Procedural Succulents and Terrariums

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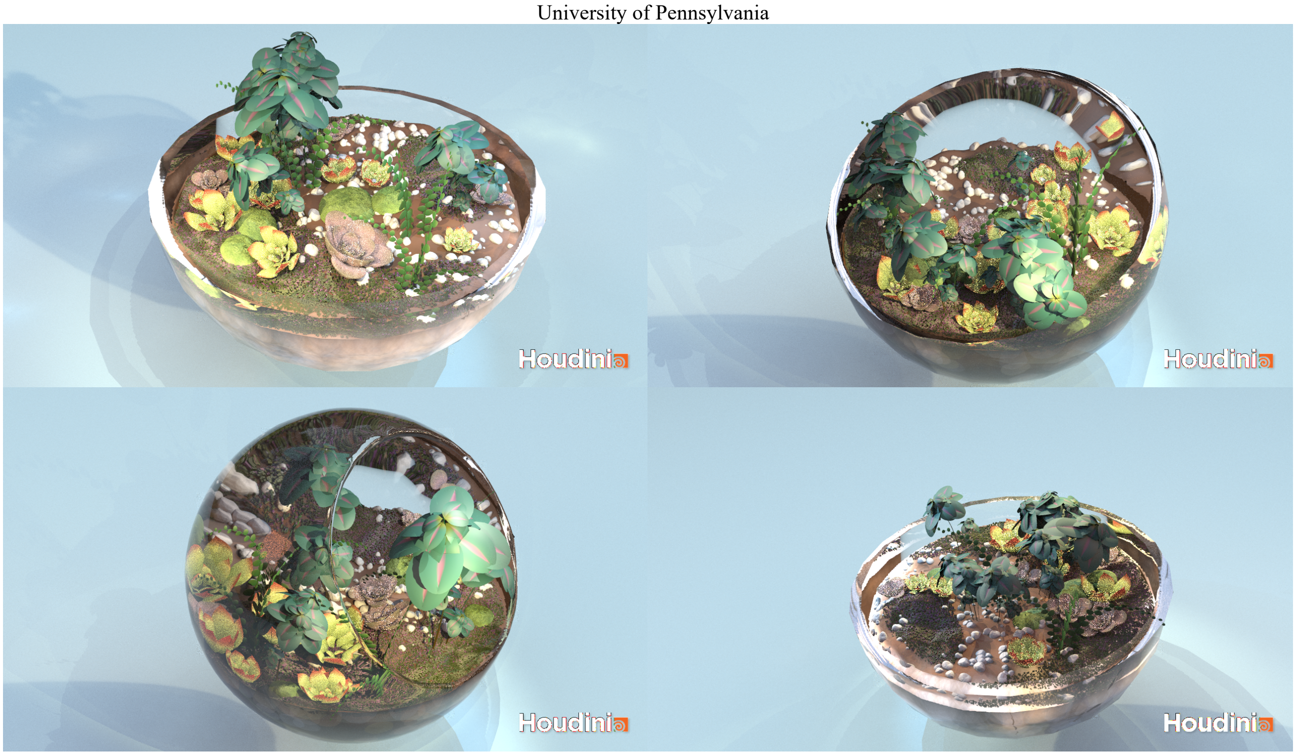

ABSTRACT

A core process in the animation pipeline is the efficient production of complex and realistic large-scale environments. To assist artists in their workflow, procedural tools based on rule-based patterns are developed to expedite the creation of vast mountains and oceans, natural organisms, to name a few. A terrarium is typically a glass container containing layers of soil, plants, water and ornaments. Simulating the conditions in the tropics, a combination of sunlight and a consistent water supply contributes to a terrarium's unique and ideal environment for plant growth.

This project will deliver an interactive and procedural tool that allows users to procedurally generate their own fully textured and rendered terrariums. Six Houdini Digital Assets (HDA) will be developed to procedurally create succulent plants or terrarium décor elements, each parameterized for rapid customization. Another HDA will be developed to place these plants amongst a terrarium landscape (soil, moss, rocks) in a structured and aesthetically pleasing manner. This HDA enables users to either create via seeded randomization, or paint areas within the glass terrarium to self-specify areas for different plants and terrarium features to spawn. Overall, this tool aims to be a microcosm of procedural landscape generation, primarily focusing on structured and constrained environments.

Google Drive: [tinyurl.com/feliyick-senior-design]

1. INTRODUCTION

Problem Statement. The field of computer graphics is no stranger to the procedural modelling and generation of environments and placement of plants, particularly trees, foliage, and flowers in sprawling landscapes above and below the ocean. However, less research and development has focused on simulating plant growth in constrained and enclosed environments, such as terrariums. While assets such as trees can be randomly scattered across a landscape (perhaps with some consideration into terrain height, slope, and weather), a tool that supports the procedural creation and placement of terrarium plants in a confined space would be beneficial addition to a 3D artists' tool kit.

Motivation. Procedural modelling tools mitigate the tedious process of hand-sculpting and modelling complex natural forms and structures on programs such as ZBrush or Autodesk Maya, and instead, allowing artists to generate infinite variations of the same object with a few button presses. However, the procedural *placement* of these procedurally generated assets is equally important for an efficient pipeline. It is a tedious task for artists to hand-place assets in a scene in a natural way that conforms with the rules of organism growth and relationships. Thus, developing a procedural tool that simulates terrarium plants and layouts would be a useful microcosm to understand how to procedurally generate and place plants in confined spaces.

Proposed Solution. The proposed solution to this problem is to create a Houdini Digital Asset (HDA) that allows users to: 1) quickly generate fully textured terrariums, 2) paint and define areas within the terrarium where they would like certain terrarium components to be placed. The HDA will be capable of simulating the growth of a variety of terrarium plants. Each of the terrarium plants can be controlled through specific controls to allow artists to manipulate its growth pattern and appearance. Using the procedural plant asset sub-tools, the HDA can automatically populate a chosen container with a systematic and aesthetically pleasing terrarium layout.

