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Grow by even Spread

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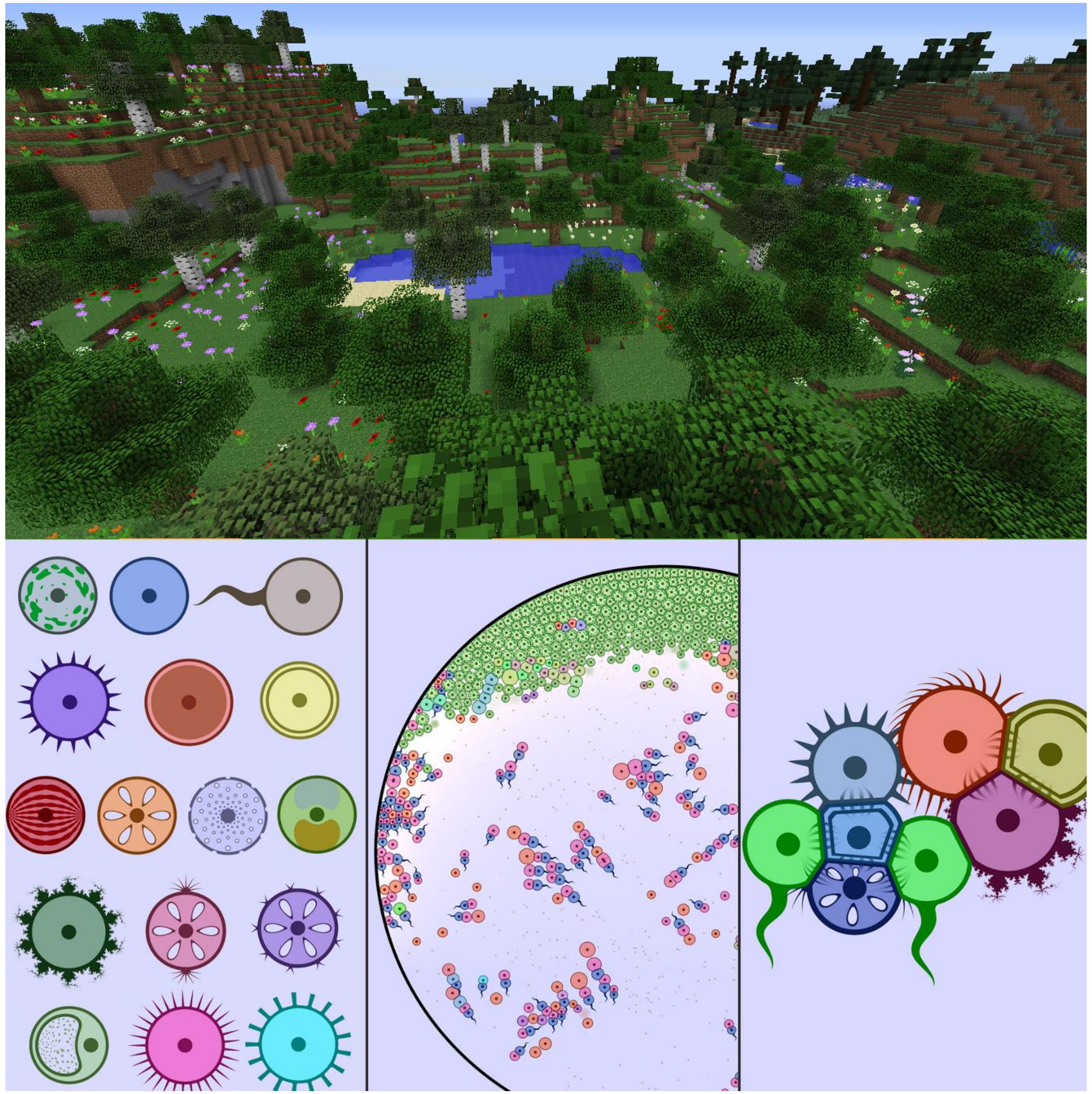
Biological Trees and Trees Generated by our Algorithm

Outline

1. Related Work
2. Fundamental Ideas
3. Features and Simulated Environmental Influences
4. Results and Behavior of the System

Related Work: Simulated Ecosystems

- Many games have design elements with some sort of ecological influence
- Yet they usually recreate high-level behavior by description
- Instead, we will try to set low level rules with many degrees of freedom
- Real-life-similar behavior should emerge from these basic rules



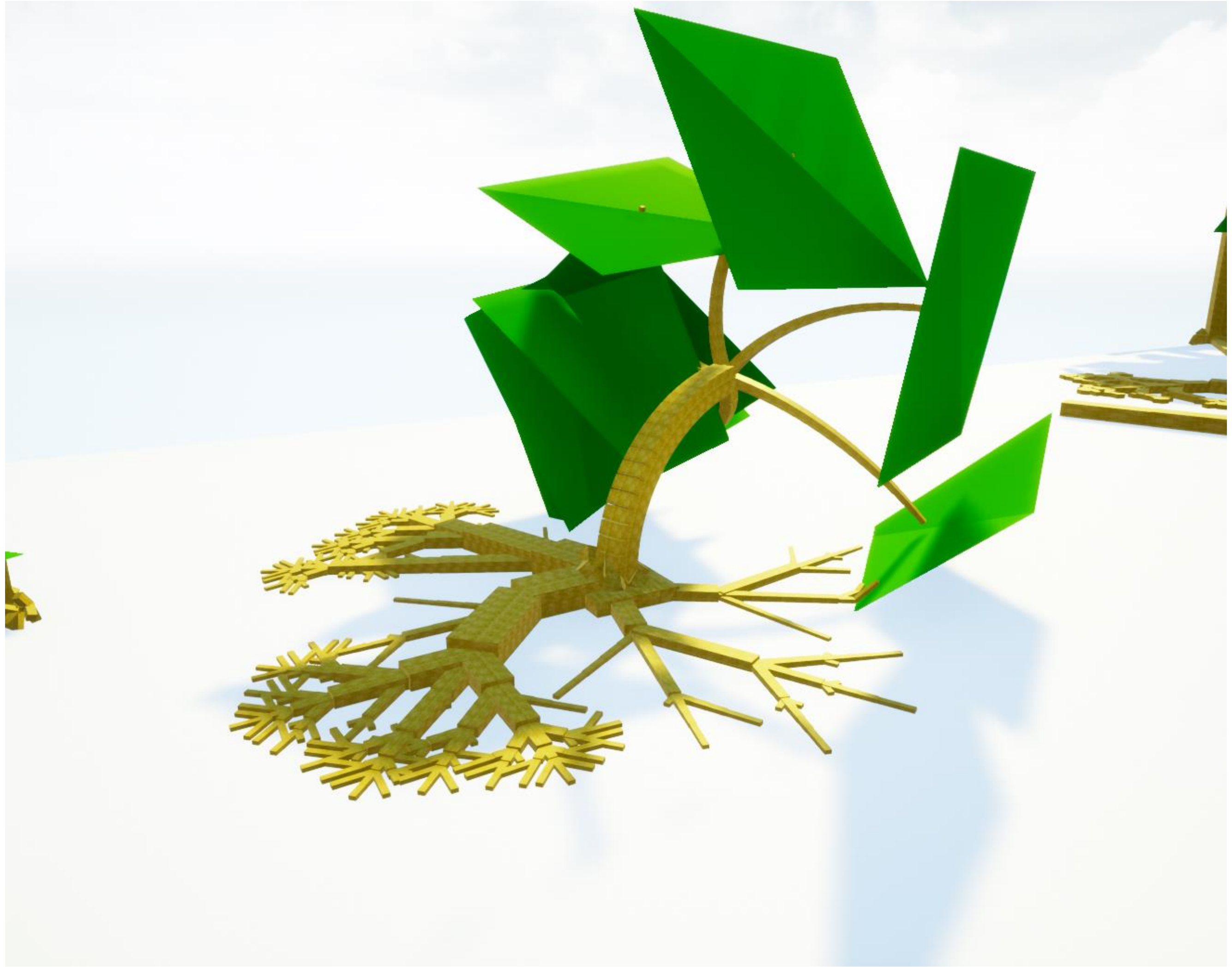
Top: Minecraft; Bottom: CellLab

Related Work: Procedural Plant Generation

- Procedural plant generation has great commercial relevance (SpeedTree)
- State of the art for generation are Lindenmayer-Systems
- L-Systems are formally defined as a string-manipulating system
- With the aid of simple drawing rules, they can express self-similarity excellently
- Thus, impressive results can be achieved (figure)
- L-Systems are unfit for low-level randoming, and interactions of different organisms based on 3D Space

