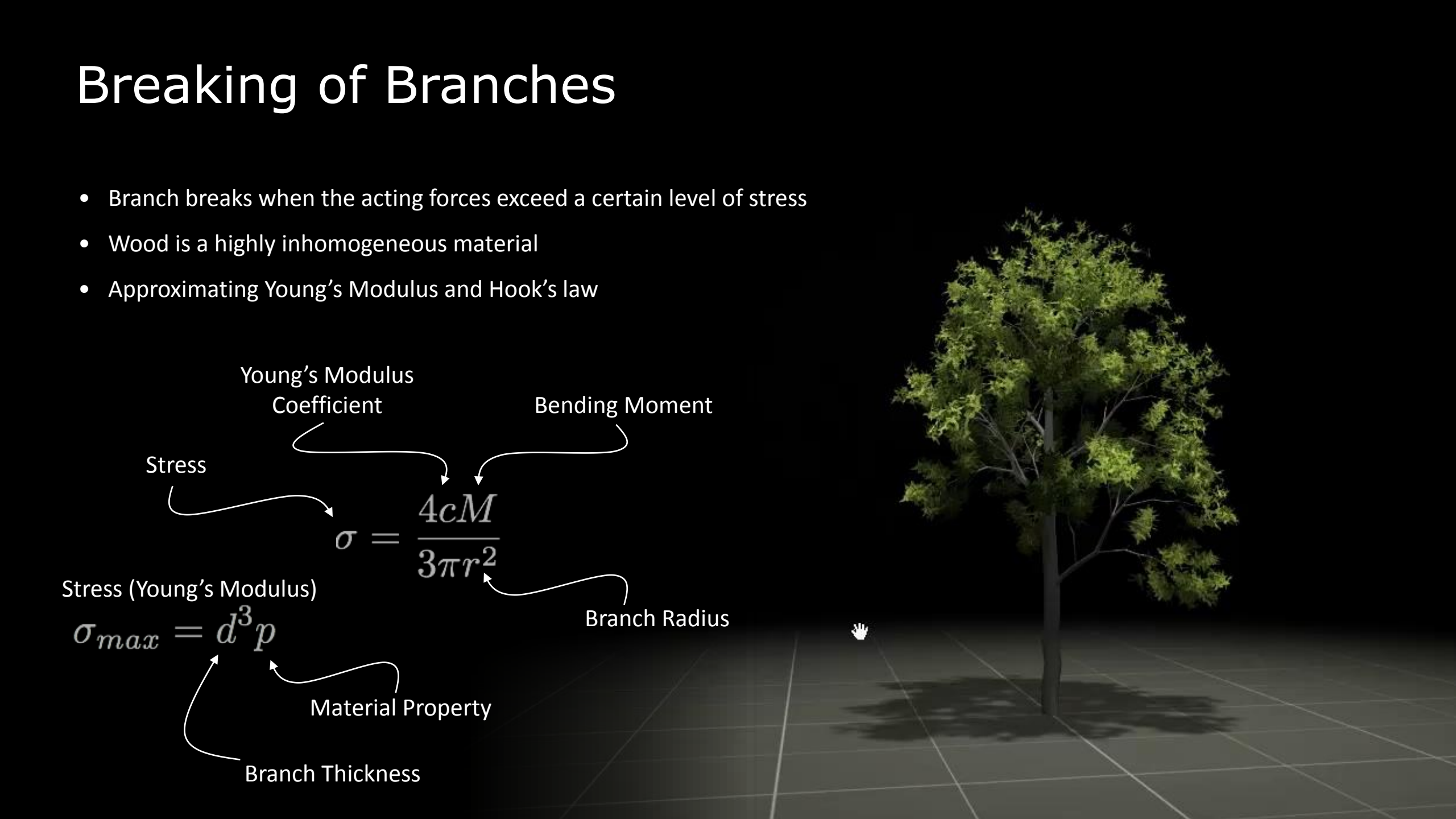
Branch Radius

Stress (Young's Modulus)