Contributions. This project makes the following contributions to the field of Computer Graphics:

- Procedurally modelling of several terrarium plants using different algorithms
- An interactive UI that allows artists to efficiently generate textured and rendered terrariums
- A demonstration of the procedural placement of plant assets in a confined space

1.1 Design Goals

The target audience for this project encompasses a variety of groups. The final terrarium painting UI will be an accessible and polished product that casual users can experiment with, and professionals can use for personal asset generation.

Professional environment/set dressers in animation or game studios may find the subproducts of this project to be also useful in their pipelines. The individual HDAs for the different terrarium plants can be used and their results can be exported individually. If artists want to substitute in their own plant models or HDAs they would be able to do so. Artists would benefit from this as the tool removes the time needed to model, texture, and arrange plants within a terrarium.

1.2 Projects Proposed Features and Functionality

I aim to implement several novel features and functionalities with my procedural tool.

- Flexible and heavily parameterized HDAs for the following types of succulent plants (these may be subject to change). These plants were picked for their distinctive looks and difference from each other. Please refer to the appendix for reference images for each of the plants.
    - Button Ferns
    - Fittonia
    - Aeonium Lily Pad
    - Kiwi Rare
- Ability for users to choose their terrarium shape, as well as the terrain heights of soil and water levels
- Polished interface that allows users to paint and place instanced plants within the interior of their terrarium along soil surfaces
- An alternative generation method: A simple 'Generate' button that gives random variations of terrariums
- A connected pipeline to Autodesk Maya/UnReal Engine 4 for efficient texturing using materials made in Substance Designer, and real time rendering

2. RELATED WORK

There has been abundant research and work on the topic of procedural modelling of assets and environments. However, there is few instances of procedural succulent modelling, and less so terrarium generation.

2.1 Terrarium Builder

Terrarium Builder is an independent project by Taylor Mullins from 2018. Her project is essentially what I want to achieve at bare minimum. Mullins' Terrarium Builder is a Houdini Digital Asset that allows users to choose their terrarium shape and select from four different types of plants to paint on top of a dirt plane. The available succulent types include hens and chicks, grass, tall ZZ plants, and an unidentifiable short and stubby plant. She also created and applied Substance Designer materials on to her terrarium to be rendered in Unreal Engine 4.

There is not much public documentation and information on her project besides a minute long demonstration video, and a handful of renders. However, her work serves a useful resource for my own Procedural Terrarium Tool, and that most of my anticipated approach and initial idea can be accomplished in Houdini.

To differentiate my project from Mullins', I aim to create a new set of succulent plants, as well as give users the freedom to adjust individual plant types. Another important distinction will be the inclusion of more uneven soil distribution and water. Mullins' soil base is a flat plane, however I want to give users the ability to have different elevation levels in their terrarium designs. [MUL18]

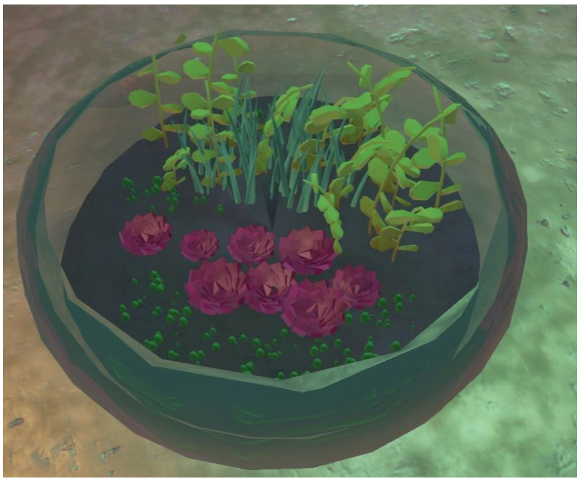

Figure 1 *Render from Mullins' Terrarium Builder when exported to Unreal Engine 4 and textured with Substance Designer Materials*

2.2 Procedural Art: Plant Generation in Houdini

This Procedural Succulents project is by Kilian Baur. In this interview conducted by 80.Lv, Baur describes the various methods and scripting he uses to create a wide variety of succulents with only a handful of parameters. More specifically, Baur's project produces rose-shaped succulents of the Echeveria family, perhaps the most common succulent seen in markets.

Baur's process involves creating a base leaf, duplicating it, and rotating it about the origin. Users can control the length, shape, and count of leaves. The plant is separated into layers of these duplicated leaves. The overall shape of the plant is dictated by at what angle each level of leaves bends which is controlled by several ramps.

Baur's project and exploration will be useful for my own interpretation of procedural succulent generation. It provides insight into what sorts of parameters I should expose to users, and ideas on how to implement some basic succulents. I will expand on Baur's work by developing a wide variety of succulents, and texturing using my own Substance materials, rather than texturing in Houdini. [BAU20]

2.3 Synthetic Silviculture: Multi-scale Modeling of Plant Ecosystems

This paper explores ecosystem simulations, in particular plant growth, tropism, and its relationship with its environment (ie. weather, or other plants). Every species is encoded with temperature and precipitation information, which in return induces a plant's probability of appearing in a particular biome.

Users can interact with a temperature-precipitation space to choose a type of biome. The program then decides what type of plants belong in these chosen conditions and simulates their growth patterns. The framework is also capable of simulating plants' competition of space by using a global shadowing method to calculate intersections between different plants.

While I will not simulate and animate growth patterns in this project, the use of temperature-precipitation to direct vegetation distribution is something I could consider implementing. More specifically, certain succulents would benefit being closer to water sources, or higher up in the terrarium. [MHS*19]

2.4 The use of positional information in the modeling of plants

This paper the three different elements that assist in breaking down plant structures and silhouettes. This includes the posture (curvature of the stem), the gradual variation of features, and applying an artist technique of modelling the basic silhouette then fine tuning the local details.