Fundamental Ideas

- L-Systems gave the initial idea, but the formal constraints of those were dropped
- Basis of the simulation are cells with certain properties and their 3D-representation
- Cells have types (e.g., “leaf”)
- Basis of growth is the division of cells into cells of the same or different type
- Every cell (except the root) has an “attachement parent”, and the childs position is calculated relatively to the parent



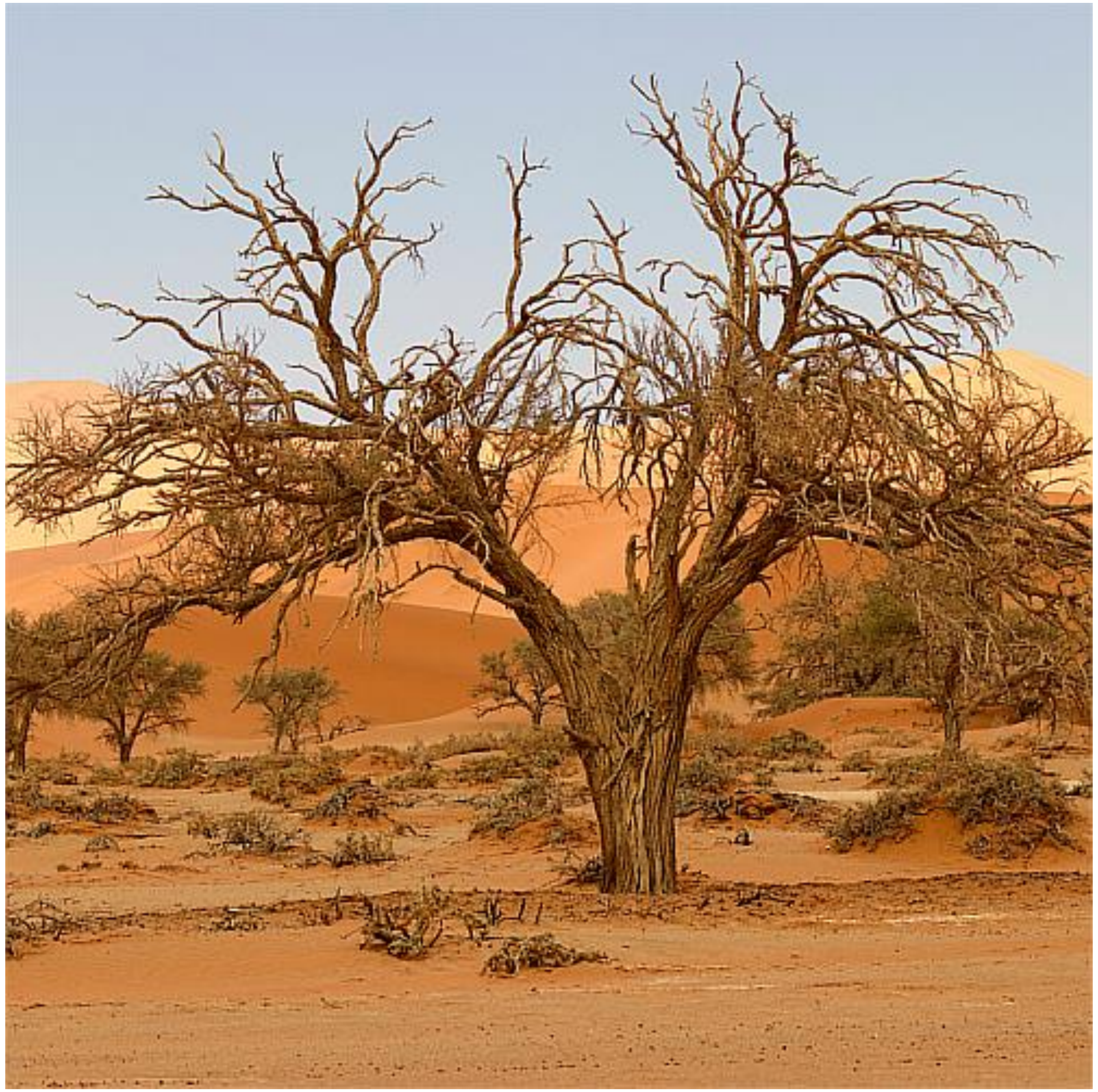
Even Spread and Self-Similarity I

- Many plant shapes are describable by even spreads with certain degrees of freedom, centered on an origin
- In general, this freedom is radially symmetric in growth direction
- Thus, the freedom is defined by α_{min} and α_{max} (the allowed deviation in growth direction)
- The growth objects then take positions with maximal distance to each other

Different Even Spreads in Blossom

Even Spread and Self-Similarity II

- For punctiform origins, the two angles represent two circles on a sphere
- E.g., for blossom leaves is $\alpha_{max} - \alpha_{min} \approx 0$
- Tree branching can be described by even spread of a small number of branches
- A tree is then a concatenation of branchings (self-similarity)
- Plant structures as different as rose blossoms, dandeilion seed heads and trees can be described by this concept



Biological Tree Branching

Division Rules

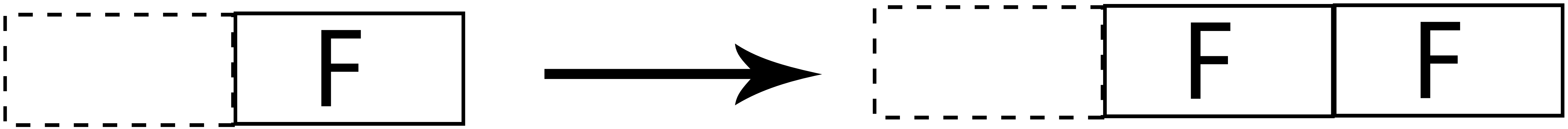
$$K \xrightarrow{\text{time}}, F, H \quad \text{(vertical)}$$

$$F \xrightarrow{\text{time}}, F, F \quad \text{(vertical)}$$

$$H \xrightarrow{\text{light}}, \overbrace{K, \ldots K}^{k} \quad \text{(horizontal)}$$

