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MODELING PLANT LIFE IN COMPUTER GRAPHICS

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Crops *in silico*

MOTIVATION

- Computer graphics is about:
  - Shape
  - Light
  - Fast feedback

OVERVIEW

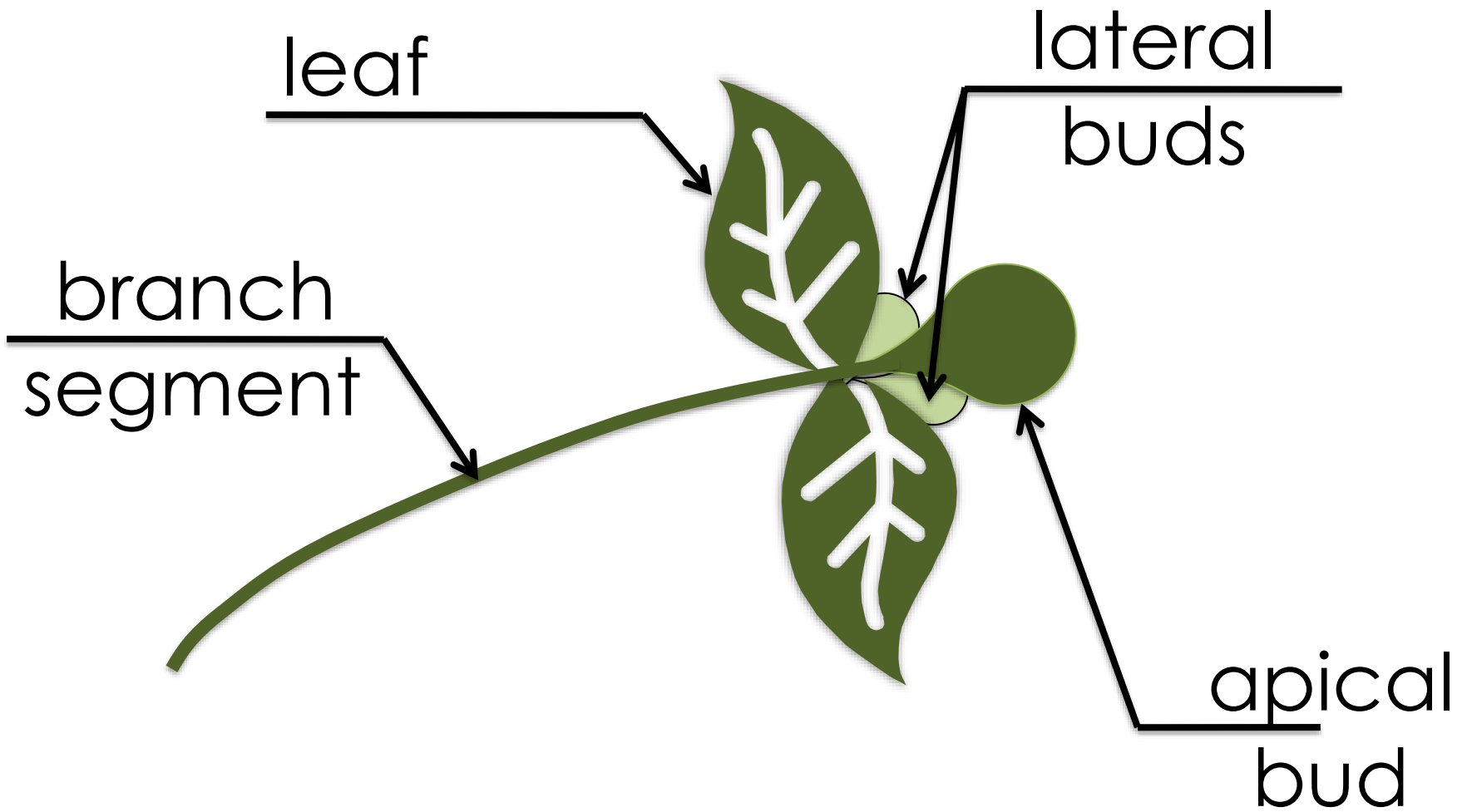
- Plant model (in Computer Graphics)
- Inverse Modeling
- Physics-based model
- Interactive models

PLANT MODELS IN CG

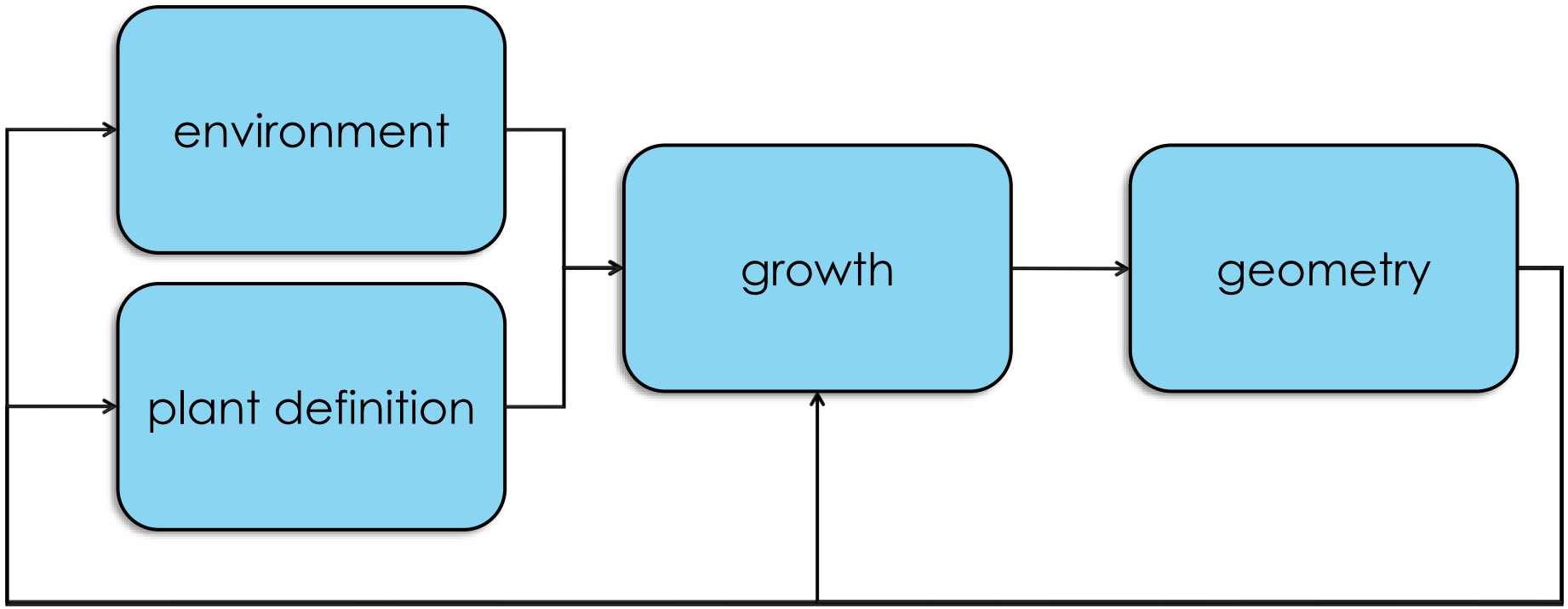
PLANTS IN COMPUTER GRAPHICS

- Biologically-based simulations
- Plant is a modular system – basic elements (leaves, internodes, etc.)
- Plant geometry is the **emergent phenomenon** from the interaction of its modules