The primary takeaway from this paper is the six provided algorithmic L-System functions to control different physical features of plants. [PMKL01]

2.5 Art-Directable Procedural Vegetation in Disney's Zootopia

As previously stated, procedural modelling of plants is heavily used in animated features to help efficiently dress a natural environment. Disney Animation Studios' *Zootopia* demanded a rich variety of vegetation of different scales. A total of six different ecosystems were featured in the film, necessitating augmented their in-house tool *Bonsai* to allowed for the creation of modular and customizable plant assets.

An interesting highlight in this brief paper is the technology that was developed in Houdini to allow artists to control the branches of a tree in any recursion level using curves systems. For my project, curve manipulation can be applied in the procedural modelling of cacti and button ferns. [KST*16]

2.6 Realistic Modeling and Rendering of Plant Ecosystems

This paper details a developed pipeline of tools to assist artists in modeling and rendering natural scenes with realistic plant distributions and interactions. To pipeline uses hand painted greyscale maps to determine spatial densities of plants. The process also notes that the map infers plant age, vigor, and preference for wet and dry areas. These grayscale maps. For each plant type are converted into colour maps, where each coloured dot represents a specific species of plant and its ecological neighbourhood.

I want to extend this painting technique into my Procedural Terrarium Tool to allow artists to control both location of specific plants as well as their densities and falloffs. [DHL*98]

3. PROJECT PROPOSAL

A series of Houdini Digital Assets (HDA) will be developed to procedurally create four different species of succulent/terrarium plants. Each plant tool will be flexible and customizable; Artists will have control over different characteristics of the plants (eg. Leaves shapes, sizing, growth direction and patterns, number of thorns, etc.) through exposed parameters. These plant tools will be used in a larger Houdini HDA – the Procedural Terrarium Tool. Users will be able to select a terrarium shape, and the tool will procedurally scatter the plants in systematic but varied or user-defined areas within the terrarium. Overall, this tool will give artists procedural variation as well as the means to fine tune their terrariums to their own artistic direction.

3.1 Anticipated Approach

The Procedural Terrarium Tool will be composed of several Houdini Node Networks – one for each of the succulent types, one for controlling the soil layer, and one for the placement of all sub-assets in the terrarium. These node networks will be combined at the end with a Merge node to produce a complete package.

Button Ferns. This node network will involve creating a parameterized base leaf shape. We then copy the leaves along sampled points on a curve (the stem). Users will be able to adjust the following parameters of the fern's structure:

- Length, width, and taper of the individual leaves
- The angle at which the stipes collectively bends downwards due to gravity
- How much each pinna fans out and inwards towards the apex of the leaf
- Length, width, and bend of the stem

Fittonia. This node network will involve creating a parameterized base leaf shape. The leaves are placed on top of a stem. Users will be able to adjust the following parameters of the Fittonia's structure:

- Scale of the leaves
- Leaves bend
- Number of leaves in a cluster
- Length, width, and bend of the stem
- Colours of the leaves

Rocks. This node network will involve creating a parameterized base aloe rock shape. Users will be able to adjust the following parameters of the rocks' structure:

- Base shape of the rock
- The type of noise applied to deform the rock's surface
- The intensity and roughness to control the level of detail

Moss. This node network will involve creating a parameterized base moss shape. Users will be able to adjust the following parameters of the moss' structure:

- Length of each moss instance
- How distorted the moss is
- Width of moss
- Colour
- Distribution and density

Shrubs and bushes. This node network will involve creating a parameterized base bush shape. Users will be able to adjust the following parameters of the shrub's structure:

- Bend of leaves
- Shape and dimensions of bush
- Colour of leaves

Aeonium Lily Pad and Rare Kiwi. This final plant node network is for probably the most recognizable succulent plant. The node network will be like the aloe plant, except the base shape of the leaves will be thicker and more bulbous. Aeonium plants can grow in bundles, so users will be able to control how many of these clusters will appear in one plant. Users will be able to adjust the following parameters of the succulent's structure:

- Number of layers, and the size distribution of the leaves in each layer
- How much the leaves fan out
- Shape of the base leaf
- Number of clusters

Soil. This node network will involve Houdini Heightfields and masking techniques to define soil areas. Using a heightfield paint node, users will be able to paint the desired shape of their soil layout.

Placement of Terrarium Plants. There are several different methods I could use to implement this feature.

Method 1. The first idea is using Houdini paint nodes, I will configure them so that users can paint on the soil terrain to define a density distribution map for each plant type. These maps would be greyscale. White would be additive, and black would be subtractive. The maps can be converted into a mesh of points where plants can be scattered. This user painting method would not implement any of the systematic ecosystem relationships. Placement of plants would be up to the user's artistic direction.

Method 2. An alternative implementation for user defined areas would utilize masks. Houdini has a powerful heightfield and masking system where users can very easily mask areas based on erosion, height, gradient, etc. I could restrain different succulents to grow within different masked areas.

Method 3. As for the automatic 'Generate' button, this could be implemented by exposing seeded parameters from Method 2. Random variables can be plugged into these parameters every time the button is pressed.

Method 4. A final idea for the placement of plants would be to use voxels. There is not a lot of discourse or online resources experimenting with this method. Houdini supports several VDB functionalities, converting any mesh into voxels, being able to store vectors or matrices of information in each voxel, accessing and manipulating each voxel, etc. I could convert my soil terrain into voxels, and store constraint information (eg. Height, distance to water source, distance to side of the terrarium) to infer what types of plants can grow at the specific voxel. This method would require more research and experimentation.

3.2 Target Platforms

This project will be developed in Houdini FX 19.0.498 and Unreal Engine 4 4.27.2. The primary scripting languages will be VEX and Python in Houdini. Several materials will be created using Substance Designer 2021.3.2 and applied on individual terrarium elements. The final product will be rendered live in UE4.