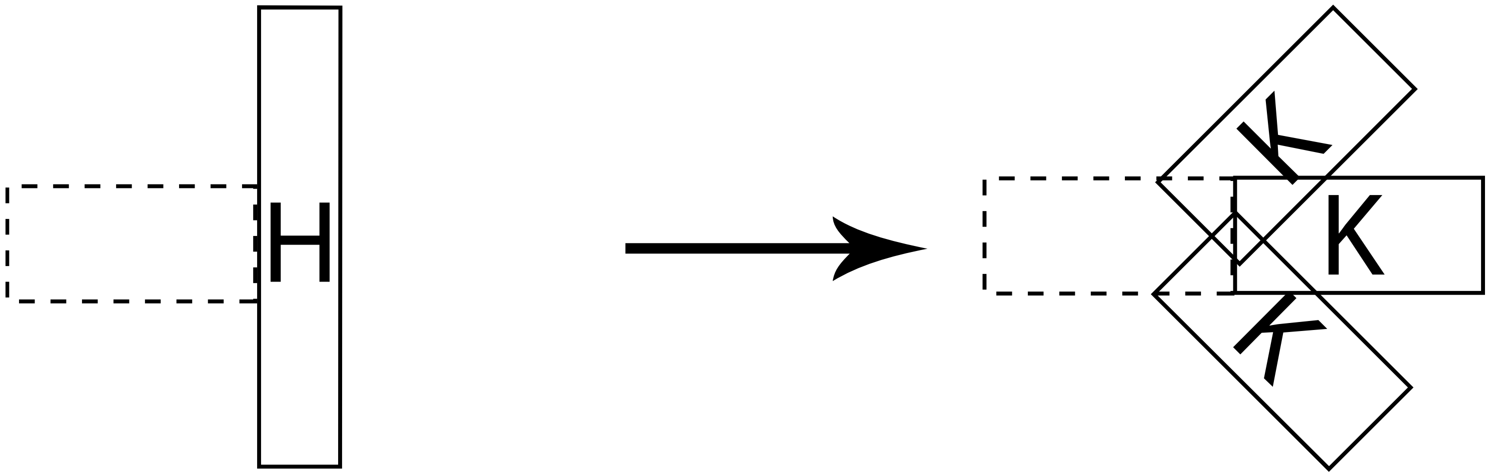
$$H \xrightarrow{\text{time}}, \overbrace{K, \ldots K}^{k'} \quad \text{(horizontal)}$$

Division Rules



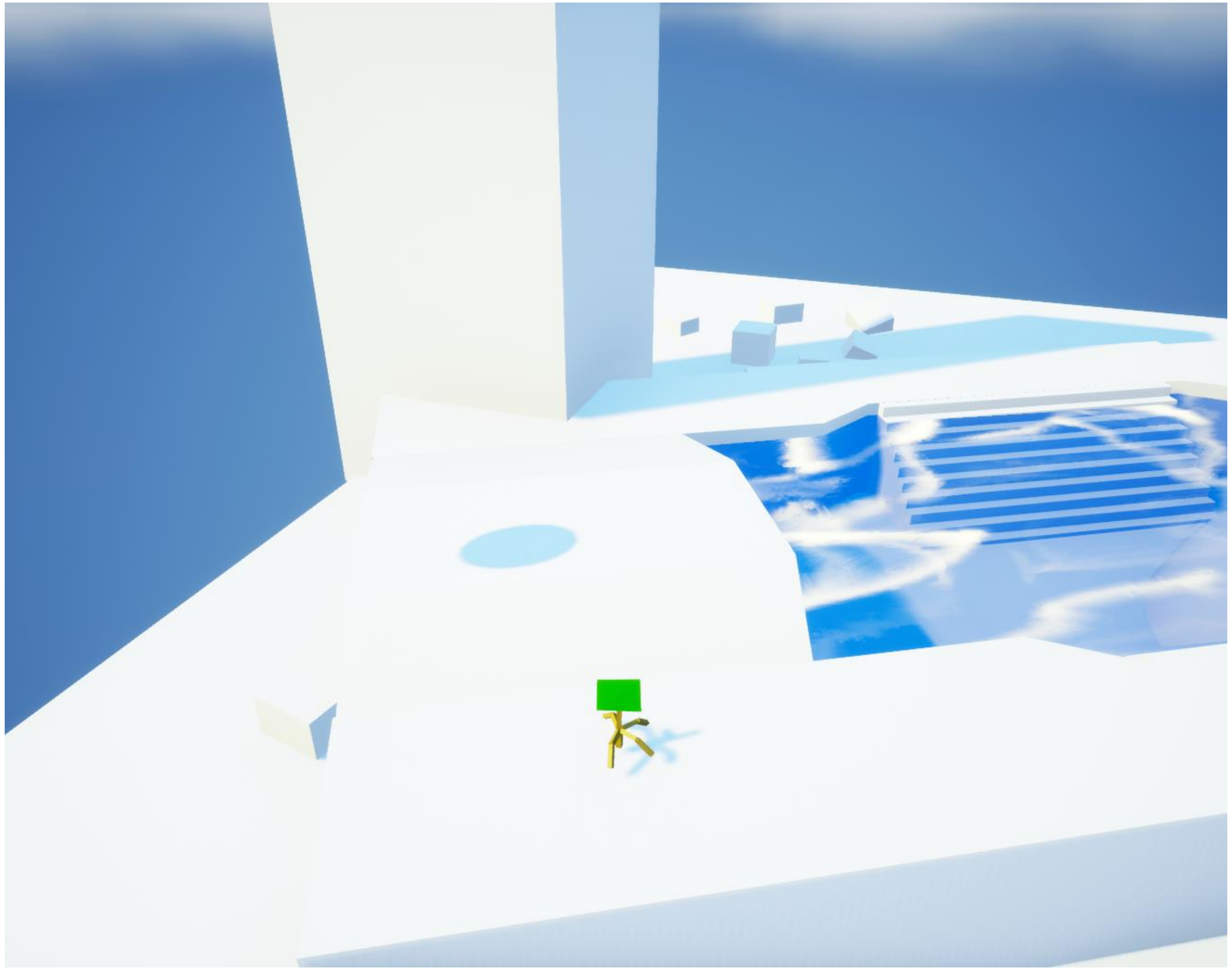
- Vertical division means „straigth“ growth into a branch
- There are multiple *F* states, so that plants grow faster near the “tip”

Division Rules



- Horizontal division means the creation of a branch fork by an even spread
- For cells not growing on the ground, *H* are the leaf cells
- *H* divides into k cells when hit by light, and into k' cells after a time t
- In general is $k > k'$ such that plants grow "towards the light"

Plant Growth Example



5 Iterations

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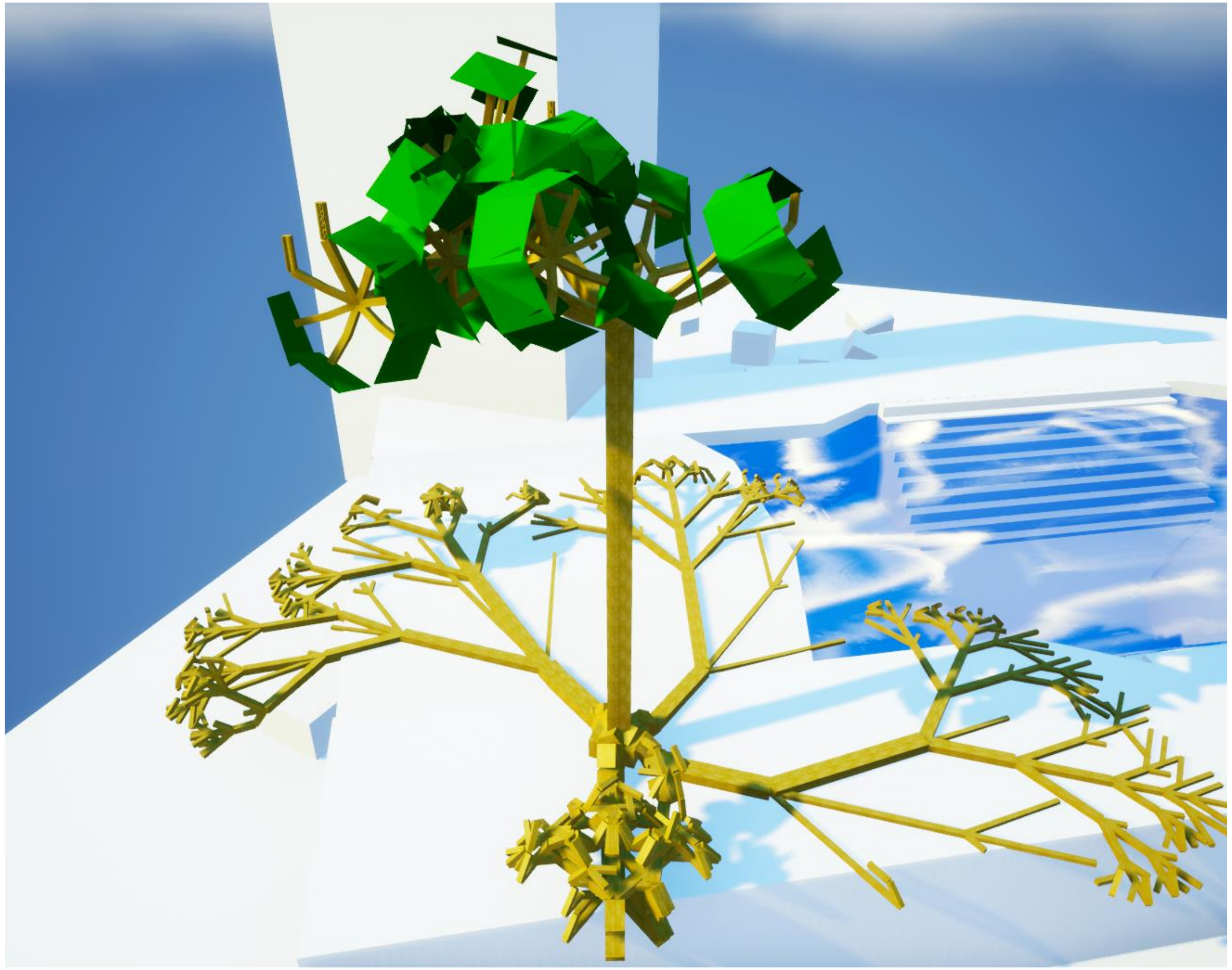
Plant Growth Example

