



**6CCS3PRJ Final Year**  
**Implementing Procedural Content**  
**Generation Algorithms in a Tile Map**  
**RPG in the Godot Game Engine**

Final Project Report

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## **Abstract**

Procedural generation refers to content in a medium that is produced algorithmically in lieu of by hand. Most notably, procedural generation algorithms are implemented in video games, for generating levels, terrain and other game contents programmatically. This project takes some of the more prominent algorithms for procedural generation- Lindenmayer Systems, Voronoi Points, Poisson Disk Generation and Simplex Noise- and implements them in a 2D tile-map-oriented RPG-like game in the open-source Godot game engine, and compares their workings and performance. My aim with this project is to (1) increase my knowledge of procedural generation in games beyond the surface level, by going in-depth into some of the algorithms that are used, and (2) use this knowledge to implement said algorithms in a 2D tiled RPG scenario in Godot, then compare how each algorithm works and performs.

### **Originality Avowal**

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Zishan Rahman

April 21, 2023

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# Chapter 1

## Introduction

Procedural Content Generation, or PCG, refers to the use of algorithms and programming in lieu of human handiwork to design and implement various contents in video games, such as levels, terrains, trees and cities. A PCG algorithm is ontogenetic when it tries to produce a foreseeable end result as it goes along. For this project, several well-known ontogenetic algorithms have been implemented in a basic 2D tile-map-oriented RPG-like game, using the open-source Godot game engine, and then comparing how each algorithm carries out the creation of levels in said game, both performance-wise and comparing the kinds of level layouts generated by each algorithm. The aim here is to weigh up the best algorithm for the chosen scenario based on how similar and how different each implementation of the algorithm provides with its level layouts, and show how every algorithm was well integrated into the chosen scenario and adapt the scenario and the algorithm as needed.

### 1.1 Report Structure

First, there will be some background provided into the work done behind this dissertation, demonstrating some understanding of PCG in video games and eventually justifying the choice to use Godot, why a 2D tile map RPG was chosen to adapt to a PCG context and why each algorithm was chosen to implement each PCG algorithm into the defined scenario.

The main report body will go through firstly how each algorithms works, and secondly go into how they were implemented into the chosen scenario at a surface-level explanation. This report goes into further detail in the Implementation section.

The Design & Specification section will firstly go through what was sought after in every



implementation of the chosen scenario, in order to be able to compare each implementation with one another and then determine how each algorithm was ranked according to the relevant criteria in the Evaluation section.

The Implementation section will go into further detail than done in the report body as to how each algorithm implemented and any code issues were worked around, including GDScript code snippets where needed.

The Legal, Social, Ethical and Professional Issues section will discuss how, firstly, any issues with any external code references used for any software artefacts were eventually worked around, and how integrity was practiced while doing so. Secondly, this section will go through the plans set out to make both the dissertation and the artefacts behind it publicly available while still taking care of any potential professional issues.

The Results & Evaluation section will go through some of the quantifiable results obtained in experimenting with theses implementations and any custom values that were set during those experiments. This report has included these tables in the Appendix, so as not to break the flow of the report itself. This section will also discuss the conclusions obtained and how each algorithm was ranked in terms of how they turned out with the given scenario, as well as how similar and different the produced level layouts were.

Finally, in the Conclusion and Future Work section, there will be a final summary of the conclusions obtained and discussed earlier, in addition to what was gained by the author of this report as a games programmer and student from this project, and where this project and its aims could be taken further.

## Chapter 2

# Background

For the author’s BSc individual project, this paper will be researching procedural content generation (PCG) algorithms and then implementing them each in a small 3D game made with the Godot Engine (and its domain-specific GDScript language).

### 2.1 Procedural Generation: Background

Procedural content generation (usually referred to as simply “procedural generation”) refers to the creation of levels and other game objects programmatically and algorithmically, in lieu of a human being doing all the work. While procedural generation algorithms can be used to generate a myriad of things, from textures (for things like trees and clouds) to music (“generative music,” as coined by legendary musician Brian Eno), by far its most common context is in automated level design, generating level layouts algorithmically in lieu of work from level designers. Game developers may opt to use procedural generation to save time and money designing levels or show off technical prowess in their games.

Procedural generation in video games has a rich history. Pioneering games such as *Rogue* (1980) took direct influence from tabletop role-playing games such as *Dungeons and Dragons*[10], and thus had a player navigate a randomly-generated world that expanded further as they went on. Such games spawned the *roguelike* and *roguelite* genres, which experienced immense popularity in the last decade. In the realm of first-person shooters, 2004’s *.kkrieger*, as seen in Figure 2.1, used procedural generation to create intricate 3D levels and fit them all into a game that takes up just 96 kilobytes of space.



Figure 2.1: The game .kkrieger, which uses procedural generation to design maps while keeping the game at a 96 kilobyte file size.[17]

Other games that use procedural generation in its levels include Elite (originally published in 1984), Elite: Dangerous (2012), Minecraft (2009), No Man’s Sky (2012) and Spelunky (2013). The latter game’s use of procedural generation has notably been covered by video games journalist Mark Brown in a YouTube video.[4]



Figure 2.2: The roguelike game Spelunky, which uses procedural generation to build intricate levels for the player character to explore.[36]

In many cases, these games end up having a **large** number of different environments that each game could generate for its players. However, by procedurally generating them upon the *loading* of the game level, in lieu of loading a layout from disk, they can save a lot of space (albeit with a considerable need for processing power, depending on the game’s and algorithms’ performance), as seen in Figure 2.1.

Using one or some different procedural generation algorithms, such as the use of Perlin, Simplex or other noise, Voronoi disks and also poisson disk generation, among others, games can load a seed to randomly generate a level every time it is played, meaning no two playthroughs

of a game with procedurally generated content are ever the same.

## 2.2 Justifying The Paper’s Choice of Engine: Godot

While a myriad of resources exist for procedurally generated game contents exist for Unity and Unreal, this paper wants to implement them in Godot, for several reasons:

- It is the engine the author of this paper has the most experience with, having already developed 2 published web games with it.
- It is not got as many resources on procedural generation compared to Unity, Unreal and some other popular game engines, particularly on the side of academic research (that is, there are not as many papers on procedural generation that pertain to Godot as they do to Unity, Unreal and other engines).
  - However, it is still very powerful and feature-rich (it has its own Open Simplex noise class, for example) and this paper is sure procedural generation algorithms can be made to work well on it.
- Compared to Unity and Unreal, Godot is a very light engine with a feature-rich editor, clocking in at under 100MB, with editors for Windows, macOS, Linux and even the web browser.

By the end of the author’s allotted time, this paper plans to have shown implementations of several procedurally generated environments in small Godot games, using a myriad of methods (such as Voronoi cells and poisson disk generation) in a myriad of contexts (anything from platformers to first-person games). With these games, this paper is planned to be the centrepiece of this whole project, with it containing this paper’s research on how each environment was implemented, as well as the findings on the algorithms themselves and how they work.

This is somewhere between a research-oriented project and an implementation-oriented project, as while the produced software artifacts provide valid proof of this paper’s understanding of some commonly used procedural generation algorithms and how to implement them in Godot, it is also about how it understands their workings. Nonetheless, the implementations provide the weight behind this paper’s motivations and are the main focus of this dissertation. They will prove that Godot is just as adept at procedural content generation as the other major players in the game engine space, and the author of this report will have gained a wealth of knowledge on PCG in the process.

### 2.2.1 Note on Differing Versions of Godot

Godot currently is at version 4, which finally received a stable release in 4<sup>th</sup> March after years of development, but concurrently there is also Godot 3, the previous stable version which is now a **Long-Term Support** release. The latter version of Godot contains several new features and breaking changes, so any project made in Godot 3 won't readily be compatible with Godot 4 (and vice-versa) without making the necessary changes and conversions. The author of this report has access to both versions of Godot and, for all the Godot projects that were made and used in this project, he have used Godot 4. Any references to other Godot 3 projects will be clearly denoted as such.

## 2.3 Justifying The Choice of Scenario: A 2D tile-map RPG-style roaming game

The scenario of this paper's choosing involves a monochrome tile-map created by Kenney.nl in a 2D RPG setting, in which the player character is a hollow "Golem" that is trying to search for and obtain a ring among a large 72x40 village, filled with trees, buildings and emptiness. The player can "chow down" trees by simply going to the cells where trees are and making them disappear. However, the player *will* stop at and collide with any buildings in the tile map. When the player collects the ring, they win the game and are able to either close the window or generate a new village to try and collect *another* ring.

The size of the tile map is determined by taking the window size, 1152x640 in **all** implementations, and then dividing it with the cell size, 16x16 in **all** implementations (again), hence returning a 72x40 tile map size. Using a large tile map like this, with 2880 available cells in total, allows for easy stress-testing of the algorithms, making them generate level layouts that are sufficiently large enough to produce a quantifiable performance result and time that can be easily compared across implementations, such that we can easily measure how one performs over the other. The use of a tile map *this* large with PCG algorithms also makes sense from a game developer's perspective as designing level layouts this large by hand, with such a small cell size as well (inherited from the size of the tile map assets), would add additional time and labour costs to them.

The use of a tiled role-playing game scenario, adapted to already-existing procedural generation algorithms, is relatively unusual in the context of procedural generation. However, it *will* allow us to go a degree beyond the scope of what is usually done for procedural content

generation in games, which is usually seen in 2D and 3D roguelikes and platformers, as well as some other world-building games such as Minecraft and Terraria, while also producing code that is relatively easy to process through and understand. The ability for the player character to consume trees and remove them from the level layout by moving into them allows that player to easily move around in what would otherwise be very crowded level layouts that would have been near-impossible to traverse. The addition of said player character, as well as the end goal of obtaining a randomly-placed ring within the given level, adds weight to the algorithms' practical use in games made with Godot, and not just for show or solely as demonstrations.

## 2.4 Justifying The Choice of Algorithms for the Above Scenario

For this paper, the following procedural content generation algorithms will be implemented within the aforementioned scenario:

1. Lindenmayer Systems (or L-Systems)
2. Perlin and Simplex Noise
3. Poisson Disk Sampling/Distribution
4. Voronoi Cells/Diagrams

Using an L-System for generating a level layout is relatively uncommon, compared to its use in generating structures such as trees and buildings. However, this paper plans to integrate a deterministic context-free L-System (or a "D0L-System") into an implementation of the scenario so that we can compare it performance-wise to the other algorithms, and see how the repeated patterns generated from L-System grammars affect comparisons to the other implementations' level layouts.

Perlin and Simplex Noise are far more commonly used for level layouts, so the author of this report has created an implementation of his scenario with one to see how it compares with the others, speed-wise and layout-wise, and see if it really is the best for the chosen scenario.

Poisson Disk Sampling is usually used for item placement in planes, even with grids, so using a grid-like implementation, we will compare how it works with in a tile map and what differences arise between its use there and in its usual uses.

Though efforts were made to make level layouts as similar as possible across implementations, there are noticeable differences between the level layouts generated by L-Systems,

Simplex noise and Poisson disk samples, and this paper touches on those when discussing those implementations in the relevant sections.

In the paper's research and implementation of Voronoi Cells the author of this report realised that the level layouts it generated for the chosen scenario were wholly unique, when compared with the other algorithm implementations, so much so that he had to re-shape his scenario and game mechanics to make both the scenario and levels generated fit with each other. Nonetheless, he believes this will serve as a unique comparison to the other algorithms and will serve as additional knowledge of procedural generation algorithms as well as more work towards understanding how to make them work in Godot games (as proven by these implementations).

## Chapter 3

# Report Body

In this chapter, this paper will explain how each of the chosen algorithms work, and how its author went around implementing them as a surface-level explanation. The paper will then briefly compare what challenges were faced for each of our implementations, and how they compare, both performance-wise and with regards to the kinds of layouts they produce, again as surface-level explanations. We go into greater detail on our implementations in the Implementation section (chapter 5), how the level layouts generated in each algorithm compare with each other in the Design & Specification section (chapter 4), and how each implementation compares overall (and also performance wise) in the Evaluation section (chapter 7). For this project, this paper chose to use the following 4 algorithms.

1. Lindenmayer Systems (or L-Systems)
2. Perlin/Simplex Noise
3. Poisson Disk Sampling
4. Voronoï Cells

All of the above algorithms are “ontogenetic.” This means that it attempts to recreate the final steps of a real-world process or mathematical calculation without going through much of the intermediary steps.[11] This contrasts with “teleological” procedural generation algorithms, which **directly** simulate and/or model part of the real world as part of its content generation.[13] This difference between them is described very well in a 2008 article for video games magazine Gamastura by Mick West:

“Two competing methodologies in procedural content generation are teleological and ontogenetic. The teleological approach creates an accurate physical model of the environment and



the process that creates the thing generated, and then simply runs the simulation, and the results should emerge as they do in nature.

The ontogenetic approach observes the end results of this process and then attempts to directly reproduce those results by ad hoc algorithms. Ontogenetic approaches are more commonly used in real-time applications such as games. (See "Shattering Reality,"[sic] Game Developer, August 2006.)"[52][50][51]

## 3.1 Algorithms

In this section, this paper will explain how each of the implemented algorithms work, then we will go into small detail as to how they were implemented. We go into further detail in the Implementation section of this report.

### 3.1.1 Lindenmayer Systems

Hungarian academic Aristid Lindenmayer devised a mathematical model for the reproduction of fungi in 1967.[31] His model involved a string of symbols, each unique symbol denoting a specific action and/or branch. Essentially, running that initial string, called the *axiom*, through a set of rules (called a *grammar*) gives us an ever-expanding string that is then taken as instructions to draw something from. Lindenmayer Systems, or L-Systems, have since been used in several scenarios beyond its initial purpose of modelling fungi, from trees to fractals. In video games, they are frequently used to aid in the creation of foliage in several environments, as well as buildings and, here, level layouts. We go over how the author of this report got his implementation to work with complex multi-rule grammars in Chapters 3.2.2 and 5.1.

#### A Basic 0L-System

The most basic form of L-System is a *0L*-System, 0 in this case referring to the fact that the grammar is *context-free*.

For this example[2], consider an alphabet  $V$ , which consists of the following symbols:

$$F, +, -$$

where F means "to go forward", and + and - denote turning right or left (respectively) a set number of degrees  $\phi$ .

Take an axiom  $\omega$ , for example:

$$F + F + F + F$$

And a set of rules  $P$  which, in this case, is of size 1:

$$F \rightarrow F + F - F - FF + F + F - F$$

We can represent this *parametric* L-system in the following form:[53]

$$G = (V, \omega, P)$$

The first 3 iterations of string replacement with this one-rule grammar  $G$  are shown here:

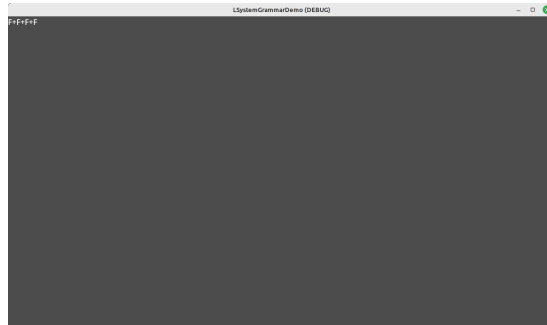


Figure 3.1: The axiom of the aforementioned simple L-System with just one rule. String size: 8.  
Source: Own work.



Figure 3.2: The first iteration of the aforementioned simple L-System with just one rule. String size: 59.  
Source: Own work.

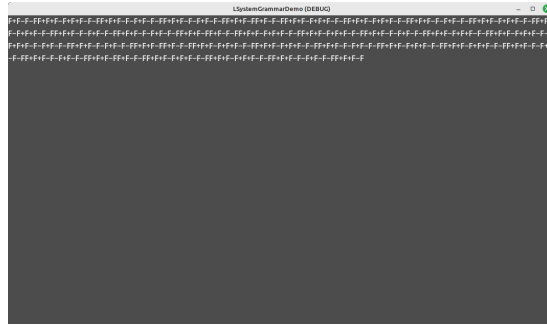


Figure 3.3: The second iteration of the aforementioned simple L-System with just one rule. String size: 475.  
Source: Own work.

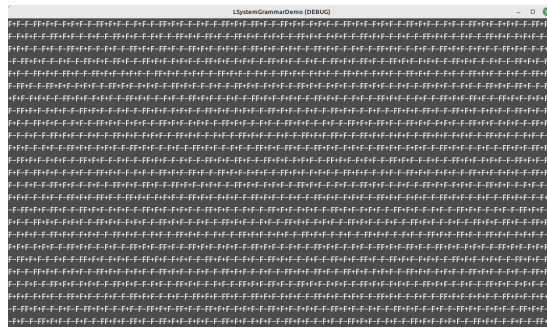


Figure 3.4: The third iteration of the aforementioned simple L-System with just one rule. String size: 3803. The string is too large to show in the window, as you can see here.  
Source: Own work.

The resulting string can be used to draw a lattice.[2] Examples of the above grammar in action are below.

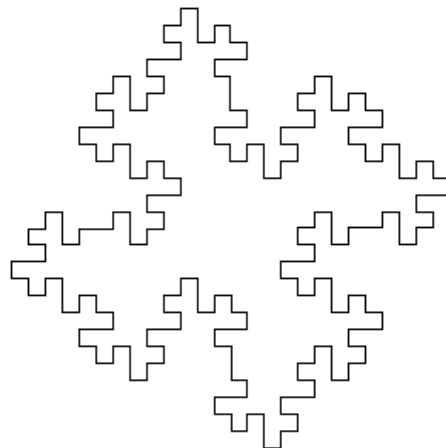


Figure 3.5: A lattice generated with the example grammar on a custom-written Classic Mac OS application specifically written for working with L-Systems.[2]

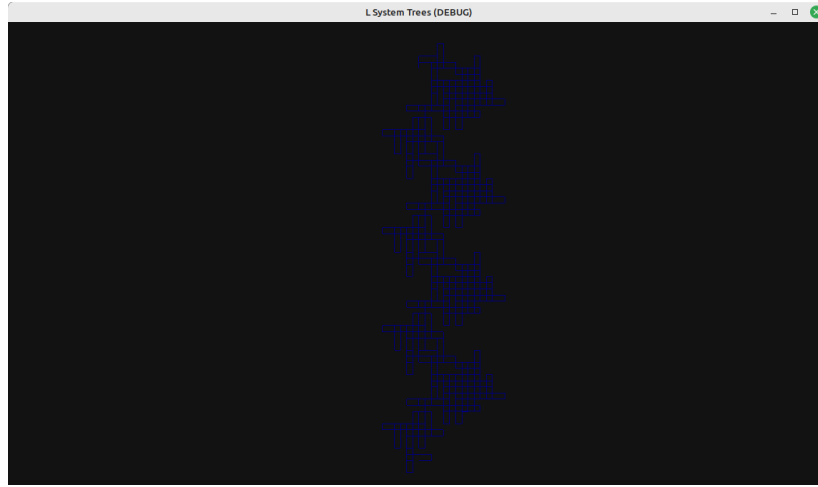


Figure 3.6: A lattice generated with the example grammar on a Godot project for drawing from L-Systems. Source: Initial project written by Alexander Gillberg for his YouTube channel Codat[20][21], and converted to Godot 4 (with the addition of the lattice grammar) by the author of this report.[22]

### A More Complex D0L-System With More Than One Rule

The grammar in the following example represents a D0L-System[37], a **deterministic** L-System using a context-free grammar; the grammar in the first example was *also* deterministic.

For this example, consider a new grammar  $G$  with the alphabet  $V$ , where  $a$  and  $b$  are the only symbols. We start with the following axiom  $\omega$ , which is just  $a$ . We now have a set of rules  $P$  which is, this time, of size 2:

$$a \rightarrow ab$$

$$b \rightarrow a$$

The first few steps of the resulting derivation can be modelled like so:

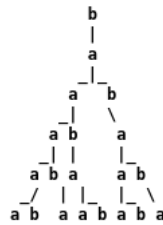


Figure 3.7: The first few steps of a derivation of our example grammar.[37]

### 3.1.2 Perlin/Simplex Noise

Traditionally, white noise images, and most other noise types, place noise pixels completely randomly, without each pixel considering the values of its neighbours[39], as you can see in Figure 3.8.