3.3 Evaluation Criteria

The evaluation criteria will be how my Houdini Digital Asset performs in terms of flexible art direction, final appearance and sytlisation, and overall workflow. I will judge my work based on comparisons to some of the related works, primarily Baur and Killian's work. In addition, I want to ensure that my Houdini Digital Asset runs efficiently without delay. My previous experiences with Houdini have been very slow in application due to how large the node network was, hindering the actual procedural benefits of the tool. Hence, I want to ensure that my final HDA is optimized and space efficient as well.

4. RESEARCH TIMELINE

I will section my research and development timeline into three versions – Alpha, Beta, and Final. I will prioritise my time with developing the HDAs of the five different succulent plants first, as well as getting the 'Generate' button to procedurally generate structurally sound terrariums. I will then focus on the painting feature, materials in Substance, and integration into UE4 last. Please reference the Gantt chart below in the appendix for a visual representation of my research timeline.

Project Milestone Report (Alpha Version)

- Completed Aeonium Lily Pad / Kiwi Rare tools
- Procedural rocks and soil layouts within varied terrarium shapes
- Testing procedural placement of two plant types on a sample terrarium

Project Milestone Report (Beta Version)

- Completed Button Fern and Bush tool
- Completing the basic terrarium landscape 'Generate' button
- Time dependent: Fittonia Tool

Project Milestone Report (Final Version)

- Terrain painting functionality and finalizing a polished user interface
- Create Substance materials and Houdini to UE4 pipeline
- Final renders

Project Final Deliverables

By the end of the semester, I will submit the following deliverables:

- Procedural Terrarium Tool Houdini Digital Asset
- Houdini Digital Assets for individual plants
- Sample renders of a variety of terrariums produced from my tool
- A narrated demonstration presentation outlining the different features and functionalities of my tool

Project Future Tasks

There are several ways for this project to be more robust and fully featured given a little more time. Some potential future directions include:

- Physics simulations within the procedural terrariums. For example, adding wind physics to individual plants, as well as collisions
- Procedural firefly crowd simulations to fly around the terrarium
- Utilising the procedural terrariums as miniature game levels in UE4. Players can run and jump on leaves and rocks, and swim in water to explore their created terrariums

5. Method

The final Procedural Terrarium Tool is composed of six distinct Houdini HDAs, one for each succulent and terrarium décor type. I started the development process by collecting reference images and looking up diagrams breaking down the structure of the different succulents. These images were used to ensure that the succulents had the correct features, as well as helped determined which nodes in the HDA to convert to adjustable parameters.

5.1 Aeonium Lily Succulent Development and Parameters

Procedural Modelling techniques were used to produce the leaves of the succulent. The base shape of a leaf was a sphere, which was then squashed and tapered to give its signature shape. Two ‘Bend’ nodes were utilized to fold in the two sides of a leaf to mimic its real-life curvature.

The challenging part was figuring out how to place these leaves in a spiral manner to create rosettes. After some research, I learned that the Aeonium Lily followed a Phyllotaxis arrangement of leaves. I implemented the Phyllotaxis algorithm via an ‘Attribute Wrangle’ node. I first wrote a function that turns polar coordinates to cartesian coordinates. A slider variable was added to control the number of leaves, as well as constants for the Golden Angle. The placement of a leaf is determined by a radius and angle, where the radius is controlled by the leaf’s index and distance from the center, and the radius is incremented by the golden angle at every iterative step. This angle and radius are converted into cartesian coordinates using the aforementioned function. This ‘Attribute Wrangle’ ultimately returned a group of points placed in a Phyllotaxis pattern.

Another pair of ‘Attribute Wrangle’ nodes was used to calculate each point’s distance from the center and adjust the scale of each leaf depending on this distance. This resulted in the center leaves being smaller, and outer leaves larger. The scale of the leaves is controlled by a curve.

Regarding parameters, artists can control the number of leaves, the bend at the base, mid-section, and tip of the leaf, and how the leaves are scaled. All these parameters are controlled via a curve editor.

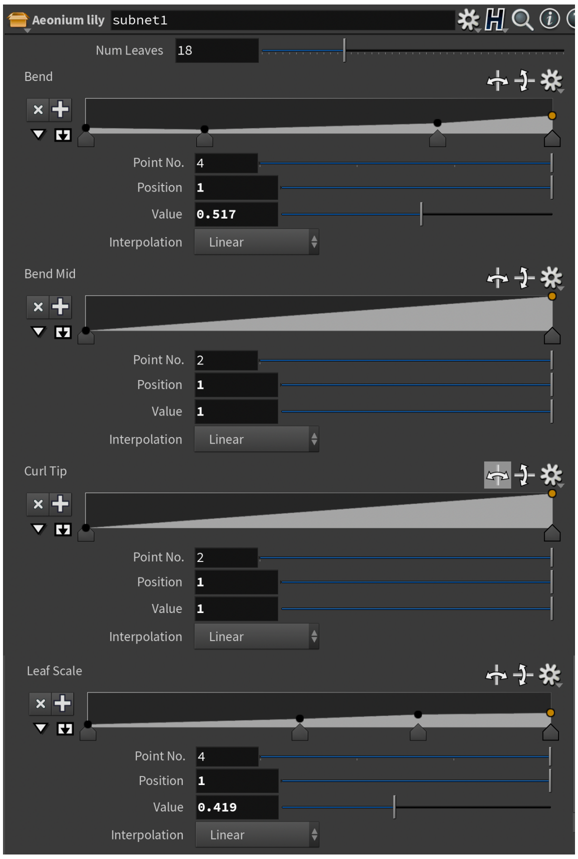

Figure 2 Aeonium Lily HDA Parameters

5.2 Kiwi Fern Succulent Development and Parameters

The Kiwi Fern Succulent was very similar to the structure of the Aeonium Lily. The only discernable difference was the shape and colour of the leaves, and that the center of each rosette had a cluster of smaller leaves, and the outer leaves were much bigger.