20 Iterations

Plant Growth Example



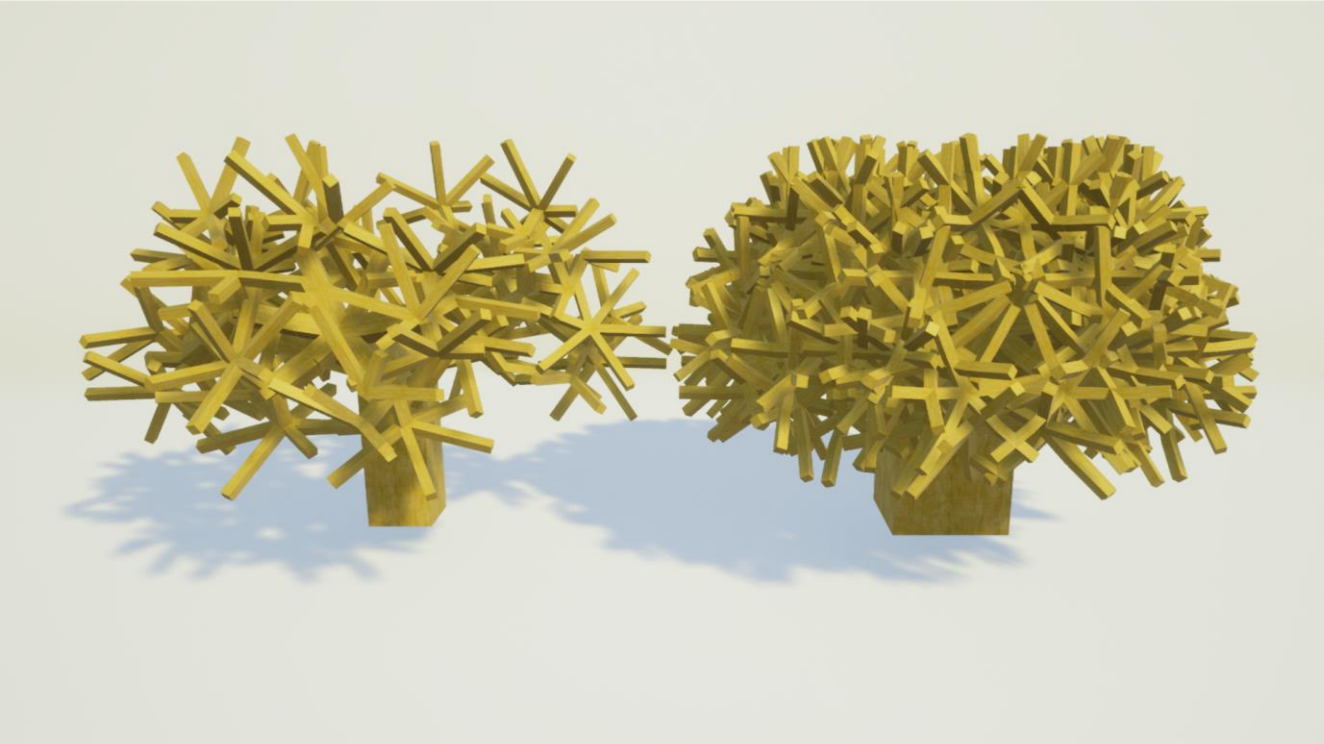
35 Iterations

Modelled Behaviors

I. Plant growth is collision checked
II. Plants grow towards light
III. Water promotes tree growth
IV. Cells that carry more weight have a higher diameter
V. Growth can be influenced by gravity
VI. Roots grow attached to the ground
VII. Wind/Storm destroys parts of plants

| Self-Collision

- Left: Self-collision disabled Right: Self-collision disabled
- In reality, branches cannot overlap
- Cells without children check for possbile collisions, and do not divide if one is found
- This greatly reduces, but does not completely prevent overlaps
- This also adds deterministic, yet seemingly unpredictable structure



