

Inspiration

It's really hard to say what makes us define something as beautiful or natural. However, generalising aesthetical preferences of the majority of people we are able to say that this aesthetics is close to some mathematical relation discovered by Leonardo Fibonacci. He discovered it while examining speed of rabbits' reproduction. If we have a closer look at this relation, it occurs that phenomena based on it are far more attractive for humans' senses. If we divide any number from Fibonacci sequence by a preceding number, we get a quotient around 1.61804, which is the golden ratio, known as early as in ancient times. How is that possible that the ancient architects knew this? Probably nature in the evolution process taught us the way we define beauty. We are not able to explain our choice's rightness because we favour it subconsciously. Leonardo Da Vinci was correct to notice that the relation between the navel's position on a human's body and the height of the body is close to 0.618. This can be seen on his sketches. In addition, most of Mozart's sonatas were divided into two parts precisely according to the golden ratio. Contemporary musicians making minimal music (Steve Reich, Terry Riley, and Philip Glass) intentionally use Fibonacci sequence. What you will see in the following is purely mathematical, but at the same time, it is a bit unpredictable. You might say there is magic in it, just as there is in the PI number.

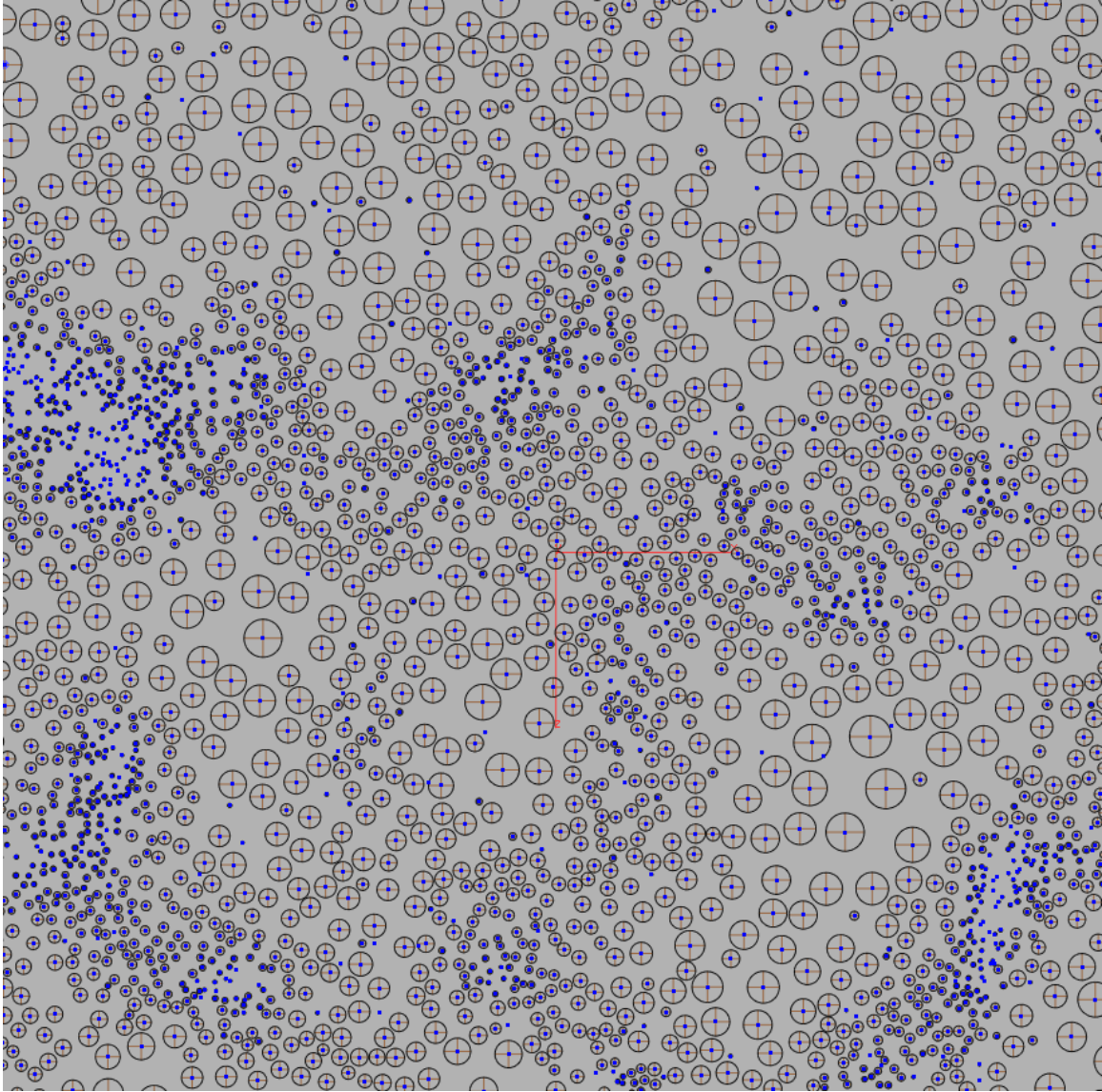


Project Target

The target of the project was to create procedural plants model, which sent themselves information and form in such a way so that in the result they make one organism. This organism is an ecosystem in which every plant, every leaf and fruit has its own not incidental place. The project takes into account basic subjects of ecology, visual analysis of ecosystems, Fibonacci sequence and collision patterns from phyllotaxis family.