However, there exists several types of **value** and **gradient** noise that *do* take surrounding pixel values into consideration, and will therefore serve more use in building levels in our games.

Value noise simply takes a lattice of points with random values and then interpolates those points based on their surrounding values. This *can* be used as a procedural texture. However, due to the simple nature of the algorithm, it's possible that the difference between several values in a region is minimal, while in other regions the values may differ immensely, resulting in a noise image that is not very smooth.

Gradient noise, on the other hand, takes point lattices and instead calculates the interpolation between tangents.[9] Since both tangents between a curve must be collinear[9], the flat and bumpy curves produced by value noise's interpolation calculations are now much less likely to be returned, as seen in Figure 3.9.[9] This results in noise images of higher and more appealing visual quality as, to quote a response from Stack Exchange by Hernan J. González[23], “it cuts low frequencies and emphasizes frequencies around and above the grid spacing.”

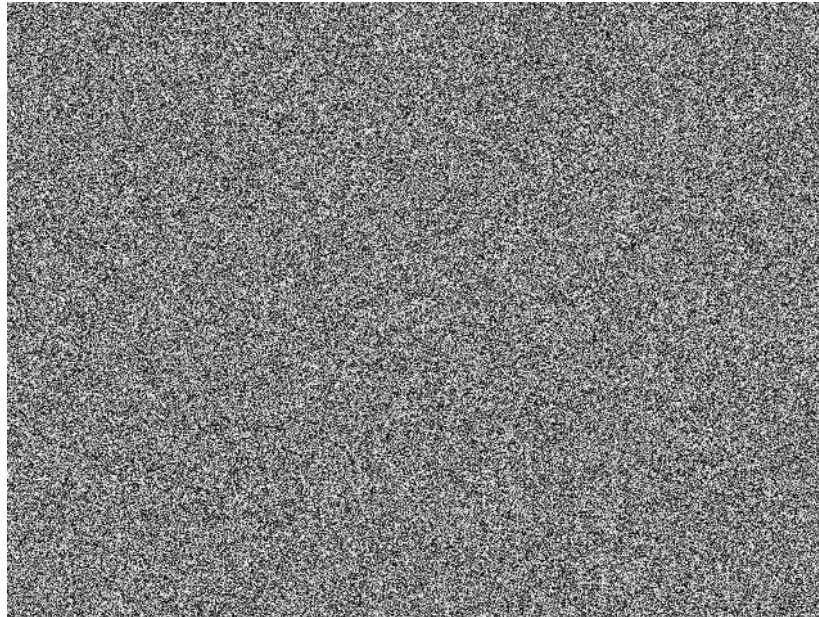


Figure 3.8: A white noise picture generated with Robson's white noise image generator.[44]  
Settings: 640 squares horizontally, 480 squares vertically, size of squares 1, colours greyscale, bias none.

# Perlin Noise



# Value Noise

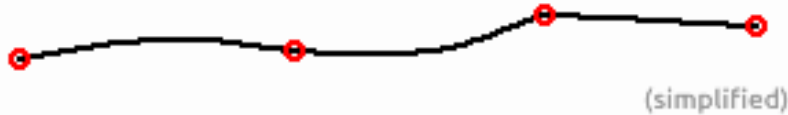


Figure 3.9: A comparison between the kinds of curves produced by Value noise interpolation and Perlin (and other Gradient) noise interpolation.[9]

Two particularly well-known Gradient noise algorithms that are commonly used for procedurally generating levels are the already mentioned Perlin Noise and Simplex Noise, both designed by American Computer Science professor Kenneth H. Perlin, with the former being an improvement on the former. Perlin Noise also takes a lattice of randomly assigned gradients, but the algorithm interpolates the dot products of those points instead of just their neighbouring values.[32] Simplex noise, meanwhile, tries to reduce the grid artifacts caused by the original algorithm, and has the added benefit of scaling better to larger dimensions.[12] Perlin filed a patent on his work in 2002 that was granted in 2005[40], which prompted the creation of the OpenSimplex noise algorithm[27][41][26] for free use; the patent has since expired in 2022, allowing free use to both Perlin and the original Simplex noise.[40]

Godot 3 previously featured an `OpenSimplexNoise` class[25][16] for generating noise textures, which used the OpenSimplex algorithm. In addition to using a “simplectic honeycomb” for its lattices[26], this algorithm also (to quote Michael Powell) “expands the range of the gradients a bit, so they can extend a little bit into neighboring cells. This theoretically makes the noise a little bit smoother, but it also means that extra cells need to be checked.”[41] Godot 4, on the other hand, allows us to use the *original* Simplex noise algorithm, as well as Perlin noise, 2 types of Value noise and a variation of Simplex noise that produces smoother, high quality noise images with an additional performance cost, and it allows us to control which algorithm we use for noise generation using the “noise\_type” property and “NoiseType” enumeration in

the “FastNoiseLite” class that is now used for noise.[32]

### 3.1.3 Poisson Disk Sampling

Poisson disk distributions are an easy way to randomly scatter objects across a field. It’s commonly used for tree placement and placement of other random objects. Points are placed over a plane, with a single point placed randomly and subsequent points calculated such that a single point has no other point lying within a given radius of said point. Different implementations of Poisson disk distributions or samples can accommodate multiple radii for points in a plane, and some implementations produce *maximal* samples- that is, a set of samples that fully cover the given plane, while still adhering to the principle that no single point has other points lying within its radius[15] (the implementation that was made for this project does **not** guarantee maximality, however).

An implementation of Poisson disk sampling was originally developed in 1991 by Don P. Mitchell[35] as a replacement for inefficient Monte Carlo “dart-throwing” algorithms.[42] Mitchell’s algorithm ran in  $\mathcal{O}(n^2)$  time, whereas Robert Brinson’s 2007 improved algorithm for Poisson disk sampling[3] ran in  $\mathcal{O}(n)$ . Subsequent quality and speed improvements to Brinson’s algorithm were published in 2019[43], 2021[42] and 2022[45]. The implementation made for this project, as well as the Unity project this was based on, were both based on Brinson’s 2007  $\mathcal{O}(n)$  algorithm.[30][29]

The following are some examples of Poisson disk distribution in action:

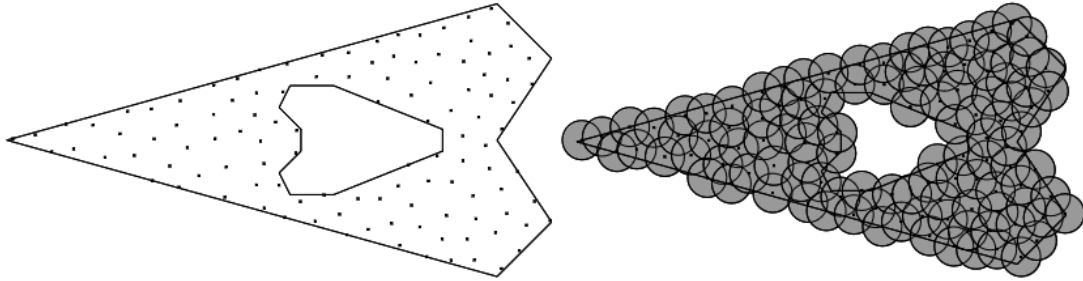


Figure 3.10: A diagram of a maximal Poisson disk distribution done on a concave plane, with the right side denoting maximality through the grey disks overlapping but not any points overlapping.[15]

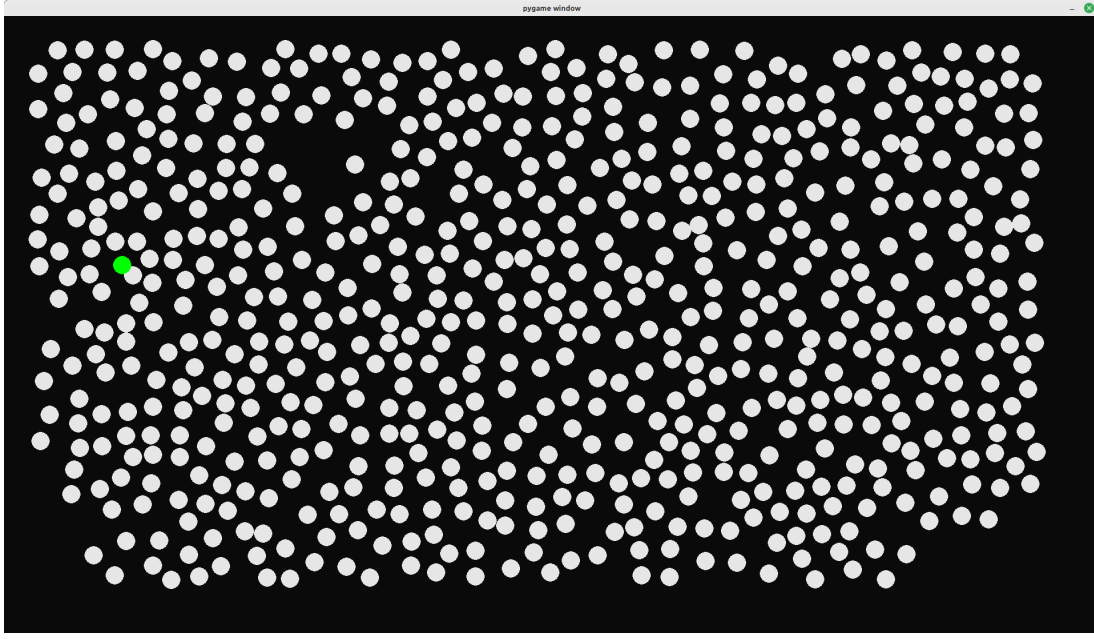


Figure 3.11: An implementation of Poisson disk sampling made in Pygame.[1] The screenshot was taken *after* all of the samples were taken.

### 3.1.4 Voronoï Cells

Named after the Ukrainian mathematician Georgy Voronoy, Voronoï cells work by taking a map of points, and randomly selecting a group of points. Within that selected group, cells are formed by calculating, in each point of the grid, the closest of the selected points to it. That is, each cell represents the group of points that are the closest to that random point (including that point in the group as well).[14] The final arrangement of cells represents a Voronoï Diagram or Voronoï Tessellation.

Distances between points can be calculated with either the Euclidean distance:

$$d_E(p, q) = \sqrt{(q_x - p_x)^2 + (q_y - p_y)^2}$$

or the Manhattan distance:

$$d_M(p, q) = |q_x - p_x| + |q_y - p_y|$$

with the Euclidean distance producing a more “triangulated” tessellation than the Manhattan distance, with straighter diagonals and cells shaped like irregular polygons, the geometry of which is more “blocky” and resembles taxicabs (hence its alternate name “Taxicab Geometry”). Two visual comparisons of the kinds of Voronoï cells generated with either distance calculation



are shown in Figures 3.12 and 3.13.

There *are* other algorithms that can be used for calculating distances, including the Delaunay Triangulation[24], which the corresponding Voronoï tessellation is dual to.[49]

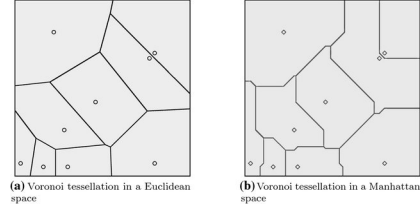


Figure 3.12: A visual comparison of the kinds of Voronoï cells generated with the Euclidean and Manhattan distance.[47]

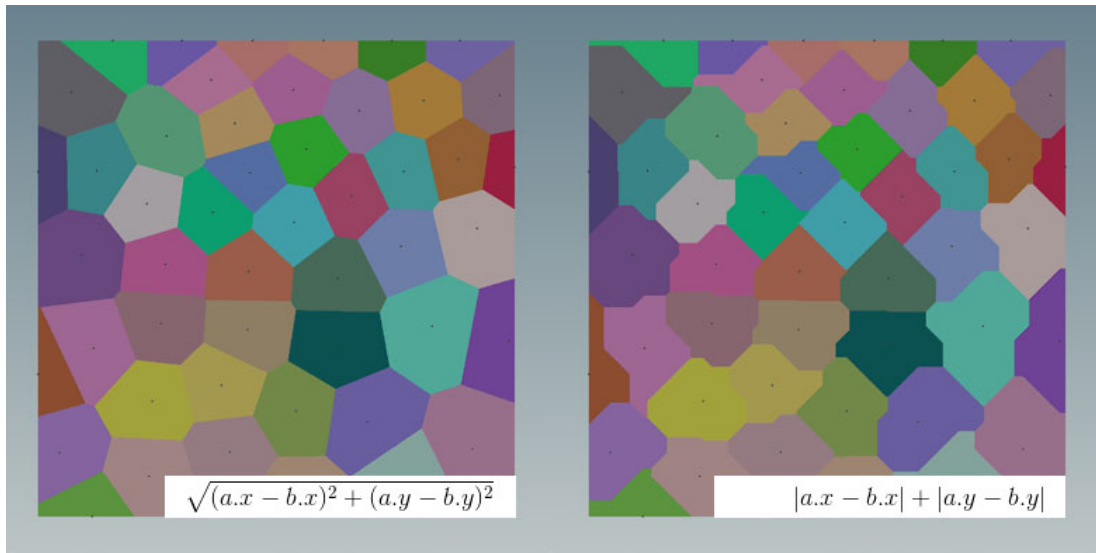


Figure 3.13: Another example of the differences between a Voronoï tessellation with distance between points calculated with either the Euclidean distance or the Manhattan distance.[48]

## 3.2 Implementations

Here we will describe, at surface level, the methods this paper's author went about implementing the above algorithms and what references were used for these implementations.

### 3.2.1 Commonalities Between Implementations

To implement the same scenario, aforementioned in the background of this report, across all 4 algorithm implementations, this paper's author had to include some of the same code and functions, as well as the same tile set shown in Figure 3.14.

From this tileset, which contains 1078 tiles, the written code uses 27 building tiles, 13 tiles

for trees and other fauna, 1 tile for the player character and one of 4 tiles for the ring. The relevant coordinates of the tiles for buildings, trees and the ring are each stored in constant arrays in the script, while the player tile's coordinates are just stored in a local constant (not an array, since there is no need for one).

To handle player placement and subsequent movement, the code has several functions. Godot's built in "physics\_process" function handles events that happen in real-time, and is commonly used, like in this context, for player movement. In it, we first store the current player's cell, "player\_movement\_cell", in "previous\_cell", then we initialise a "direction" based on which input movement was pressed ("Vector2i.LEFT" when "ui\_left" was pressed, and so on). Then we add the player's current cell with the direction to calculate the potential "new\_movement\_cell". If this cell is within the bounds of the environment, as well as either a tree or empty space (or the ring), it moves there, and the previous cell gets erased. If the player ends up moving into the cell where the ring is, the player wins the game, and all movement is paused while a winner's dialog popup shows up. The player moves **very** quickly in our games, and we have yet to figure out how to slow down this movement while also not making movement so slow that the game drags; the player will not want to have to continually press down an arrow key to move to 1 cell in a map of 2880 cells. Since the performance of the algorithms are more important in this project, however, we decided to leave the very fast player movement as is.

There are written "place\_player" and "place\_ring" functions that handle the random generation of the player's and ring's initial starting positions. Both use the "\_get\_random\_placement\_cell" helper function to retrieve a new cell, and both use a while loop to make sure the randomly generated cell isn't already occupied. In both functions the placement cells are assigned and calculated **before** the while loop, so that their placements do not default to just (0, 0) in the beginning.

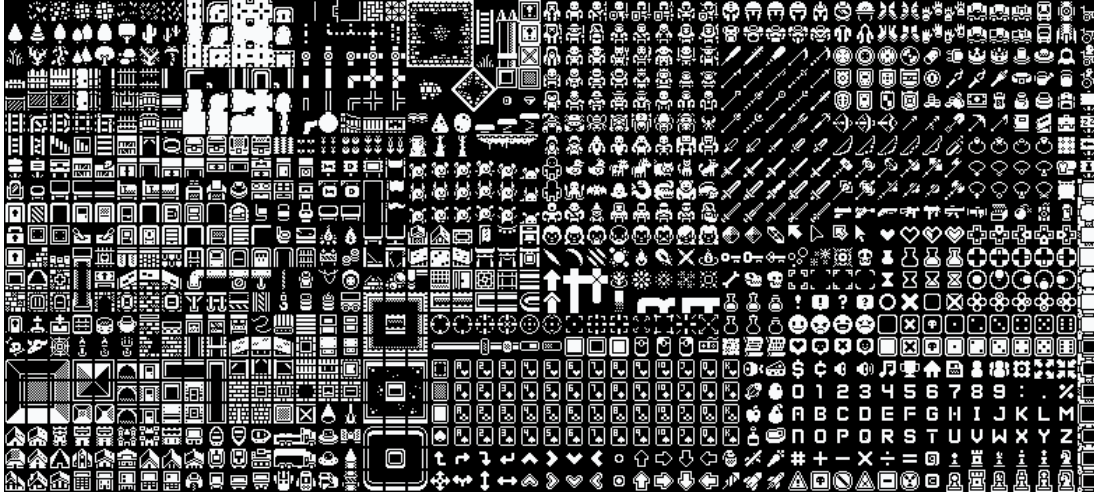


Figure 3.14: The tileset used for all 4 implementations of the chosen scenario with PCG algorithms.[28] Of all the 1078 tiles, of size 16x16, in this tileset, only 45 of them get referenced in the written code.

Across all implementations, there are two local variables, “x\_tile\_range” and “y\_tile\_range”. Both of these calculate the dimensions of our tile map by taking the display window’s respective x and y dimensions from the project’s settings (1152x640) and divides them by the respective x and y dimensions of the cell size (16x16). “x\_tile\_range” should resolve to 72 upon runtime, and “y\_tile\_range” should equal 40, giving us our 72x40 tile map that gives us a total of 2880 cells to work with in our games.

Finally, there are two dialog popups added to each scene tree, one for describing the game’s story (“AcceptDialog”, of type “AcceptDialog”) and another for when the game ends after the player has collected the ring (“WinDialog”, of type “ConfirmationDialog”). For “AcceptDialog” the “confirmed” and “canceled” signals are both connected to the function “\_on\_AcceptDialog\_closed”, which hides the popup and unpauses the game. For “WinDialog”, on the other hand, “confirmed” is connected to “\_on\_WinDialog\_confirmed” and “canceled” is connected to “\_on\_WinDialog\_canceled”. “\_on\_WinDialog\_confirmed” is meant to generate a new level layout, while “\_on\_WinDialog\_canceled” is meant to close the game, both when the cancel button (labelled “Get Me Out of Here”) is clicked and when the cross on the top-right corner of the popup is clicked. However, as of now, only the top-right corner of both popups does what it is supposed to; clicking any of the other buttons from both popups, for some reason, does nothing at the moment, and the author of this paper *and* the code *did* make sure, in his code, that the signals were properly connected. However, the games themselves still run as they are supposed to, and the integration of the algorithms into the levels in the games are more important here, so since *they* still work, he decided to leave the popups,

their behaviour and their code as they were. *If* they are engine issues, regarding the buttons, they may hopefully get fixed in future versions of Godot.

### 3.2.2 Lindenmayer System

The implementation of an L-System was very simple. Inspiration was taken from a YouTube video on implementing an L-System for drawing line graphics in Godot by Alexander Gillberg.[20] In the code from the Godot 3 project Gillberg made in that video[21][20], he created a custom “Rule” class in GDScript, with which he defined new rules. This paper’s author forked his project, converted it to Godot 4 and used it to create the lattice graphics in Figure 3.6.[22] He did this mainly as a reference for the implementation of L-Systems in the game itself.

