Universität Konstanz

Modelling Plants
- from procedural to data-driven

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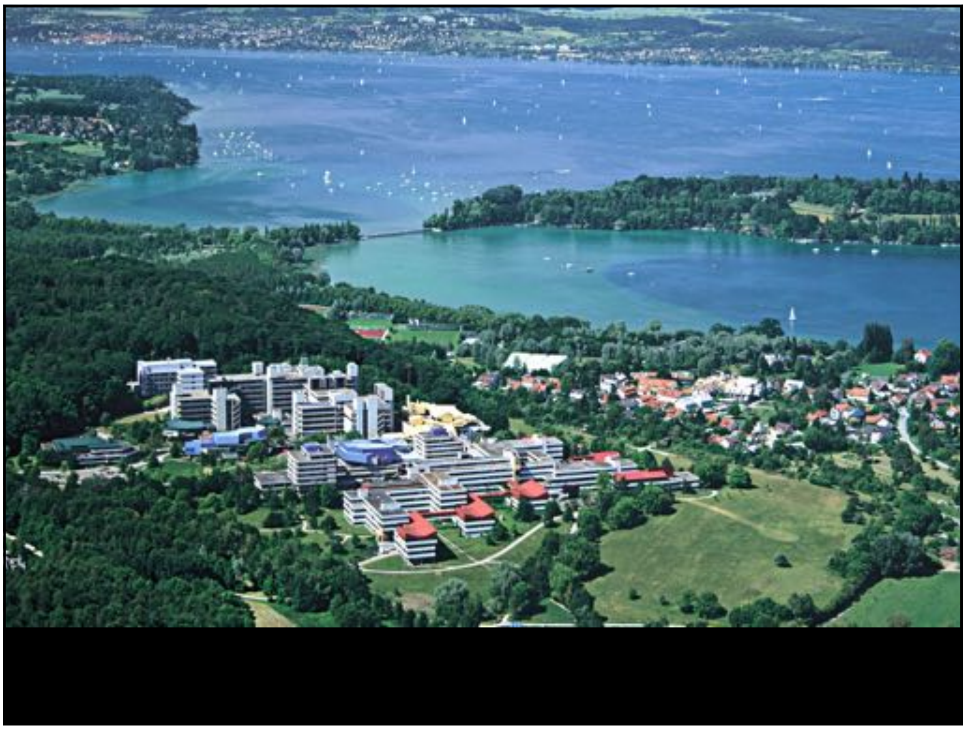
Where I am from…



Ways of modelling trees

- **Rule-based modeling**
  - Uses formal grammars or other mechanisms
  - Very general but hard to control
- **Procedural modeling**
  - Specialized parameterizable algorithms
  - Quite specific but easy to control
- **Today: data driven**

Lindenmeier-Systems

- Formal grammars
- contrast to Chomsky-Grammars: parallel execution
  - All possible applications of rules to a string are produced in parallel

Lindenmayer Systems

Example:

V = {f,F,+,-}

ω = F--F--F

P = { F::=F+F--F+F}

derived text:

- F--F--F
- F+F--F+F--F+F--F+F--F+F--F+F
- F+F--F+F+F+F--F+F--F+F--F+F+F+F--F+F--F+F--F+F+F+F--F+F--F+F--F+F+F+F--F+F--F+F--F+F+F+F--F+F--F+F--F+F+F+F--F+F

Lindenmayer Systems

- next step: graphical interpretation
- Prusinkiewicz: turtle metapher
  - attach pen to turtle, move turtle on the drawing plane
  - turtle has state (position, angle)
  - turtle moves straight into current direction until changes are made

Lindenmayer Systems

- **F**: move turtle in current direction about given (fixed) length l, draw a line
- **f**: move turtle in current direction about given (fixed) length l without drawing
- **+**: increase angle about given amount δ
- **-**: decrease angle about given amount δ
- [store current graphics state on stack
-] read (and pop) graphics state from stack

Lindenmayer Systems

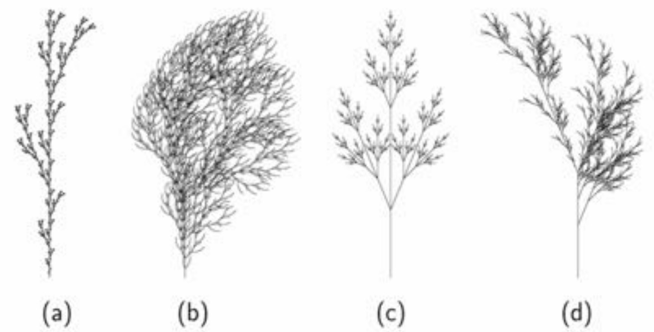


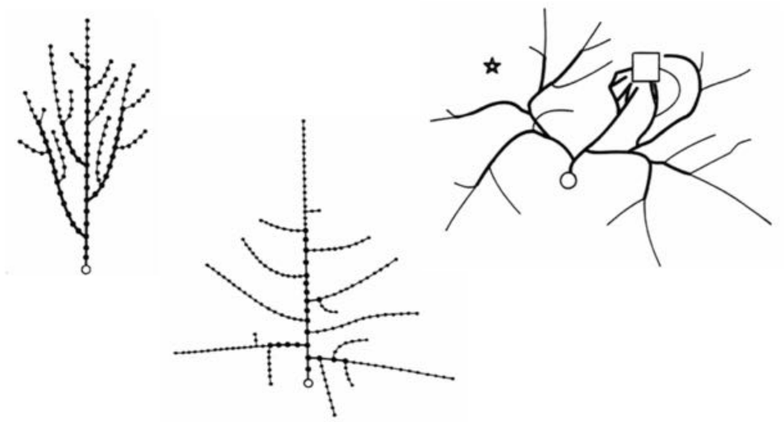
Abbildung	n	δ	w	P
(a)	5	25,7°	F	{ F ::= F[+F]F[-F]F }
(b)	4	22,5°	F	{ F ::= FF-[-F+F+F]+[+F-F-F] }
(c)	7	25,7°	X	{ X ::= F[+X][-X]FX, F ::= FF }
(d)	5	22,5°	X	{ X ::= F[[X]+X]+F[+FX]-X, F ::= FF }

Lindenmayer Systems

⇒ 3D Objects: 3d angles, triangulation

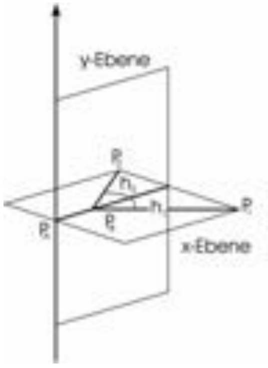
Procedural modeling of plants

1967 E. Cohen: the first model



Procedural modeling of plants

1977: Honda, Fischer: three-dimensinoal models



Procedural modeling of plants

1985: Reeves and Blau (Pixar)