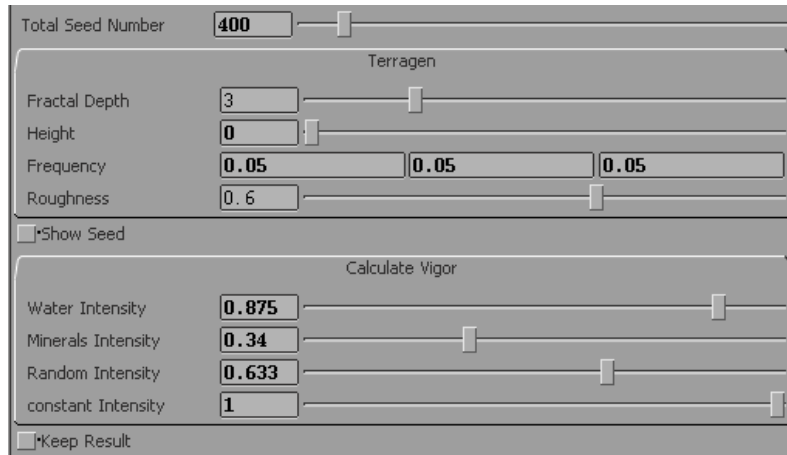
The Seeds Simulation

The seeds simulation has influence on the whole ecosystem. Can say that it's very event because seeds don't have any influence on what circumstances there are on the ground they are put on. Picture below shows an example of such simulation:



The most important task of every seed is to take the highest place for the future plant. If two seeds are close to each other and the area taken by them spreads fast then they fight for their place and the one that gained more energy for life wins. It's also possible to push the enemy away, but it happens rarely when the energies of the seeds are similar and not enough to win with the enemy. In that case, it comes to a division of the zone by collisions.

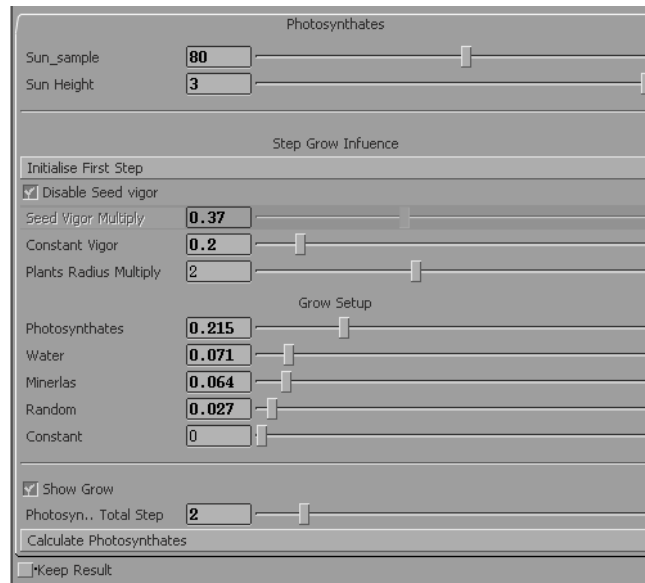
The seeds accumulate the value of the Vigor that is a result of the comparison of the supplies that they have, with the settings in the window which controls those simulations:



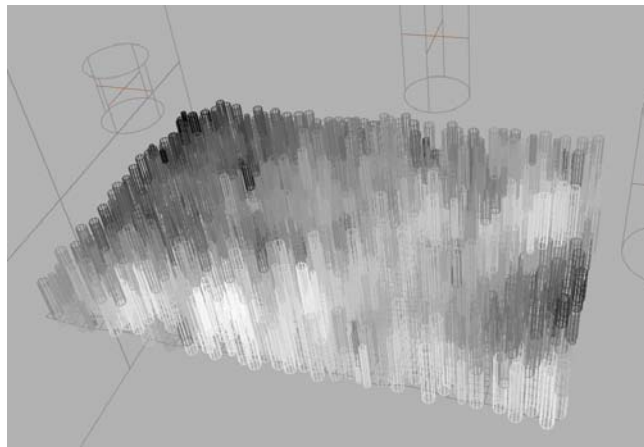
In the bookmark Calculate Vigor we set what decides about plants' growth speed. If water has big influence, only those seeds that have enough access will grow good. Water Intensity favours only those seeds with the optimal amount of water. Option Constant Intensity makes all seeds' growth faster at the same time, what makes them thinning. In other words, plants begin to gain more place and compete with themselves killing each other.