PLANT MODULES



A GENERIC PLANT MODELING SYSTEM



DEVELOPMENTAL MODEL

Geometric Params

Growth Rate
Internode Length
Internode Angle Factor
Apical Control Level
Apical Dominance Factor
…

Environment Params

Gravitropism
Phototropism
Pruning Factor
Low Branch Pruning Factor
Gravity-bending Strength
…

Bud Fate Params

Apical Angle Variance
Number of Lateral Buds
Branching Angle Mean and Variance
Roll Angle and Variance
Apical and Lateral Light Factor
…

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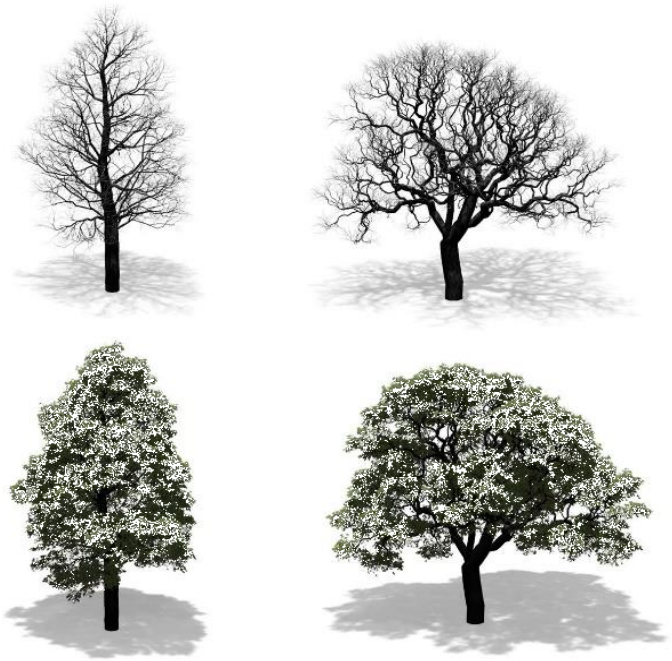
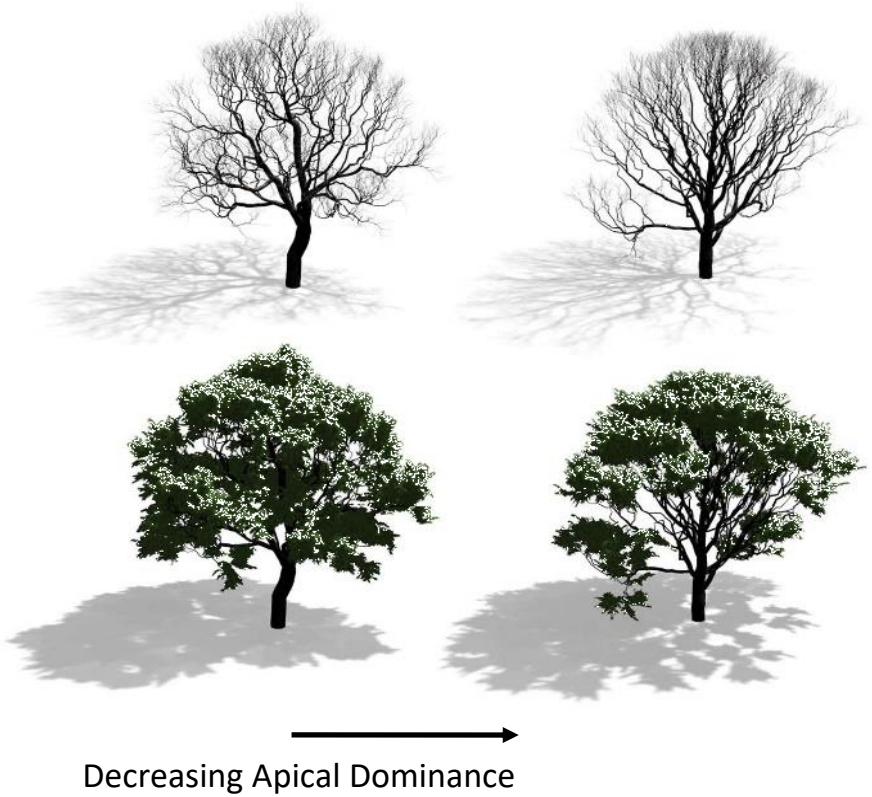
DEVELOPMENTAL MODEL

Increasing Branching Angle



Decreasing Apical Control



Decreasing Apical Dominance

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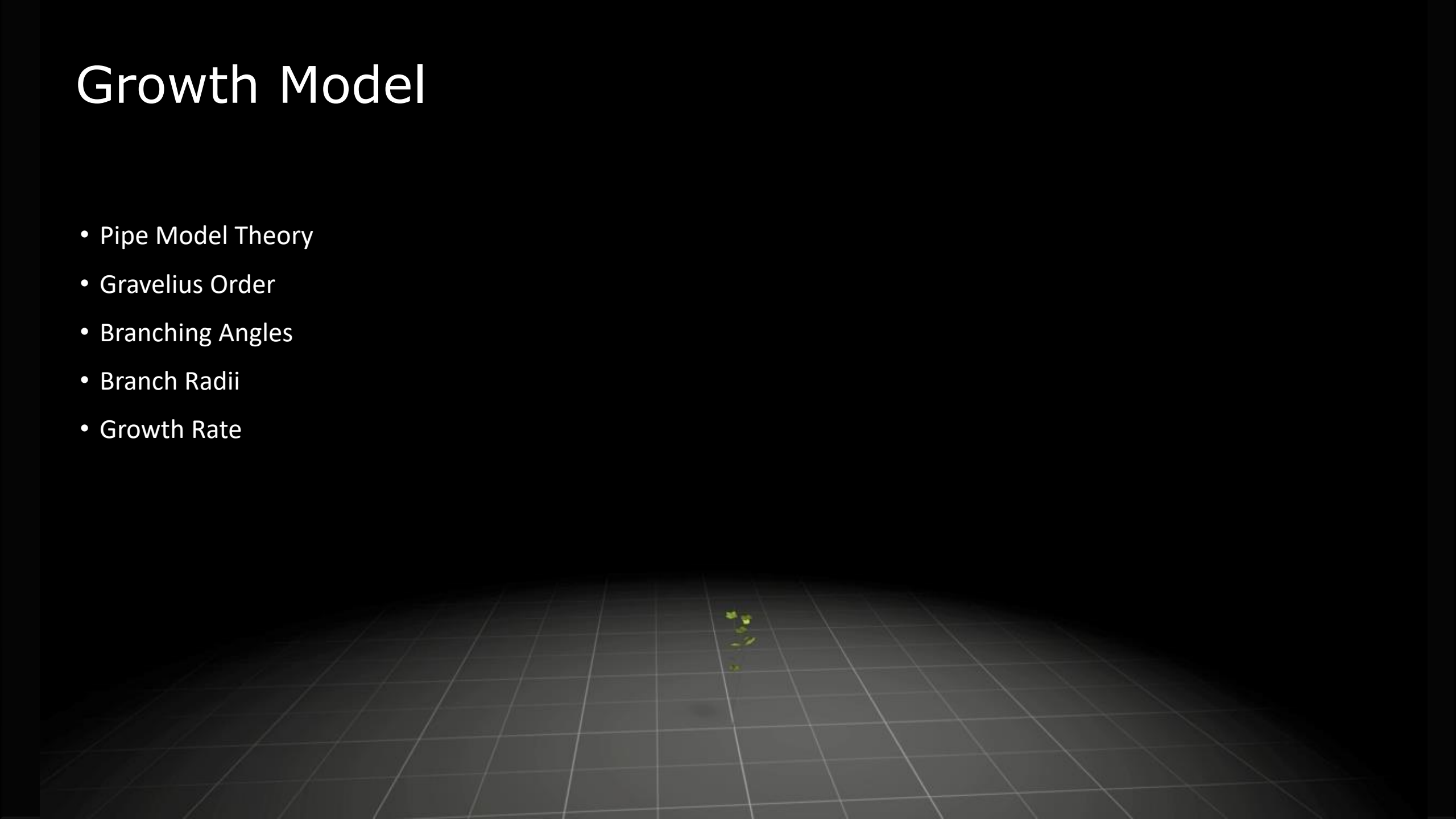
Growth Model