- feature film „The adventures of Andrew and Wally B.“
- simple branching structure
- particle systeme for leaves (a particle for each leaf)
- appropriate rendering creates very realistic look

Procedural modeling of plants

1985: Bloomenthal, geometric modeling of trees

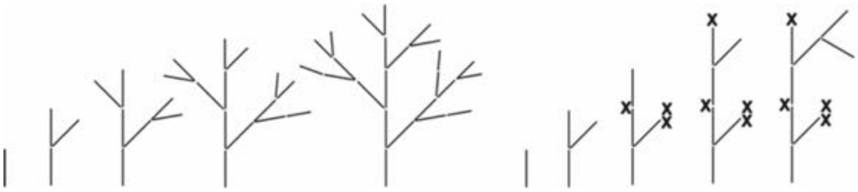
Procedural modeling of plants

1986: Oppenheimer, fractal tree model (recursive)

Procedural modeling of plants

1988 de Reffye et al.

- biologically oriented growth
- buds: probability to grow, rest or die
- basis of AMAP / NatFX

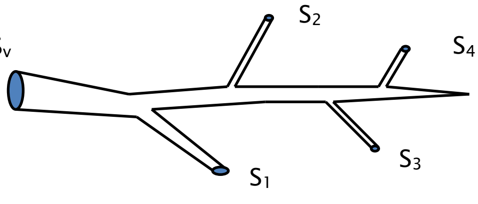


Procedural modeling of plants

Procedural modeling of plants

1994: Holton

- allometric rules obtained from da Vinci:
- area of father branch equals sum of areas of children ($S_v = S_1 + .. + S_4$)

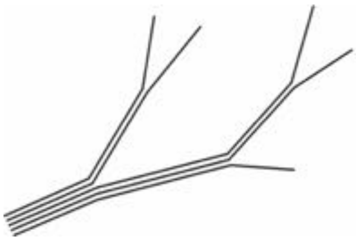


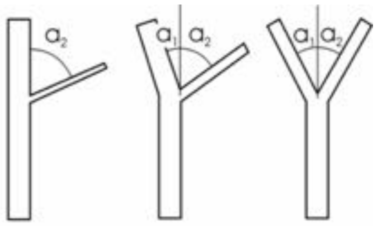
Procedural modeling of plants

1994: Holton

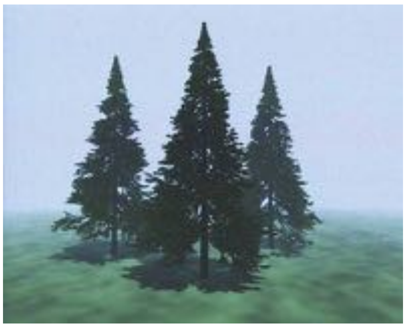
Modeling idea:

- branches consist of pipes, that connect leaves with roots
- # of pipes determines width and branching angle
- creates proportionen of da Vinci





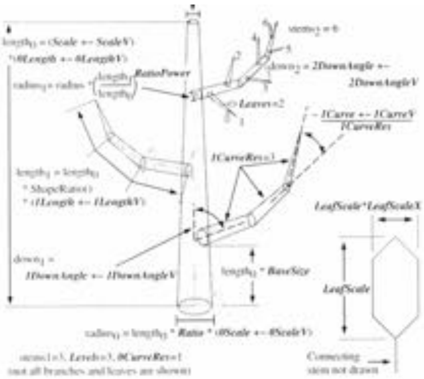
Procedural modeling of plants

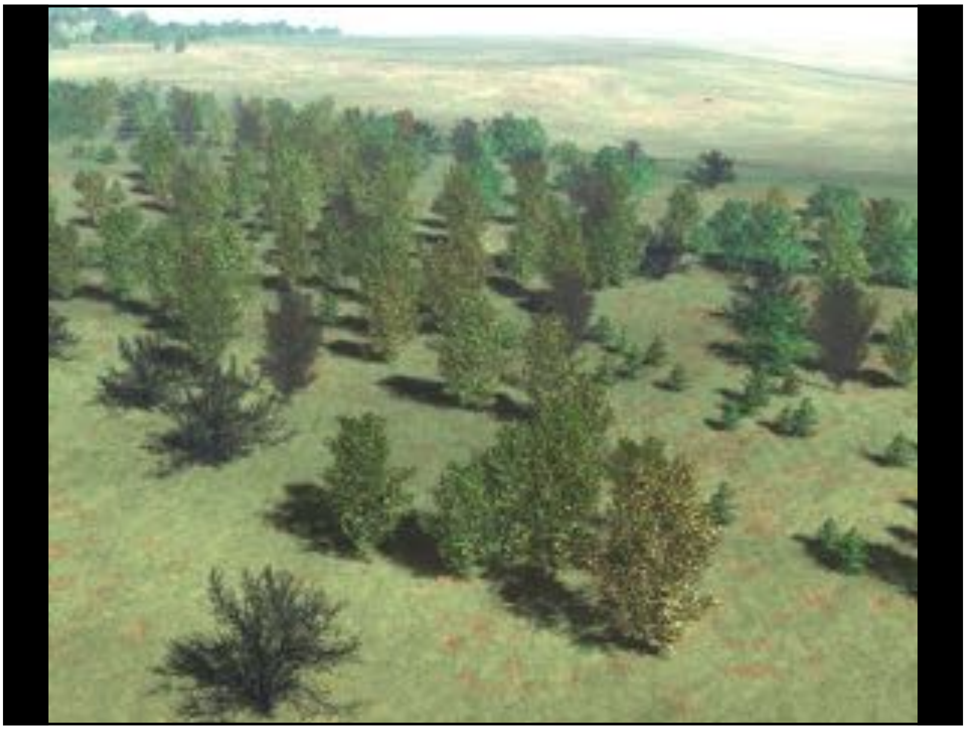


Procedural modeling of plants

1995: Weber & Penn:

- procedural model with 50 para-meters
- allows maximum freedom for modeling
- done for military simulations





Procedural Modeling of Plants

1989: Greene, winding plants

2008: Ivy Generator (Thomas Luft)

Xfrog

- First system for practically producing plant models
- Combines rule-based and procedural generation

- Objects are described by a graph
- **Nodes**: procedural elements
  - Geometry production
  - multiplication
- **Links:** simple form of rule-basis
  - Addition
  - multiplication