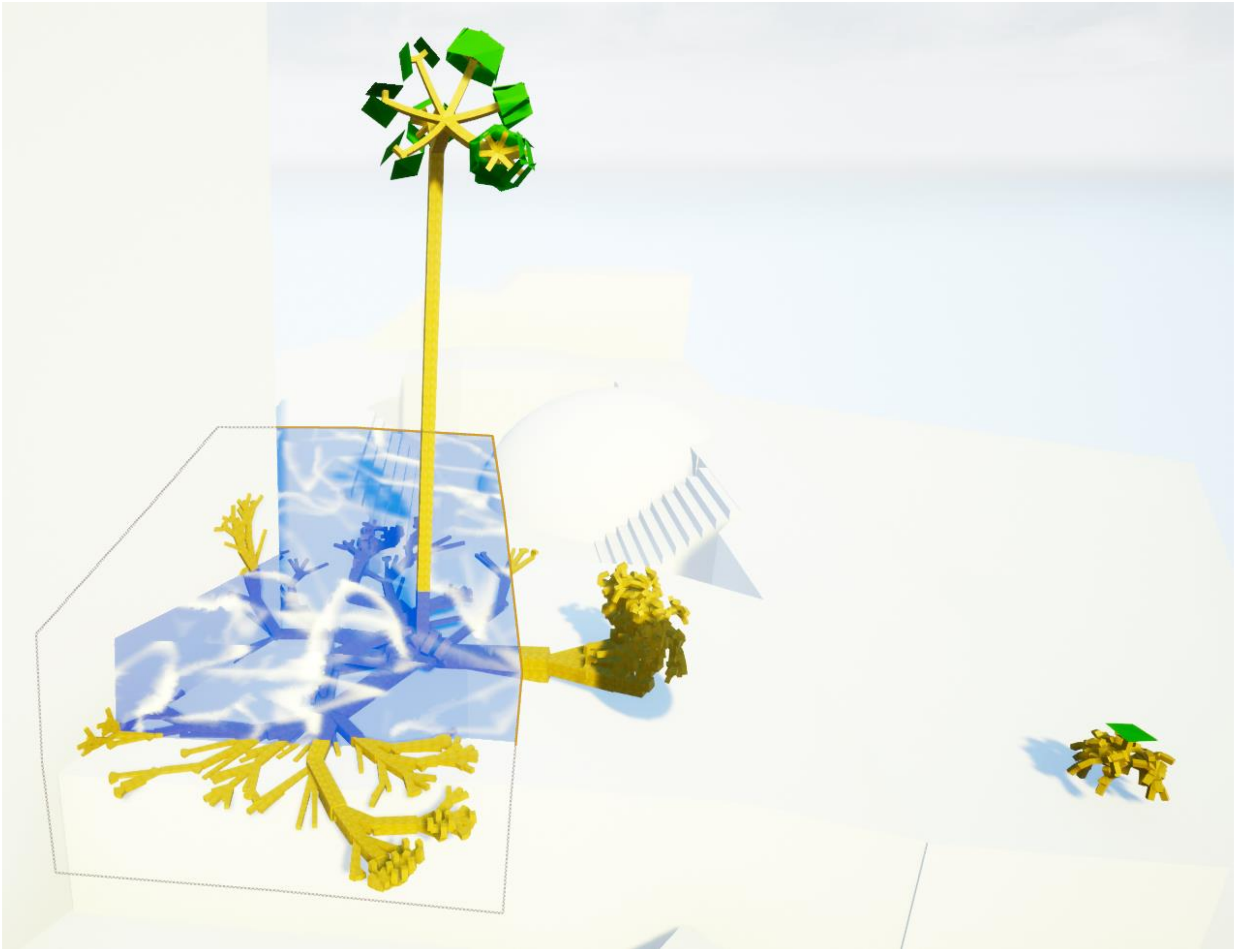
II Growth to Light

- Plants grow "towards the light", as $k > k'$
- Precisely, leafs divide in less time and into more child cells if they are hit by light
- Thus, trees in light have more branches
- The more light hits a tree, the more cells it is allowed to have
- Trees that get hit by a lot of light have smaller leafs (weigthed with a property)

Identical Tree In Light and Penumbra

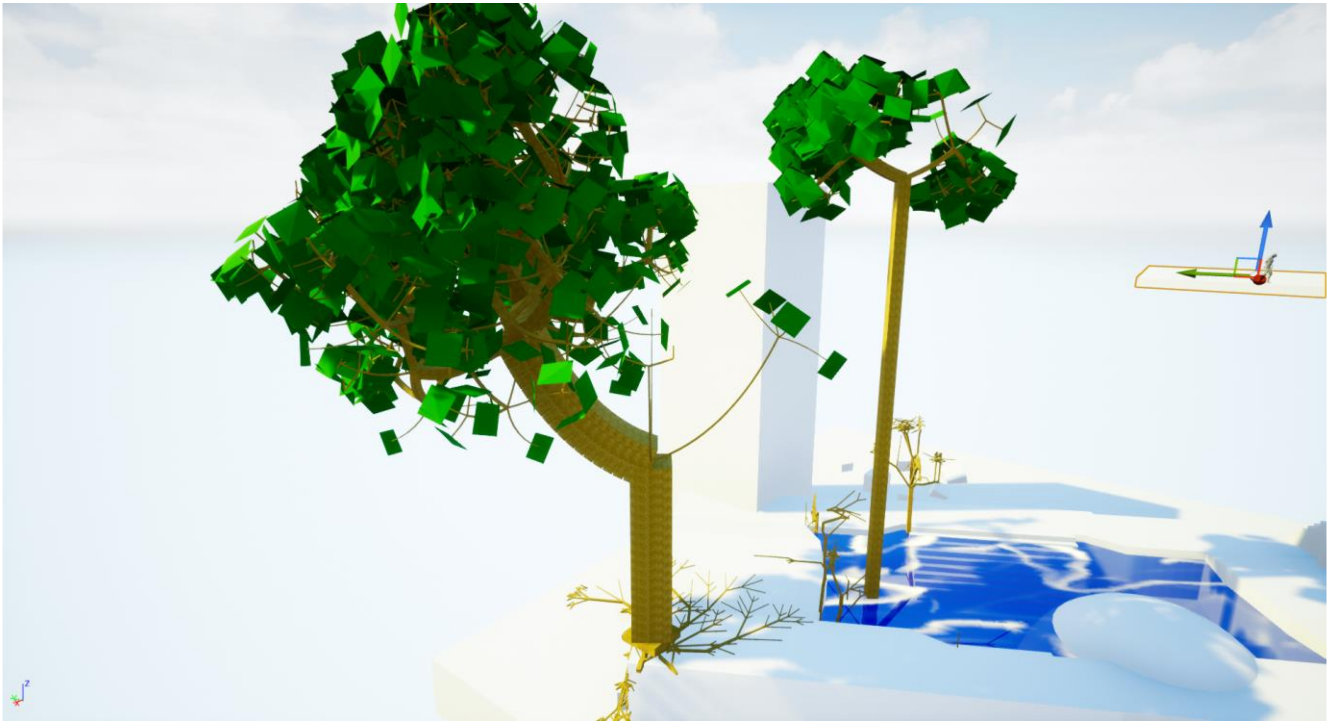
III Influence of Water

- The plant in the water grows way more than the other one
- Distance to light source similar, properties/"genes" identical
- Water is not necessary, but promotes growth to diversify the vegetation
- Plants check every iteration how many cells overlap water, and thereby raise the allowed total amount of cells