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



INVERSE BIOLOGICAL TREES

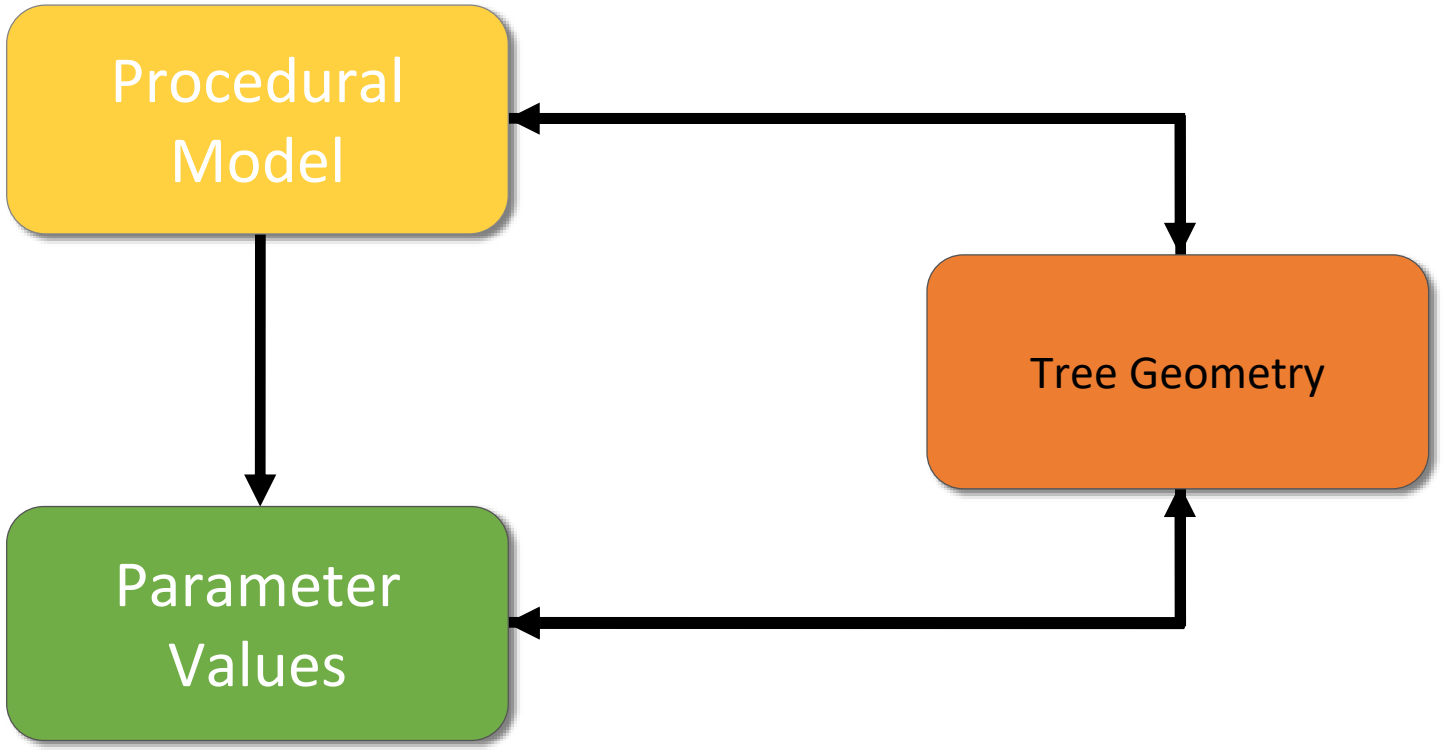
INVERSE BIOLOGICAL TREES

?

```
Angle={COUNT} : set angle used by '+' and '-' below to 360/{COUNT}
Angle {COUNT} : set angle used by '+' and '-' below to 360/{COUNT}

Axiom={COMMANDS} : set starting set of commands to {COMMANDS}
Axiom {COMMANDS} : set starting set of commands to {COMMANDS}

{COUNT}+  : turn left {COUNT} times. if {COUNT} is omitted, use 1
{COUNT}-  : turn right {COUNT} times. if {COUNT} is omitted, use 1

|         : turn 180 degrees or the largest possible turn < 180 degrees

f         : draw a line using the current direction/length
g         : move forward instead of drawing

\{ANGLE}  : turn left {ANGLE} degrees
/{ANGLE}  : turn right {ANGLE} degrees

d         : draw a line using the current direction/length
m         : move forward instead of drawing

[         : save state (position, angle, size, etc.)
]         : restore state

!         : reverse the meaning of '+' and '-' and '\' and '/'

@{SCALE}  : multiply the current line length by {SCALE}
@q{SCALE} : multiply the line length by the square root of {SCALE}
@I{SCALE} : multiply the line length by the reciprocal of {SCALE}

c{INDEX}  : set color map index to {INDEX}

<{COUNT}  : increment color map index by {COUNT}
>{COUNT}  : decrement color map index by {COUNT}

{LETTER}={COMMANDS} : associate {COMMANDS} with character {LETTER}
```

Stava, O., Pirk, S., Kratt, J., Chen, B., Mech, R., Deussen, O., and Benes, B., (2014) Inverse Procedural Modeling of Trees , in Computer Graphics Forum, Vol 33(6), pp. 118-131,

Procedural Modeling



OPTIMIZATION

- Find parameters for the developmental model
- Maximize similarity between the input and the generated instance
- *What does similar mean?*

Fitness function based on geometry, shape and structure

Input Mesh

?