Modeling a plant

Description of a tree


MPI Saarbrücken


Kryzstoph Plonka


Jan-Walter Schliep

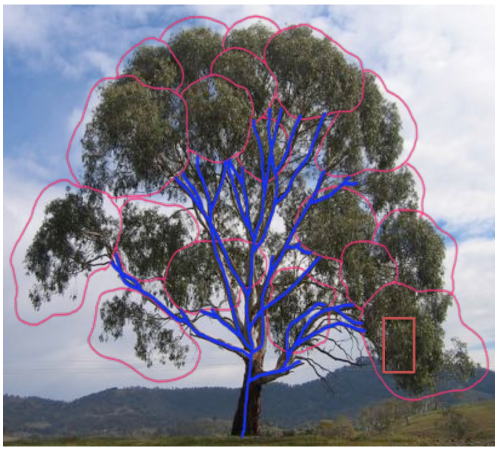

Jan-Walter Schliep


Holger Schömann


Image: Thomas Jarosch

Data Driven Tree Modeling

Data-driven Tree Description



Main Branching Structure
+
Foliage Shapes
+

Species-related Foliage Details

Y. Livny, S. Pirk, Z. Cheng, F. Yan, O. Deussen, D. Cohen-Or, B. Chen: **Texture-Lobes for Tree Modeling**
ACM Transactions on Graphics (Proceedings of SIGGRAPH 2011), 30(4), Article No. 53

Data-driven Tree Description

Real Tree

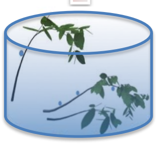
Point Set

Lobe-based Representation

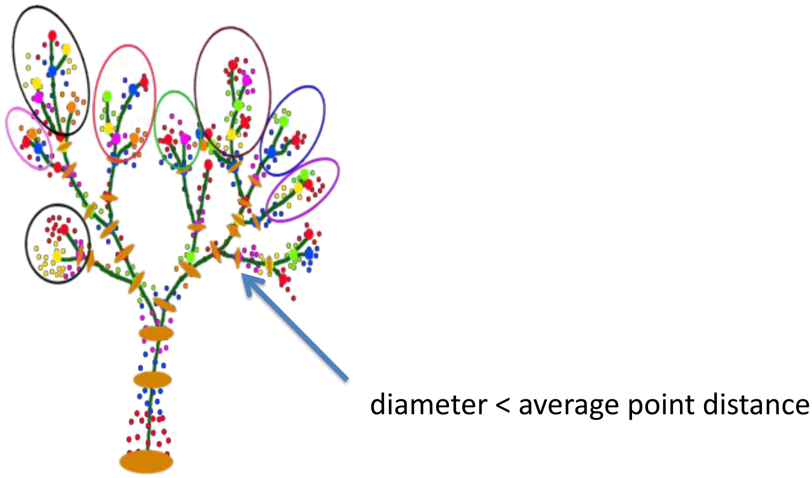
3D Reconstruction

Classification

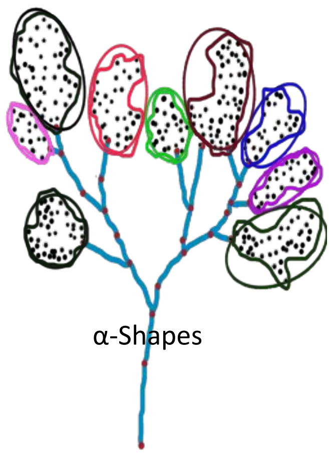
Species Patches



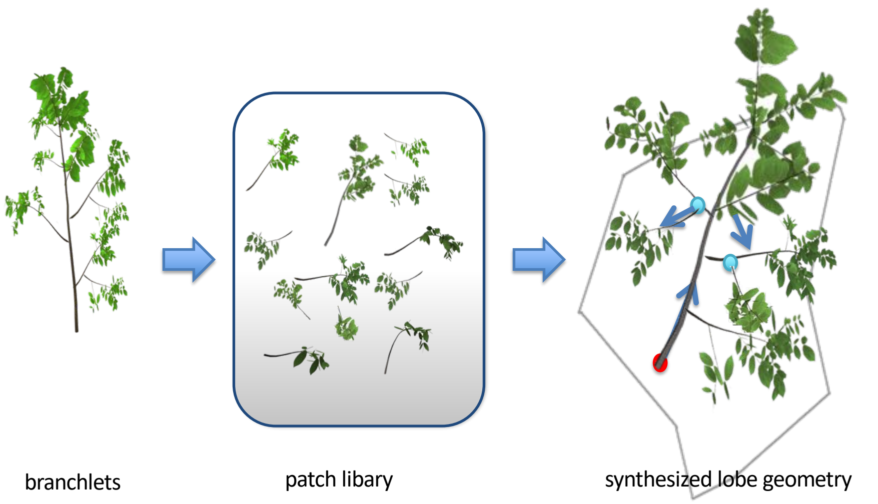
Lobe-based Representation



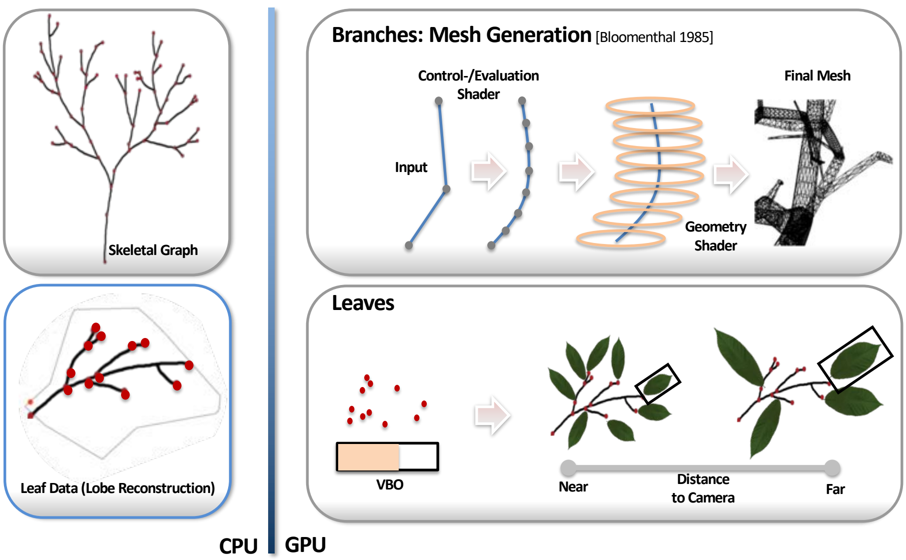
Lobe-based Representation



Lobe details (foliage)