$$\sigma_{max} = d^3 p$$

Material Property

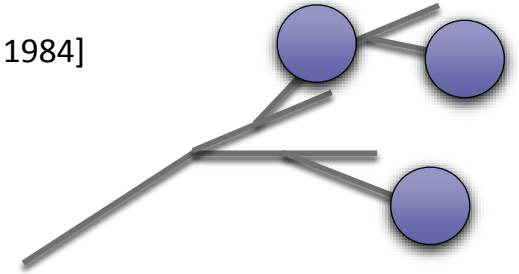
Branch Thickness



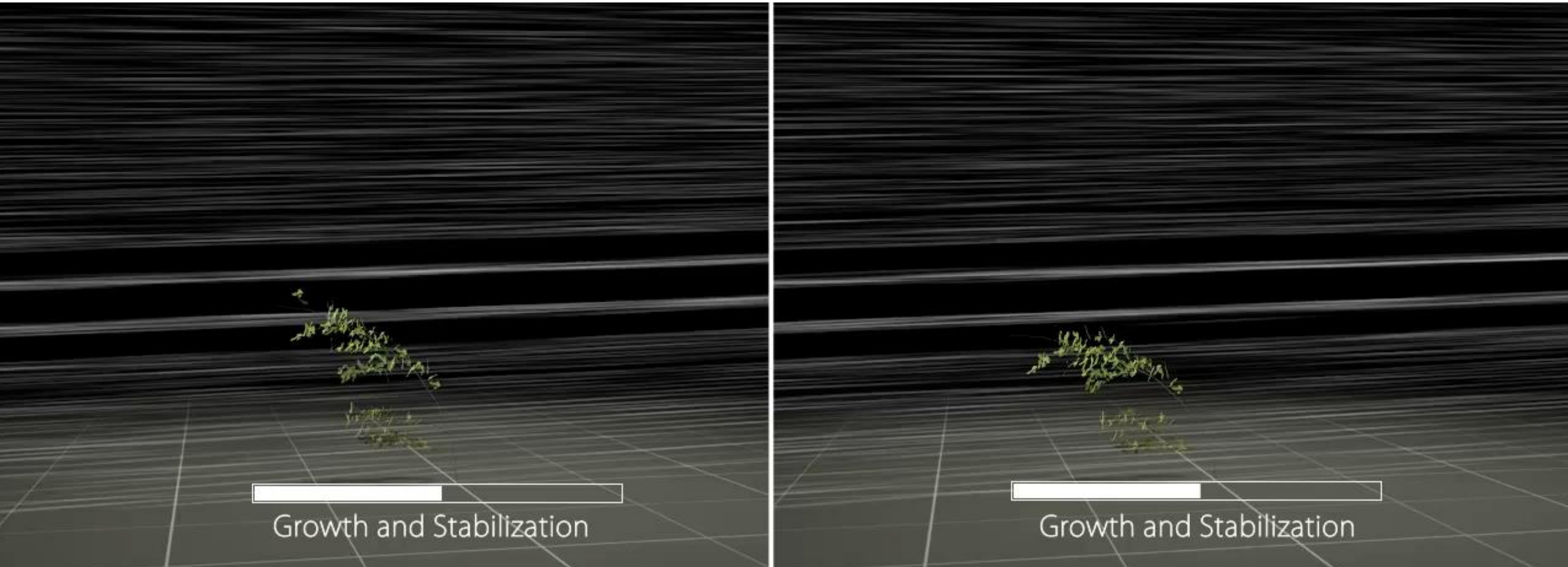
Bud Abrasion and Drying