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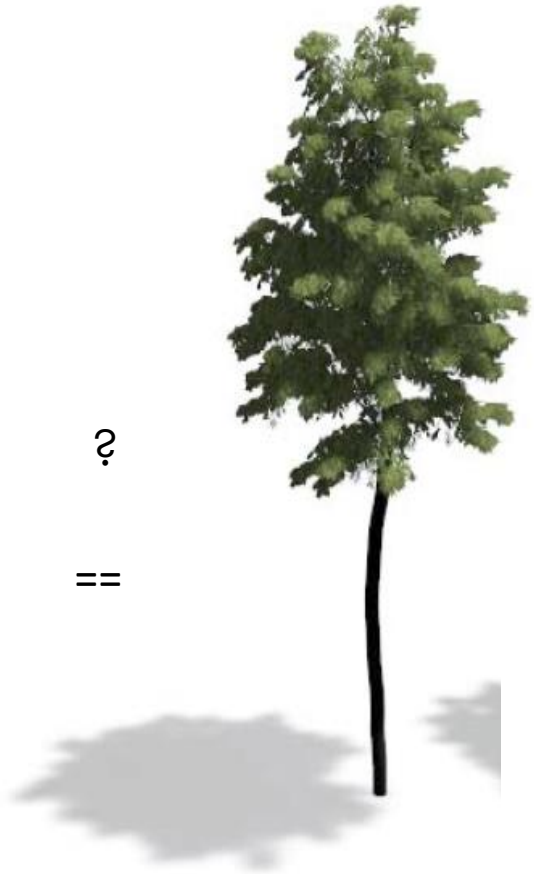
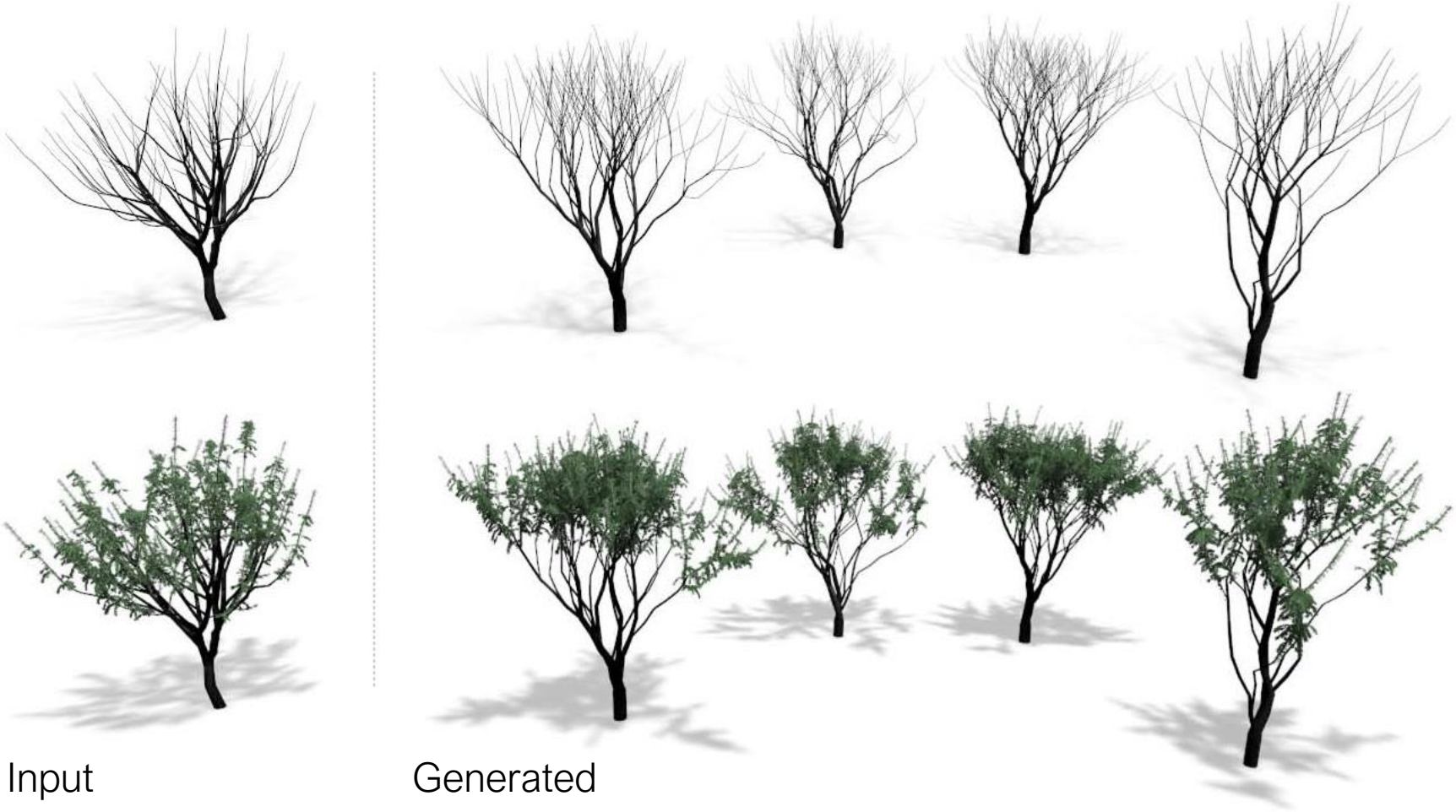


Generated Output

INVERSE MODEL



Input

Generated

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INVERSE MODEL

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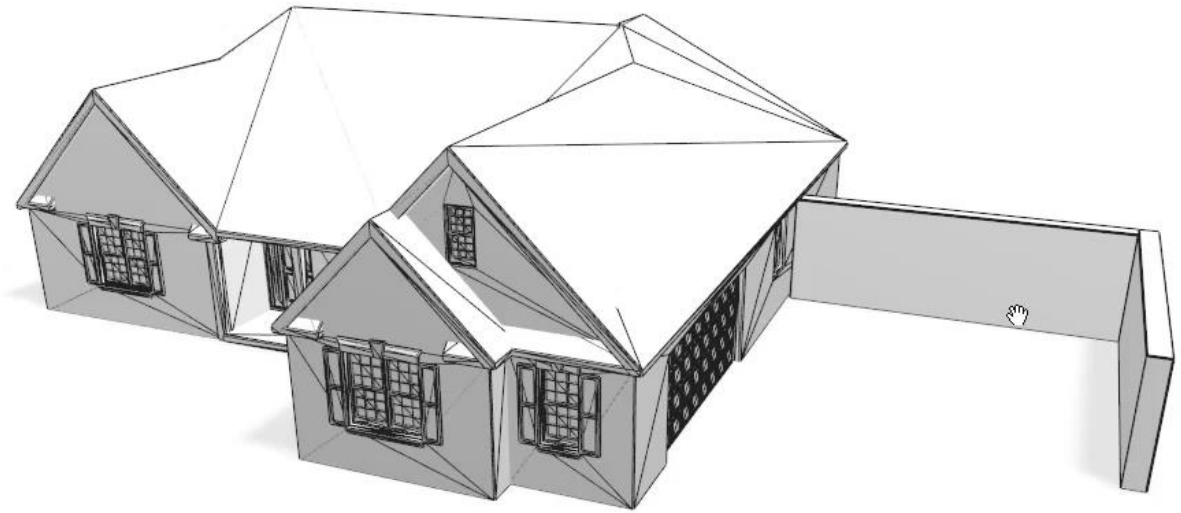
INVERSE MODEL