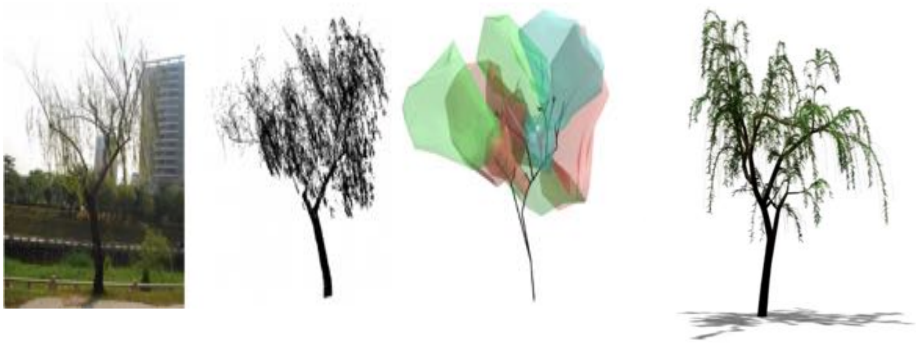


Mesh Construction



Results: Bischofia Trichocarpa

Results: Delonix



Results: Willow Tree

Other species

Populating an Urban Landscape

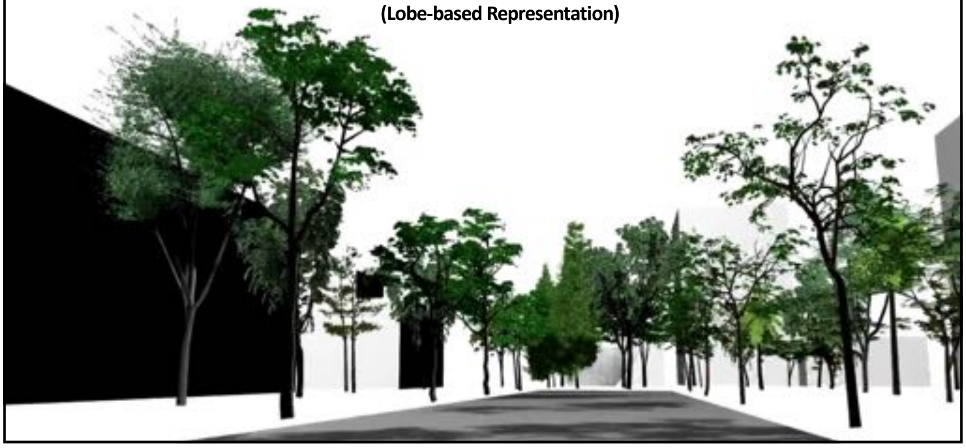
20 Different Species

10,000 Distinctive Models

20 x 100 kB
(Species Information)

10,000 x 15 kB
(Lobe-based Representation)

152 MB (2 MB + 150 MB)
for the entire scene

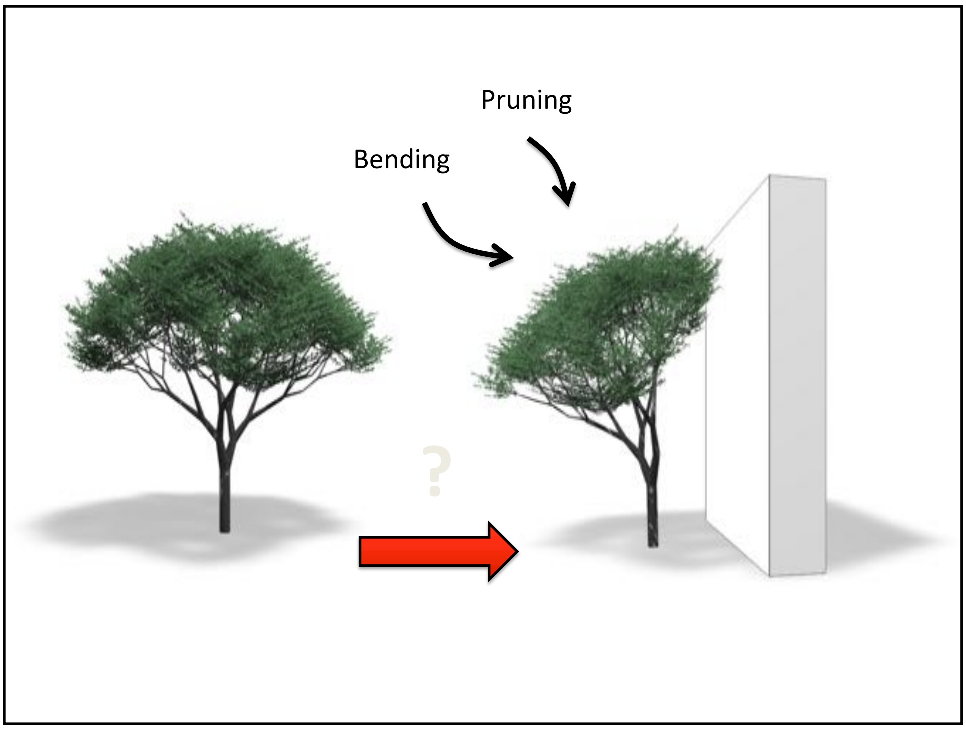


Problems so far:

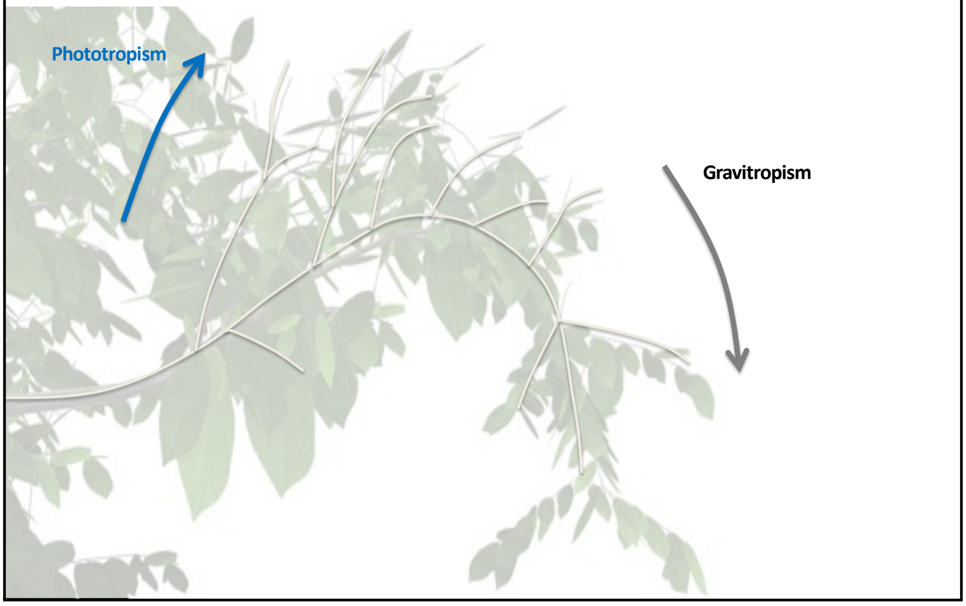
- **The captured models are static**
  - no growth, no interaction
- **Users don‘t want to model directly**
  - Plants should react to enivronment
  - Variety of objects should be created with minimal user intervention