The Photosynthesis

From the previous simulation we know how much space seeds take and what life conditions they have. Assume that seeds have sprouted and there appeared little plants. A necessary factor is the photosynthesis, which is calculated from the average access to the sun in a day cycle. Here is the tool for this simulation:



Let me mention only the most important options: "sun sample" describes how often a plant's access to the light must be checked. For example, if sun shines for 15 hours within a day and we would like to do measurement every 10 minutes we must set that value to 90(15h*60m/10m). Turning on "Disable Set Vigor" we give our plants second chance, where "Vigor" sets "Constant Vigor". In section "Grow Setup" we describe what influences the daily plants' growth. "Photosynthates Total Step" describes how many of the virtual days simulation should last. All those possibilities of settings are made with visual effects in mind and there is a possibility to break previous dependency (seeds simulation) what enlarges the influence of the user on the final effect.



Lssystem children and relationships between plants

From each seed there grows a parent. The amount of children born depends on the energy accumulated by the seed. Options available for this simulation:

Show Options

*System Line *Wire *Simulation *Final Result

Keep Result

General	Root	Branch
General Setup		
Max Segments	20	
Gravity	20	
Grow Influence		
Photosynthates	1	
Water	0.484	
Minerals	0.242	
Constant	0.035	
Random	0.384	
Random Seed	0.2	
Min Grow to Live	0.433	

General	Root	Branch
Contrast Influence	1	
Contrast Center	0.5	
Width	3	
Min Width	0.8	
Max Width	6	
Segments	8	
Min Segments	3	
Max Segments	20	

General	Root	Branch
Offset To Root		
Linear Offset	-0.7	
Age Offset	0	
Number Of Branch		
Contrast Influence	2.58	
Contrast Center	0.231	
Branch Number	3	
Min Branch Number	0	
Max Branch Number	10	
Branch Segments		
Contrast Influence	2.406	
Contrast Center	0.667	
Segments	7	
Min Segments	3	
Max Segments	20	
Branch Random	7	
Branch Width		
Contrast Influence	1.54	
Contrast Center	0.464	
Branch Width	2	
Min Width	0.5	
Max Width	4	
Random Width	2	

More important options:

"Max Segments" - the maximum amount of the generation for Lsystem.

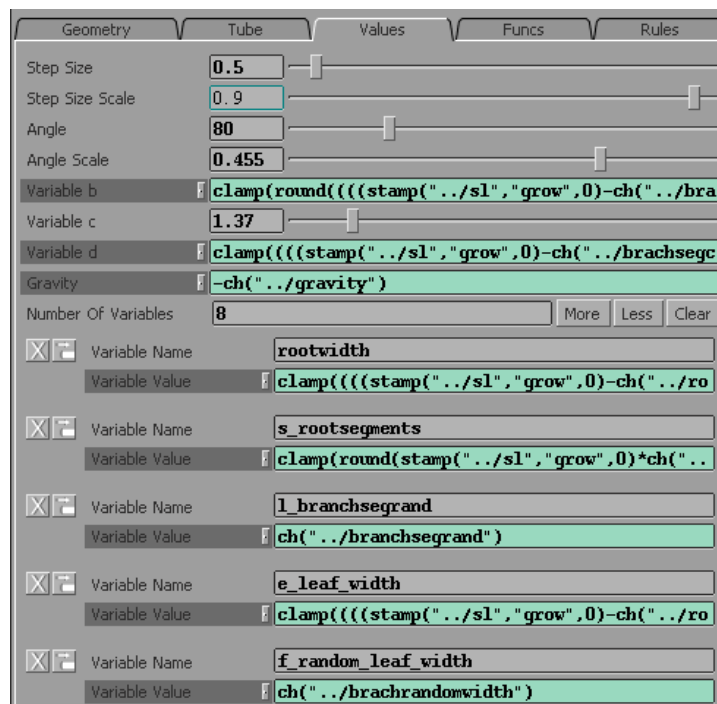
„Grow Influence” - what has influence on the energy of every parent. This energy is the base to calculate its thickness and height and also the amount and look of the children.

„Min Grow To Live” - the minimal energy to life.

In the bookmark "Root" we shape the parents. Using "Contrast Influence" and "Contrast Center" we can control the differences between places rich in energy and poor in it.

Bookmark "Branch" is more complex but it works similarly to "Root". Big part of the calculations is done out of our direct influence. So for example, the main distance between a child and a parent results from their thickness and is calculated automatically.