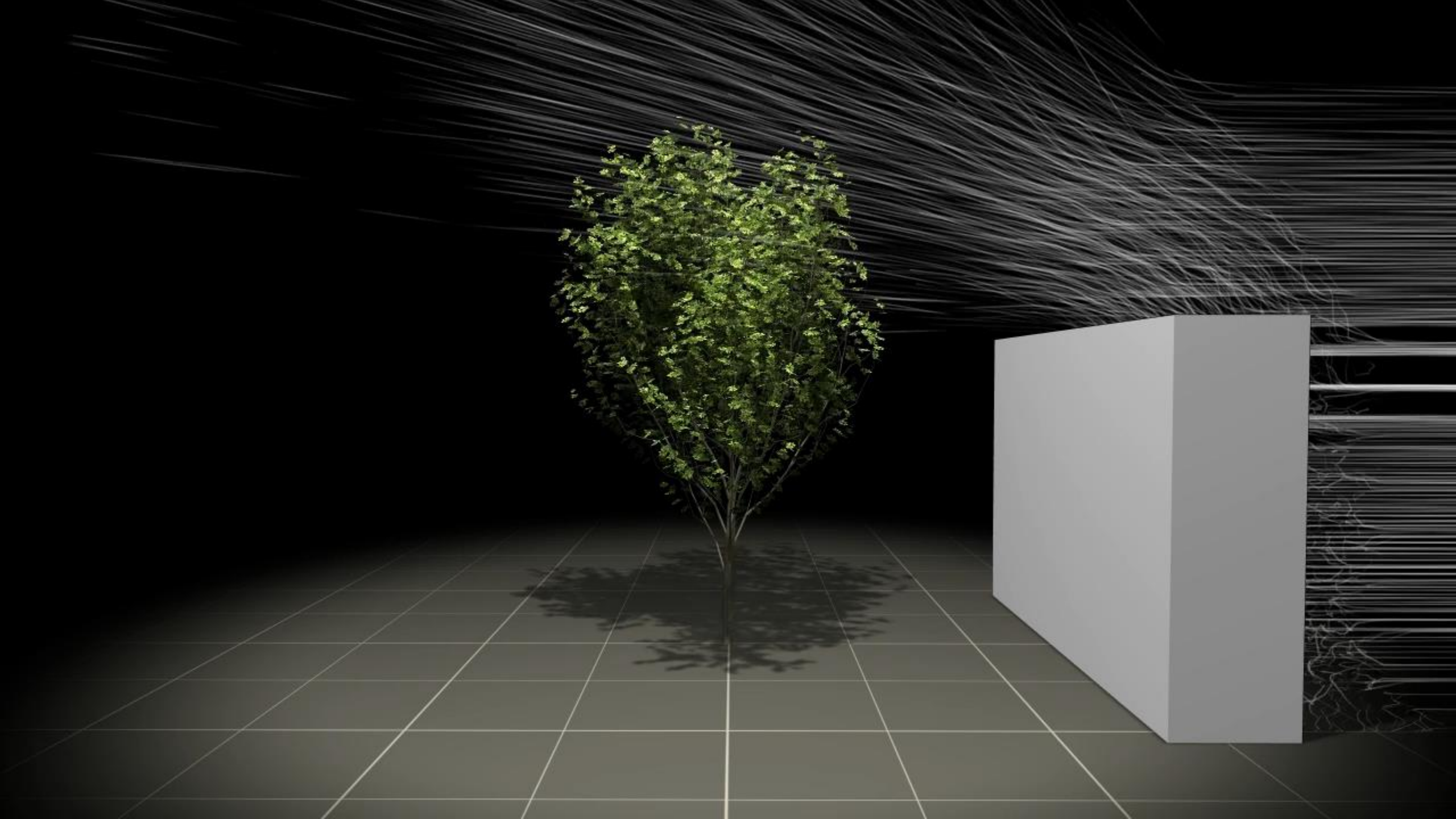
- Wind dries out or abrades buds
- Detect particles and neighboring branches
- User-defined threshold to terminate buds