With the implementation in our *game*, the “get\_new\_character” method in that L-System was adapted to work with the dictionary this paper originally had the L-System implemented in. The new “get\_new\_replacement” method in our implementation allows for there to be more than one grammar rule while the L-System still performs as it should. The original L-System iterated through the original string *directly*, which produced unintended consequences in grammars with multiple rules, as seen here when trying to implement the D0L-System that was mentioned earlier[37]:

$$b \rightarrow a \rightarrow aa \rightarrow aaa \rightarrow aaaa \rightarrow aaaaa \dots$$

By using an empty string buffer and inserting rule replacements there instead, this new implementation is now able to perform substitutions accordingly; the correct computation of the D0L-System is denoted in Figure 3.7 and repeated below:

$$b \rightarrow a \rightarrow ab \rightarrow aba \rightarrow abaab \rightarrow abaababa \dots$$

With the L-System string parsing algorithm in place, the next step was to paint the cells of each tile. With this, we iterated through every cell of the tilemap using a nested for-loop. With the parsed string, we then accessed the character of the string at an incremented index using an iterator variable we defined before the for-loops. The string consists of three different characters repeated multiple times, “O”, “W” and “B”. For each string index, if the character is “W”, paint a tree, if it is “B”, paint a building, and if it is an “O”, leave the cell blank and paint nothing. The player and ring then get placed afterwards.

Even for a large-sized tile map with 2880 cells, a constant L-System  $G$ , with the symbols

O, W and B and the following grammar

$$O \rightarrow OWO$$

$$W \rightarrow WB$$

$$B \rightarrow BWO$$

can parse the axiom OWB, paint tile map tiles with the resulting string **and** place the player and ring in just 19 milliseconds on average. This was the default grammar used by the L-System in the game. The Godot project also includes 3 more grammars, one that generated more buildings (and impossible level layouts), another that generated more trees and another that generated more empty space. These can be easily selected with the “ruleset” export variable in the Godot editor. Further variance can be added with the addition of a randomly generated axiom, capped at a maximum height or smaller (minimum 1). If said option is enabled in the Godot editor, the default value in the export variable for setting this cap is 10, and since it is an export variable, it too can be adjusted in the editor as the developer sees fit.

### 3.2.3 Perlin/Simplex Noise

The Simplex Noise implementation works with Godot’s built-in Noise library. Within a Sprite2D node’s Texture attribute, a new “NoiseTexture2D” field was set inside of it. In its “Noise” attribute a new “FastNoiseLite” scene was created, which generates a noise texture for us to use. The seed can be set in the sprite’s script file.

As with the other implementations, there are two separate arrays, one for trees and another for buildings. For each cell in the TileMap, the code then took the noise pixel from the generated texture at that exact point (scaling with the cell size accordingly), using the “get\_noise\_2d” method built-in with Godot, and then, depending on the value retrieved, decided, firstly, whether or not to place a plant/tree tile there and, secondly, whether or not to place a building tile there. As a result, not every cell in the TileMap has tiles on it. On any one of those empty cells, the Player tile will then get placed.

For the generation of the noise itself, we *could’ve* added a “Sprite2D” node to the scene tree, the root of which was the “TileMap”, and gave it a “NoiseTexture2D” texture and set its “noise” property to a newly-created “FastNoiseLite” instance, the latter of which contains the actual noise data. In the early stages of this implementation’s development, that’s what was done, and this paper’s author created a script that solely set the seed of the “FastNoiseLite”

resource to a random integer (using the “randi” method). However, for a more authentic result, and to forgo the need of an additional node and noise texture that will not even be visible in the final product, it was eventually decided to create the noise for this algorithm implementation entirely programmatically. The code now stored the “FastNoiseLite” instance in its own class variable “noise”, and instantiated it with the “set\_noise” method when starting the game (the “\_ready” function automatically runs when the game starts).

Initially having done the noise integration with a sprite node and noise texture allowed the author of this report to experiment with some of the “FastNoiseLite” class’s properties before finally resorting to programmatic noise creation. An instance of this class, by default, uses the “Simplex Smooth” noise algorithm, a version of the Simplex algorithm that produces higher quality noise images at the expense of slower speed.[32] We can also use just “Simplex” noise for higher speed, as well as the original “Perlin” noise algorithm.[32] Godot also allows us to use two kinds of Value noise, as well as a “Cellular” type that combines algorithms like Worley Noise and Voronoï diagrams to create “regions of the same value.”[32] There were problems with the “Cellular” noise type when experimenting with it, for reasons we will get into later, but the other noise types were made readily accessible in an “export” variable in the scene script (that is, a variable that can be easily accessed in the Godot editor when the TileMap node is clicked on) when this paper’s and the code’s author removed the sprite node and decided to programmatically make the noise. When the “set\_noise” function is called, the noise type is assigned through the “\_get\_noise\_type” function, which returns an integer value depending on the type of noise selected, and the returned result is cast to “FastNoiseLite”’s “NoiseType” enumeration[32] before it gets assigned (this prevents an “INT\_AS\_ENUM\_WITHOUT\_CAST” warning from the Godot editor’s linter for GDScript[34]).

Furthermore, there are 3 other export variables in the TileMap script for this implementation that directly correlate to some of “FastNoiseLite”’s properties. The “noise\_frequency” variable in the script correlates to the “frequency” property in “FastNoiseLite”, which, as both names suggest, sets the noise frequency; the higher the frequency, the rougher and more granular the noise[32], which is probably why it is set to 0.01 by default.[32] The “fractal\_type” and “cellular\_distance\_type” in the script **directly** correspond to the “fractal\_type” and “cellular\_distance\_function” properties respectively, to the point where both even use the relevant enumerations from “FastNoiseLite” directly (“FractalType” and “CellularDistanceFunction” respectively).[32] The relevant values are all assigned accordingly in “set\_noise”.

In terms of determining whether or not to place buildings or trees (or nothing), inspiration

was taken from a YouTube tutorial by Gingerageous Games utilising Godot 3[18][19] (which breaks in Godot 4). His tutorial used multiple “TileMap” nodes in a single scene tree with a “Node2D” root, and controlled each individual tile map, representing a specific part of the environment (such as grass and roads), and used a floating point “cap” to determine whether or not to place a tile in a cell based on the noise pixel retrieved at that cell’s coordinate.[18][19] Since we are using just one tile map for everything (trees and buildings), a conflict had to be mitigated where the building cap was smaller than the tree cap. If that were the case then, since the tree cells get painted first in the Godot 4 implementation, no buildings would ever get painted. To mitigate this, an additional condition was added to the if-statement for painting building cells (in the same line, to prevent creating a nested if-statement), which would allow the algorithm to overwrite an already painted tree cell with a building cell subject to a randomly generated floating point number (between 0 and 1 inclusive) being below a pre-defined floating point number in the exported variable “building\_overtakes\_tree”. This would then allow there to be a controlled proportion of buildings compared to trees (the higher the proportion, the more buildings compared to trees), regardless of whether the building cap was lower than the tree cap or not, and the algorithm would still perform as normal should the reverse be the case.

### 3.2.4 Poisson Disk Sampling

The Poisson Disk Sampling implementation was based on a Unity tutorial by Sebastian Lague[29][30], in which he used his algorithm to draw points onto a grid. He based his algorithm on Bridson’s  $\mathcal{O}(n)$  algorithm.[3] The way he wrote *his* implementation was such that the radius of the circle would be equal to the diagonal of each square in the grid by default (when the radius was 1.0), ensuring that no point ever lies within the radius of another.

This paper’s implementation of the Poisson Disk Sampling algorithm mostly took from him, with some changes. Lague did his implementation in the C# language and, while Godot 4 *does* have a separate version with C# and .NET support, this paper opted to use the standard GDScript distribution of Godot 4 with all of our implementations. This meant that the code had to be adapted to work with not just the tile map but also the way GDScript worked. For one thing, the “grid” array in the “generate\_points” had to be manually initialised by inserting arrays into an empty array, the quantity determined by what would have been the outer length of the 2D array (and what basically *was* this in Lague’s implementation), that being the ceiling function of the x-dimension of the sample region size divided by the cell size. From there, in each of the nested arrays, the value 0 had to be programatically inserted to all of them, the

quantity of the *zeroes* also being determined by what would have been the *inner* length of the 2D array (and what basically *was* this in Lague’s implementation), that being the ceiling function of the y-dimension of the sample region size divided by the cell size.

Adapting Lague’s implementation from C# and Unity to GDScript and Godot involved some extensive research into Unity’s API. When calculating the angle in “GeneratePoints”/“generate\_points”, for example, the equivalent of Unity’s “Random.value” in Godot is “randf” (which *has* no static class to be called from). Furthermore, GDScript has a “TAU” constant that does the “Mathf.PI \* 2” calculation done in Lague’s Unity implementation. The “sqrMagnitude” method used in Lague’s “isValid” function becomes “length\_squared” in the “is\_valid” method. When implementing “isValid” in GDScript this paper’s author also had to make sure the inner and outer dimensions of the grid could be adequately accessed. We go over how that was achieved in the Implementation section of this report (see chapter 7).

Though Lague’s original implementation in Unity *may* be maximal, due to the nature of the tile map in Godot 4, some cells will be missed out on due to rounding and other conversions to integers when painting tiles and checking for valid cells. This leaves some blank spaces in the final level, which is part of what is desired for this scenario, as shown in the Design & Specification section of this paper.

### 3.2.5 Voronoï Cells

This paper’s author based his implementation of this algorithm on some JavaScript code posted by an anonymous contributor to the Procedural Content Generation Wiki on the Wikidot platform in 2017, in which a brute-force implementation of the algorithm was implemented.[14] An auxiliary function in the JavaScript code, “randRange”, was taken out of *this* implementation, since Godot has a built-in “randi\_range” function that serves the exact same purpose.[33] As he got further and further with his implementation of Voronoï diagrams in Godot, he realised the way the algorithm inherently worked meant that the level layouts it designed would be wholly unique, especially compared to the other three algorithms for which he made implementations of the chosen scenario.

For example, unlike the other implementations, the algorithm ensure that all cells of the tilemap were **always** covered (to start with, in our game’s context), whereas the other implementations always left some cells unpainted. The nature of Voronoï tessellations also meant that groups of trees and buildings were bunched together, with no guarantee that they would ever form coherent connections that would make sense in a level of our scenario. This meant



that the ring and player placements had to be altered so that, instead of being placed in non-existent empty cells, they would replace the cell of a tree.

Even *with* that, there would be no guarantee that a player would be able to complete a level successfully. For example, if a player and ring were spawned in different Voronoï cells of trees, and both of those cells were separated by cells of buildings such that they could not ever be feasibly reached, the game would be impossible to finish. Therefore, a new input event was created, “reset\_position”, which can be triggered by pressing *either* the G key on a standard computer keyboard *or* the right-click mouse button. Triggering the event respawns the player character in a different position, which could be occupied by either a tree or the ring, ensuring that the ring can still be collected and, therefore, game can still be won. The code for when this event is triggered is essentially a rehash of the code for “place\_player”, except that the new cell **can** be the cell occupying the ring, and also the previous cell’s contents will be deleted (as the player is no longer at that position).

While the differences are drastic and very noticeable, the author of this paper has nonetheless kept working on this implementation and included it in the project artefacts. He believe that the fact that he was able to work through it and implement a working version of the chosen scenario with it (albeit with some changes) adds further strength to this paper’s claims that Godot can work well with procedural generation algorithms, even ones where use in the context of a tile map RPG would be rarer, as well as proving the author’s strengths as a games programmer in making tile maps work with PCG algorithms.

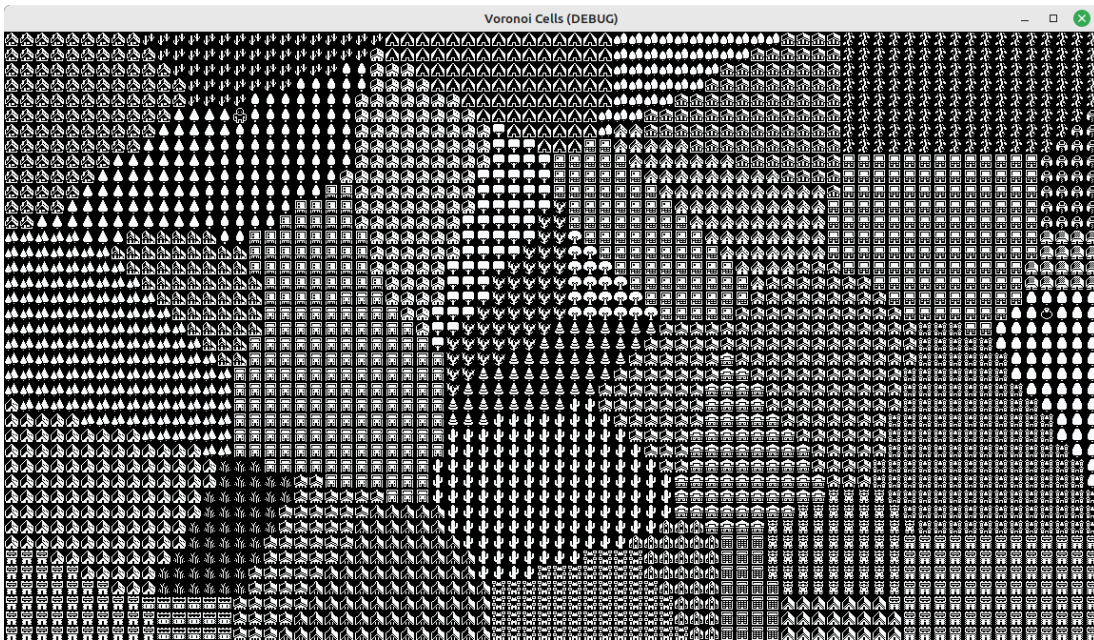


Figure 3.15: An example of the Voronoï cells implementation of the scenario in action.

## Chapter 4

# Design & Specification

Here, this paper will provide an abstract level of how the performance of each content generation algorithm was compared and how it was ensured that each implementation could produce as similar/like-for-like results as possible (and where they *couldn't* do so). More specifics and quantified data are delved into in Chapter 7.

### 4.1 What Was Sought After For In The “Best” Implementation Of The Chosen Scenario

To help determine what was wanted from these implementations and how similar they should be, it was decided, after repeatedly trying out the implementations as they were continually worked on and finessed, that they should adhere to the following *specification*, which best fit the chosen scenario:

- They should produce levels that are able to be completed every time; that is, the player character should be able to collect the ring and win the game every single time.
  - This was part of the motivation between the idea that there should be free space to move around from the outset.
- There should ideally be an ample amount of free space to move around.
  - While the golem can “eat” trees to gradually create new free space over time, it was highly desired for the levels to *start* off relatively spatial in this regard, while also still containing a very highly ample amount of trees and buildings within the boundaries of the levels.

- The golem and ring should be spawned separately from the generated environment.
  - By *always* placing the tree and golem in an empty space that *was not* always the top-right corner (or spawning at a tree for the Voronoi cells implementation where all cells are occupied), it would ensure that the player can start and win the game by roaming on empty space and consuming trees on the way to collect the ring.
  - This was *also* part of the motivation behind having free space from the outset.
- The trees and buildings should be scattered around *with purpose* (that is, they should *look* very random while also being highly calculated behind the scenes), such that it should be quite hard, but not necessarily impossible, to discern which algorithm was behind which level.
  - In the final implementations, like in Figure 7.1, the levels they generate should *seem* relatively similar to one another, albeit not necessarily identical.
- Levels should be generated fairly quickly while still adhering to the other principles in the given specification.
  - While each algorithm did not need to be the *fastest*, necessarily, any processing times above 500ms would not be advisable.

## 4.2 Comparing Layouts-Wise

Comparing the layouts involved trying out the implementations throughout their continuous development for this project. This involved tweaking values and calculations around.

For instance, the Voronoi cells implementation involved the use of two different distance calculations that produced wildly differing cells and cell shapes.

The “FastNoiseLite” class in Godot includes various configurable properties for noise images, such as the frequency of the noise, the fractal type used to alter the generated noise and even the noise algorithm used.

In the Voronoi Cells implementation, we can choose whether to use the Euclidean or Manhattan distance calculation, each producing different kinds of Voronoi tessellations as shown in Figures 3.12 and 3.13.

Other default variables that have noticeable effect on layouts include the point radius and rejection samples in the Poisson Disk Sampling implementation and the “Use Random Axiom” setting (and its related “Upper Limit” setting) in the L-System implementation.

### 4.3 Comparing Performance-Wise

Comparing each implementation performance-wise was far easier than comparing them layout-wise, since this did not rely on assessing layouts by eye. Checking the quantified performance time for all algorithms involved both a print statement in the “\_ready” function **and** the processing time showing in the opening story dialog, the text of which was *also* set in the “\_ready” function.

Calculating the processing time in the “\_ready” function for all implementations involves:

1. The calculations and processing of the algorithm itself.
2. The painting of cells using results returned by the algorithm.
3. The random placement of the golem.
4. The random placement of the ring.

# Chapter 5

## Implementation

Here, this paper will go a degree deeper as to how each algorithm was made to work with the chosen scenario. Where possible, it plans to use code snippets from the work its author have done to justify how and why things were implemented the way they were.

### 5.1 Lindenmayer System

To implement our basic grammar in Godot (see chapter 3.1.1), we can take each rule and replace each string in accordance to our one rule, using the replace method, as demonstrated in Figure 5.1.

For handling more than one rule, we can instead use a new string buffer variable where, for each character in our string, we can attain a new string and append it to our string buffer. The resulting string is then returned and interpreted. This can be represented in Godot as demonstrated in Figure 5.2, which uses two functions to perform string replacement. The first function “get\_new\_replacement” performs the character replacement according to the L-System’s grammar rules, while the second function “replace\_string” uses a string builder variable to allow for replacement of characters without directly affecting the original string and causing unwanted side effects (see chapter 3.2.2 and also the tutorial in the following citations[20][21][22], from which major inspiration was taken for the L-System implementation). The “get\_new\_replacement” function was eventually used in the final implementation, whereas the code in the “replace\_string” function was adapted into this implementation’s “parse” function, shown in Figure 5.5, in which some export variables were accounted for and the number of iterations was controlled through a while loop rather than a for loop, the while

condition being that the string size was smaller than the total number of cells. The string that “parse” returns chops off any excess characters.

This can *then* be used to handle more complex grammars that can handle more than one rule in which characters in strings are replaced by other strings of variable length, as seen in the example in Chapter 3.1.1.

With a constant use of the same grammar rules and axiom, one issue that arose in the development of levels in our scenario, with L-Systems, is the lack of variance in the kinds of tiles placed, and it was hard to figure out how to deviate even slightly from the eventually recognisable patterns the algorithm and default grammar (see chapter 3.2.2) would create. Thus a mitigation was developed for this by allowing a choice between the provided axiom or a random one (the user/developer can also change the axiom in Godot’s editor). This is down to the exported variables in the L-System node’s script that was implemented (the L-System node’s parent is the “TileMap” root node). The relevant ones from the “l\_system.gd” script file are shown in Figure 5.3. If “use\_random\_axiom” is set to true (and it is by default), then it takes a maximum character limit “upper\_limit” (again an export variable configurable in the Godot editor itself) and then it generates a string of a length **up to** that limit- that is, the length of the returned string between 1 and the limit, both inclusive- using the alphabet that all of the provided grammars adhere to (“O” for blank space, “W” for trees and “B” for buildings). The axiom is then assigned to the “string” script variable in the “paint” method by calling the “paint” method and assigning the return type to it.