Adaptive Data-driven Plant Models

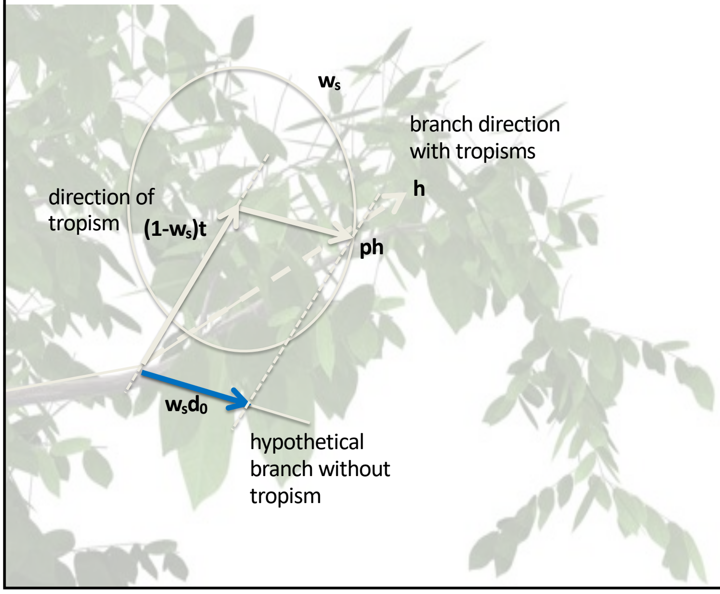
S. Pirk, O. Šťava, J. Kratt, M. Abdul-Massih, B. Neubert, R. Měch, B. Beneš, O. Deussen:
Plastic Trees: Interactive Self-Adapting Botanical Tree Models
ACM Transactions on Graphics, (Proceedings of SIGGRAPH 2012), 31(4), Article No. 50



Backward modeling

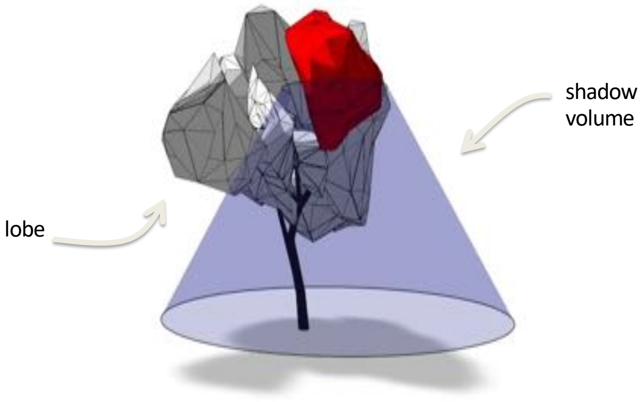


Backward modeling



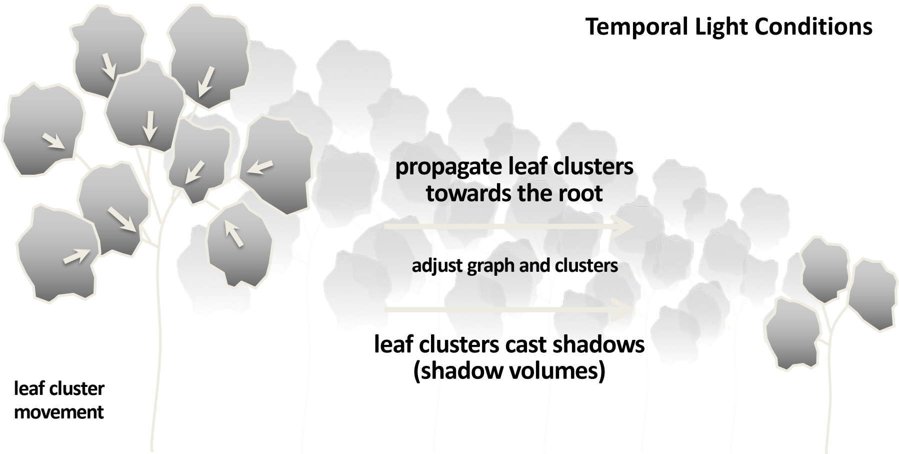
Backward modeling

How much light was cast onto a part of a tree?