Thus, it was simple to adjust a few things from my Aeonium Lily HDA. I adjusted the shape of the leaves by tapering the ends more and widening the mid-section to give the leave a diamond coffin shape. I adjusted curve parameters such that the scale and bend of leaves were more exponential. Because the Kiwi Fern is based off the Aeonium Lily, the interactable parameters in the HDA are the same.

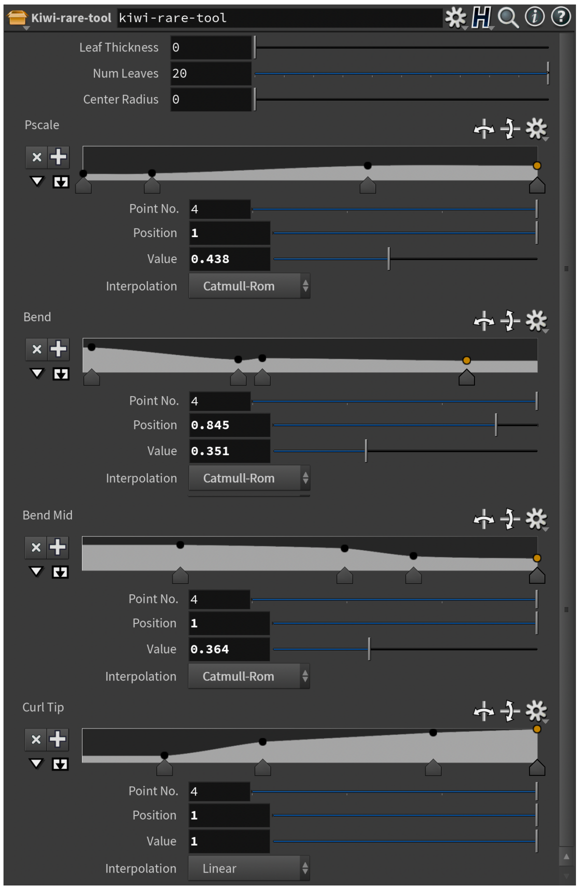

Figure 3 Kiwi Rare HDA Parameters

5.3 Button Fern Development and Parameters

Vastly different from the Aeonium Lily and Kiwi Rare, the Button Fern succulent is a stemmed plant with small round leaves that alternate along the stem. Another notable feature of Button Ferns that I wanted to accomplish was how individual ferns cluster and droop away from the center.

The node network for the Button Ferns starts with a line with evenly spaced points and has a slight bend and jitter to provide randomized curvature. The bend of the individual fern is controlled in a later 'Attribute Wrangle' node. Figuring out how to place the leaves on alternating sides of the stem was a small challenge. My solution was to initially orient the normals of all the points in the same direction, in my case the x-axis. A 'Group Range' node was then used to select every other point along the stem, and a 'Attribute Wrangle' with a few lines of VEX was used to rotate the normals by some angle. The scale of the leaves was also adjusted such that through the base of the stem to the tip, the leaves were scaled from large to small. The leaves are simple squashed spheres.

Unlike the Aeonium Lily and Kiwi Rare, Button Ferns are not placed in a Phyllotaxis structure. Instead, they are randomly clustered around the origin and fan out. My solution was to start with a circle mesh, with randomly scattered points. These points were then sorted based on its proximity to the origin. A float attribute was then added to each point named 'gradScale'. This attribute controlled the length and bend of the fern based on its proximity to the center.

In terms of parameters, users can adjust the density of leaves on each fern, colour of leaves, the number of ferns in a cluster, and the minimum and maximum range of lengths and bends.

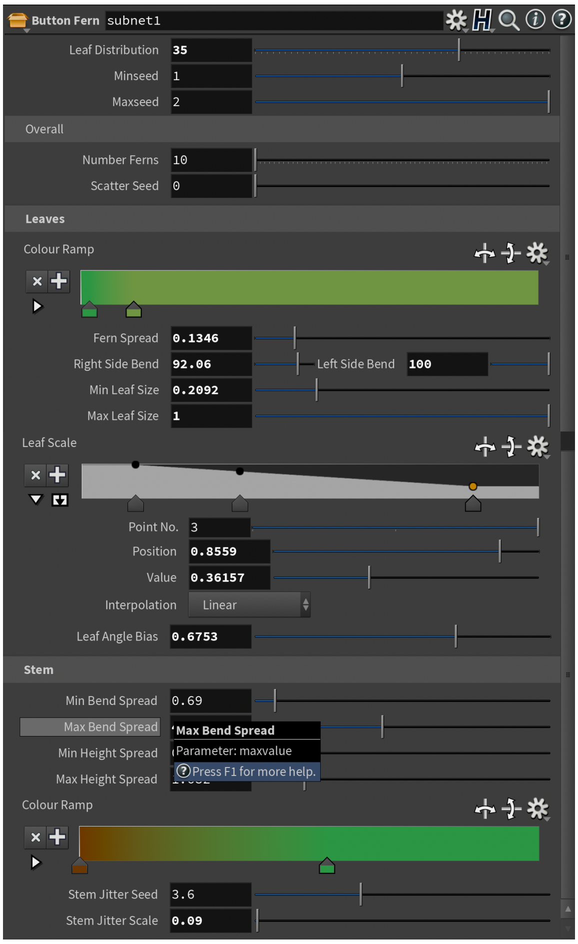

Figure 4 Button Fern HDA Parameters

5.4 Soil Terrain Development and Parameters

Houdini has a set of very powerful and useful nodes to procedurally create terrains or 'Heightfields'. These 'Heightfield' nodes give users the ability to create terrains based on different noise functions, simulate erosion and terracing of terrain, and scatter elements such as trees, rocks, etcetera on its surface in a controlled manner via masking. Thus the 'Heightfield' nodes were a useful start to developing the soil.