For the sake of creativity and additional experimentation, additional grammars were devised that can be configured with the “ruleset” variable. The “Default” grammar is as described in 3.2.2, and the additional grammars generate higher proportions of either buildings, trees or empty space depending on which one is chosen (with the “more buildings” grammar producing levels that are impossible to finish in our scenario). The grammars themselves are detailed in Figure 5.4, and the method used to return the specifically set grammar in “parse” is shown in Figure 5.6.

```
1 string = string.replace(rule["from"], rule["to"]) #Here the rules
    were stored in dictionaries.
```

Figure 5.1: A line of code that demonstrates directly replacing characters in a string according to our L-System grammar’s rules.

```

1  func get_new_replacement(character: String) -> String:
2      for rule in rules:
3          if rule["from"] == character:
4              return rule["to"]
5      return character
6
7  func replace_string(string: String) -> String:
8      var new_string = ""
9      for character in string:
10         new_string += get_new_replacement(character)
11     return new_string

```

Figure 5.2: Two GDScript functions for replacing characters in an L-System grammar with more than one rule. The first function was used in the final L-System implementation of the scenario. The second function was adapted into the “parse” function of *this* implementation. Both functions are in the `l_system.gd` script file.

```

1  @export var use_random_axiom: bool = true
2  ## Defines how many characters a random axiom can have MAXIMUM.
   Only used when use_random_axiom is true.
3  @export var upper_limit: int = 10

```

Figure 5.3: The `use_random_axiom` and `upper_limit` variables used when allowing a random axiom for an L-System grammar and then setting a maximum character limit for it.

$$O \rightarrow BWOB$$

$$W \rightarrow WBOBO$$

$$B \rightarrow BB$$

$$O \rightarrow WWO$$

$$W \rightarrow WBWO$$

$$B \rightarrow BWWO$$

$$O \rightarrow OOBWO$$

$$W \rightarrow OB$$

$$B \rightarrow OW$$

Figure 5.4: The other 3 grammars created for the L-System implementation, aside from the default one covered in chapter 3.2.2. More buildings, more trees and more space respectively.



```

1  func _size() -> int:
2      return tile_map.x_tile_range * tile_map.y_tile_range
3
4  func rand_axiom() -> String:
5      var string_buffer: String = ""
6      var limit: int = randi_range(1, upper_limit)
7      for i in range(limit):
8          string_buffer += ["O", "W", "B"].pick_random()
9      return string_buffer
10
11 func parse() -> String:
12     if use_random_axiom:
13         axiom = rand_axiom()
14         string = axiom
15     if not use_custom_ruleset or ruleset != "Default":
16         rules = _get_ruleset()
17     var size: int = _size()
18     while len(string) <= size:
19         var new_string = ""
20         for character in string:
21             new_string += get_new_replacement(character)
22         string = new_string
23     string = string.substr(0, size)
24     return string

```

Figure 5.5: The parse function in `l_system.gd`, which takes the `rand_axiom` and `_get_ruleset` functions (if needed; the latter is shown in Figure 5.6), then gets the string size through `_size`. Then, the string replacements described in 5.2 are carried out in the while loop, before the string is then returned (albeit without any excess characters that will not be used in the paint method to paint the cells in the tile map).

```

1  func _get_ruleset() -> Array[Dictionary]:
2      match ruleset:
3          "More Buildings (IMPOSSIBLE)": return MORE_BUILDINGS
4          "More Trees": return MORE_TREES
5          "More Space": return MORE_SPACE
6          _: return DEFAULT

```

Figure 5.6: The `_get_ruleset` function used in the `parse` method in figure 5.5.

## 5.2 Perlin/Simplex Noise

While the “noise\_type” export variable is a selection of strings that are eventually taken from to return an enumeration for “NoiseType”, a member of the “FastNoiseLite” class[32], the “fractal\_type” and “cellular\_distance\_type” export variables more directly correspond to the relevant enumerations from “FastNoiseLite”, as described earlier in chapter 3.2.3 and shown in Figure 5.7. The *other* export variable is “noise\_frequency”, which corresponds to the “frequency” property in “FastNoiseLite”. This is again shown in Figure 5.7.

Initiating the noise variable is done in the “set\_noise” function, in which, after instantiating the “FastNoiseLite” class, the relevant export variables are then taken in and assigned their values accordingly, with the noise type handled through the “\_get\_noise\_type” function, which returns an integer that is then cast to the “NoiseType” enumeration. By contrast, all the other attribute assignments- “frequency”, “fractal\_type” and “cellular\_distance\_function”- were far more simple, since we can just use the values of “noise\_frequency”, “fractal\_type” (*in the script’s export variable, **not** the noise instance*) and “cellular\_distance\_type”, and assign them accordingly. Both functions are shown in Figure 5.8.

In both Figures 5.7 and 5.8, there is a commented out export variable, “octaves”. This paper wanted to see if changing the number of octaves in our noise image (or, rather, “layers”) would have an effect on the level layouts designed (the default is 5[32]). Unfortunately, in the report author’s experiments, he found that it did not have any noticeable effect, so it was decided to leave the default number of octaves as is.

Painting the tiles in our tile map involves a “paint\_points” method in which we iterate through every single cell of our tile map. For each cell in that map, we then check first if

it can paint a tree. If the noise value retrieved at the given pixel from the noise image is smaller than the maximum limit we set for trees, “tree\_cap”, then we paint a tree tile at that cell. Then, we check for buildings. As described in chapter 3.2.3, additional Boolean checks had to be implement for when “tree\_cap” was smaller than “building\_cap”, so that buildings could still get placed. First, we check that “building\_cap” is smaller than *or equal to* “tree cap” **and**, if so, whether or not we overwrite the tree tile with a building tile in the same place, subject to a random float between 0 and 1 falling below the probability value set in “building\_overtakes\_tree”. The *alternative*, for when “building\_cap” is smaller than “tree\_cap”, is to check whether the current “noise\_point” is smaller than the “building\_cap” we set. In both cases, of course, that cell cannot already be occupied by something else. If those conditions are true, we can then paint a building tile. The code behind this part of the algorithm is shown in Figure 5.9.

```

1  var noise: FastNoiseLite
2  @export_enum("Perlin", "Simplex", "Simplex Smooth", "Value", "Value
    Cubic") var noise_type: String = "Simplex Smooth"
3  @export var fractal_type: FastNoiseLite.FractalType
4  @export var cellular_distance_type: FastNoiseLite.
    CellularDistanceFunction
5  #@export_range(1, 10, 1) var octaves: int = 5
6  @export_range(0.0, 1.0) var noise_frequency: float = 0.894

```

Figure 5.7: The noise, noise\_type, fractal\_type, cellular\_distance\_type and noise\_frequency script variables in tile\_map.gd. The latter three are export variables, and the latter two of *those* are assigned to the enumerations FractalType and CellularDistanceFunction respectively (both are members of the FastNoiseLite class).[32] noise\_type, meanwhile, uses an external function called to assign properties to a newly created FastNoiseLite instance which is assigned to the noise script variable. noise\_frequency here corresponds to the frequency attribute in FastNoiseLite. Notice the commented out octaves variable. Changing the number of octaves used had no effect on the level layouts produced, so the default number of octaves (5) was left as is.

```

1  func _get_noise_type() -> int:
2      match noise_type:
3          "Perlin": return 3
4          "Simplex": return 0
5          "Value": return 5
6          "Value Cubic": return 4
7          _: return 1 # Return Simplex Smooth by default
8
9  func set_noise() -> void:
10     noise = FastNoiseLite.new()
11     noise.frequency = noise_frequency
12     noise.noise_type = _get_noise_type() as FastNoiseLite.NoiseType
13     noise.fractal_type = fractal_type
14     noise.cellular_distance_function = cellular_distance_type
15     # noise.fractal_octaves = octaves
16     noise.seed = randi()

```

Figure 5.8: The `set_noise` method in the `tile_map.gd` script, which uses the earlier defined `_get_noise_type` method to assign the noise type. The noise type returned is then cast from an integer to an enumeration of type `NoiseType` (from `FastNoiseLite`). The `fractal_octaves` line is commented out because, when experimenting with octaves, there were no real observable effects they could have on the level layouts generated, so the default number of octaves (5) was left as is.

```

1  func paint_tiles() -> void:
2      for x in range(x_tile_range):
3          for y in range(y_tile_range):
4              var noise_point: float = noise.get_noise_2d(x * tile_set.
                  tile_size.x, y * tile_set.tile_size.y)
5              if noise_point < tree_cap and not get_used_cells(0).has(
                  Vector2i(x, y)):
6                  set_cell(0, Vector2i(x, y), 0, trees.pick_random())
7              if ((building_cap <= tree_cap and randf() <
                  building_overtakes_tree) or (building_cap > tree_cap
                  and noise_point < building_cap)) and not
                  get_used_cells(0).has(Vector2i(x, y)):
8                  set_cell(0, Vector2i(x, y), 0, buildings.pick_random())

```

Figure 5.9: The `paint_tiles` method in the `tile_map.gd` script iterates through the tile map and gets each noise pixel from the relevant part of the noise image. It first tries to paint a tree tile there, subject to the `noise_point` value being below the limit set for trees. Then, it decides whether or not to paint a building there. The conditions for painting building tiles are as described in chapter 3.2.3 and further elaborated on earlier in *this* chapter, 5.2.

## 5.3 Poisson Disk Sampling

To be able to access the inner and outer grid sizes in our implementation of this algorithm, since GDScript does not have a concept of different “Array”s and lists, the lengths of the inner and outer grid were stored in local variables in the “`generate_points`” function. Those local variables, “`grid_x_axis_size`” and “`grid_y_axis_size`” as shown in Figures 5.10 and 5.11, essentially store the same grid size values as in Lague’s implementation, right down to performing the same division in a ceiling function, to the inner grid and the outer grid respectively. Since these dimensions would also be needed for “`is_valid`”, instead of creating 2 more script variables, the code instead took them in as 2 additional method parameters, as shown in Figures 5.12 and 5.13, and used them accordingly when calculating the maximum and minimum bounds for searching the nearest points of the cell, as shown in 5.14. Doing it this way ensured that the computation of this algorithm would stay efficient and not stall with an adequate (not too high) number of rejection samples.

```

1  var grid_x_axis_size: int = ceili(sample_region_size.x/cell_size)
2  var grid_y_axis_size: int = ceili(sample_region_size.y/cell_size)

```

Figure 5.10: The lines used to determine the inner and outer dimensions of the grid array.

```

1  for i in range(grid_x_axis_size):
2      grid.append([])
3      for j in range(grid_y_axis_size):
4          grid[i].append(0)

```

Figure 5.11: The nested for-loop that initialises the grid array.  
First, each inner array is initialised and inserted, then a number of zeroes, determined by the grid's y-dimension, are inserted.

```

1  if is_valid(candidate, sample_region_size, cell_size, radius,
    points, grid, grid_x_axis_size, grid_y_axis_size):

```

Figure 5.12: The line that uses the grid's x and y dimensions as parameters. This calls the `is_valid` method using those additional parameters (see Figure 5.13).

```

1  func is_valid(candidate: Vector2, sample_region_size: Vector2,
    cell_size: float, radius: float, points: Array[Vector2], grid:
    Array[Array], grid_x_axis_size: int, grid_y_axis_size: int) ->
    bool

```

Figure 5.13: The function `is_valid`, which takes in 2 additional parameters denoting the x and y dimensions of the grid array used in `generate_points`.

```

1  var search_end_x: int = min(cell_x + 2, grid_x_axis_size - 1)
2  var search_end_y: int = min(cell_y + 2, grid_y_axis_size - 1)

```

Figure 5.14: The relevant lines of code in `is_valid` that reference the grid's x and y dimensions, stored in additional variables as aforementioned.

## 5.4 Voronoi Cells

The original JavaScript implementation, as mentioned before, had a “randRange” function that was taken out, as it was not needed at all, but there was also an additional “mapSize” parameter in “definePoints” that, in *our* “define\_points” function, didn’t really need, since the code makes sure the map’s dimensions were readily accessible via the “x\_tile\_range” and “y\_tile\_range” script variable. Therefore, the second parameter in “define\_points” was taken out, as shown in Figure 5.15, and substituted it with “x\_tile\_range” and “y\_tile\_range” accordingly, as shown in Figure 5.17.

The type of each Voronoi cell was determined by taking, and then deleting, a value from the “types” array. Said array is local to that function, and it is initialised by duplicating the “trees” array, then appending it with the “buildings” array, making sure the same type cannot be used for a Voronoi cell twice. Duplicating the array before merging it essentially makes sure that the *original* “trees” array is not affected by deletions performed on the “types” array. This computation is shown in Figure 5.16, and the deletion operation is shown in Figure 5.18.

Another addition to our implementation of the algorithm was the choice of using either the Euclidean distance or Manhattan distance for calculating the distance between points that would form cells. This was done with a function “calculate\_points\_delta”, as shown in Figure 5.23 and used in Figure 5.22, which is called on the calculation of “delta” in “define\_points”. The function takes the contents of the exported variable “distance”, as well as the current “x” and “y” coordinates and point ID “p” during the current points delta calculation. It then checks if the String value in “distance” denotes either the Euclidean distance or the Manhattan distance, then it finally returns the appropriate calculation. Using the Manhattan distance instead of the Euclidean distance does indeed yield a considerable performance increase (as well as creating fewer Voronoi cells by using a smaller “random\_starting\_points” value), which we touch on in the Evaluation chapter.

Furthermore, our implementation would often paint cells in the tile map that were out of bounds, so to mitigate this when painting them, an additional function “`_is_in_bounds`” was written, as shown in Figure 5.21 and used in Figure 5.20, for checking whether a painted cell (that is, the coordinates of the current point **plus** the delta/difference between it and the closest of the randomly selected starting points to it) is within the boundaries of the tile map. If it is not, then it does not get painted, though it is not deleted from the point’s citizens array either.

```
1  func define_points(num_points: int) -> void:
```

Figure 5.15: The `define_points` function header, with no argument for the map’s size. The `num_points` value that gets taken in during runtime is determined by the script’s export variable `random_starting_points`.

```
1  var types: Array[Vector2i] = trees.duplicate()
2  types.append_array(buildings)
```

Figure 5.16: The `types` array being initialised in `define_points`, with its values taken from the `trees` and `buildings` arrays, such that no type can be used for a cell twice, while also making sure that the original `trees` and `buildings` arrays are not affected by the deletions on `types`.

```
1  var x: int = randi_range(0, x_tile_range)
2  var y: int = randi_range(0, y_tile_range)
```

Figure 5.17: Godot’s built-in `randi_range` function being used in place of a self-defined one in `define_points`.

```
1  var type: Vector2i = types.pick_random()
2  types.erase(type)
```

Figure 5.18: The types of each Voronoi cell being picked and the erased in `define_points`.



```

1  const EUCLIDEAN: String = "Euclidean distance"
2  const MANHATTAN: String = "Manhattan distance"
3  @export_enum(EUCLIDEAN, MANHATTAN) var distance: String = MANHATTAN

```

Figure 5.19: The applicable values of the exported variable distance.

```

1  if _is_in_bounds(point["x"], citizen["dx"], point["y"], citizen["dy
    "]):
2      set_cell(0, Vector2(point["x"] + citizen["dx"], point["y"] +
        citizen["dy"]), 0, point["type"])

```

Figure 5.20: The appropriate block of code in the paint\_points function that checks to see if a point would be in bounds or out of bounds before painting it in its relevant tile map cell. It does **not** delete the point if it lies out of bounds.

```

1  func _is_in_bounds(x: int, dx: int, y: int, dy: int) -> bool:
2      return x + dx >= 0 and x + dx < x_tile_range and y + dy >= 0 and
        y + dy < y_tile_range

```

Figure 5.21: The \_is\_in\_bounds function called in the code snippet in Figure 5.20.

```
1  var delta: float = calculate_points_delta(x, y, p)
```

Figure 5.23: The calling of `calculate_points_delta` from Figure 5.22 in `define_points`, using the current `x` and `y` coordinates and point ID `p` in the iteration when grouping tile map cells together to form Voronoi cells from the randomly selected starting points.

```
1  func _squared(x: int) -> int:
2      return x ** 2
3
4  func calculate_points_delta(x: int, y: int, p: int) -> float:
5      if distance == EUCLIDEAN:
6          return sqrt(_squared(points[p]["x"] - x) + _squared(points[p]
7              ["y"] - y))
8      return abs(points[p]["x"] - x) + abs(points[p]["y"] - y)
```

Figure 5.22: The `calculate_points_delta` function being called in Figure 5.23. `_squared` is a self-defined helper function that is only used for the Euclidean distance calculation; it does as it says (it squares the number taken into it and returns the result).

## Chapter 6

# Legal, Social, Ethical and Professional Issues

Throughout the course of this project, the author of this report made sure he abode by the principles set out in the Code of Conduct & Code of Good Practice issued by the British Computer Society[46], acting with integrity, honesty and transparency in the way potential licensing issues with the work produced for this dissertation, and the other work used as both reference and inspiration, were all properly handled. Throughout this report, the ways external code, articles and other references were used in both the writing and the software artefacts have been thoroughly discussed and also elaborated on. References and inspirations for code in those artefacts were also clearly and transparently denoted via the inclusion of comments in script files. To further ensure full transparency in the research done behind this project, every single citation, even remotely tangential ones, are cited in the bibliography of this report as appropriate. In this chapter, the ways in which the licenses of code references in the implementations were adequately dealt with are detailed in the following section 6.1, while the details on plans behind the author of this report releasing his *own* code and report, both for public access, are detailed in section 6.2.

### 6.1 Using Other People's Resources

As this project has been continually worked on, it has been ensured, with confidence, that the resources used were freely available to use in an academic context such as this.

For example, the Unity tutorial used as an inspiration of our Godot Poisson Disk Sampling

implementation[29] has its project files under the MIT License[30], a permissive open-source license which means it can be freely used and adapted with, even commercially.[38] This meant that our Godot implementation could use his Unity implementation as a basis without fear of any legal implications. Nonetheless, to act with integrity, it has been denoted properly, in this report and in code comments, that his work has been taken from and adapted, citing it accordingly in the bibliography as well.

As aforementioned in chapter 3.2.5, the JavaScript code example taken from the Procedural Content Generation wiki[14], for the Voronoi Cells implementation, was submitted by an anonymous Wikidot contributor in 2017. Like most if not all of the Wiki's contents, it is licensed under the Creative Commons Attribution-ShareAlike 3.0 License (all contents of the wiki follow this license unless otherwise specified); that is, the article and its contents (including the JavaScript code example) can be freely used and adapted, subject to the condition that the original source is attributed **and** that any transformed work, *like the Godot implementation*, **must** be published under the same or a compatible license.[5] Since there are no listed compatible source code licenses that can be use in lieu of this license[7], the Voronoi cells implementation must therefore abide by the license contents of the original article in the source code, since both it and the original JavaScript code are similar to a noticeable, although not entirely like for like, degree (even though *our* implementation is in GDScript and not JavaScript). We will go over how all of the project artefacts will eventually be released to the public, as well as the L<sup>A</sup>T<sub>E</sub>X source code and B<sup>I</sup>B<sub>T</sub>E<sub>X</sub> citations of this report, in the following section 6.2.

Projects that have been used as references on a smaller scale were also accounted for. While the Godot 3 TileMap noise tutorial referenced in chapter 3.2.3 is up on GitHub, it has no readily attached license to it.[19] However, since no substantial code from it whatsoever has been taken from or adapted, and the scripting APIs for Godot 3 and Godot 4 are vastly different, *especially* in the context of tile maps, it is therefore highly justified that *our* implemented code will not pose an issue, and so this, and all the other self-produced artefacts, can be posted on GitHub under conditions that are further explained in the following section 6.2.

To produce the screenshot in Figure 3.6, the author of this report forked an existing Godot 3 project on GitHub[21], taken from a YouTube video tutorial on how to use an L-System to draw line graphics in Godot[20], converted it to Godot 4 and added an additional set of rules to it based on the example lattice grammar featured in chapter 3.1.1.[22] While the conversion was done by the author of this report, and some other own code contributions of his were also to the fork, the author of this report does not regard this as a substantial part of his project,

and thus have not included it in the source code listings in chapter C. The person behind the code has previously denoted appreciation of other people’s forks of his code, so the lack of readily available code license in his original repository is not believed to be a substantial issue here. Nonetheless, since small parts of his code have been adapted to work with the L-System implementation, he has been emailed him directly for his permission to do both that and add the permissive MIT license to the new fork, and his permission was received from a private email conversation had between the author of this report and him on Tuesday 18<sup>th</sup> April 2023:

*“Well, haven’t done anything with the channel in years, everything is more or less up for grabs. So you have my permission to use anything and/or everything however you like. You can add the MIT license to your fork.*

*You can refer to this conversation if needed!”*

He has been made aware that his work will be properly and clearly cited in both the dissertation and the released artefact. The MIT license has already added the license to the new fork.[22]

Any usage of external screenshots in Figures throughout this document are properly cited and linked to in the bibliography. Screenshots that were self-produced by the author of this report are clearly denoted as such in Figure captions. Any usage of code snippets in Figures were written by him, and any external references used as bases for these snippets were clearly and properly cited as such.