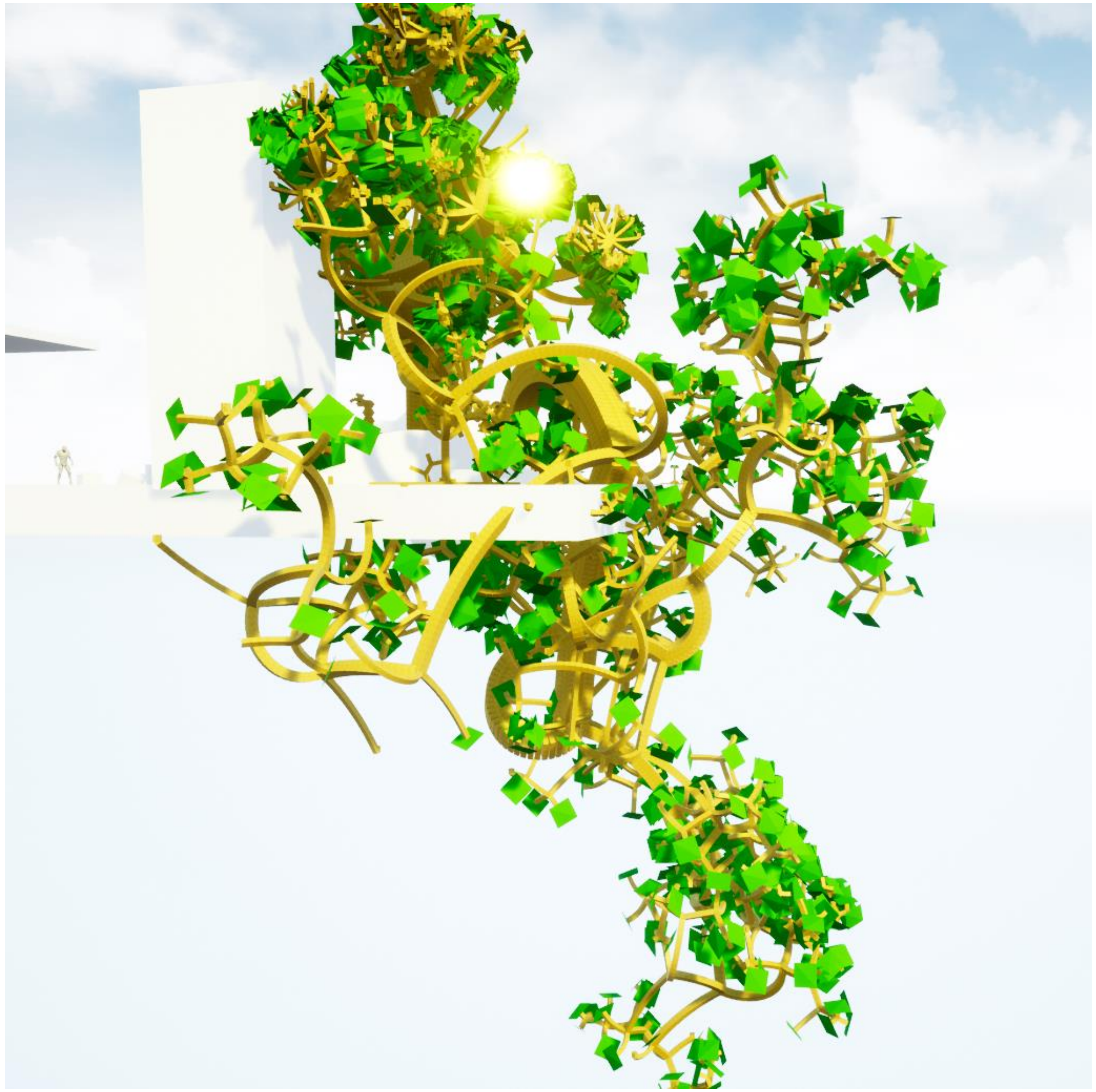
IV Cell Diameter Growth

- Real life trees are bigger where they have to carry a lot of weight (e.g., at the trunk)
- Cell diameter raises with the number of “attachement descendants” they have
- The two property-identical trees visualize the difference in growth shape of trees in water
- Also, they are an example for positive correlation with gravity



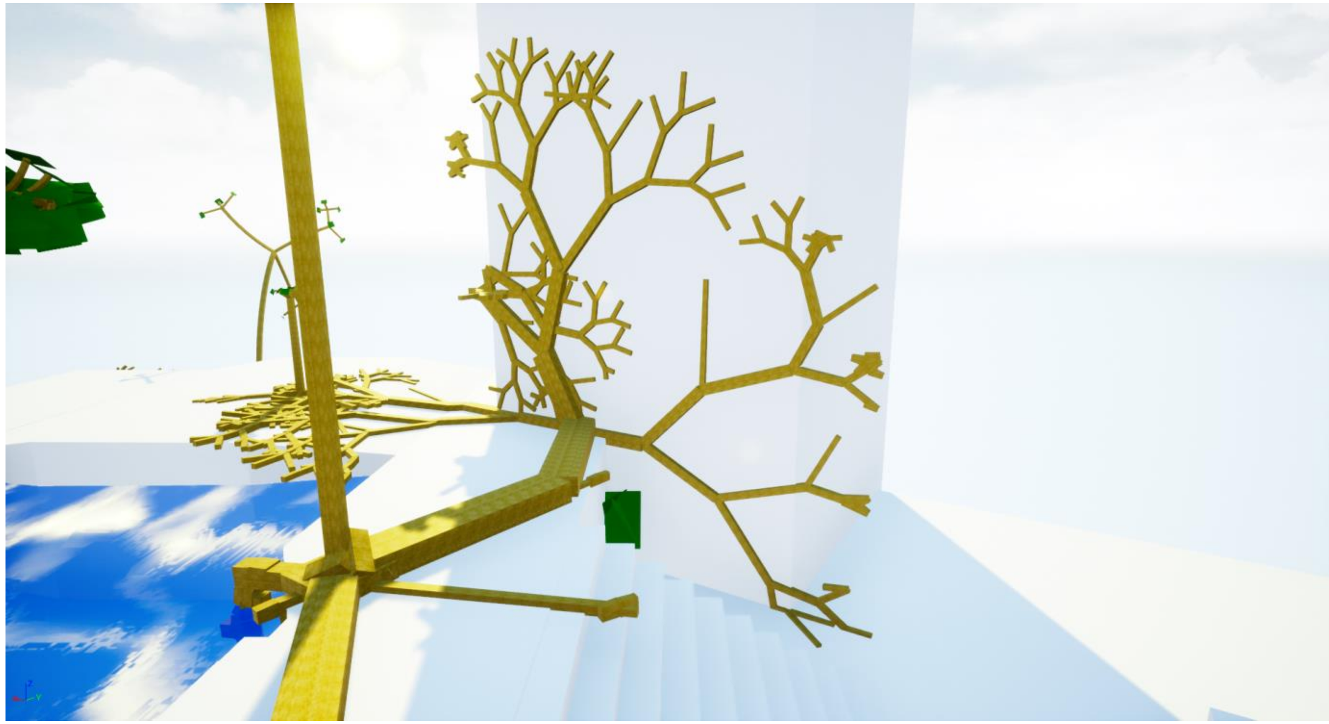
V Influence of Gravity

- Negative correlation with gravity leads to trees "bending over"
- Many plants, e.g. palms, ferns and willows, show this behavior
- The twisted structure of the shown plant emerges as a combination of downward growth and horizontal cell division
- This is also especially prone to provoke mistakes in collision detection