Crops *in silico*

INTERACTIVE PLANT MODELS

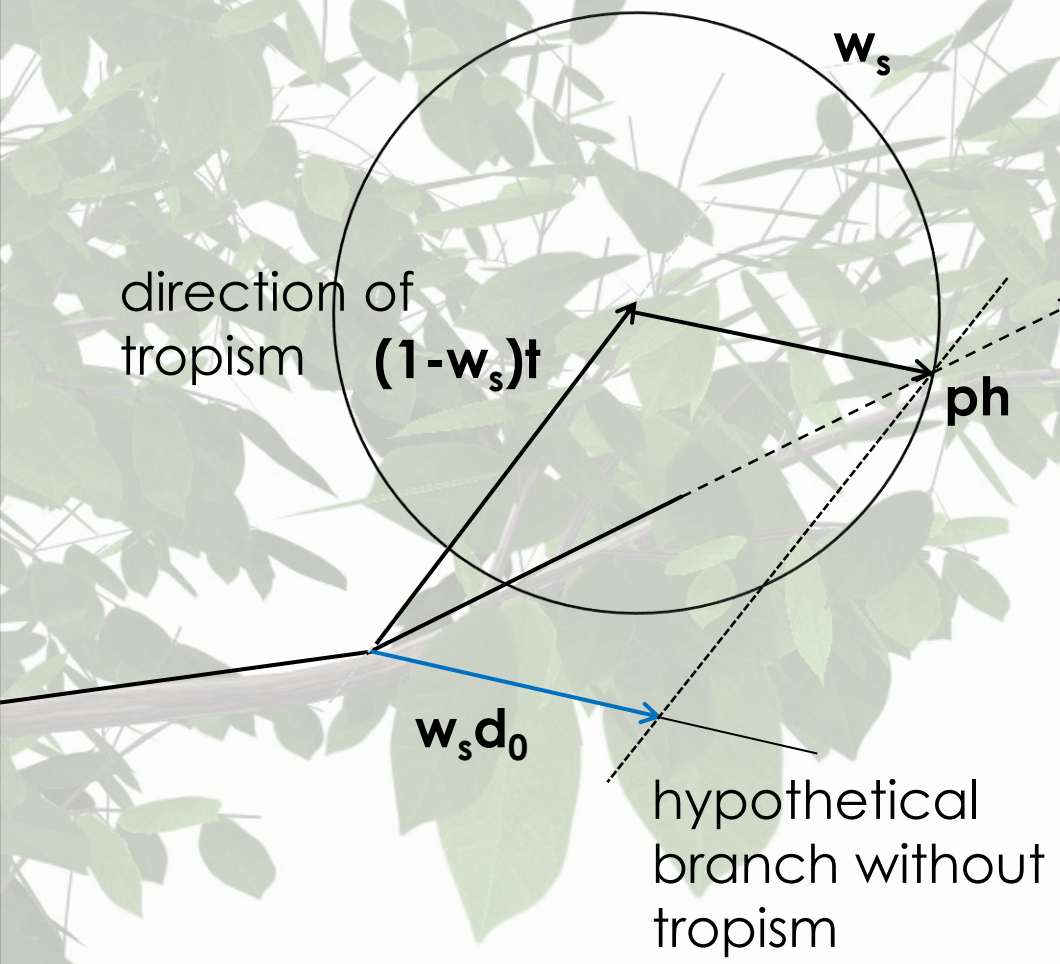
PLASTIC TREES

Pirk, S., Stava, O., Kratt, J., Massih-Said, M.A., Neubert, B., Měch, R., Benes, B., and Deussen, O. (2012) Plastic trees: interactive self-adapting botanical tree models. *ACM Trans. Graph*. 31, 4



ENVIRONMENT AWARE TREES

INVERSE TROPISM



Backward modeling to estimate influence of tropisms to the original model

→ allows to apply tropisms triggered by the new environment

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DYNAMIC INTERACTION - BENDING

New Direction

combination of tropisms

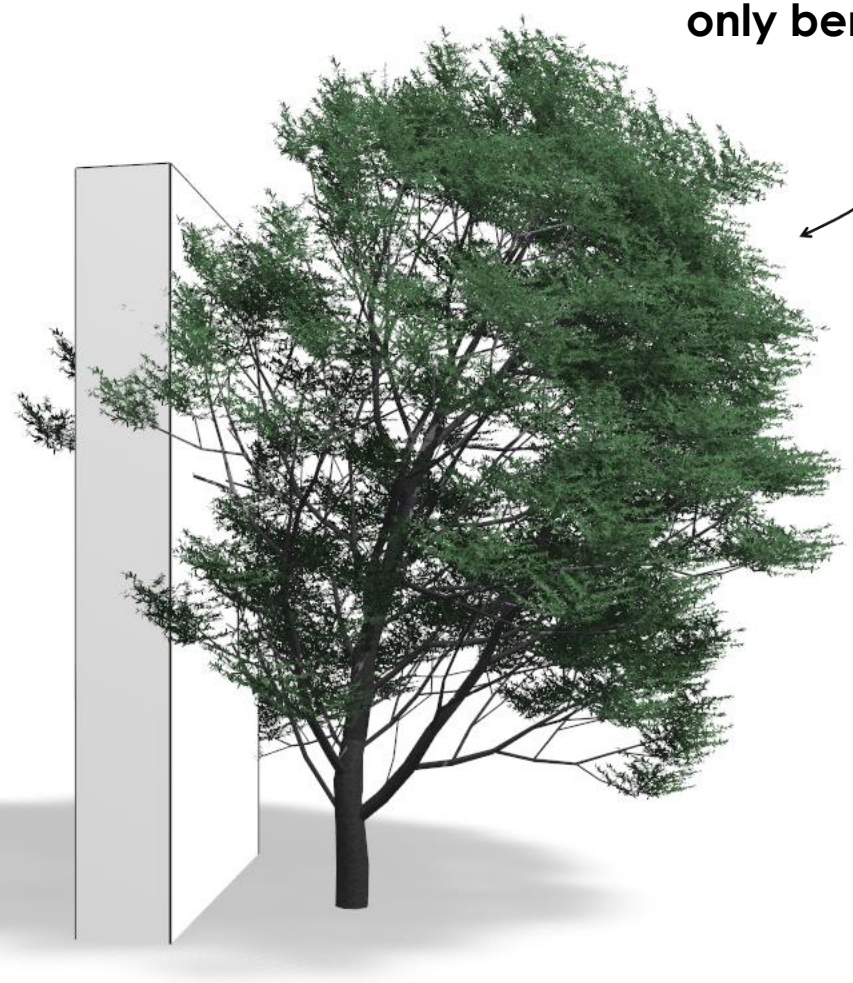
$$\vec{h} = w_s \vec{d}_0 + (1 - w_s) \frac{\sum w_\tau \vec{t}_\tau}{\sum w_\tau}$$

new direction

start weight

normalized direction

weights of tropisms



Transformations represent changes in the tree growth.