In system those options are changed for variables:



Lsystem rules:

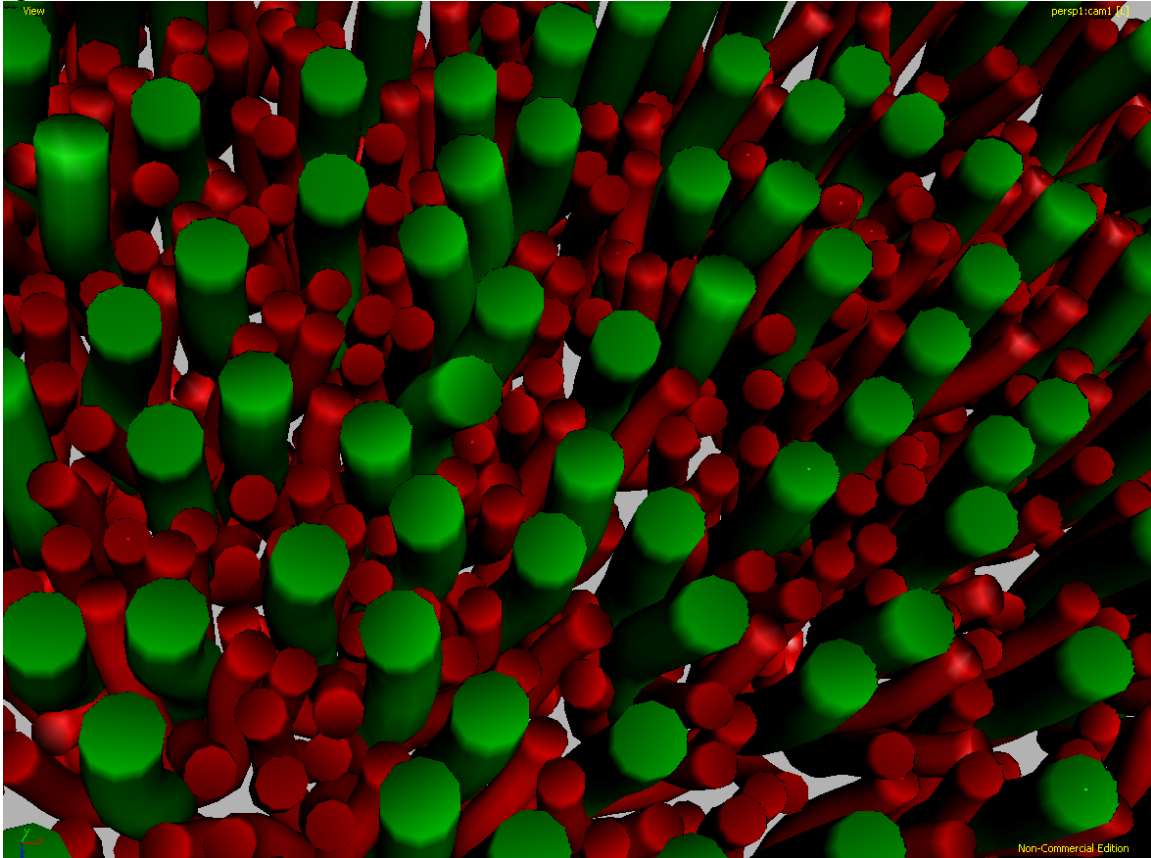
Premise A(b)C(s)

Rule1 $A(i):i>0=/(137.5)[\&(90)f(r+h+i*j)B(d+(rand(i)-0.5)*1,e+(rand(i)-0.5)*f)]A(i-1)$