## 6.2 How The Author’s Own Artefacts Will Be Released

The author of this report has planned for his source code to both the dissertation and artefacts to be released on GitHub for public access. In order to do so, all of his repositories must be properly assigned licenses so that his usage intentions and any repository usage conditions are clearly defined.

For both the report and all the artefacts, the Creative Commons Attribution-Sharealike 4.0 license, as described in the previous section, was chosen and assigned. The aforementioned license allows for commercial and non-commercial usage on the condition that (1) the concerned product is properly attributed to when used and (2) any adaptations of and modifications to this work are released under the same license (or a compatible one, or a later revision of it).[6] The concerned product can be used *verbatim* (i.e. as is) without having to share their work under this license, but when it is adapted upon, *then* the share-alike conditions apply.

Although it is not widely considered good practice to apply Creative Commons licenses to

code[8], the author still believes that CC-BY-SA-4.0 is the best license for his project overall. As well as resolving any complications with the Voronoi cells implementation, again as discussed in the previous section (CC-BY-SA-4.0 is compatible with the CC-BY-SA-3.0 license used in the original JavaScript code, as CC-BY-SA-3.0 allows for licensing newly adapted works under later versions of the license[7]), it also ensures that all of the original Godot implementations are still available for public viewing and modification while also ensuring others can still modify it and everyone else who *isn't* modifying it has the freedom to view these modifications. In that regard, it *is* similar to copyleft licenses such as the GPL and LGPL, though, as of the time of this publication, only the former is listed as compatible with CC-BY-SA-4.0.[7]

In an academic context, it ensures that all of the work and code that has been put into this report by the author of this report, as well as the implementations, are still available when the code is taken and then built upon by someone else (and that these modifications are also made available for others to see how the author's work was built upon). Applying the license to this dissertation, as well as the artefacts, allows him to ensure that all aspects of the work the author has done are viewable by everyone, and any improvements made to this work, by him or anyone else, are also viewable and publicly recognised.

#### **Note on the Godot Project Used to Create Some Screenshots in Chapter 3.1.1 & Why It Has Been Included With The Rest of The Artefacts**

Some of the self-produced screenshots, specifically the ones in Figures 3.1, 3.2, 3.3 and 3.4, are taken from a Godot project created by the author of this report early on, during the learning process on how L-Systems worked for this dissertation. It has eventually been decided to include it in the source code listings in chapter C, primarily because much of the code in there (specifically in the script file DemoNode.gd) is used in the final project, but also because the commit history shows the process the author of this report initially went through in building an L-System that could handle multiple grammar rules, as detailed in chapters 3.1.1, 3.2.2 and 5.1. Do note, however, that it is not as important to the project's motives as the main four algorithm implementations.

## Chapter 7

# Results & Evaluation

Here, we will discuss how the implementations of the algorithms in our scenario were tested and ensured that they ran as they should.

### 7.1 Software Testing

Due to the nature of the project (being several implementations of a computer game), the testing behind this project has solely revolved around trial-and-error, messing around with the exported variables in the Godot editor to see how things worked and what configurations worked best for our scenario. This involved taking many screenshots of generated levels and examining things by eye, seeing how layouts compared across implementations.

Despite this, it was eventually decided to run some simple performance tests to see how long each algorithm ran. These tests took some of the custom export variables from the scene scripts and ran them several times, with an average time calculated to the nearest millisecond. The results of these tests are all in table in the Appendix.

### 7.2 Comparing the Different Algorithms and Drawing Conclusions on Which Ones Are Best

#### 7.2.1 Performance

With the L-System implementation, there were no problems whatsoever running the game very quickly on the author of this report's machine, and quickly got satisfactory results. The table in Figure A.3 shows that the processing times remained miniscule, even as the maximum length

of the axiom increased. With the default values for all export variables, it took an average of 16ms for the L-System implementation to generate levels, by far the fastest out of all the implementations that were created for this report, as shown in table A.6.

While the Noise implementation was slower than the L-System implementation by a magnitude, it was still satisfactorily quick. Some timed tests were run in which this paper’s author tested how some of the properties affected the time it took to generate the noise. These tests are referred to in tables A.1, in which each noise algorithm was paired with each cellular distance function, and A.2, in which each noise algorithm was paired with each fractal type. With the default values set here, it was found that it took an average of 81ms, as shown in table A.6.

With Poisson Disk Sampling, the higher the number of rejection samples (that is, the higher the maximum number of times a cell was sampled before it was either accepted or ultimately rejected), the longer it took to generate a complete level layout, and even then, due to the nature of the tile map compared to the algorithm’s *usual* use (of scattering dots on a plane), it was not maximal (not all points had cells painted for them; some cells had their tiles overwritten as well). Using 8 rejection samples was usually enough to yield a satisfactory level layout while also keeping level creation times to a satisfactory minimum. It took an average of 268ms to work with 8 rejection samples in the tests in table A.4, and 197ms in some additional tests done in table A.6. If the rejection samples were set to a too high value, there was a high chance that the game would hang and not return any cell points at all, because it just took *way* too long to process. However, that does not always happen; as referenced in the caption of table A.4, on one occasion, when the value of rejection samples was set to 18, the game *did* stall, and had to be restarted again so that enough processing times could be recorded.

Voronoi Cells took the longest to compute on average. Computations with the Euclidean distance measurement took longer than those measured with the Manhattan distance, and the number of random starting points (and therefore the number of unique Voronoi cells in a single tessellation) increased level generation times as well. Both of those results are solidly proven in table A.5, as well as table A.6, in which, even *with* the default values set, it *still* took 455ms on average, far longer than any of the other implementations.

### 7.2.2 Layouts

Of the 4 implementations that were made for this project, the Noise and Poisson Disk Sampling implementation were by far the most similar, followed by the L-System implementation, and then the Voronoi Cells implementation, which was far and away the most unique.



While the noise implementations varied greatly depending on what settings were used, and the way the implementation was designed allowed for very many possibilities as to how the noise would turn out (and how it would affect the final level), the results that were returned produced the most similar results to that of the Poisson Disk Sampling implementation had the following configurations:

- Noise Type (“noise\_type”): Simplex Smooth
- Fractal Type (“fractal\_type”): Fractal None
- Cellular Distance Type/Function (“cellular\_distance\_type”): Distance Euclidean
- Noise Frequency (“noise\_frequency”): 0.894
- Tree Cap (“tree\_cap”): -0.048
- Building Cap (“building\_cap”): -0.252
- Building Overtakes Tree (“building\_overtakes\_tree”): 0.12

The default noise frequency in “FastNoiseLite” is 0.01, which results in smoother and less disparate noise. As seen in Figure 7.2, the smoother noise and lower frequency results in a distinct kind of level layout in which represents some of the noise values in the image very clearly, such that tiles (both buildings and trees) are bunched together in partially interconnected groups, forming long, large lines of painted tiles. To describe this as best as possible, it is easy to discern that the level layout was determined from a noise image. Using a higher noise frequency to produce rougher noise, and more disparate level layouts, yields results like in Figure 7.1, which makes it very similar to the layouts yielded in the Poisson Disk Sampling implementation and, to a lesser extent, the L-System implementation. While the author of this report’s personal tastes are fond of the former kind of level layout, part of the aim of this project was to compare in terms of which could produce the most similar, and, compared to the L-System and Poisson Disk Sampling implementations, the Noise implementation with the frequency set to 0.01 was far too distinct, hence the want to change it up.

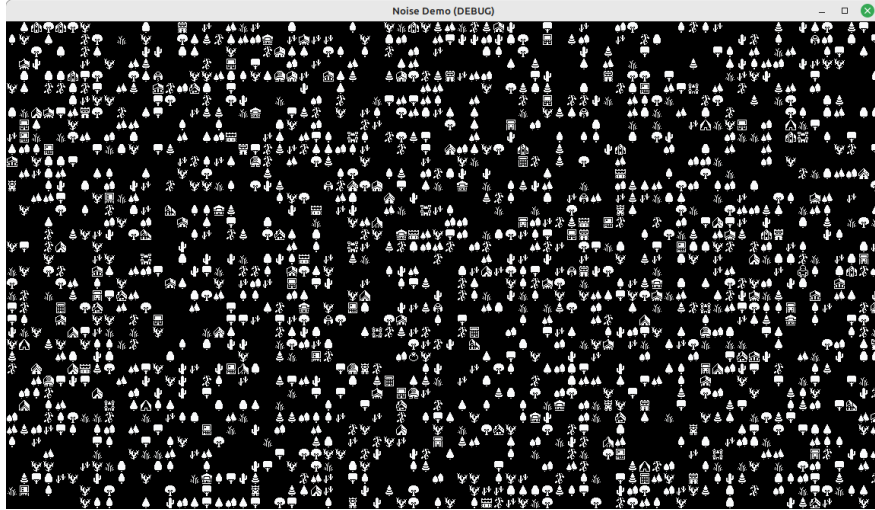


Figure 7.1: A level of our scenario generated in the Simplex Noise implementation, using all of the default values shown here. The level took a total of 99 milliseconds to be made.

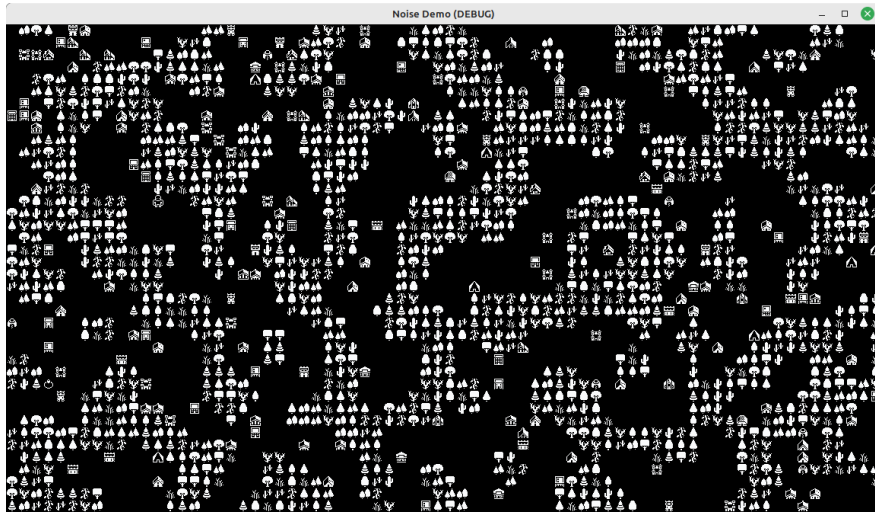


Figure 7.2: A level of our scenario generated in the Simplex Noise implementation, setting the noise frequency to 0.01 (the default value for noise frequency in “FastNoiseLite”) and using the rest of the defaults shown here. The level took a total of 104 milliseconds to be made.

The Poisson Disk Sampling implementation also produced similar levels, with the main difference higher level processing times, as shown in section 7.2.1. The lower the number of rejection samples, the quicker the processing times, but the lower the number of tiles painted in the tile map. This is shown in Figures 7.4 and 7.5, with the latter being a particularly egregious example. Figure 7.3, on the other hand, shows a level created with the default number of rejection samples (8), and is similar to the level generated with Simplex noise in Figure 7.1.

I also have 3 other export variables:

- “point\_radius”, which sets the distance between points during calculation, in that no point can be within a radius distance of other points. By default it is set to 1.0. The higher the value, the more spaced apart painted tiles are, as seen in Figure 7.6.
- “paint\_building\_probability”, which determines whether or not to print a building tile in lieu of a tree tile at a cell (overwriting any existing tile if there is any at that cell). By default it is set to 0.125, the higher the value (between 0.0 and 1.0 inclusive), the more likely a building is to be painted and the more buildings that will appear in the final level, as seen in Figure 7.7.
- “region\_size”, which, by default, is set to the current tile map size (72, 40), although that does not show properly in the editor. These values can be changed for a smaller region size, which can result in faster processing times, but this is not best advised for our chosen scenario, due to the fact that not all cells in the current tile map will be covered this way.

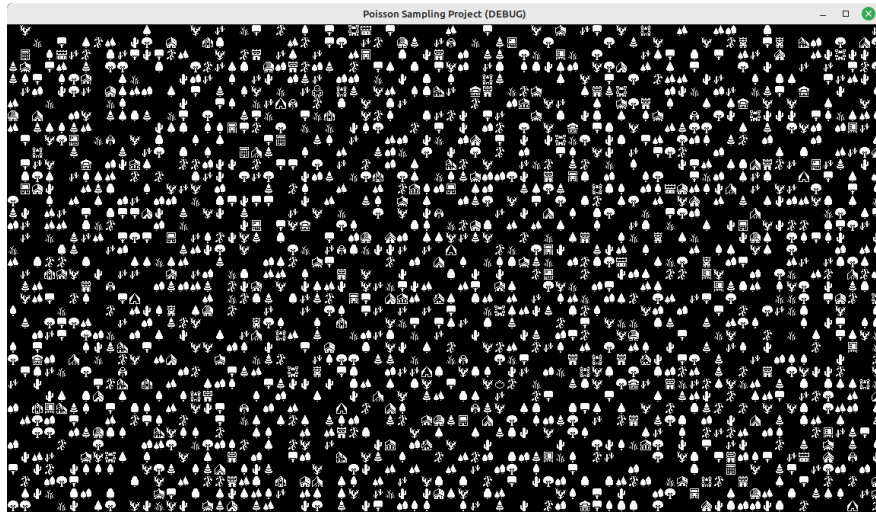


Figure 7.3: A level layout set with the default number of rejection samples (8). This level took 222ms to create.

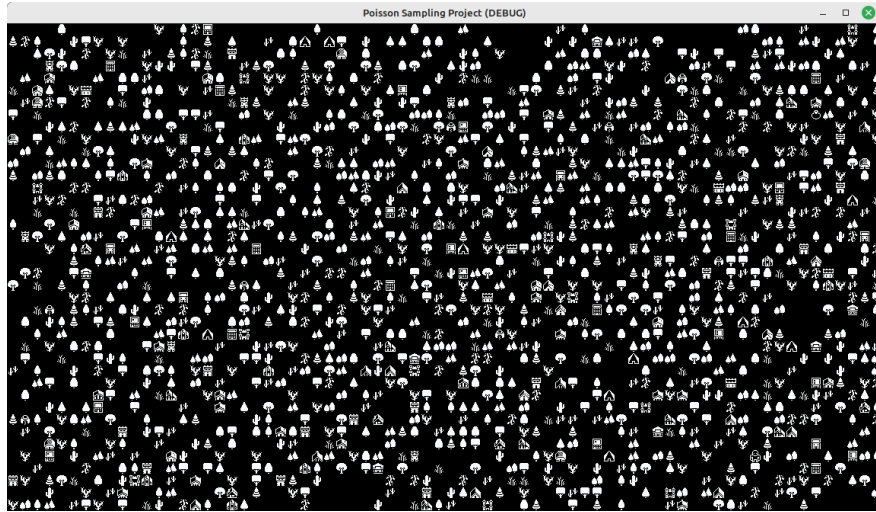


Figure 7.4: A level layout set with the number of rejection samples set to 3 instead of 8. There are a somewhat smaller number of painted tiles in this level than the level in Figure 7.3. This level took 87ms to create.

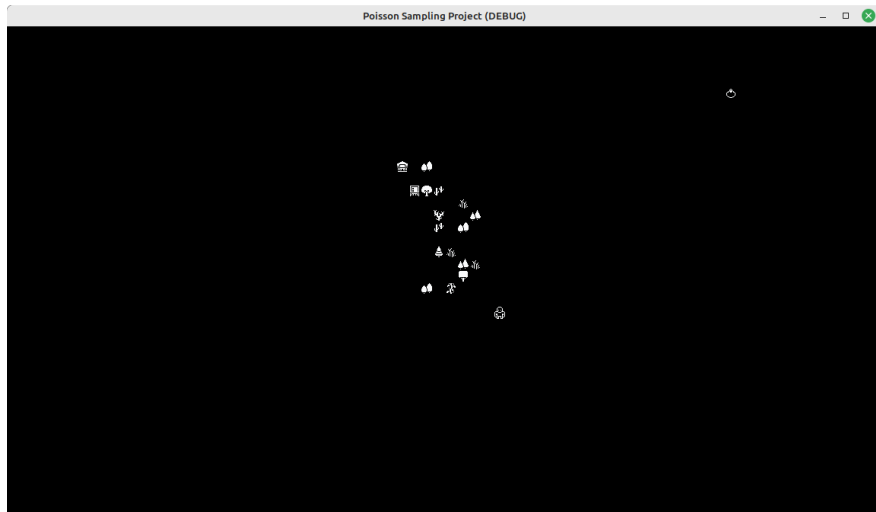


Figure 7.5: A level layout set with the number of rejection samples set to 1 instead of 8. This level barely has any cells painted on it, certainly far less than the levels shown in Figures 7.3 and 7.4. This level took 3ms to create.

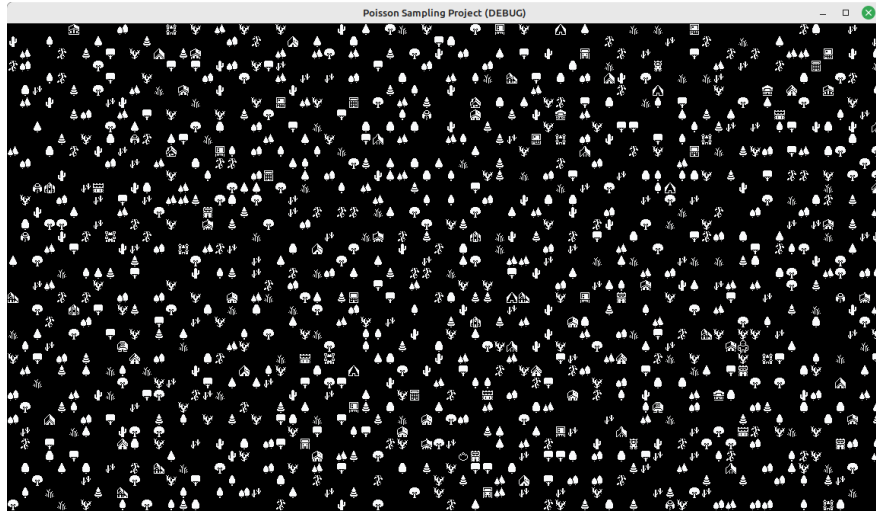


Figure 7.6: A level layout set with the radius (“point\_radius”) to 1.564 instead of the default 1.0. As you can see, this results in further spaced-apart cells and more empty space. This level took 135ms to create.

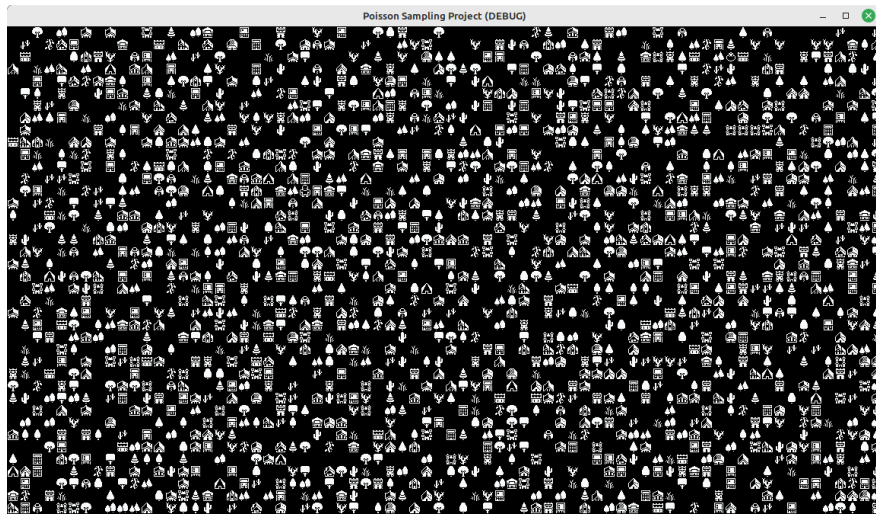


Figure 7.7: A level layout set with the probability of buildings being painted over trees set to 0.5 instead of the default 0.125. As you can see, this results in more building tiles being painted in the tile map than usual. This level took 293ms to create.