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DYNAMIC INTERACTION - PRUNING

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

Amount of Light received by the leaf-cluster.

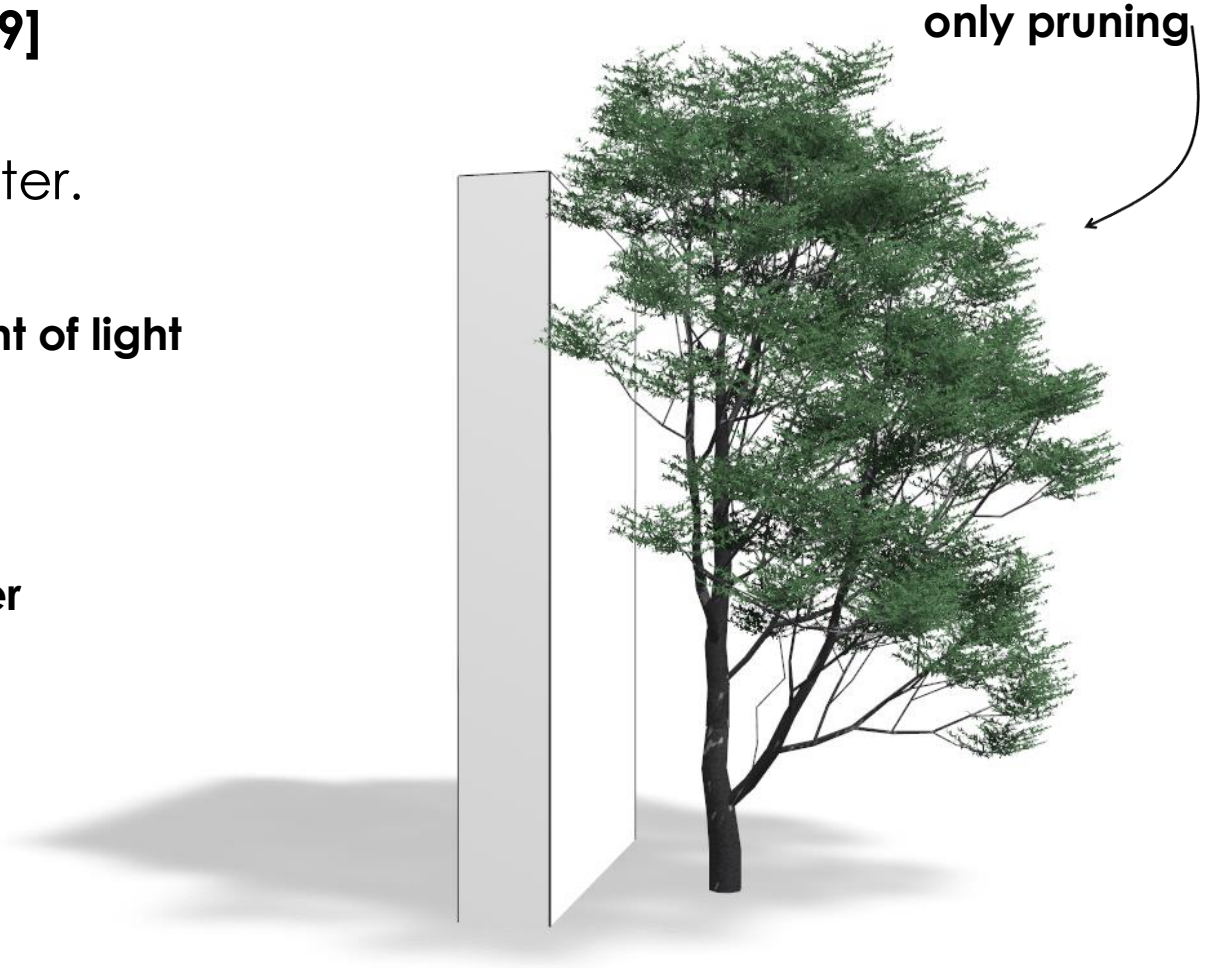
$$\varphi_{t_s} = \sum_{c \in C_s} 2\pi {r_c}^2 i_c$$

normalized amount of light

amount of resources (light)

radius of a given cluster

l_t: **sum of distances**



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

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TREE/OBSTACLE INTERACTION

Original Model | Bending | Pruning | Bending + Pruning | Result

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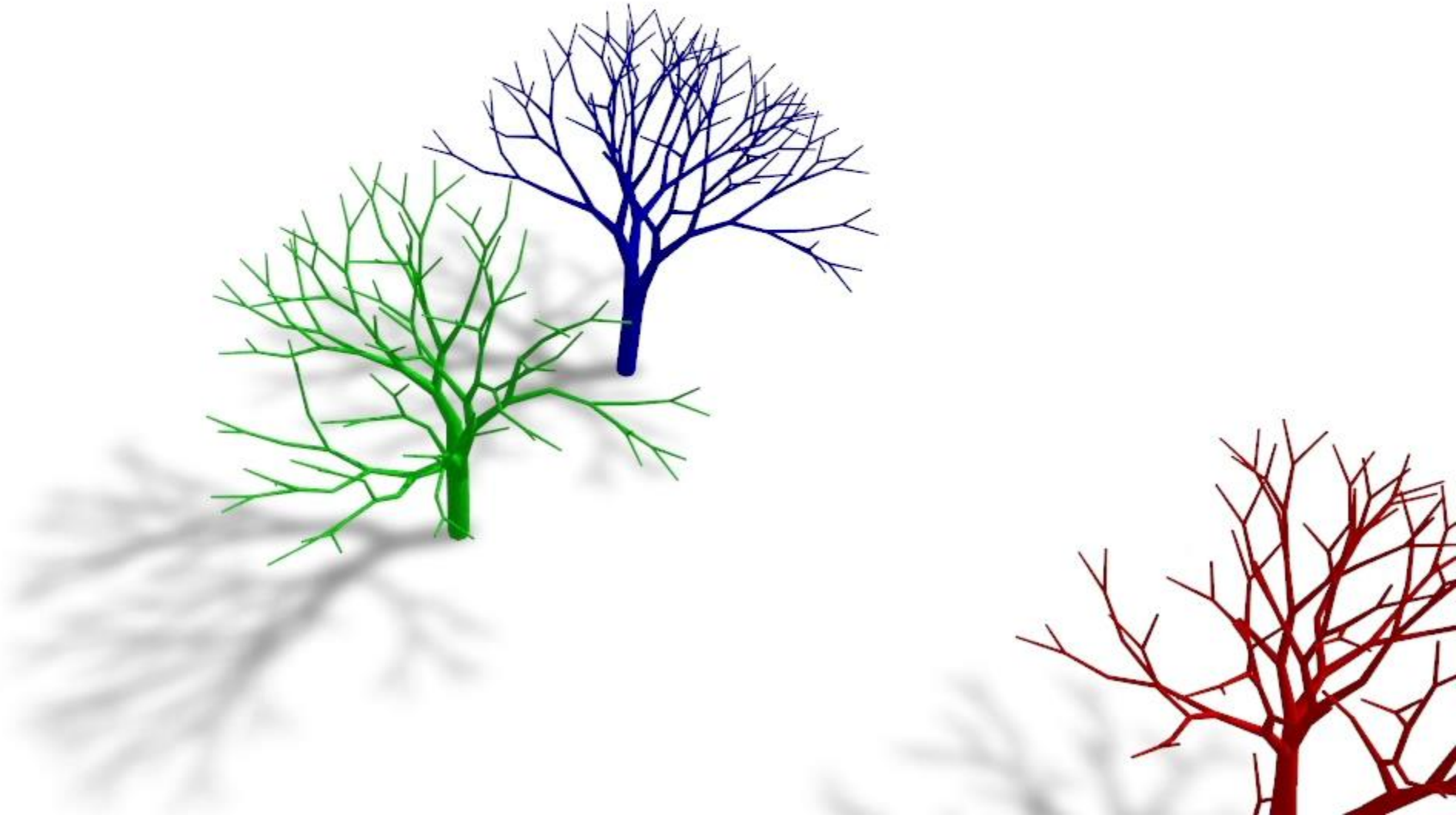
TREE/TREE-INTERACTION