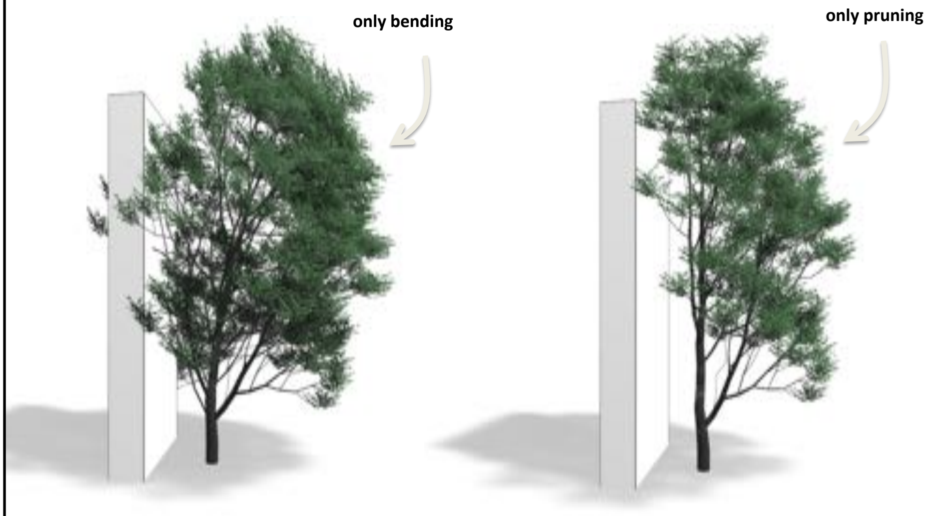


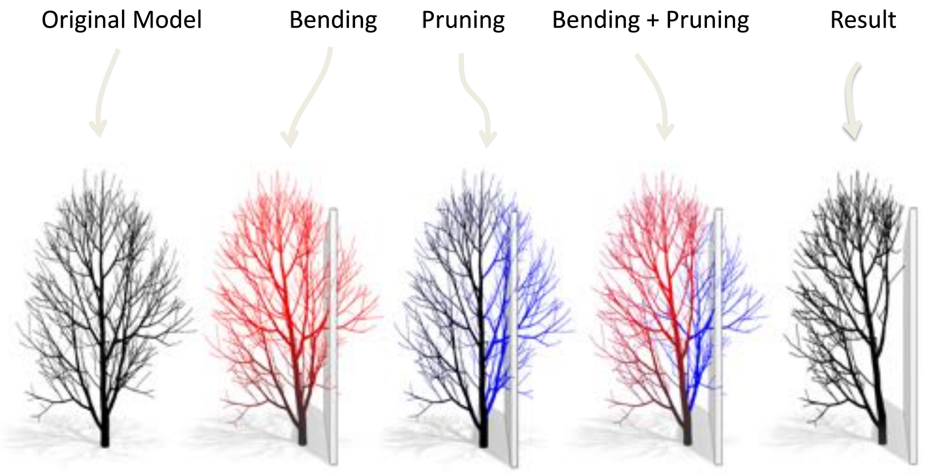
→ required for bending/pruning

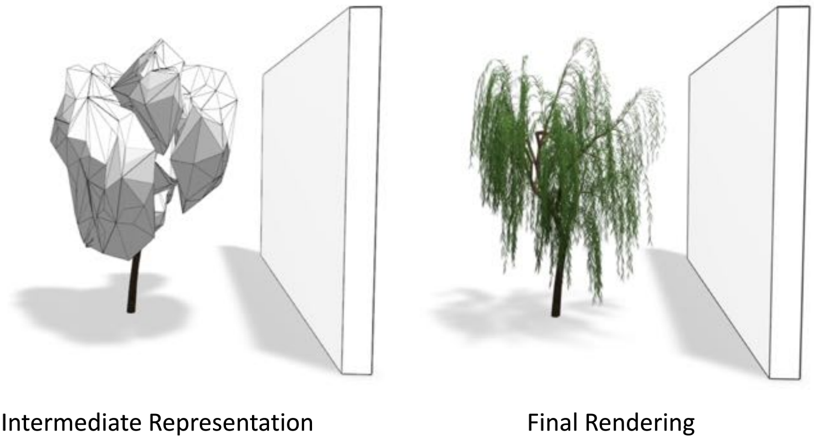
Backward modeling

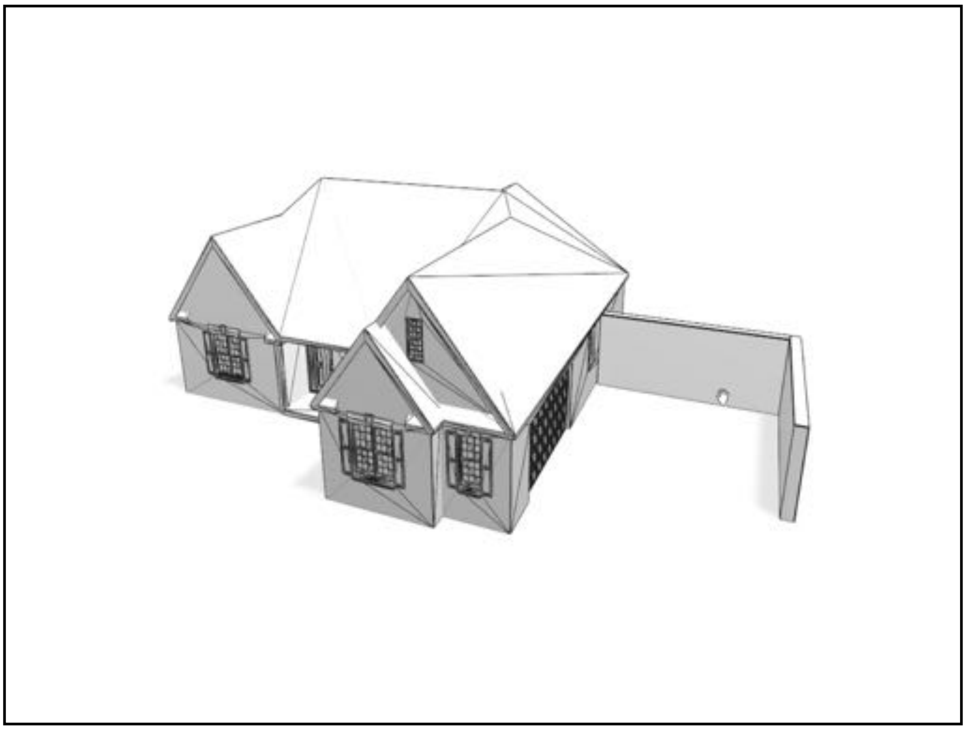


Interaction with obstacle




Original Model
Bending
Pruning
Bending + Pruning
Result


Intermediate Representation
Final Rendering

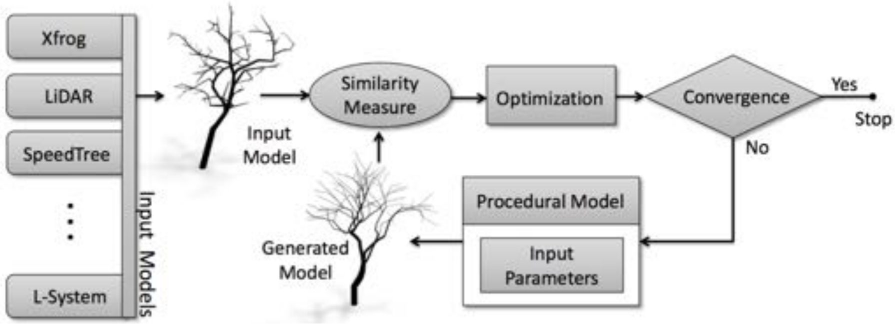


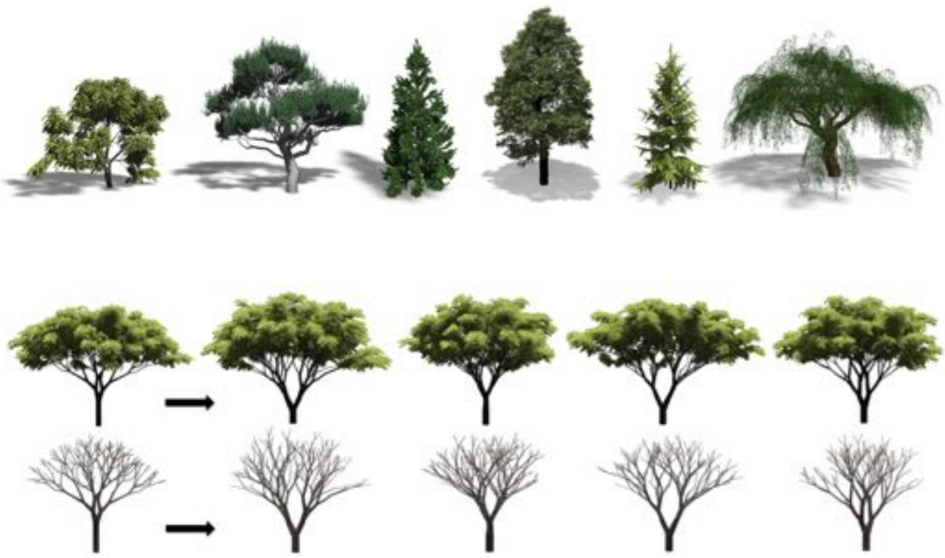

5x faster

Inverse Procedural Modelling

Problem:

- **Inverse modelling (find rules for a given geometry) is NP-hard**
- works only if we reduce the parameter space
- **Thus**: parametric rules are given, parameters are optimized


Xfrog
LiDAR
SpeedTree
L-System
Input Models
Input Model
Similarity Measure
Optimization
Convergence
Yes
Stop
No
Procedural Model
Input Parameters
Generated Model



Computer Graphics Forum, 2014

Inverse Procedural Modeling of Trees

Ondrej Stava[1] and Sören Pirk[2] and Julian Kratt[2] and Baoquan Chen[3]
and Radomír Měch[1] and Oliver Deusseen[2] and Bedrich Benes[4]

[1]Adobe Inc, USA
[2]University of Konstanz, Germany
[3]Shenzhen Institute of Adcanced Technology, China