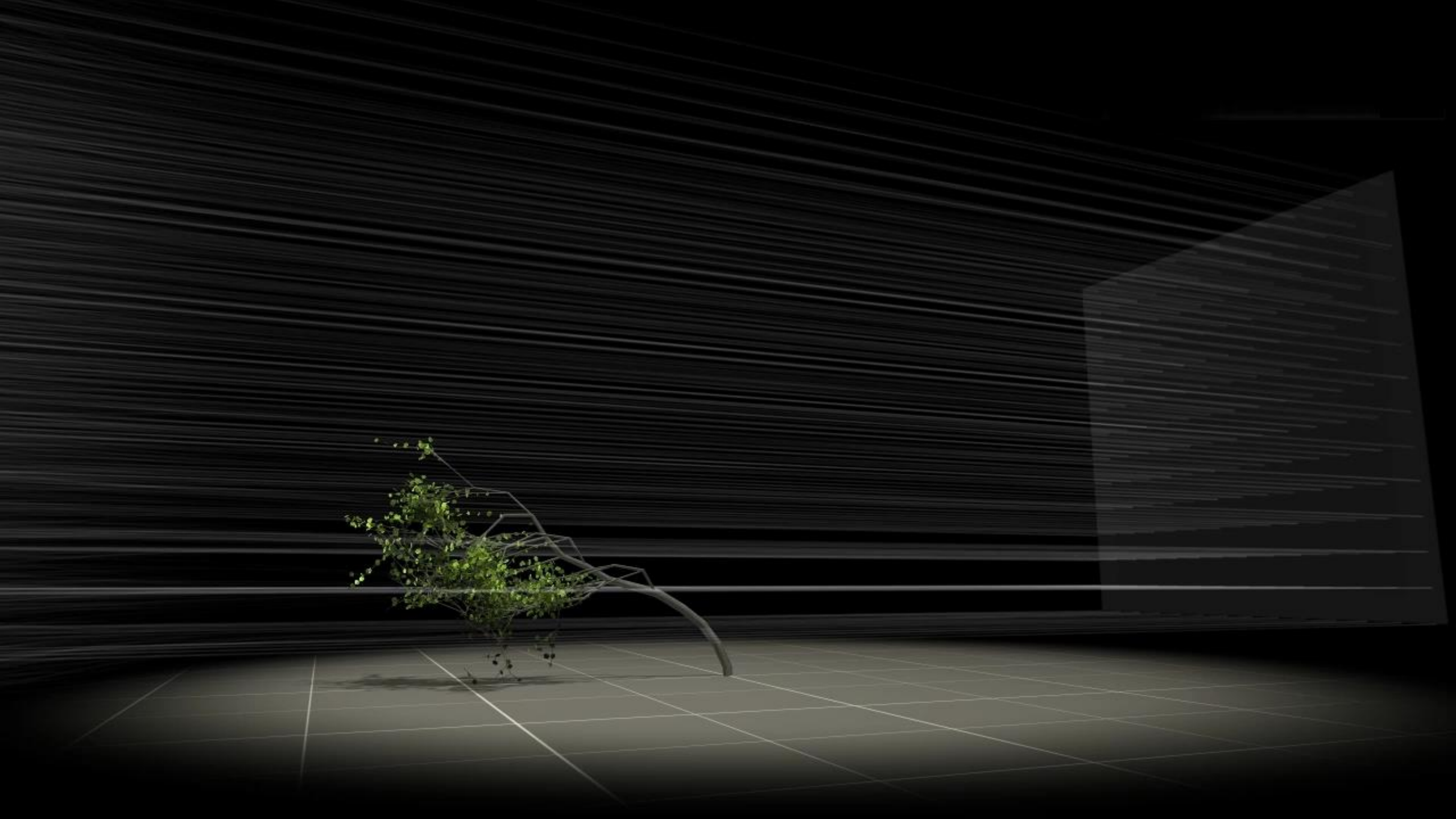
[Putz and Parker 1984]