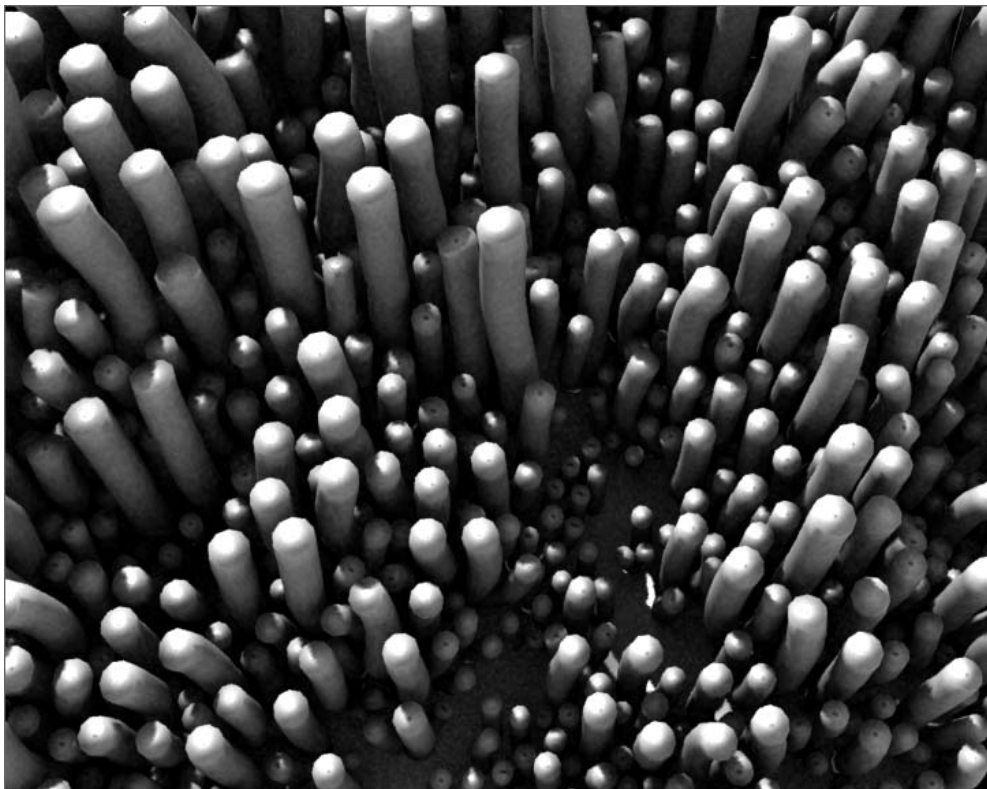
Rule2 $C(i):i>0=a("Cd",0,1,0)a("root",1)F(r*2,r)J(r)C(i-1)$

Rule3 $B(i,w):i>0=a("Cd",1,0,0)TF(w,w/2)J(w/2)B(i-1,w)$

Then there are calculations between plants. In the result, every plant has its own space, which is not shared with any of the other plants. Here is the result of such simulation: (green-root, red-children)

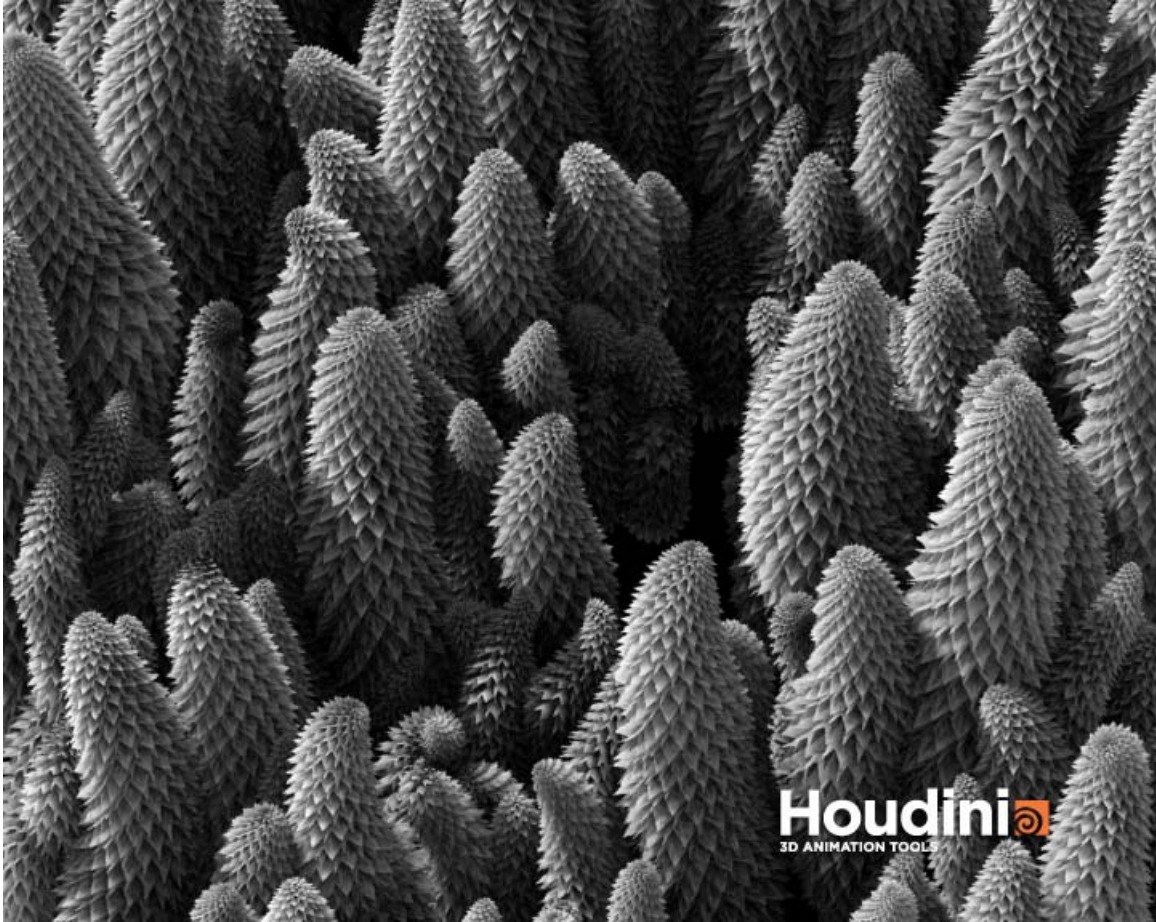


Summing that information, we get the main outline of the ecosystem:

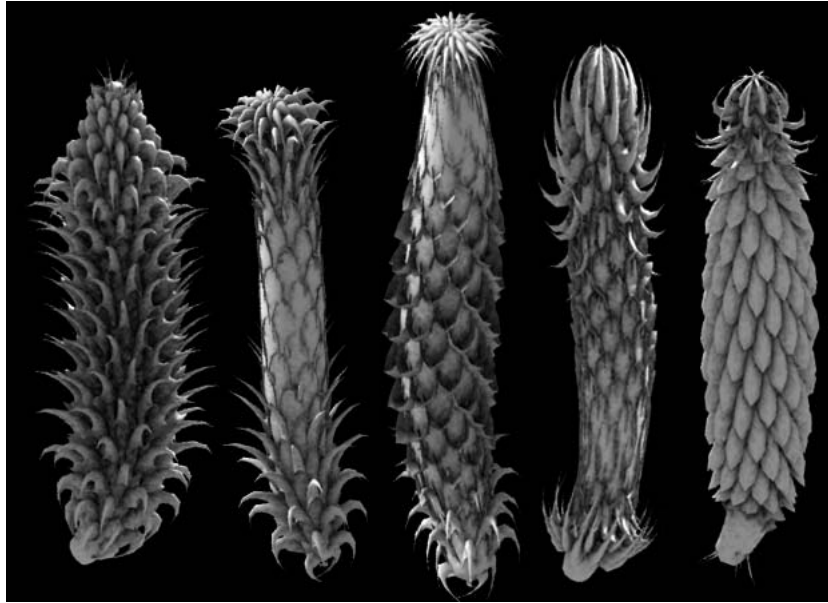


The Individual Shapes

Inspired by cones I began to study base shapes of plants. This is the first try of connecting Fibonacci sequence and Phyllotaxis:



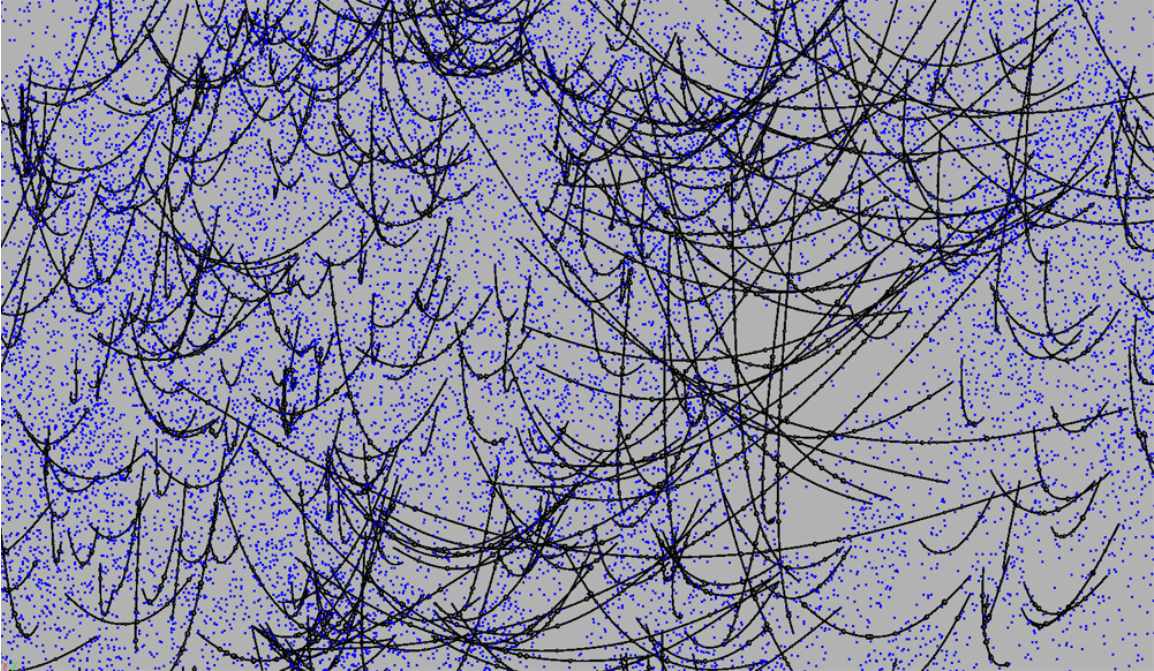
Simple modifications of those shapes let me get some nice-looking forms and what's more important individual parts always arranged in a natural way.