With L-Systems, it was found that level layouts, particularly with the default grammar, had noticeable patterns and were more “maze-like”. It seemed that one could not go into the L-System implementation of the scenario without noticing that points were not entirely scattered around. Some variance was added by setting a random axiom, up to a specified *maximum* length, but any variance it *did* add was very little compared to how much was needed for our scenario (see Figures 7.8 and 7.9).

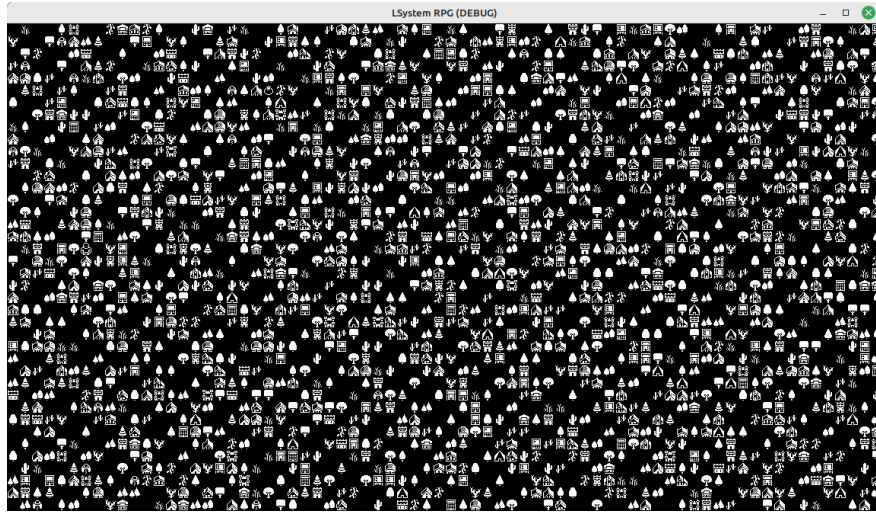


Figure 7.8: A level layout created with the L-System implementation using the default grammar and all other default variable settings. This level took 19ms to create.

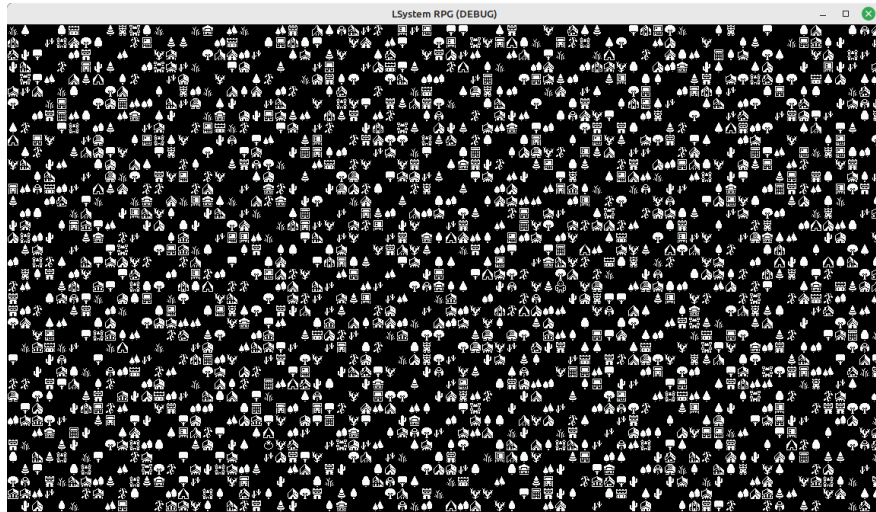


Figure 7.9: A level layout created with the L-System implementation using the default grammar and all other default variable settings. This level took 24ms to create.

As aforementioned, the Voronoi Cells implementation produced wholly unique level layouts compared to the other 3 implementations. This is mainly because every cell in the tile map, in the generated level, will be covered by either a tree or a building from the outset, hence the need for the golem and the ring to be painted over existing trees. Furthermore, the *minimum* value for the number of random starting points (and therefore the number of Voronoi cells in a single tessellation) is 15, 2 more than the number of tree tiles; it had to be done this way to **really** ensure that a level would even be *remotely* playable, which greatly affected the kinds of layouts that could be generated. Figures 7.10 and 7.11 show 2 different levels, the former created with 15 starting points, producing the same number of unique Voronoi cells, with the



Manhattan distance calculation, and the latter created with *25* starting points, producing the same number of unique Voronoi cells, with the *Euclidean* distance calculation. Neither level is any similar to the levels produced by *any* of the other implementations, nor are they the most appropriate for our chosen scenario.

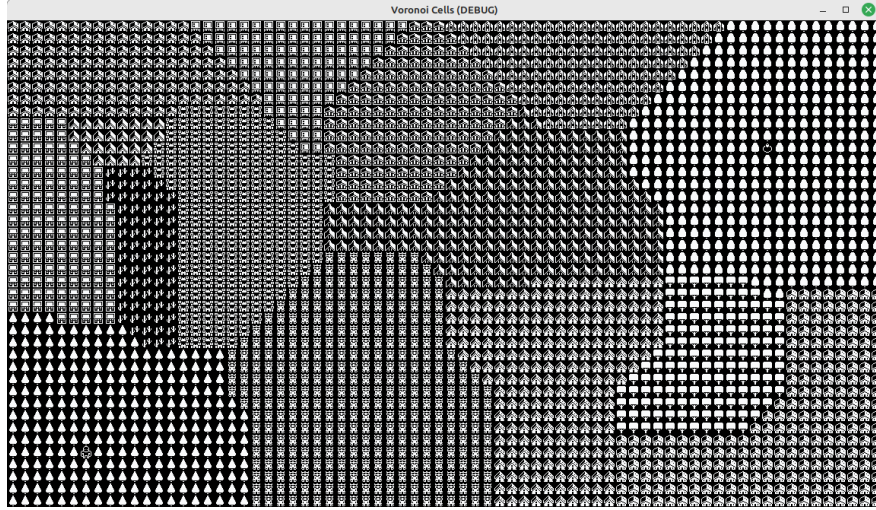


Figure 7.10: A level layout created with the Voronoi Cells implementation, using the Manhattan distance and 15 random starting points (therefore 15 unique cells). This level took 367ms to create.

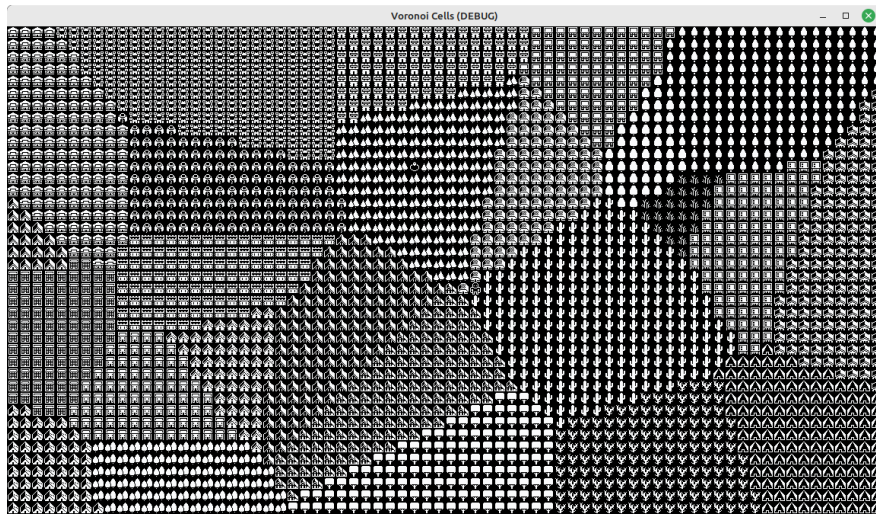


Figure 7.11: A level layout created with the Voronoi Cells implementation, using the Euclidean distance and 25 random starting points (therefore 25 unique cells). This level took 658ms to create.

## 7.3 Final Ranking On Which Algorithm Is Best For the Chosen Scenario

The following is a final ranking on which algorithm this paper has decided is best for the chosen RPG scenario, 1 being the most preferred and 4 being by far the least. This section also discusses similarities between the generated levels across all implementations, as part of the aim of this project was to also try producing as similar levels across all implementations as possible.

### 1. Perlin/Simplex Noise

- Produces easily navigable layouts with random-*looking* tree and building placement and ample, but not too much, empty space, all in a reasonably fast time, with much configuration done (see default values).

### 2. Poisson Disk Sampling/Distribution

- Produces very similar level layouts to that of Perlin/Simplex Noise. However, it is slightly less preferable to that of Perlin/Simplex Noise due to the longer processing times.

### 3. Lindenmayer System

- Produces somewhat different level layouts to those of the previous 2 implementations, with a more maze-like arrangement and little variance between generated levels due to the nature of L-Systems.

### 4. Voronoi Cells

- Produces **very** different level layouts to those of the previous 3 implementations, with **all** cells being covered in the final arrangement, so much so that the scenario, as well as the code behind the player and ring, had to be changed accordingly.



## Chapter 8

# Conclusion and Future Work

To conclude, the author of this report gained a wealth of knowledge about the way some of the most popular procedural content generation algorithms work, and how they are typically integrated into working games. He also learnt how he could leverage the features of the Godot game engine for some of them; for example, the “FastNoiseLite” class allows a Godot game developer to generate noise textures in Value, Perlin and even Simplex noise and then modify them accordingly with additional frequency settings, fractal types and cellular distance functions. By implementing them in a self-designed 2D tiled RPG scenario, he was able to get 4 procedural generation algorithms well-integrated into working games, proving Godot’s technical proficiency in making these kinds of games work, and proving his own abilities as a games programmer. He was also able to compare the implementations of his chosen algorithms in such a way that the differences, in terms of both performance times and the kinds of levels they produced, could very easily be discerned. The motives of this project can be pushed still further by measuring and comparing the performances of these algorithms in Big-O notation, including even more ontogenic algorithms such as Worley Noise, the Diamond-Square algorithm, Markov Chains and Cellular Automata, as well as teleological algorithms such as the Rain Drop algorithm and Reaction-Diffusion systems, using a larger tile map on all of these algorithms and even using a different, more intensive scenario entirely, such as a 3D walking simulator/open-world game. With procedural generation for level design, the possibilities are practically endless.

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# Appendix A

## Extra Information

### A.1 Tables & Test Cases

This section contains tables and test cases mentioned in the Evaluation section of this report. They are included here as they remain peripheral to the main body of this report, and would break up the theme and flow of the text if it appeared in the body, as would the source code listings featured in chapter C and the detailed user guide featured in chapter B.

	Noise type				
Cellular Distance Function	Simplex Smooth	Simplex	Perlin	Value	Value Cubic
Euclidean	81ms	83ms	80ms	82ms	92ms
	84ms	88ms	74ms	84ms	105ms
	83ms	83ms	74ms	83ms	74ms
	AVG: 83ms	AVG: 85ms	AVG: 76ms	AVG: 83ms	AVG: 90ms
Euclidean Squared	81ms	74ms	81ms	90ms	76ms
	77ms	91ms	73ms	119ms	109ms
	84ms	79ms	80ms	93ms	82ms
	AVG: 81ms	AVG: 81ms	AVG: 78ms	AVG: 101ms	AVG: 89ms
Manhattan	83ms	93ms	82ms	80ms	81ms
	107ms	101ms	72ms	81ms	72ms
	82ms	87ms	80ms	94ms	101ms
	AVG: 91ms	AVG: 94ms	AVG: 78ms	AVG: 85ms	AVG: 85ms
Hybrid (Euclidean & Manhattan)	77ms	87ms	85ms	85ms	76ms
	96ms	122ms	74ms	85ms	77ms
	82ms	87ms	83ms	87ms	77ms
	AVG: 85ms	AVG: 99ms	AVG: 81ms	AVG: 86ms	AVG: 77ms

Figure A.1: A table denoting some performance tests done with comparing the noise algorithms, the cellular distance functions and the combination pairs between them. This was done on the Noise implementation of the game; the “tests” were simply checking how long it took to create levels on the author of this report’s computer, and all the other script variables were assigned to their default values as described in chapter 4. Each noise type and cellular distance function pair was run 3 times, with the mean time (including potential outliers) calculated afterwards *to the nearest integer*. Be advised that the author of this report did these tests on his computer, so on different computers, results can, and likely *will*, vary.



	Noise type				
Fractal Type	Simplex Smooth	Simplex	Perlin	Value	Value Cubic
None	92ms	89ms	84ms	101ms	77ms
	86ms	152ms	98ms	86ms	88ms
	123ms	99ms	95ms	97ms	86ms
	AVG: 100ms	AVG: 113ms	AVG: 92ms	AVG: 95ms	AVG: 84ms
FBM (Fractional Brownian Motion)	77ms	81ms	73ms	78ms	68ms
	93ms	87ms	79ms	137ms	64ms
	87ms	93ms	73ms	82ms	87ms
	AVG: 86ms	AVG: 87ms	AVG: 75ms	AVG: 99ms	AVG: 73ms
Ridged	23ms	74ms	15ms	27ms	14ms
	25ms	69ms	16ms	28ms	9ms
	23ms	70ms	16ms	26ms	11ms
	AVG: 24ms	AVG: 71ms	AVG: 16ms	AVG: 27ms	AVG: 11ms
Ping Pong	59ms	67ms	108ms	128ms	163ms
	54ms	77ms	105ms	71ms	172ms
	58ms	64ms	111ms	72ms	164ms
	AVG: 57ms	AVG: 69ms	AVG: 108ms	AVG: 90ms	AVG: 166ms

Figure A.2: A table denoting some performance tests done with comparing the noise algorithms, the fractal types and the combination pairs between them. This was done on the Noise implementation of the game; the “tests” were simply checking how long it took to create levels on the author of this report’s computer, and all the other script variables were assigned to their default values as described in chapter 4. Each noise type and fractal type pair was run 3 times, with the mean time (including potential outliers) calculated afterwards *to the nearest integer*. Be advised that the author of this report did these tests on his computer, so on different computers, results can, and likely *will*, vary.

use_custom_axiom = false axiom = "OWB"	use_custom_axiom = true upper_limit = 3	use_custom_axiom = true upper_limit = 10	use_custom_axiom = true upper_limit = 25
21ms	25ms (length = 2)	20ms (length = 4)	9ms (length = 25)
17ms	13ms (length = 2)	11ms (length = 9)	14ms (length = 2)
21ms	21ms (length = 1)	21ms (length = 8)	21ms (length = 21)
20ms	16ms (length = 1)	18ms (length = 5)	20ms (length = 24)
20ms	11ms (length = 2)	11ms (length = 4)	15ms (length = 14)
AVG: 20ms	AVG: 17ms	AVG: 16ms	AVG: 16ms

Figure A.3: A table denoting some performance tests done with comparing the lengths of axioms used in L-Systems. Obviously, this was done on the L-System implementation of the game; the “tests” were simply checking how long it took to create levels on the author of this report’s computer, as well as how long the randomly generated axioms were (where appropriate), and all the other script variables were assigned to their default values. Each of the shown settings were run 5 times, with the mean time (including potential outliers) calculated afterwards *to the nearest integer*. Be advised that the author of this report did these tests on his computer, so on different computers, results can, and likely *will*, vary.

rejection_samples	3	8	13	18
time	170ms	337ms	444ms	503ms
	103ms	224ms	392ms	505ms
	111ms	242ms	388ms	670ms
	AVG: 128ms	AVG: 268ms	AVG: 408ms	AVG: 559ms

Figure A.4: A table denoting some performance tests done with comparing the number of rejection samples used for Poisson Disk Sampling. Obviously, this was done on the Poisson Disk Sampling/Distribution implementation of the game; the “tests” were simply checking how long it took to create levels on the author of this report’s computer, and all the other script variables were assigned to their default values. Each of the shown settings were run 3 times, with the mean time (including potential outliers) calculated afterwards *to the nearest integer*. The bottom cell of the rightmost column, with tests done with 18 rejection samples, is highlighted red because, while testing with 18 rejection samples, at one time the program hung without returning any cell points within 10 seconds. The test had to be retaken another time. Be advised that the author of this report did these tests on his computer, so on different computers, results can, and likely *will*, vary.

	Random Starting Points			
Distance type	15	20	30	40
Euclidean distance	393ms	496ms	775ms	968ms
	385ms	504ms	744ms	970ms
	362ms	497ms	723ms	967ms
	AVG: 380ms	AVG: 499ms	AVG: 747ms	AVG: 968ms
Manhattan Distance	364ms	441ms	645ms	843ms
	346ms	470ms	630ms	835ms
	346ms	437ms	650ms	908ms
	AVG: 352ms	AVG: 449ms	AVG: 642ms	AVG: 862ms

Figure A.5: A table denoting some performance tests done with comparing the distance calculation algorithms, the number of random starting points and the combination pairs between them. This was done on the Voronoi Cells implementation of the game, and thus the number of random starting points corresponds directly to the number of unique Voronoi cells generated for each level. The “tests” were simply checking how long it took to create levels on the author of this report’s computer. Each of the shown settings were run 3 times, with the mean time (including potential outliers) calculated afterwards *to the nearest integer*. Be advised that the author of this report did these tests on his computer, so on different computers, results can, and likely *will*, vary.

L-System	Perlin/Simplex Noise	Poisson Disk Sampling/Distribution	Voronoi Cells
24ms	78ms	176ms	502ms
10ms	78ms	190ms	425ms
14ms	82ms	210ms	455ms
14ms	91ms	216ms	449ms
17ms	75ms	193ms	442ms
AVG: 16ms	AVG: 81ms	AVG: 197ms	AVG: 455ms

Figure A.6: A table denoting some performance tests done with comparing all of the algorithms implemented with the chosen scenario. This was done on every single implementation implementation of the game; the “tests” were simply checking how long it took to create levels on the author of this report’s computer, and every implementation was tested with its default variable values. Each of the implementations were run 5 times, with the mean time (including potential outliers) calculated afterwards *to the nearest integer*. Be advised that the author of this report did these tests on his computer, so on different computers, results can, and likely *will*, vary.

# Appendix B

## User Guide

### B.1 Opening Godot

You will first need to download Godot 4 to run all the provided artefacts.

To run the projects in the .zip file, extract the projects into one folder. Then open Godot 4 (all projects in the source code listings folder are Godot 4 projects, **not** Godot 3 projects). When you start Godot for the first time, the project manager should be completely empty, without any projects, as described in Figure B.1. Projects have to be imported either one-by-one (by clicking “Import” and going to the relevant project and opening it) or by clicking “Scan”, then going to a folder of Godot projects and selecting it. The projects can then be opened in the project manager and edited as needed in Godot. Click “Scan”, then go to the folder where you extracted the projects, then click the “Select Current Folder” button, as shown in Figure B.2, and all the projects should show up in the editor, as shown in Figure B.3. You can then double click on any one project (or click on it once and click the “Edit” button) to open it in the Godot editor, an example of which is shown in Figure B.4. Alternatively, to run the project itself without opening the editor, using the currently saved values for exported script variables where appropriate, click on the project *once* and click the “Run” button.