TREE/TREE-INTERACTION

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PLASTIC TREES

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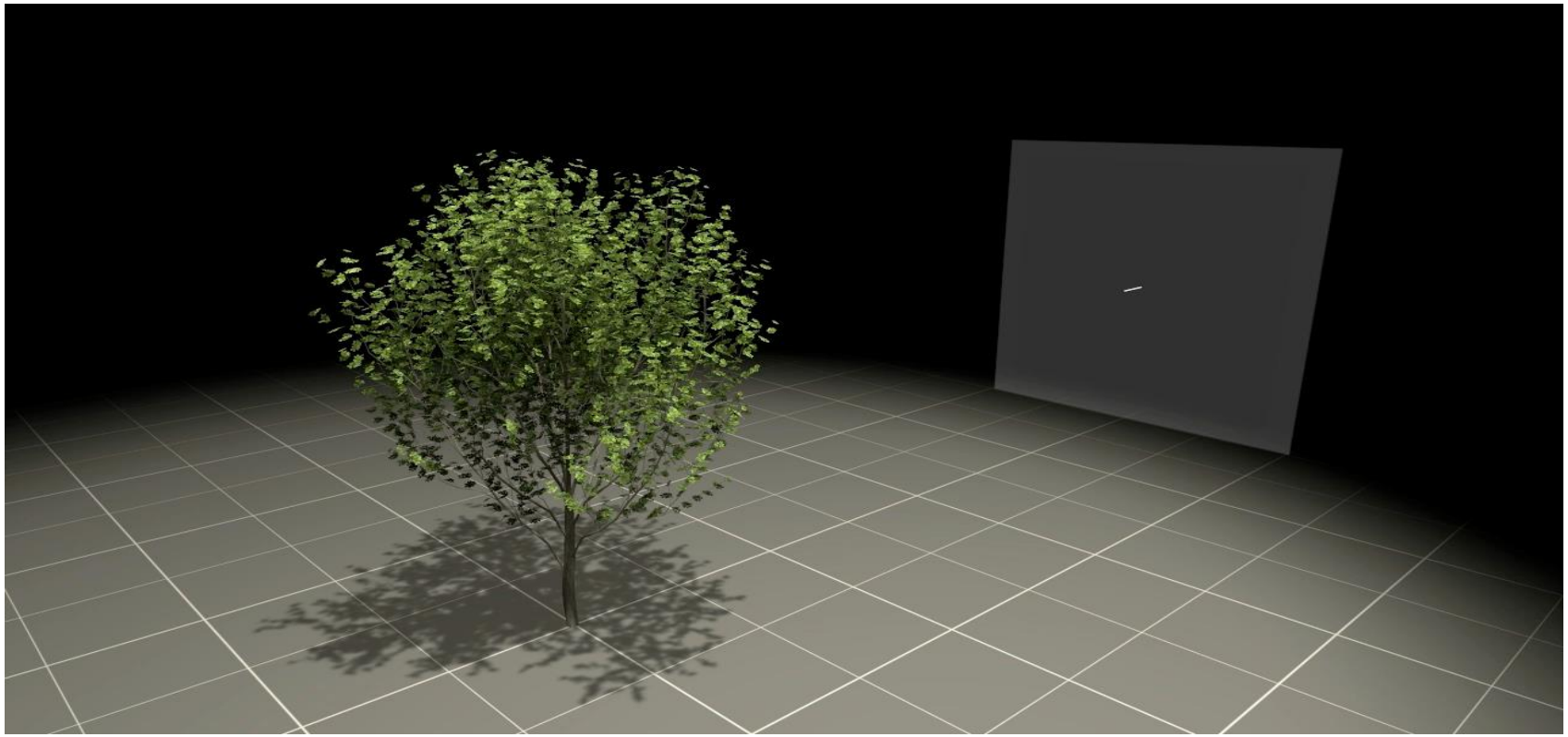
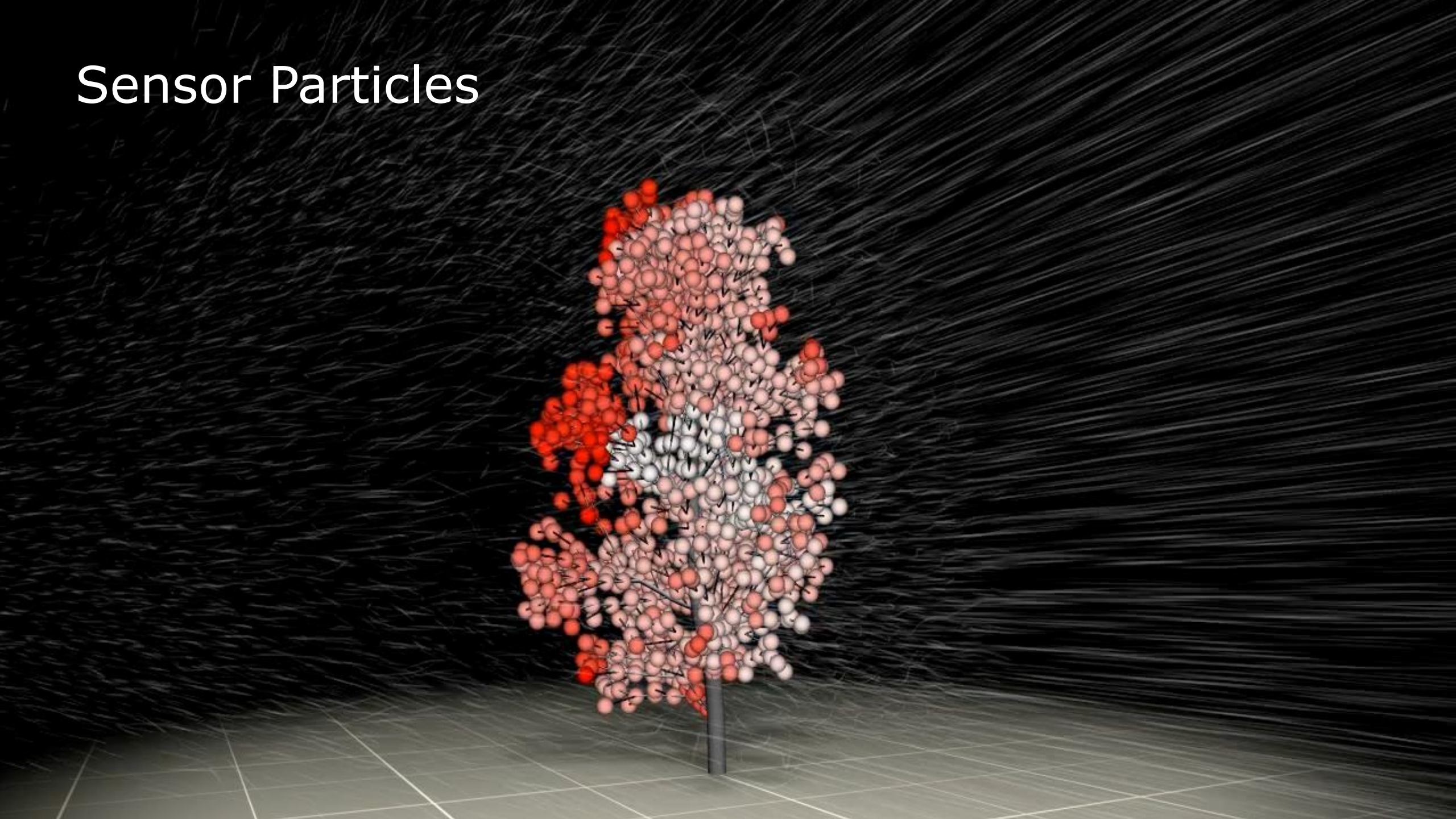
INTERACTIVE PLANT MODELS WITH PHYSICS