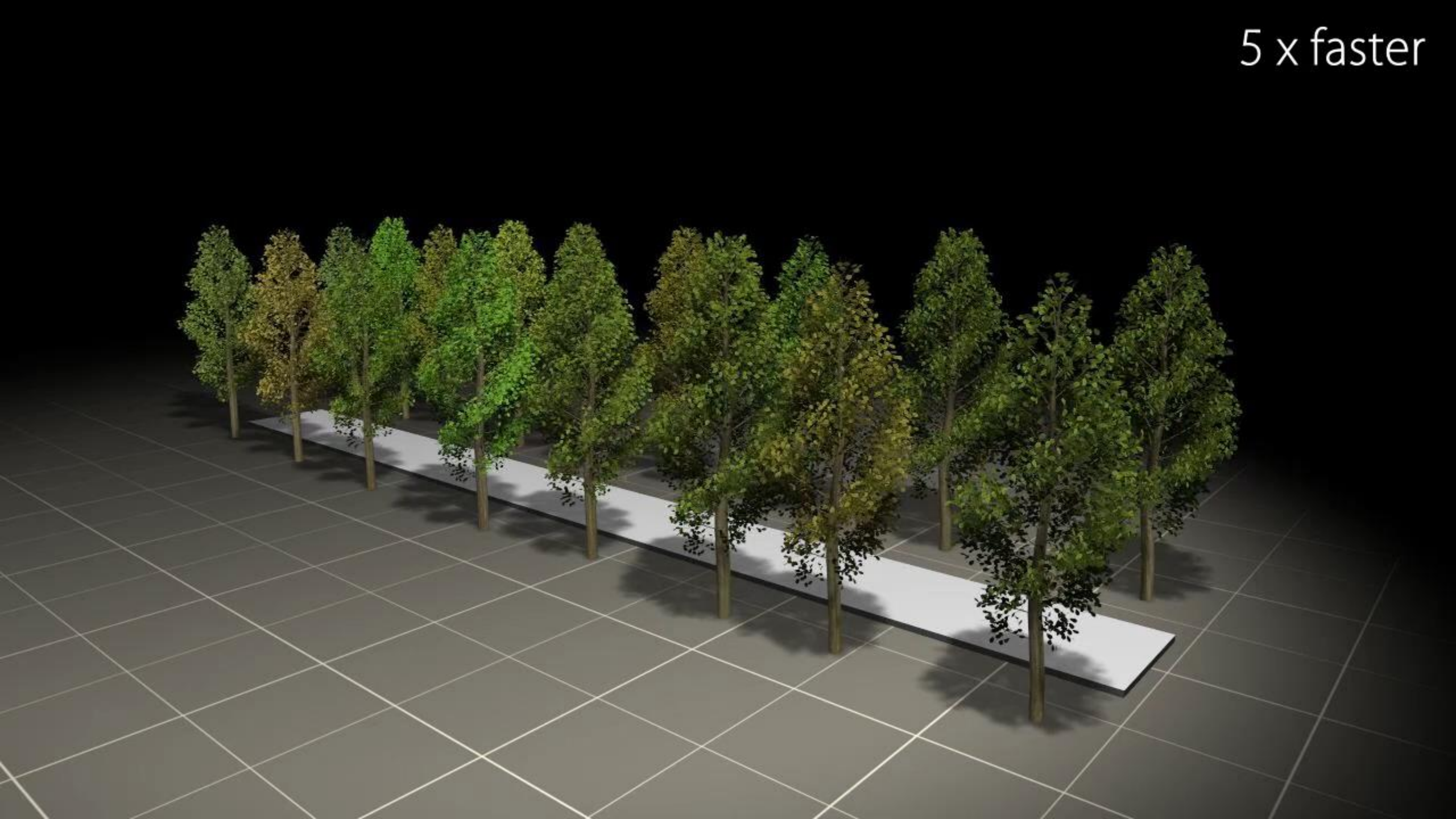


Off On








5 x faster