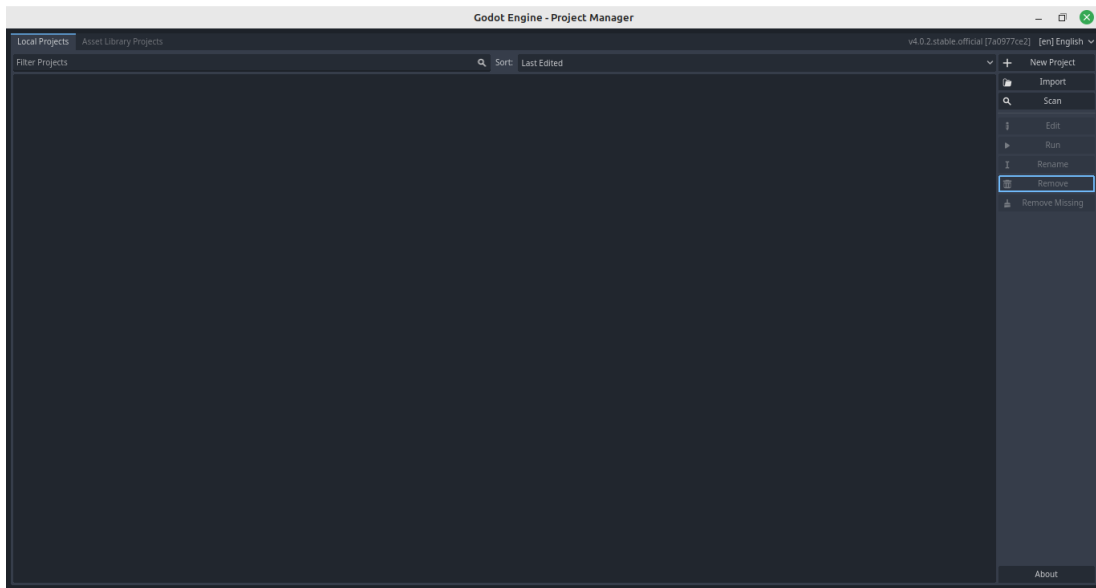


Figure B.1: The Godot editor, when it is opened for the first time, does not show any projects in the editor (the Steam version bundles several example projects). Projects need to be imported either one-by-one or by scanning a folder of Godot projects.

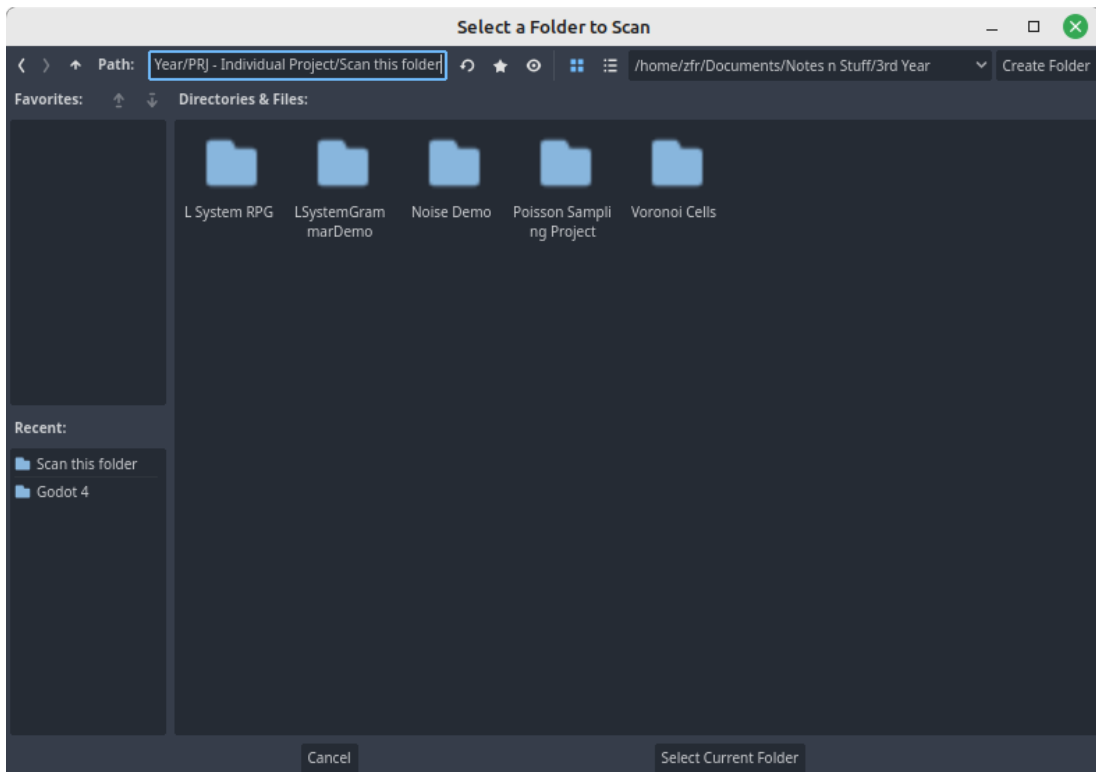


Figure B.2: You can click the "Scan" button in the project manager (in Figure B.1), then go to the relevant folder where your project are in Godot's built-in file explorer. Here, the artefacts behind this project have been exported into a separate folder called "Scan this folder" as an example.

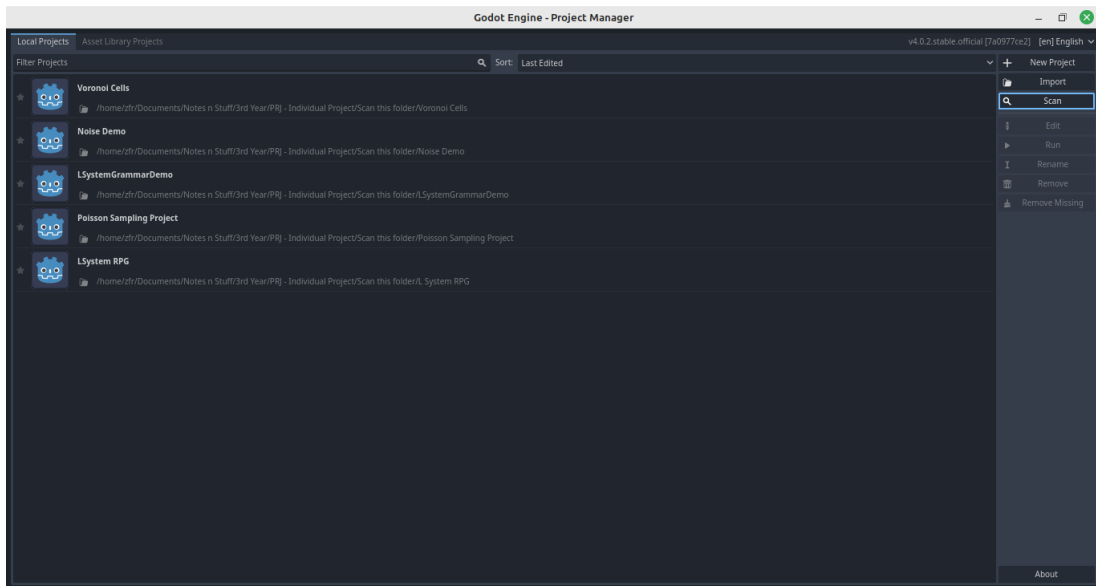


Figure B.3: Once some Godot projects have been imported into the project manager, you should be able to easily view the list and double-click on any one of the projects to edit them, which will open the editor after closing the project manager. You could also click the “Edit” button, or click “Run” to run the game without having to open the editor itself.

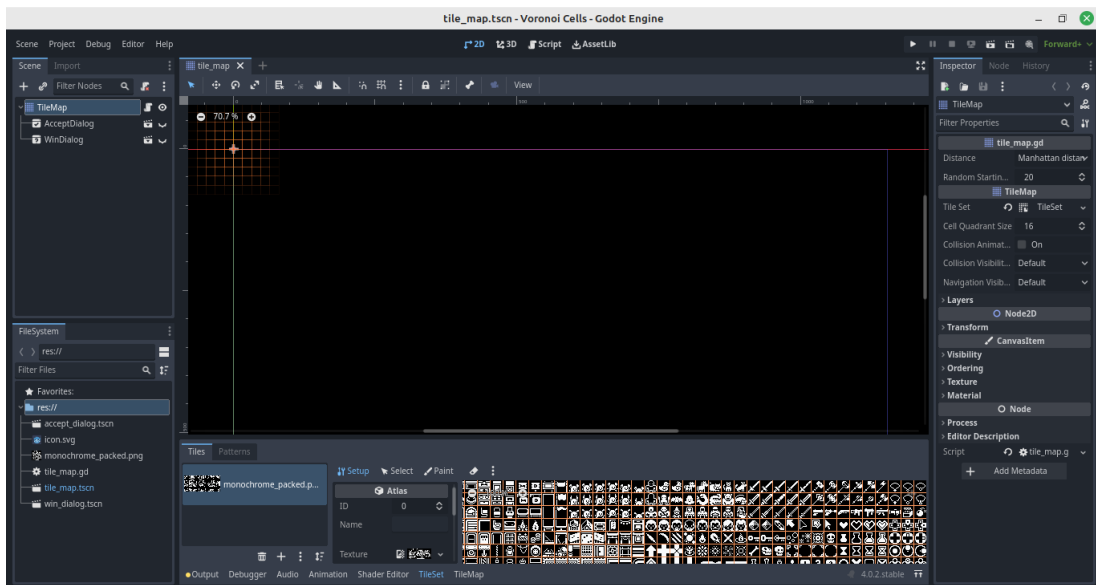


Figure B.4: The Godot editor open with the Voronoi cells project as an example. A visual description of the editor’s contents is in chapter B.2.

## B.2 The Godot Editor

As you open up the Godot editor, you will see the main scene view in the center, as shown in Figure B.4, using the Voronoi cells implementation as an example. The left-hand side shows

the scene tree at the top, and the file system (from the root folder of the project) at the bottom. Meanwhile, the right hand side shows the currently selected node's export variables, *including the custom export variables* defined in the node's script file, and two other tabs, "Node" (which shows a list of signals for the scene that could be called in a script) and "History" (which shows the sequence of recent actions performed on the scene during the current session). Above this is also a set of buttons which can be used for playing the project and/or the current scene. We go over how to run the current project in chapter B.4.

## B.3 Custom Export Variables

When you click on some of the scenes in the projects, there may be some "exported" variables from scripts that are visible to you in the editor (examples include the "Distance" and "Random Starting Points" variables in the Voronoi Cells project). You can hover over the variable names in the editor and it will show a brief description of what the variable correlates to in the script. We will now go over the different export variables across all of the provided artefacts in this section.

### B.3.1 Lindenmayer System

All of the custom export variables defined in scene scripts for your use are in the child node "LSystem" (it is saved into its own scene file, but it is chiefly a child node of the root node "TileMap"). Open the "TileMap" scene (if it is not already opened for you when you launch the Godot editor) and click on the "LSystem" node in the scene tree to edit it.

#### 1. axiom

- **Type:** String
- **Documentation:** The starting string from which the grammar starts applying its rules. Here it may be self defined, or randomly defined when "use\_random\_axiom" is true.
- **Default value:** "OWB"

#### 2. use\_random\_axiom

- **Type:** Boolean (bool)
- **Documentation:** Uses a random axiom with the currently set grammar, computed upon runtime, with a length up to (but not strictly) the value of upper\_limit. For

example, if `upper_limit` is set to 15, the generated axiom can be 15 characters, or it can be just 5 characters.

- **Default value:** `true`

### 3. `upper_limit`

- **Type:** Integer (`int`)
- **Documentation:** Defines how many characters a random axiom can have MAXIMUM. Only used when “`use_random_axiom`” is `true`.
- **Default value:** 10

### 4. `use_custom_ruleset`

- **Type:** Boolean (`bool`)
- **Documentation:** Allows the use of a customly defined ruleset made through amending the rules array in the editor.
- **Default value:** `false`

### 5. `ruleset`

- **Type:** String enumeration of the following choices:
  - (a) “Default”
  - (b) “More Buildings (IMPOSSIBLE)”
  - (c) “More Trees”
  - (d) “More Space”
- **Documentation:** Denotes a series of pre-defined rulesets for this L-System grammar, of alphabet O (blank space), W (trees and fauna) and B (buildings), that can be chosen and then used on runtime. Can choose between a default ruleset, a ruleset that produces more buildings, a ruleset that produces more trees and a ruleset that produces more empty space.
- **Default value:** “Default”

### 6. `rules`

- **Type:** Array of dictionaries



- **Documentation:** The set of rules that the L-System grammar uses. Shows the “default” ruleset in the Godot editor for the user to see. If “use\_custom\_ruleset” is set to true, this array can be edited with a custom defined ruleset that will be used on runtime, so long as it adheres to the alphabet of O (blank space), W (trees and fauna) and B (buildings).
- **Additional information:** The “\_get\_ruleset” function uses the String value in “ruleset” to set the value for “rules” on runtime, *if* “use\_custom\_ruleset” is false (which it *is* by default).
- **Default value:** The “Default” grammar, as shown in Figure B.5.

```

1      [
2      {
3          "from": "O",
4          "to": "OWO "
5      },
6      {
7          "from": "W",
8          "to": "WB "
9      },
10     {
11         "from": "B",
12         "to": "BWO "
13     }
14 ]

```

Figure B.5: The “Default” grammar used for the “rules” export variable, stored in the constant “DEFAULT” in `l_system.gd`. See `l_system.gd` for the other grammars represented as arrays of dictionaries.

### B.3.2 Perlin/Simplex Noise

#### 1. noise\_type

- **Type:** String enumeration of the following choices:

- (a) “Perlin”
- (b) “Simplex”
- (c) “Simplex Smooth”
- (d) “Value”
- (e) “Value Cubic”

- **Documentation:** Defines the type of noise generation algorithm to use. Equates to the “noise\_type” property in FastNoiseLite.
- **Default value:** “Value Cubic”

## 2. fractal\_type

- **Type:** Enumeration of the following choices:
  - (a) “Fractal None”
  - (b) “Fractal FBM”
  - (c) “Fractal Ridged”
  - (d) “Fractal Ping Pong”
- **Documentation:** Defines the type of method used to combine octaves of a noise image into a fractal. Directly equates to the FractalType enumeration in FastNoiseLite.
- **Default value:** “Fractal None”

## 3. cellular\_distance\_type

- **Type:** Enumeration of the following choices:
  - (a) “Distance Euclidean”
  - (b) “Distance Euclidean Squared”
  - (c) “Distance Manhattan”
  - (d) “Distance Hybrid”
- **Documentation:** Defines the function used to calculate the distance between the nearest/second-nearest point(s). Directly equates to the CellularDistanceFunction enumeration in FastNoiseLite.
- **Default value:** “Distance Euclidean”

## 4. noise\_frequency

- **Type:** Floating point number (float) between 0.0 and 1.0 inclusive

- **Documentation:** Defines the frequency of the generated noise, the higher the frequency, the rougher and more granular the noise.
- **Additional information:** The default value for “frequency” in the “FastNoise-Class” is 0.01, resulting in very smooth and distinct noise.
- **Default value:** 0.894

#### 5. tree\_cap

- **Type:** Floating point number (float) between -1.0 and 1.0 inclusive
- **Documentation:** Defines the upper limit to set for painting a tree tile on a specific noise pixel. If the value returned by the “get\_noise\_2d” method (in FastNoiseLite) is smaller than this, then it gets painted.
- **Default value:** -0.048

#### 6. building\_cap

- **Type:** Floating point number (float) between -1.0 and 1.0 inclusive
- **Documentation:** Defines the upper limit to set for painting a building tile on a specific noise pixel. If the value returned by the “get\_noise\_2d” method (in FastNoiseLite) is smaller than this, then it gets painted. If the value of “building\_cap” is smaller than “tree\_cap,” then decide whether or not to paint a building cell there with “building\_overtakes\_tree.”
- **Default value:** -0.252

#### 7. building\_overtakes\_tree

- **Type:** Floating point number (float) between 0.0 and 0.5 inclusive
- **Documentation:** Only used when “building\_cap” is smaller than “tree\_cap.” Determines the probability that a building tile would be painted in a cell where a tree tile was, or could be, also painted. Whether or not the cell actually is painted over is decided on computation time.
- **Default value:** 0.12

### B.3.3 Poisson Disk Sampling

#### 1. paint\_building\_probability

- **Type:** Floating point number (float) between 0.0 and 1.0 inclusive
- **Documentation:** The probability that a building gets painted at a cell in lieu of a tree. The higher this probability, the more likely a building tile gets painted instead of a tree tile.
- **Default value:** 0.125

## 2. point\_radius

- **Type:** Floating point number (float) between 0.5 and 2.5 inclusive
- **Documentation:** The radius value used to measure distances between points for the algorithm. The longer the radius, the further apart points are during the algorithm's processing, and the further apart painted cells are in the game.
- **Default value:** 1.0

## 3. region\_size

- **Type:** Vector2
- **Documentation:** The size of the region in which the algorithm is performed. Set to the "default" tile map size (72, 40) in the script, shown as (0, 0) in the Godot editor. Can be changed to use a smaller region for the algorithm itself, of course resulting in less cells covered within the boundaries set for this game, though the algorithm will perform faster due to less cells being checked.
- **Default value:**
  - **x:** The value in "x\_tile\_range" (72)
  - **y:** The value in "y\_tile\_range" (40)

## 4. rejection\_samples

- **Type:** Integer (int) between 1 and 50 inclusive
- **Documentation:** The maximum number of times a cell is checked before it is ignored. A cell can be accepted and painted on before this maximum number is reached. The higher this value, the more times a cell is checked, therefore the higher the algorithm's processing time.
- **Default value:** 8

### B.3.4 Voronoi Cells

#### 1. distance

- **Type:** String enumeration of the following choices:
  - (a) “Euclidean distance”
  - (b) “Manhattan distance”
- **Documentation:** Determines whether or not the Euclidean or Manhattan distance formula is used for calculation of the deltas between points within Voronoi cells.
- **Default value:** “Manhattan distance”

#### 2. random\_starting\_points

- **Type:** Integer (int) between 15 and 40 inclusive
- **Documentation:** Determines the number of points randomly picked from at the start. Therefore, it also determines the number of cells in our Voronoi tessellation.
- **Default value:** 20

### B.3.5 The Basic L-System Demo Used to Create the Screenshots in Chapter 3.1.1

There is only one export variable for this: “choices”, which allows you to choose which one of the three provided rulesets to use. “choices” is the default ruleset, and either “deterministic” or “basic” can be chosen. It is in the “DemoNode” scene, the only scene of this Godot project. Quoting the documentation comment, this export variable “Allows you to decide which ruleset to use. See the script file for the sources of said rulesets.” The ruleset is assigned with the “set\_values” function.

## B.4 Running the Godot Projects

To *run* the current project in the Godot editor, go to the bar above the Inspector, Node and History tabs on the right-hand side. You will find a ► button which will play the main scene of the project (in the artefacts, the main scenes have already been set; if it were not already set, you would have been asked to set one). If closing the window to stop the project does not work, hit the ■ button to end it. If you want to replay the current project without having to stop it, hit the ► button again. Although **both** the icon **and** the colour of the ► button will have changed by then, it will be in the same position as before.

As described in section 3.2.1, only the close button of both the popup dialogs in the game seems to work properly for the moment, but this does not adversely affect the game functioning properly, nor does it adversely affect this project, so this is trivial.

## Appendix C

### Source Code

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## C.1 Instructions

If needed, use the table of contents provided to browse through the code listings in this section. Each listing folder will have a short description, a link to its public GitHub repository, and a listing for each readable source file. Use the .zip folder containing the project artefacts to edit and run them in Godot.