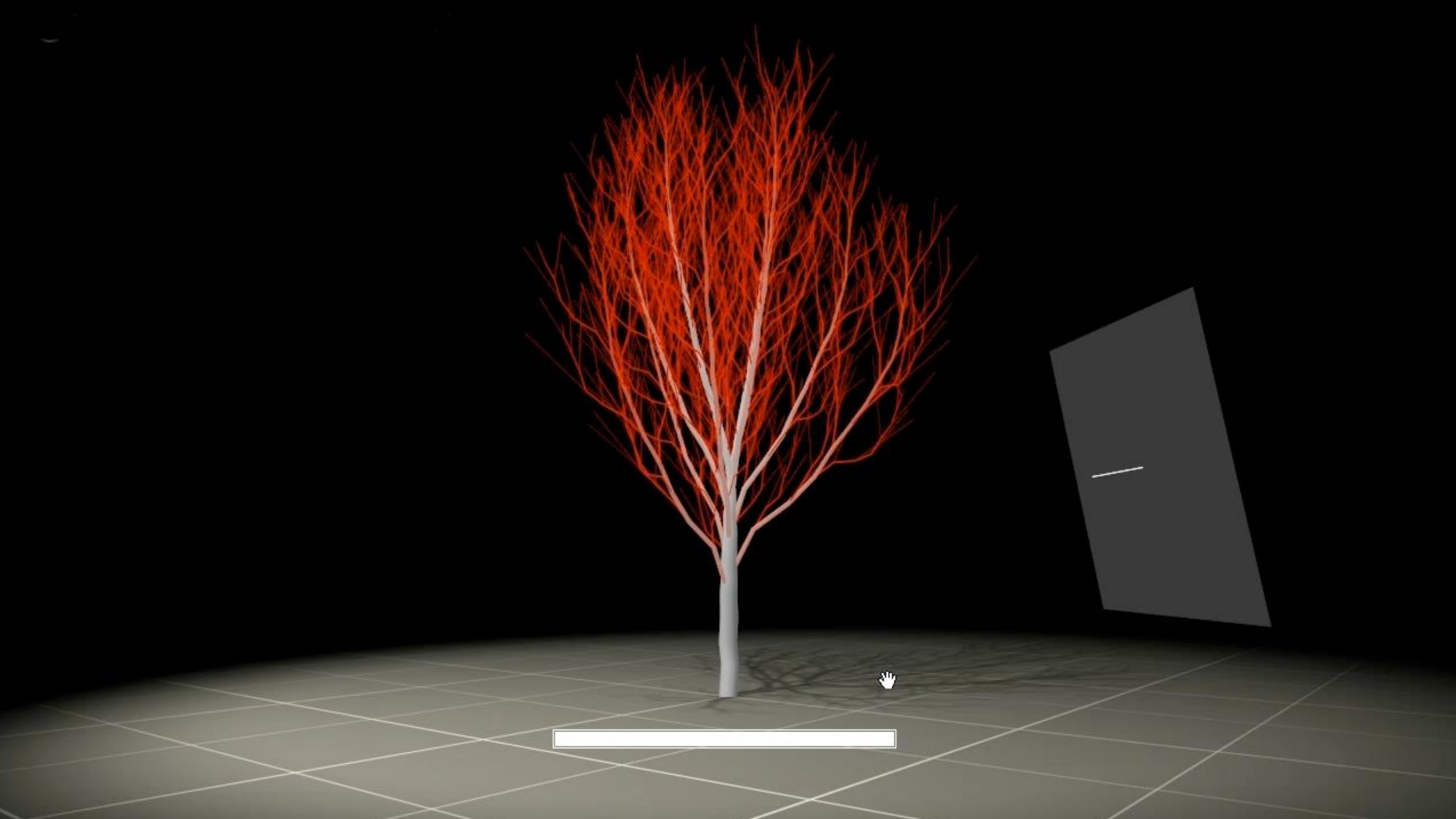
PHYSICS INTERACTION

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



Sensor Particles






5 x faster

CONCLUSIONS

- Plants can be viewed as complex dynamic systems
- Shape is an emergent phenomena
- Many things "pass through" the complexity
  - Phyllotaxis
  - Bud ⇒ Blossom ⇒ Fruit cycles
  - Geometry
- They are complex yet "regular"
- Simulations provide emergent geometry

OPEN PROBLEMS

- Control
- Capturing real plants and bringing them into simulations
- Understanding complex dynamics (feedback cascades of events)
- Model validation