The issue with the 'Heightfield' nodes is that it assumes a large expansive scale (ie. sprawling grass fields and mountains). To ensure space and speed efficiency, I had to adjust the 'Heightfield' such that it fit the miniscule scale of the terrarium. Once the artist has created their ideal soil structure, the 'Heightfield' is converted into a mesh, remeshed, and smoothed to create a low poly object.

5.5 Terrarium Décor Development and Parameters

Small rocks, moss, and shrubs are typical decorative elements in terrariums and are scattered across the soil surface.

To model the rocks, a variety of noise was applied to the point positions and colour on a base sphere to emulate the rough facets and surface. Examples of noise include Perlin and Worley noise. Multiplier floats were extracted as parameters such that artists can quickly adjust the roughness and detail in the rocks.

The moss is the simplest procedural element in the terrarium. It is a line with several resampled points, and a point jitter applied to each point to mimic the tangled look of moss. To give more of a unique look, patches of moss are coloured in green, while other patches are coloured in purple.

The last décor element are small shrubs and bushes. To procedurally generate bushes, noise was applied to a base hemisphere. After a quick remesh, leaves are copied to the points on the mesh. Artists are able to customize the dimensions of the shrub, the density of leaves, the irregularity of its shape, and leaf colours.

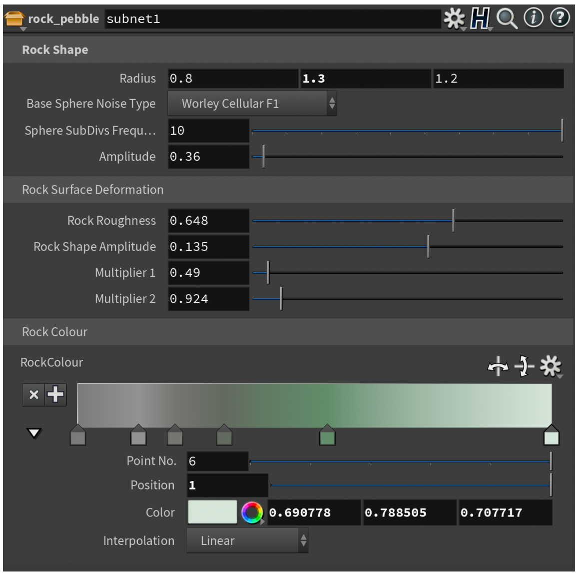

Figure 5 Small Pebbles HDA Parameters

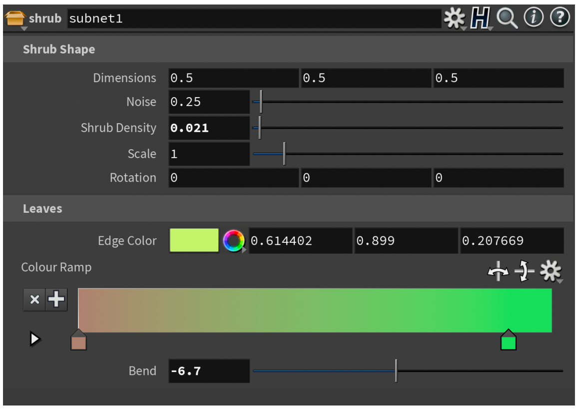

Figure 6 Shrubs and Bushes HDA Parameters

5.6 Fittonia Development and Parameters

Like the Button Fern succulent, the Fittonia Succulent is a stemmed leafy plant. The signature feature of this plant is its green leaves with purple veins which typically gather in groups of two to four. Each leaf group is placed along the stem; Leaves shrink in size as they go up the stem. The leaves also angle and droop downwards.

The Fittonia Plant HDA was created towards the end of the project as I felt the terrarium was missing a leafy plant. Due to the limited time, my resulting Fittonia HDA is a rough draft of a final version. The leaves are procedurally modelled and coloured using a ‘Simple Leaf Generator’ provided by Houdini. Leaves are then grouped in groups of two to four, and then instanced along the top of stem created in a similar manner to the Button Fern.

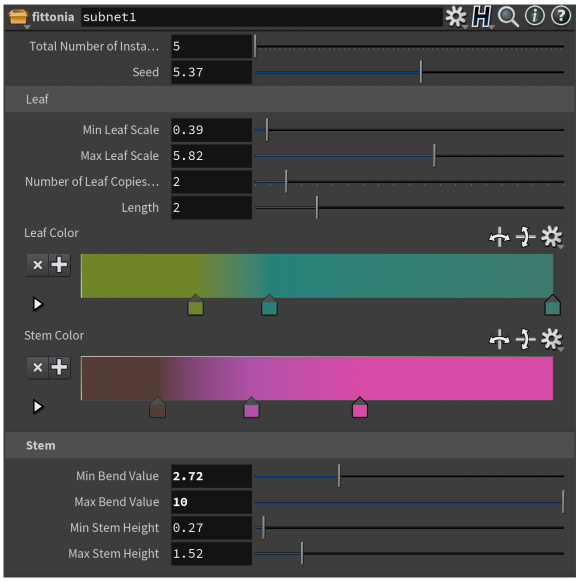

Figure 7 Fittonia HDA Parameters

5.7 Seeded Scattering of Terrarium Plants and Decor

After creating the basic HDAs for the Aeonium Lily, Kiwi Rare, and Button Fern succulents, and setting up a basic terrarium shape with soil terrain, the next objective was to procedurally place our assets in a structured and aesthetically pleasing manner.

Houdini has nodes built in that do scatter objecssts on a surface: ‘Scatter’ and ‘Copy to Points’. However, these nodes were limiting as they do not adjust point distances and object scales to prevent intersections. This system also doesn’t take advantage of the proceduralism and parameters of the HDAs; a singular instance of the input asset is copied to the scattered points.

Another issue with the ’Scatter’ node is that the scatter is uniformly distributed. However, the ‘Scatter’ node takes in a ‘density’ attribute to control how points cluster and disperse. An ‘Attribute Wrangle’ node was used to create a density attribute based on a noise function; The input to the noise function is the point’s position offset by some amplitude and exponential power. This method was the perfect set up for the following algorithm, as it ensures some points were clustered, and some were isolated on their own.