In the result, all plants are made from the ground/base and the shape of each of them is closely linked with the seed. Every element corresponds with stem, which passes information needed to describe their position and shape. Therefore, each of the plants is special and its shape is not accidental.



Spider's Net

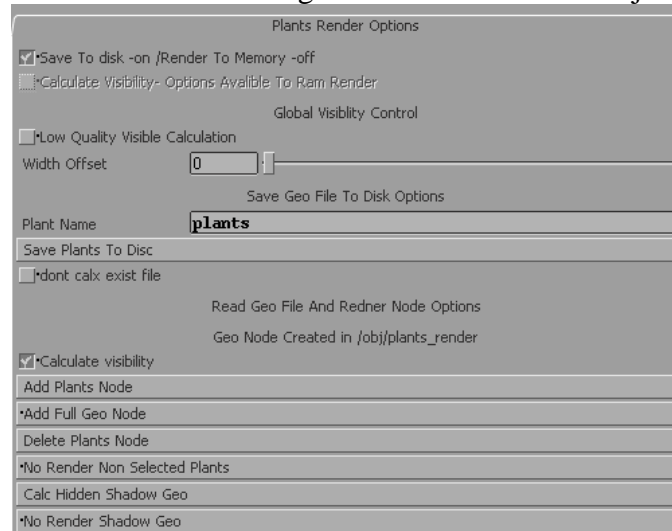


The Picture shows a try of putting 2500 spiders' webs between 24000 points placed at the ends of leafs without any collision. This simulation's efficiency is low (25%), but it gives confidence that none of the spiders' web intersects with a plant. The time of the calculation takes about 20 minutes.

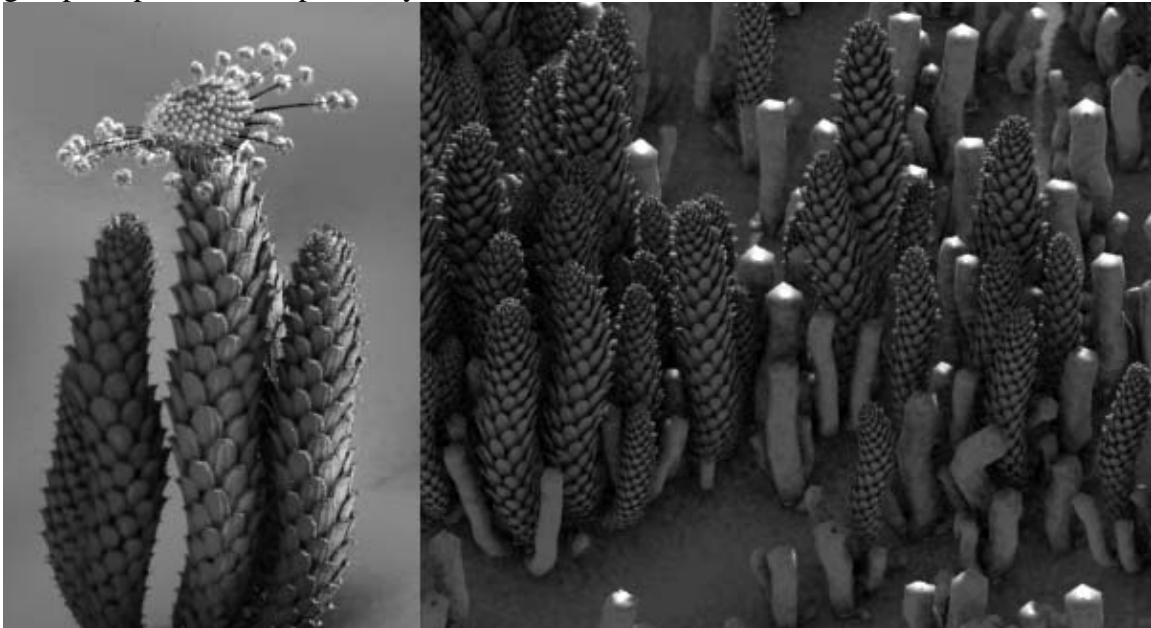
The technical side of the rendering



During rendering bigger number of plants, there was a problem with too big usage of memory. As I wasn't sure about the camera shot nor the shape of the plants, I had to create a system which would limit its usage and wouldn't make the job harder.



Option "Render To Memory" is made to modify shapes and to quickly preview little groups of plants or simple ecosystems.