[4]Purdue University, USA

Animating the Morphogenesis of Trees

S. Pirk, T. Niese, O. Deussen, B. Neubert:
Capturing and Animating the Morphogenesis of Polygonal Tree Models,
ACM Transactions on Graphics (Proceedings of Siggraph Asia), Volume 31 Issue 6, November 2012,

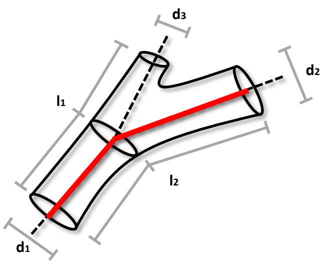
Idea:

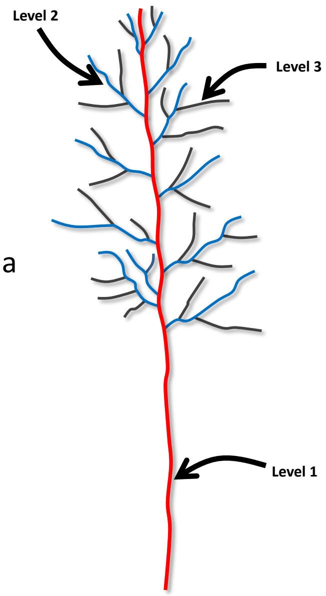
- **Plastic trees:**
  - simple backward computation for interaction
  - Not applicable to create younger/older trees
- **Now:**
  - more elaborate computation for growth animation
  - allows for dynamically changing the age of the models

Skeletal Graph
- Gravelius Order
- Branch Age
- Growth Rate

Measuring the Order of Branches

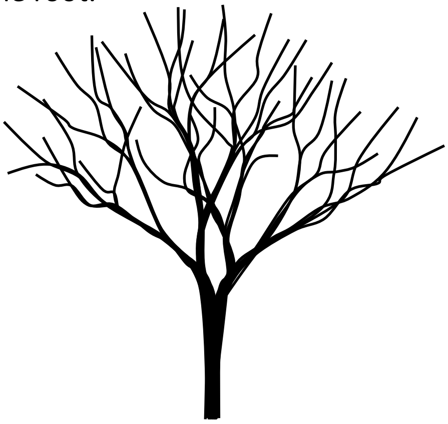
Graveliuls Order:
- Ordering method for identifying hierarchies.
- Determine main trunk based on Angle between branches.
- Also considering length and thickness of a branch.





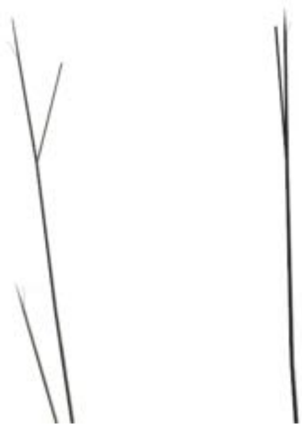
Pipe Model Theory

Plant forms emerge form vascular systems.
- units connecting the leaves to the root.
- provides us with branch radii.



[Shinozaki et al. 1964]