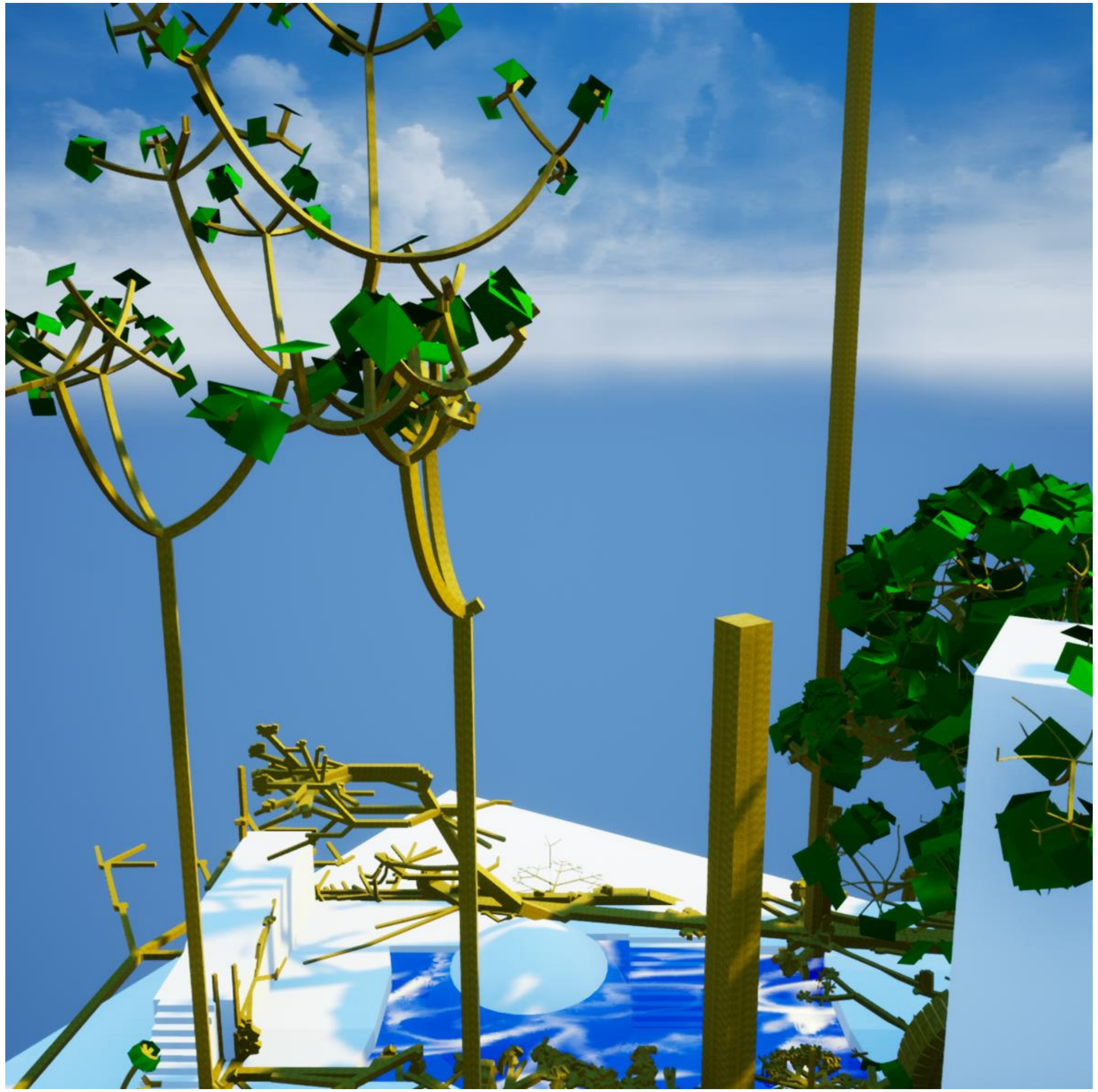
VI Growth in a Plane

- Roots are an integral part of plants, visually and biologically
- Simulating growth in the earth is complicated, and not visually interesting
- Thus, roots grow in a plane (the ground) which even spread is limited to
- If roots hit an obstacle, a new plane is calculated from the hit
- The system can also be used to represent vines



VII Wind

- Wind is another important influence that defines biological growth of plants
- This was modelled by Raytraces that put “wind weight” on hit cells, destroying them if over a threshold
- Initially the system was designed to make damaged branches fall down by gravity
- Unfortunately, Unreal does not support physics for non-static InstancedStaticMeshes



Comparison: Tree-Growth

- The tree in the front (*A*) is close to the light
- The tree in the back (*B*) has access to water
- *A* reaches max cell count earlier, and builds a broader tree crown
- B grows higher

10 Iterations

Comparison: Tree-Growth

- The tree in the front (*A*) is close to the light
- The tree in the back (*B*) has access to water
- *A* reaches max cell count earlier, and builds a broader tree crown
- *B* grows higher