The biggest challenge in this project was preventing intersections between plants. My initial research resulted in the following solution: as an individual plant type is being scattered on to the soil, if an intersection occurs, replace the plant with an empty object. While this method worked and prevented inter-plant intersections, it did not prevent intra-plant intersections. Furthermore, it was extremely slow as it required a for loop for to check intersections between each plant type. Ultimately this method was not feasible.

After some research and experimentation, I found a tutorial from a YouTube channel called Pixel Fondue [PIX18] on a technique called pscale fitting to assist with the intersection problem. Essentially, the algorithm approximates the largest scale of a point such that it does not intersect with its neighbours. For each point, find the maximum difference between the distance between itself and its N nearest neighbours and the point's current radius. After filtering out the points with a new scale ratio greater than 1, we are left with a group of points with approximated scales to prevent intersection with its neighbours.

To take advantage of the succulent HDAs seeded parameters, I used the 'Copy Stamp' instead of the 'Copy to Points' node. The 'Copy Stamp' enables for several temporary variables to be initialized and passed into the input HDAs. In this case, the temporary variables could be randomized values within a range that could help control the number of leaves, bend of a stem, et cetera.

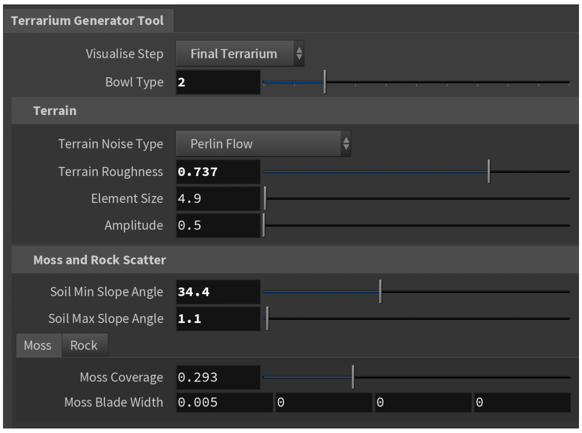

Figure 8 Terrarium Generator UI

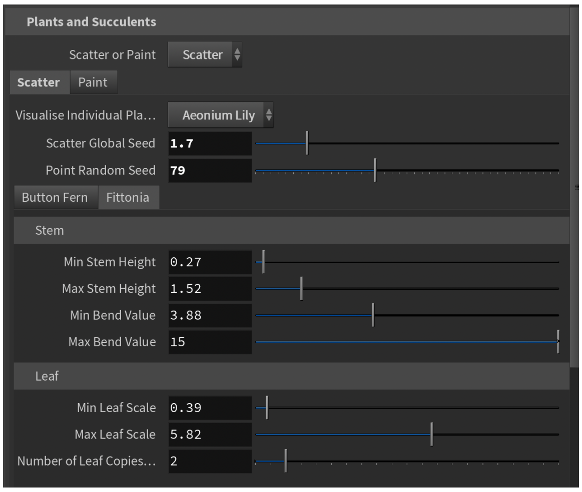

Figure 9 Seeded Scattering UI

5.8 Painting Tools for Terrarium Plant Placements

Two methods were trialed for the painting feature. The first method involved painting masks for different attributes via the 'Paint a Mask' node. These masks defined areas would define where individual succulents were allowed to generate. Within these masks, points would be scattered, and succulents would be 'Copy Stamp'ed to them. While this method worked in some aspects, the main issue was with the intersections between and within succulent types. For a similar reason as the first method attempted in section 5.7, this method was too slow and costly.

After implementing the algorithm from Pixel Fondue's channel, I discovered the 'Group Paint' node, which allows users to brush over points and add or remove them from a point group. Therefore, with the precomputed points generated from the algorithm, the areas users paint on the soil will overlap with certain points, and the spawned succulents will be perfectly scaled, and no intersections will occur.

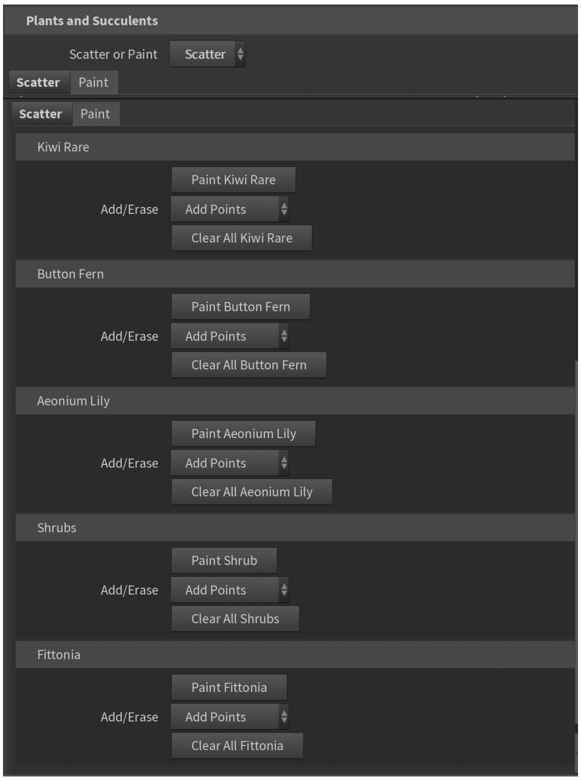

Figure 10 Painting UI

6. RESULTS

6.1 Procedural Terrarium Tool Houdini Digital Asset

The final product from my Senior Design Project is a complete Houdini Digital Asset that can procedurally generate terrariums. The terrariums produced feature a glass bowl, soil, and scattered rocks, moss, and four different succulents. The HDA has an intuitive user interface that enable artists to produce a wide variety of terrariums via seeded parameters, or to paint self-defined areas for certain succulents to spawn.