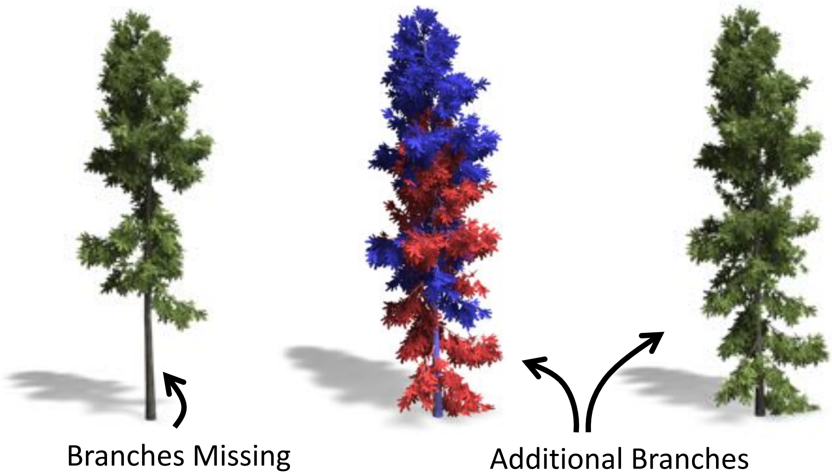
Angle/Radii Interpolation



Intermediate Results

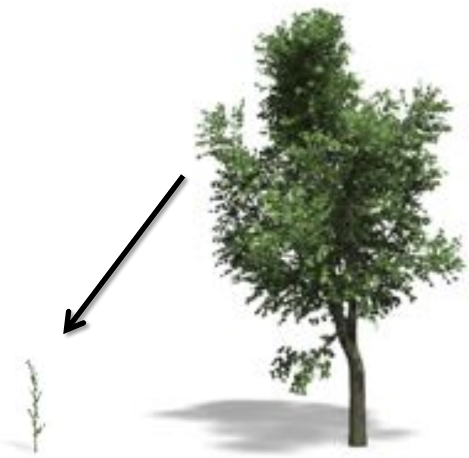
Missing Branches and Leaves

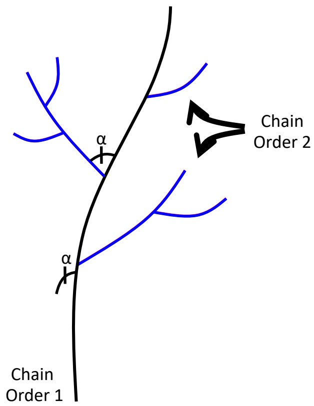
Adding Missing Structures



Utilizing Self-Similarity

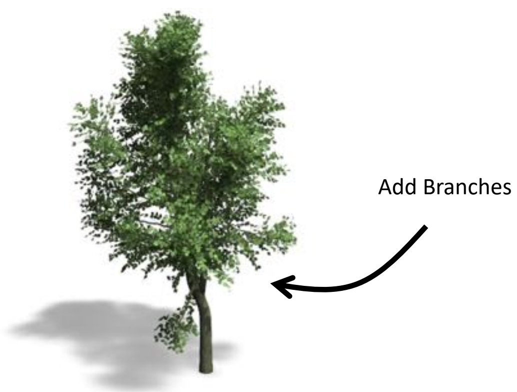
⇒ Copy and Move Branches





Utilizing Self-Similarity

Animation with additional branches.



Animation with additional branches removed over time.

Crown Ratio

General idea:

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

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

Crown Ratio

Overlap Region

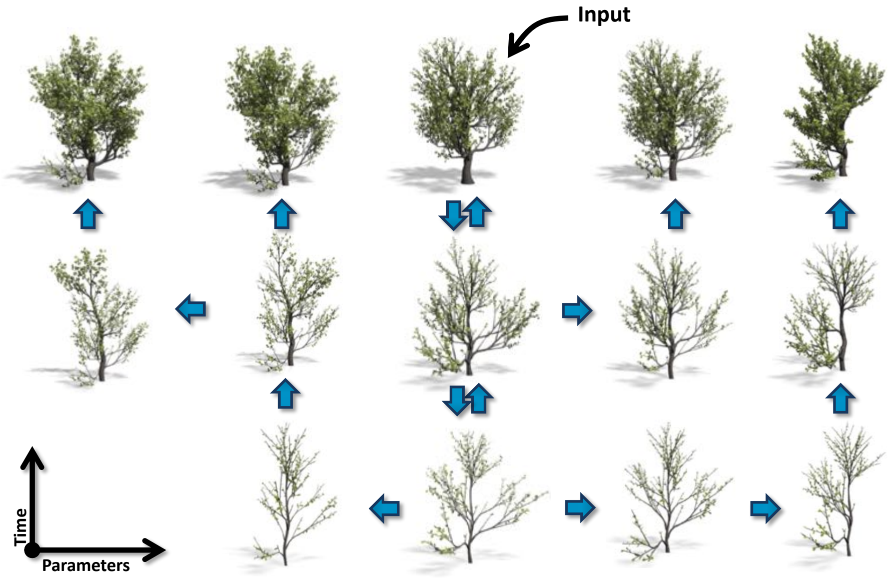
Final Animation of Growth

No Additional Branches

Additional Branches

Additional Branches and Pruning

Growth-based Editing



Growth-based Editing

Individual Growth
of Branches

Various Species

Different Inputs



L-Systems

Xfrog

LiDAR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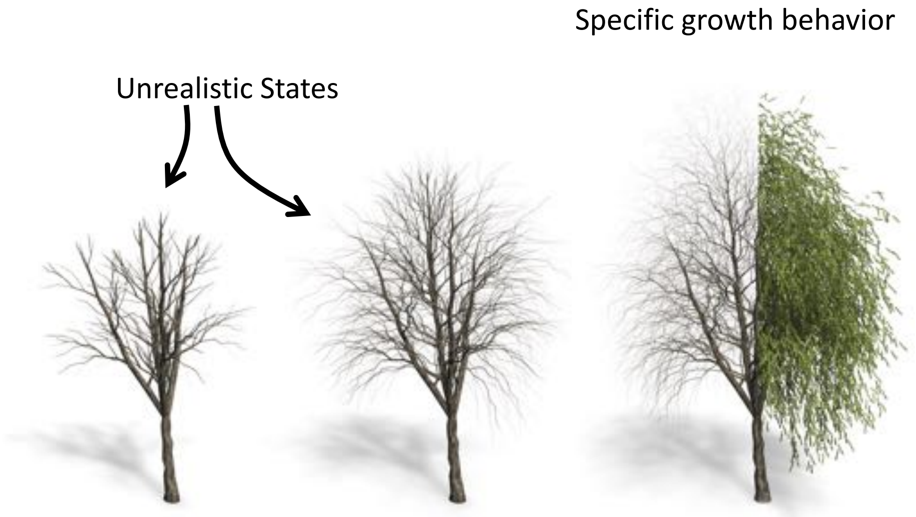
<Thickness factor="2.0" min_thickness="0.00847911"/>
<Branching_Angle mean="45" deviation="5"/>
<Main_Angle mean="0" deviation="8"/>
<Roll_Angle mean="130" deviation="3"/>
<Tropism photo="0.05" gravi="-0.01" level_factor="0.001"/>
<Gravity val=".09009" max_bending="0.89"/>
<Apical_Dominance val="5.59" age_factor="0.979996997" dist_factor="0.5"/>
<Apical_Control val="5.5" age_factor="0.91" levl_factor="0.91"/>
<Pruning strength="0.48" low_branch_pruning="5.5" translucency="0.3"/>
<Internode length="0.55" age_factor="0.95"/>
<Buds numLateral="1" lateral_killP="0.01" apical_killP="0.000"/>
<Buds_Light lateral_factor="0.03" apical_factor="0.5001"/>
<Resources cost="4.25"/>
</Model>
```



Limitations

⇒ so far only monopodial trees

Limitations



Interactive wind-based modeling

Windy Trees: Modeling Stress Response of Botanical Tree Models

submission id: 0268

Summary

- Early years: **pure modelling approaches**
  - L-Systems (rule-based grammars)
  - Procedural systems
- **Modelling of ecosystems**
  - Biological simulation (individuals that interact)
- **Data-driven approaches**
  - Efficient storage of captured models
  - Making static models dynamic
  - Inverse procedural modeling