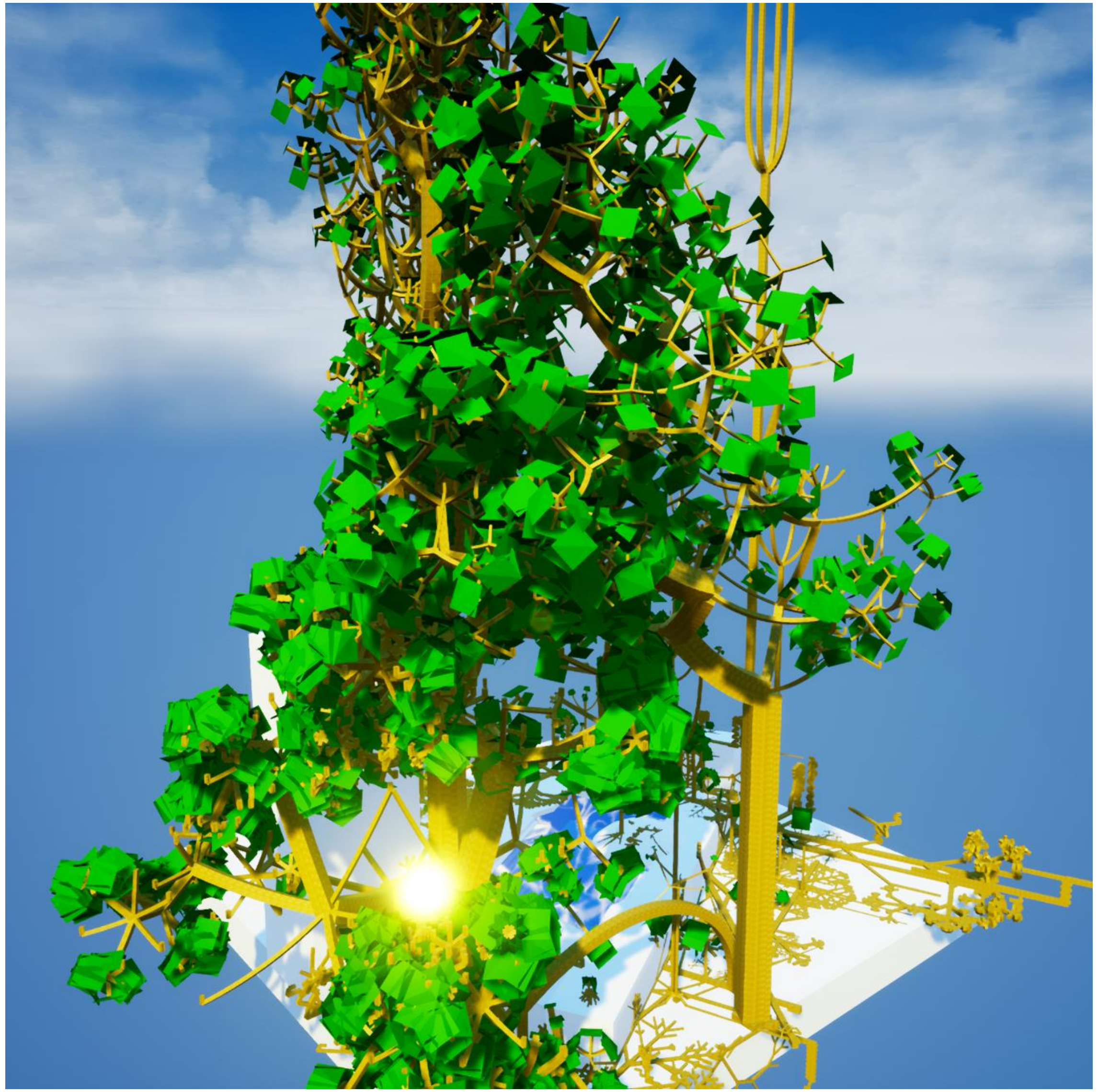
30 Iterations

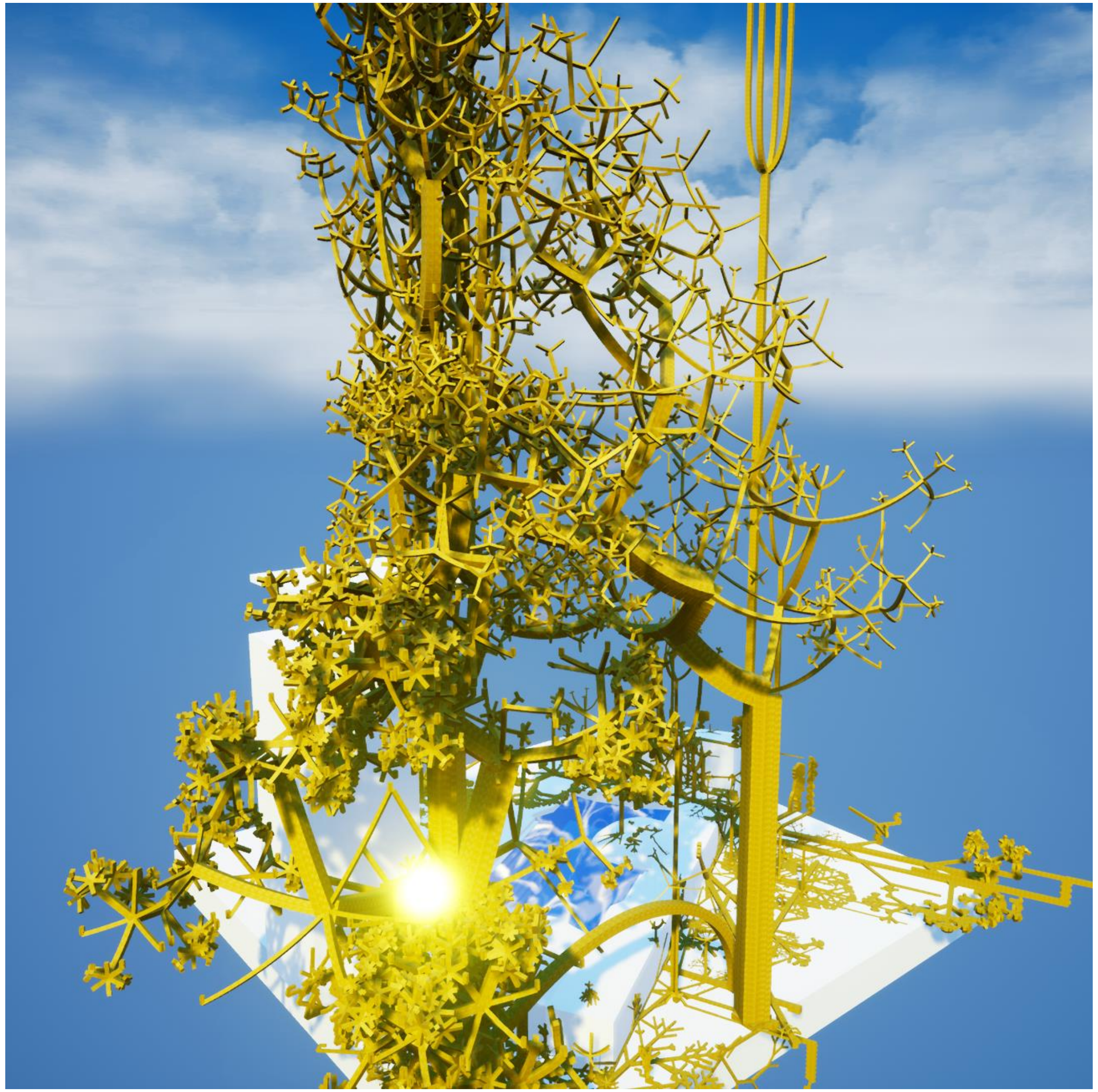
Comparison: Tree-Growth

- The tree in the front (*A*) is close to the light
- The tree in the back (*B*) has access to water
- *A* reaches max cell count earlier, and builds a broader tree crown
- *B* grows higher

45 Iterations

Comparison: Leafs Visible and Hidden





Program Features and Controls

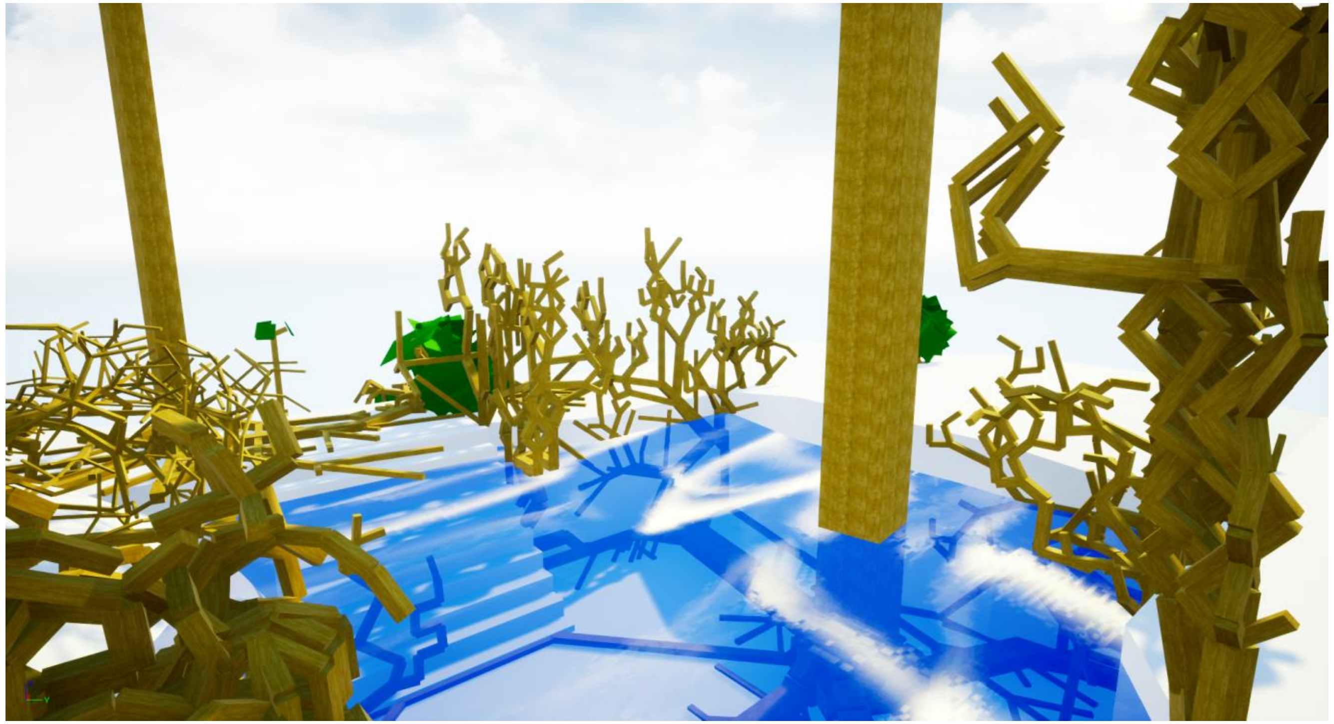
- One map where exact values for a plant can be set
- One map that renders many plants at once (a “forest”)
- Character Control by industry-standard `WASD`/mouse
- Jumping and flying by `Space`
- `I` rerenders the single tree, and adds ten iterations for the forest
- `M` switches Maps
- `P` toggles leaf rendering
- `O` rerandoms the tree and resets the forest

Performance: Iteration Subtask Times

	Run A	Run B
Meshes Calculation & Setup	109.137 ms	17.924 ms
Cell Division in Data Structure	51.654 ms	4.699 ms
Raytrace for Light	19.551 ms	15.450 ms
Raytrace for Wind	8.910 ms	9.611 ms
Weight & Wind Burden	2.146 ms	4.769 ms
Water Influence	0.016 ms	1.064 ms
Total Iteration Time	191.473 ms	53.595 ms

- GPU: Nvidia GTX 760
- CPU: Intel i5-4670K 3.40GHz
- When not growth iterating, the program always hits 60 fps
- Iteration time and distribution on subtasks varies greatly

Impressions: Roots



Impressions II: With Player Character

Going Forward

Simulated Ecosystems

- This work constitutes a basis to simulate ecosystems
- For example, further work could include nutrient circulation
- This would require periodic plant death, and decomposers to return nutritients
- Later, completely differently structured organisms („animals“) could be added

Even Spread and Self-Similarity

- The possbilities of the plant description model were only scratched on the surface
- Current Algorithms yield unsatisfactory results for non-circular degrees of freedom
- Other plantal objects (e.g., blossoms) could be recreated with the model
- The model could also be extended to allow non-punctiform origins (e.g., for pine cone shaped behavior)

Thank you for your attention. Any Questions?

Pictorial Sources

- Real life forest: Wikimedia: “Daintree Rainforest 4.jpg**”** (commons.wikimedia.org/wiki/File:Daintree_Rainforest_4.jpg) viewed on 01/28/19
- Minecraft: Minecraft Wiki: “Flower Forest Overview.png” (minecraft.gamepedia.com/File:Flower_Forest_Overview.png) viewed on 01/28/19
- CellLab: CellLab Website (cell-lab.net) viewed on 01/28/19
- L-Systems: Wikipedia: “L-systems” (en.Wikipedia.org/wiki/L-system) viewed on 01/28/19
- Rose: Wikimedia: “Hundsrose.jpg” (commons.wikimedia.org/wiki/File:Hundsrose.jpg) viewed on 01/28/19
- Tree: Wikimedia: “Baum im Sossusvlei.jpg” (commons.wikimedia.org/wiki/File:Baum_im_Sossusvlei.jpg) viewed on 01/28/19