When using the Procedural Terrarium Tool, artists are first greeted with a 'Visualise Step' drop down menu. The dropdown is available so the artist can see and tweak each individual aspect of the terrarium construction, such as the bowl shape, soil heightfield, each individual succulent type, and the finished product. This feature is incredibly important for run time as the node network is only being computed and updated in necessary increments. For example, changing the shape of a succulent's leaves should not require the soil heightfield to remesh, or for succulent point scales to be recomputed.

With each dropdown option in the 'Visualise Step' menu, the artist can tweak the relevant parameters. If the 'Individual Plant', or 'All Plants' option is selected, the artist may choose how to place plants on the soil: 'Scatter' or 'Paint'. For the 'Scatter' parameter set, the artist can simply change the global seed to get a brand-new layout of succulents by one click. As for the 'Paint' settings, each succulent is given 'Paint', 'Add/Erase', and 'Clear All' buttons. As their names suggest, clicking the relevant button, the artist's mouse pointer is converted into Houdini's painting tool. Brush sizes can be changed via scrolling, and the user can simply paint on the soil surface where they want certain succulents to go.

7. CONCLUSIONS and FUTURE WORK

To demonstrate the abilities of the Procedural Terrarium Tool, I rendered six images of six different terrariums generated by the HDA. Each of the terrariums feature unique succulent and décor placements, soil heightfields, and bowls. Due to the 'Visualise Step' feature, these terrariums were able to be generated efficiently. The different succulent types and décor were quickly textured using Houdini's 'UV Quickshade' node, alongside standard 'Materials' with adjusted specular and subsurface scattering properties. Each image was rendered with three-point lighting and took around 15 minutes to complete.

Overall, majority of the goals set in the initial planning of the project have been fulfilled. This includes a set of HDAs to generate succulents and décor, and the main HDA that builds terrariums via seeded scattering or defining areas by painting. However, there are a handful of goals that have not been explored. The tool currently textures each asset with a simple diffuse colour or gradient. Building Substance Painter Smart Materials could add valuable stylization, realism, and completion. In addition to materials, setting up an exportation pipeline to Autodesk Maya and Unreal Engine 4 would also be a worthwhile addition. Other future work includes adding animations to simulate the growth of terrarium plants over time, as well as simulating phototropism.

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Figure 11 *Reference image of Button Ferns*

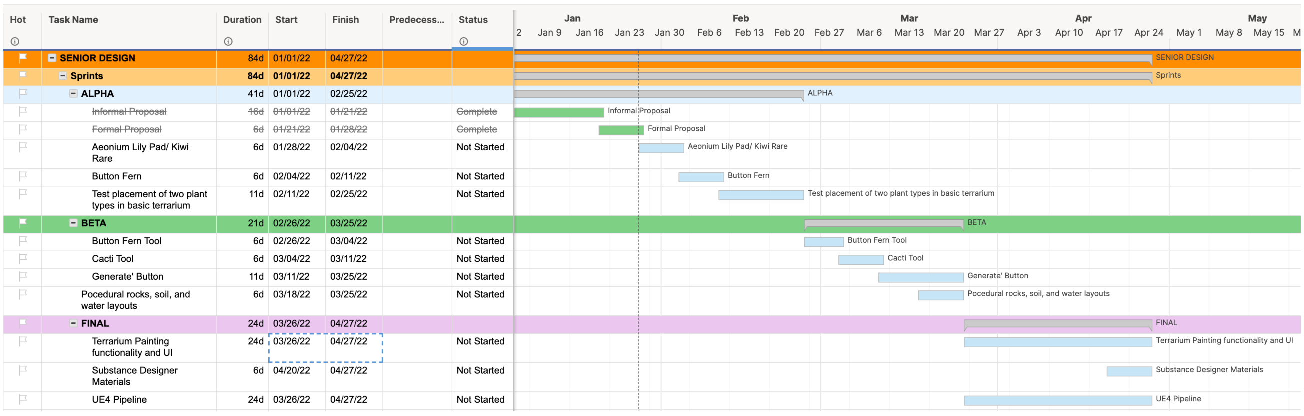
Figure 12 *Reference image of Fittonia*

Figure 13 *Reference image of rocks and pebbles*

Figure 14 *Reference image of moss and shrubs*

Figure 15 *Reference imag eof Aeonium Lily Pad*

Figure 16 *Reference image of Kiwi Rare*



Hot	Task Name	Duration	Start	Finish	Predecess...	Status
	SENIOR DESIGN	**84d**	**01/01/22**	**04/27/22**		
	Sprints	**84d**	**01/01/22**	**04/27/22**		
	ALPHA	41d	01/01/22	02/25/22		
	~~Informal Proposal~~	~~16d~~	~~01/01/22~~	~~01/21/22~~		~~Complete~~
	~~Formal Proposal~~	~~6d~~	~~01/21/22~~	~~01/28/22~~		~~Complete~~
	Aeonium Lily Pad/ Kiwi Rare	6d	01/28/22	02/04/22		Not Started
	Button Fern	6d	02/04/22	02/11/22		Not Started
	Test placement of two plant types in basic terrarium	11d	02/11/22	02/25/22		Not Started
	BETA	21d	02/26/22	03/25/22		
	Button Fern Tool	6d	02/26/22	03/04/22		Not Started
	Cacti Tool	6d	03/04/22	03/11/22		Not Started
	Generate' Button	11d	03/11/22	03/25/22		Not Started
	Pocedural rocks, soil, and water layouts	6d	03/18/22	03/25/22		Not Started
	FINAL	24d	03/26/22	04/27/22		
	Terrarium Painting functionality and UI	24d	03/26/22	04/27/22		Not Started
	Substance Designer Materials	6d	04/20/22	04/27/22		Not Started
	UE4 Pipeline	24d	03/26/22	04/27/22		Not Started

Figure 17 *Gantt chart for my project timeline*