„Render To Disk” is for rendering the whole scenes, which made the use of memory lower of about 50%. Button „Save Plants To Disk” recorded 3 versions of each plant to disk. Then they were connected to "Geometry Node", which loaded simplified geometry and localized plants in the viewport and then created their bboxes in rendering time. Special kind of scripts enabled simple creation and changing options in big amount of nodes, where every plant had its own unique ID number:

```
plants712 plants1439plants88 plants246 plants394 plants547 plants745 plants878 plants1024plants1173plants  
plants346 plants1048plants45 plants198 plants295 plants467 plants660 plants825 plants924 plants1039plants1239  
47 plants728 plants1440plants89 plants254 plants395 plants548 plants766 plants879 plants1025 plants1181plants  
plants371 plants1058plants46 plants199 plants297 plants468 plants693 plants826 plants925 plants1100plants1240  
67 plants733 plants1441plants101 plants255 plants397 plants551 plants768 plants880 plants1026 plants1182plants  
plants408 plants1060plants48 plants201 plants303 plants474 plants694 plants827 plants926 plants1101plants1241  
68 plants735 plants1442plants102 plants256 plants398 plants552 plants769 plants884 plants1027 plants1183plants  
plants440 plants1069plants49 plants202 plants304 plants475 plants696 plants831 plants946 plants1102 plants1242  
69 plants743 plants1458plants104 plants257 plants399 plants608 plants770 plants888 plants1028 plants1184plants  
plants443 plants1098 plants50 plants203 plants305 plants476 plants697 plants833 plants947 plants1104 plants1243  
70 plants764 plants1460plants105 plants258 plants400 plants612 plants771 plants894 plants1029 plants1185plants  
plants469 plants1114plants51 plants204 plants306 plants477 plants705 plants834 plants948 plants1105 plants1244  
128 plants783 plants1461plants126 plants259 plants401 plants613 plants772 plants895 plants1031 plants1191plants  
plants470 plants1128 plants53 plants205 plants301 plants478 plants706 plants835 plants949 plants1113 plants1245  
131 plants812 plants1475plants127 plants260 plants406 plants615 plants801 plants896 plants1032 plants1192plants  
plants471 plants1145 plants54 plants207 plants312 plants479 plants707 plants836 plants950 plants1116 plants1247  
132 plants813 plants1479plants129 plants262 plants409 plants616 plants802 plants897 plants1049 plants1194plants  
plants472 plants1162 plants58 plants208 plants313 plants480 plants708 plants837 plants973 plants1117 plants1248  
133 plants814 plants1481plants130 plants263 plants410 plants618 plants803 plants898 plants1050 plants1195plants  
plants473 plants1163 plants59 plants209 plants315 plants482 plants709 plants843 plants975 plants1129 plants1249  
134 plants828 plants7 plants147 plants264 plants416 plants619 plants804 plants899 plants1051 plants1202plants  
plants497 plants1164plants61 plants210 plants316 plants483 plants710 plants844 plants976 plants1130 plants1250  
135 plants829 plants8 plants151 plants265 plants417 plants620 plants805 plants901 plants1052 plants1205plants  
plants498 plants1165 plants62 plants211 plants329 plants500 plants711 plants846 plants977 plants1131 plants1252  
136 plants830 plants9 plants152 plants267 plants419 plants621 plants806 plants902 plants1053 plants1206plants  
plants499 plants1170 plants72 plants220 plants330 plants516 plants713 plants847 plants978 plants1132 plants1253  
137 plants859 plants10 plants153 plants268 plants420 plants622 plants807 plants903 plants1061 plants1220plants  
plants545 plants1171 plants73 plants221 plants332 plants517 plants714 plants852 plants979 plants1133 plants1270  
138 plants893 plants11 plants156 plants272 plants441 plants628 plants809 plants904 plants1067 plants1221plants  
plants549 plants1172 plants74 plants223 plants333 plants519 plants715 plants856 plants986 plants1134 plants1271  
148 plants918 plants12 plants157 plants283 plants442 plants629 plants810 plants905 plants1068 plants1222plants  
plants550 plants1207 plants75 plants224 plants344 plants520 plants716 plants857 plants992 plants1135 plants1273  
149 plants928 plants15 plants161 plants284 plants444 plants631 plants811 plants906 plants1070 plants1223plants  
plants573 plants1208 plants76 plants225 plants345 plants526 plants717 plants858 plants993 plants1137 plants1274
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Both methods have the possibility to change invisible for a camera plants for their simplified equivalents. This solution is good even for generating shadow, reducing memory usage from 5% to 40%. Additionally "Render to Disk" can pass the whole geometry during rendering time.

Additional solution which makes the job on the final image much faster, is ambient light precomposition projected on plants' shaders on camera's NDC:



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