Modeling Plant Life in Computer Graphics

Environmental Response

Siggraph 2016 Course

Sören Pirk, Bedrich Benes, Takashi Ijiri, Yangyan Li, Oliver Deussen, Baoquan Chen, Radomír Měch
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

Plastic trees: interactive self-adapting botanical tree models.  
Environment Aware Trees

Automatic modification of 3D tree models
Skeletal Graph

- Branch Age
- Growth Rate
Tree Analysis - Tropisms

Phototropism

Gravitropism
Inverse Tropism

- Backward modeling to estimate influence of tropisms to the original model
- → allows to apply tropisms triggered by the new environment

\[ \text{direction of tropism} = (1-w_s)t \]

- hypothetical branch without tropism
- branch direction with tropisms

\[ \text{h} \]
Dynamic Interaction - Bending

New Direction

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

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.

\[
\varphi_{ts} = \sum_{c \in C_s} 2\pi r_c^2 i_c
\]

- \( \varphi_{ts} \): normalized amount of light
- \( r_c \): radius of a given cluster
- \( i_c \): amount of resources (light)
- \( C_s \): leaf-cluster
- \( l_t \): sum of distances

Branch is pruned when ratio \( \varphi_{ts}/l_t < \text{thres} \)
Tree/Obstacle Interaction

Original Model → Bending → Pruning → Bending + Pruning → Result
Tree/Tree-Interaction
Bending/Pruning Result

http://www.flickr.com/photos/harveydogson/4095300141/

http://www.flickr.com/photos/jlwhitfield1/2731012752/
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.
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.
Plant forms emerge from vascular systems.

Assembly of leaf units connecting the leaves to the root.

Provides us with branch radii.

[Shinozaki et al. 1964]
Angle/Radii Interpolation

Angle Interpolation
- Current Angle
- Initial Angle
- Angular Velocity
- Duration

Radii Interpolation
- Child Radii
- Current Radius
- Original Model Coefficient

Power Law of Branching
- \( r_p = \left( \sum r_i^n \right)^{1/u} \)
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

\[ a_i = \frac{dv_i}{dt} = -\nabla p + \mu \nabla^2 v + \rho g \]

Kernel Smoothing Function

\[ A(x) = \sum_{j=1}^{N} \frac{m_j}{\rho_j} A_j W(x - x_j, h) \]

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)
\[ I = \frac{mr^2}{3} \]

Wind Force
\[ F_W = S_b \sigma \nu \]

Damping Force
\[ D = - (\hat{\omega} \times \hat{e}) \mu \omega |\omega| \]

Restoration Force
\[ R = d_r \kappa \alpha \]

Propagation Force
\[ P_{i-1} = - \sum k_i F_{Ri} \]

Leaf Force
\[ L = S_l \sigma v e \]

\[ F = F_W + R + D + P + L \]
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

\[ \sigma_{max} = \frac{4cM}{3\pi r^2} \]

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

Stress (Young’s Modulus) \( \rightarrow \) Branch Radius

Bending Moment \( \rightarrow \) Branch Thickness

Young’s Modulus Coefficient \( \rightarrow \) Stress

Material Property \( \rightarrow \) 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]