*“I verify that I am the sole author of the programs contained in this folder, except where explicitly stated to the contrary.” - Zishan Rahman, 21<sup>st</sup> April 2023*

## C.2 GD4LSystemRPG

These are the source code listings for the L-System implementation of the 2D tile-map RPG scenario in the Godot game engine. The link to the publicly available source code repository is here: <https://github.com/Zishan-Rahman/GD4LSystemRPG>

### C.2.1 .gitattributes

```
1  # Normalize EOL for all files that Git considers text files.
2  * text=auto eol=lf
```

### C.2.2 .gitignore

```
1  # Godot 4+ specific ignores
2  .godot/
```

### C.2.3 project.godot

```
1  ; Engine configuration file.
2  ; It's best edited using the editor UI and not directly,
3  ; since the parameters that go here are not all obvious.
4  ;
```

```

5   ; Format:
6   ;   [section] ; section goes between []
7   ;   param=value ; assign values to parameters
8
9   config_version=5
10
11  [application]
12
13  config/name="LSystem RPG"
14  run/main_scene="res://tile_map.tscn"
15  config/features=PackedStringArray("4.0", "Forward Plus")
16  config/icon="res://icon.svg"
17
18  [display]
19
20  window/size/viewport_height=640
21
22  [rendering]
23
24  environment/defaults/default_clear_color=Color(0, 0, 0, 1)

```

#### C.2.4 l\_system.tscn

```

1   [gd_scene load_steps=2 format=3 uid="uid://d0v18e7ms571f"]
2
3   [ext_resource type="Script" path="res://l_system.gd" id="1_elydp"]
4
5   [node name="LSystem" type="Node"]
6   script = ExtResource("1_elydp")

```

#### C.2.5 l\_system.gd

```

1  extends Node
2
3  class_name LSystem
4
5  @onready var tile_map: TileMap = get_parent()
6  ## The starting string from which the grammar starts applying its
   rules. Here it may be self defined, or randomly defined when
   use_random_axiom is true.
7  @export var axiom: String = "OWB"
8  ## Uses a random axiom with the currently set grammar, computed
   upon runtime, with a length up to (but not strictly) the value
   of upper_limit. For example, if upper_limit is set to 15, the
   generated axiom can be 15 characters, or it can be just 5
   characters.
9  @export var use_random_axiom: bool = true
10 ## Defines how many characters a random axiom can have MAXIMUM.
   Only used when use_random_axiom is true.
11 @export var upper_limit: int = 10
12 ## Allows the use of a customly defined ruleset made through
   amending the rules array in the editor.
13 @export var use_custom_ruleset: bool = false
14 @onready var string: String = axiom
15 ## Denotes a series of pre-defined rulesets for this L-System
   grammar, of alphabet O (blank space), W (trees and fauna) and B
   (buildings), that can be chosen and then used on runtime. Can
   choose between a default ruleset, a ruleset that produces more
   buildings, a ruleset that produces more trees and a ruleset
   that produces more empty space.
16 @export_enum("Default", "More Buildings (IMPOSSIBLE)", "More Trees"
   , "More Space") var ruleset: String = "Default"
17 ## The set of rules that the L-System grammar uses. Shows the "
   default" ruleset in the Godot editor for the user to see. If
   use_custom_ruleset is set to true, this array can be edited

```

with a custom defined ruleset that will be used on runtime, so long as it adheres to the alphabet of O (blank space), W (trees and fauna) and B (buildings).

```
18 @export var rules: Array[Dictionary] = DEFAULT
19
20 const DEFAULT: Array[Dictionary] = [
21   {
22     "from": "O",
23     "to": "OWO"
24   },
25   {
26     "from": "W",
27     "to": "WB"
28   },
29   {
30     "from": "B",
31     "to": "BWO"
32   }
33 ]
34 const MORE_BUILDINGS: Array[Dictionary] = [
35   {
36     "from": "O",
37     "to": "BWOB"
38   },
39   {
40     "from": "W",
41     "to": "WBOBO"
42   },
43   {
44     "from": "B",
45     "to": "BB"
46   }
47 ]
```

```

48  const MORE_TREES: Array[Dictionary] = [
49      {
50          "from": "O",
51          "to": "WWO"
52      },
53      {
54          "from": "W",
55          "to": "WBWO"
56      },
57      {
58          "from": "B",
59          "to": "BWWO"
60      }
61  ]
62  const MORE_SPACE: Array[Dictionary] = [
63      {
64          "from": "O",
65          "to": "OOBWO"
66      },
67      {
68          "from": "W",
69          "to": "OB"
70      },
71      {
72          "from": "B",
73          "to": "OW"
74      }
75  ]
76
77  const buildings: Array[Vector2i] = [
78      Vector2i(0, 19),
79      Vector2i(1, 19),
80      Vector2i(2, 19),

```

```

81     Vector2i(3, 19),
82     Vector2i(4, 19),
83     Vector2i(5, 19),
84     Vector2i(6, 19),
85     Vector2i(7, 19),
86     Vector2i(8, 20),
87     Vector2i(0, 20),
88     Vector2i(1, 20),
89     Vector2i(2, 20),
90     Vector2i(3, 20),
91     Vector2i(4, 20),
92     Vector2i(5, 20),
93     Vector2i(6, 20),
94     Vector2i(7, 20),
95     Vector2i(8, 20),
96     Vector2i(0, 21),
97     Vector2i(1, 21),
98     Vector2i(2, 21),
99     Vector2i(3, 21),
100    Vector2i(4, 21),
101    Vector2i(5, 21),
102    Vector2i(6, 21),
103    Vector2i(7, 21),
104    Vector2i(8, 21)
105 ]
106 const trees: Array[Vector2i] = [
107     Vector2i(0,1),
108     Vector2i(1,1),
109     Vector2i(2,1),
110     Vector2i(3,1),
111     Vector2i(4,1),
112     Vector2i(5,1),
113     Vector2i(6,1),

```

```

114     Vector2i(7,1),
115     Vector2i(0,2),
116     Vector2i(1,2),
117     Vector2i(2,2),
118     Vector2i(3,2),
119     Vector2i(4,2)
120 ]
121
122 func _get_ruleset() -> Array[Dictionary]:
123     match ruleset:
124         "More Buildings (IMPOSSIBLE)": return MORE_BUILDINGS
125         "More Trees": return MORE_TREES
126         "More Space": return MORE_SPACE
127         _: return DEFAULT
128
129 func get_new_replacement(character: String) -> String:
130     for rule in rules:
131         if rule["from"] == character:
132             return rule["to"]
133     return character
134
135 func _size() -> int:
136     return tile_map.x_tile_range * tile_map.y_tile_range
137
138 func rand_axiom() -> String:
139     var string_buffer: String = ""
140     var limit: int = randi_range(1, upper_limit)
141     for i in range(limit):
142         string_buffer += ["O", "W", "B"].pick_random()
143     return string_buffer
144
145 func parse() -> String:
146     if use_random_axiom:

```



```

147         axiom = rand_axiom()
148         string = axiom
149         if not use_custom_ruleset or ruleset != "Default":
150             rules = _get_ruleset()
151         print("Axiom length: " + str(len(axiom)))
152         var size: int = _size()
153         while len(string) <= size:
154             var new_string = ""
155             for character in string:
156                 new_string += get_new_replacement(character)
157             string = new_string
158         string = string.substr(0, size)
159         return string
160
161     func paint() -> void:
162         string = parse()
163         var i: int = -1
164         for x in range(tile_map.x_tile_range):
165             for y in range(tile_map.y_tile_range):
166                 i += 1
167                 if string[i] == "O": # "O" = BLANK
168                     pass # Do not paint any cell.
169                 elif string[i] == "W": # "W" = TREE
170                     tile_map.set_cell(0, Vector2i(x, y), 0, trees.
171                                     pick_random())
172                 elif string[i] == "B": # "B" = BUILDING
173                     tile_map.set_cell(0, Vector2i(x, y), 0, buildings.
174                                     pick_random())

```

## C.2.6 tile\_map.tscn

```

1  [gd_scene load_steps=6 format=3 uid="uid://bwhvtqld3yo8m"]

```

```

2
3  [ext_resource type="TileSet" uid="uid://c168x78r0tful" path="res://
    Tiles.tres" id="1_l3nwg"]
4  [ext_resource type="Script" path="res://tile_map.gd" id="2_wrxl8"]
5  [ext_resource type="PackedScene" uid="uid://d0v18e7ms571f" path="
    res://l_system.tscn" id="3_ktw1n"]
6  [ext_resource type="PackedScene" uid="uid://cau5jgogdnf53" path="
    res://accept_dialog.tscn" id="4_060oh"]
7  [ext_resource type="PackedScene" uid="uid://b5q8ovcigrvyr" path="
    res://win_dialog.tscn" id="5_3s48a"]
8
9  [node name="TileMap" type="TileMap"]
10 tile_set = ExtResource("1_l3nwg")
11 format = 2
12 layer_0/name = "Things"
13 script = ExtResource("2_wrxl8")
14
15 [node name="LSystem" parent="." instance=ExtResource("3_ktw1n")]
16
17 [node name="AcceptDialog" parent="." instance=ExtResource("4_060oh"
    )]
18
19 [node name="WinDialog" parent="." instance=ExtResource("5_3s48a")]

```

### C.2.7 tile\_map.gd

```

1  extends TileMap
2
3  @onready var l_system: LSystem = $LSystem
4
5  var x_tile_range: int = ProjectSettings.get_setting("display/window
    /size/viewport_width") / tile_set.tile_size.x

```

```

6  var y_tile_range: int = ProjectSettings.get_setting("display/window
    /size/viewport_height") / tile_set.tile_size.y
7
8  const PLAYER_SPRITE: Vector2i = Vector2i(24, 7)
9  var player_placement_cell: Vector2i
10 const rings: Array[Vector2i] = [
11     Vector2i(43, 6),
12     Vector2i(44, 6),
13     Vector2i(45, 6),
14     Vector2i(46, 6)
15 ]
16 var ring_placement_cell: Vector2i
17
18 # Called when the node enters the scene tree for the first time.
19 func _ready() -> void:
20     randomize()
21     var start_time: float = Time.get_ticks_msec()
22     l_system.paint()
23     place_player()
24     place_ring()
25     var new_time: float = Time.get_ticks_msec() - start_time
26     print("Time taken: " + str(new_time) + "ms")
27     $AcceptDialog.dialog_text = "You're a hollow Golem who seeks the
        ultimate treasure; a ring that's got something on top of it
        . It's somewhere in this large village and barely visible to
        your naked eyes, which took us " + str(new_time) + "
        milliseconds to generate (" + str(new_time / 1000.0) + "
        seconds), but you'll stop at nothing to get what you want.
        You can chow down every tree and fauna that stands in your
        way of the ring, but your Achilles heel is any bricks and
        mortar, which WILL make you stop at your tracks. Since it's
        easy to get lost in here, we'll tell you that you're in
        position " + str(player_placement_cell) + " in this big

```

```

    village of size " + str(Vector2i(x_tile_range, y_tile_range)
    ) + ". The ring is in position " + str(ring_placement_cell)
    + ", but it is YOUR job to traverse the village, chow down
    the trees and get it for yourself, so are you ready to
    attain the treasure that is rightfully yours?!"

28     $AcceptDialog.visible = true
29     $AcceptDialog.confirmed.connect(_on_AcceptDialog_closed)
30     $AcceptDialog.canceled.connect(_on_AcceptDialog_closed)
31     $WinDialog.confirmed.connect(_on_WinDialog_confirmed)
32     $WinDialog.canceled.connect(_on_WinDialog_canceled)
33     get_tree().paused = true
34
35     func _on_WinDialog_confirmed() -> void:
36         get_tree().reload_current_scene()
37
38     func _on_WinDialog_canceled() -> void:
39         get_tree().quit()
40
41     func _on_AcceptDialog_closed() -> void:
42         $AcceptDialog.visible = false
43         get_tree().paused = false
44
45     func _get_random_placement_cell() -> Vector2i:
46         return Vector2i(randi() % x_tile_range, randi() % y_tile_range)
47
48     func place_player() -> void:
49         player_placement_cell = _get_random_placement_cell()
50         while get_used_cells(0).has(player_placement_cell):
51             player_placement_cell = _get_random_placement_cell()
52         set_cell(0, player_placement_cell, 0, PLAYER_SPRITE)
53
54     func place_ring() -> void:
55         ring_placement_cell = _get_random_placement_cell()

```

```

56     while get_used_cells(0).has(ring_placement_cell):
57         ring_placement_cell = _get_random_placement_cell()
58     set_cell(0, ring_placement_cell, 0, rings.pick_random())
59
60     func _is_not_out_of_bounds(cell: Vector2i) -> bool:
61         return cell.x >= 0 and cell.x < x_tile_range and cell.y >= 0 and
            cell.y < y_tile_range
62
63     func _physics_process(_delta: float) -> void:
64         var previous_cell: Vector2i = player_placement_cell
65         var direction: Vector2i = Vector2i.ZERO
66         if Input.is_action_pressed("ui_up"): direction = Vector2i.UP
67         elif Input.is_action_pressed("ui_down"): direction = Vector2i.
            DOWN
68         elif Input.is_action_pressed("ui_left"): direction = Vector2i.
            LEFT
69         elif Input.is_action_pressed("ui_right"): direction = Vector2i.
            RIGHT
70         var new_placement_cell: Vector2i = player_placement_cell +
            direction
71         if (not get_used_cells(0).has(new_placement_cell) or l_system.
            trees.has(get_cell_atlas_coords(0, new_placement_cell)) or
            new_placement_cell == ring_placement_cell) and
            _is_not_out_of_bounds(new_placement_cell):
72             player_placement_cell = new_placement_cell
73             set_cell(0, previous_cell, 0) # deletes contents of previous
                cell (atlas_coords = Vector2i(-1, -1))
74             set_cell(0, player_placement_cell, 0, PLAYER_SPRITE)
75             if player_placement_cell == ring_placement_cell:
76                 $WinDialog.visible = true
77                 get_tree().paused = true
78
79     # ALGORITHM AND CUSTOM EXPORT VARIABLES ARE IN LSYSTEM NODE

```

### C.2.8 accept\_dialog.tscn

```
1  [gd_scene format=3 uid="uid://cau5jgogdnf53"]
2
3  [node name="AcceptDialog" type="AcceptDialog"]
4  title = "Tree-Munching Time!"
5  position = Vector2i(326, 100)
6  size = Vector2i(500, 421)
7  mouse_passthrough = true
8  ok_button_text = "Bring it on!"
9  dialog_text = "You're a hollow Golem who seeks the ultimate
    treasure; a ring that's got something on top of it. It's
    somewhere in this large village and barely visible to your
    naked eyes, but you'll stop at nothing to get what you want.
    You can chow down every tree and fauna that stands in your way
    of the ring, but your Achilles heel is any bricks and mortar,
    which will make you stop at your tracks. Are you ready to
    attain your treasure?w Golem in a black-and-white world, in
    search for your most desired treasure. It's a ring with
    something on top of it. And you'll stop at nothing to get what
    you want. You can chow down every tree and fauna that stands in
    your way of the ring, but your Achilles heel is any bricks and
    mortar, which will make you stop at your tracks. Are you ready
    to attain the treasure that is rightfully yours?!"
10 dialog_autowrap = true
```

### C.2.9 win\_dialog.tscn

```
1  [gd_scene format=3 uid="uid://b5q8ovcigrvyr"]
2
3  [node name="WinDialog" type="ConfirmationDialog"]
4  title = "You Found the Treasure!"
```

```

5   position = Vector2i(326, 100)
6   size = Vector2i(500, 421)
7   mouse_passthrough = true
8   ok_button_text = "Get Me a New Village"
9   dialog_text = "You found your treasure! Well done, you!"
10
11   Would you like to travel to a new village in the hopes of finding
        another ring? Or would you like to take your treasure home now?
        "
12   dialog_autowrap = true
13   cancel_button_text = "Get Me Out of Here"

```

### C.2.10 icon.svg.import

```

1   [remap]
2
3   importer="texture"
4   type="CompressedTexture2D"
5   uid="uid://b45qexb3wmhym"
6   path="res://.godot/imported/icon.svg-218
        a8f2b3041327d8a5756f3a245f83b.ctex"
7   metadata={
8     "vram_texture": false
9   }
10
11   [deps]
12
13   source_file="res://icon.svg"
14   dest_files=["res://.godot/imported/icon.svg-218
        a8f2b3041327d8a5756f3a245f83b.ctex"]
15
16   [params]

```

```

17
18   compress/mode=0
19   compress/high_quality=false
20   compress/lossy_quality=0.7
21   compress/hdr_compression=1
22   compress/normal_map=0
23   compress/channel_pack=0
24   mipmaps/generate=false
25   mipmaps/limit=-1
26   roughness/mode=0
27   roughness/src_normal=""
28   process/fix_alpha_border=true
29   process/premult_alpha=false
30   process/normal_map_invert_y=false
31   process/hdr_as_srgb=false
32   process/hdr_clamp_exposure=false
33   process/size_limit=0
34   detect_3d/compress_to=1
35   svg/scale=1.0
36   editor/scale_with_editor_scale=false
37   editor/convert_colors_with_editor_theme=false

```

### C.2.11 monochrome\_packed.png.import

```

1   [remap]
2
3   importer="texture"
4   type="CompressedTexture2D"
5   uid="uid://dic8oic1ybjoyq"
6   path="res://.godot/imported/monochrome_packed.png-6
      b9bd1c64dd50f72acd3afd14d1ac34f.ctex"
7   metadata={

```



```

8   "vram_texture": false
9   }
10
11   [deps]
12
13   source_file="res://monochrome_packed.png"
14   dest_files=["res://.godot/imported/monochrome_packed.png-6
        b9bd1c64dd50f72acd3afd14d1ac34f.ctex"]
15
16   [params]
17
18   compress/mode=0
19   compress/high_quality=false
20   compress/lossy_quality=0.7
21   compress/hdr_compression=1
22   compress/normal_map=0
23   compress/channel_pack=0
24   mipmaps/generate=false
25   mipmaps/limit=-1
26   roughness/mode=0
27   roughness/src_normal=""
28   process/fix_alpha_border=true
29   process/premult_alpha=false
30   process/normal_map_invert_y=false
31   process/hdr_as_srgb=false
32   process/hdr_clamp_exposure=false
33   process/size_limit=0
34   detect_3d/compress_to=1

```

### C.2.12 Tiles.tres

```

1   [gd_resource type="TileSet" load_steps=3 format=3 uid="uid://

```

```

    c168x78r0tful"]
2
3  [ext_resource type="Texture2D" uid="uid://dic8oic1ybjyq" path="res
    ://monochrome_packed.png" id="1_fqi6r"]
4
5  [sub_resource type="TileSetAtlasSource" id="
    TileSetAtlasSource_qer06"]
6  texture = ExtResource("1_fqi6r")
7  0:0/0 = 0
8  1:0/0 = 0
9  2:0/0 = 0
10 3:0/0 = 0
11 4:0/0 = 0
12 5:0/0 = 0
13 6:0/0 = 0
14 7:0/0 = 0
15 8:0/0 = 0
16 9:0/0 = 0
17 10:0/0 = 0
18 11:0/0 = 0
19 12:0/0 = 0
20 13:0/0 = 0
21 14:0/0 = 0
22 15:0/0 = 0
23 16:0/0 = 0
24 17:0/0 = 0
25 18:0/0 = 0
26 19:0/0 = 0
27 20:0/0 = 0
28 21:0/0 = 0
29 22:0/0 = 0
30 23:0/0 = 0
31 24:0/0 = 0

```

32 25:0/0 = 0  
33 26:0/0 = 0  
34 27:0/0 = 0  
35 28:0/0 = 0  
36 29:0/0 = 0  
37 30:0/0 = 0  
38 31:0/0 = 0  
39 32:0/0 = 0  
40 33:0/0 = 0  
41 34:0/0 = 0  
42 35:0/0 = 0  
43 36:0/0 = 0  
44 37:0/0 = 0  
45 38:0/0 = 0  
46 39:0/0 = 0  
47 40:0/0 = 0  
48 41:0/0 = 0  
49 42:0/0 = 0  
50 43:0/0 = 0  
51 44:0/0 = 0  
52 45:0/0 = 0  
53 46:0/0 = 0  
54 47:0/0 = 0  
55 48:0/0 = 0  
56 0:1/0 = 0  
57 1:1/0 = 0  
58 2:1/0 = 0  
59 3:1/0 = 0  
60 4:1/0 = 0  
61 5:1/0 = 0  
62 6:1/0 = 0  
63 7:1/0 = 0  
64 8:1/0 = 0

65     9:1/0 = 0  
66     10:1/0 = 0  
67     11:1/0 = 0  
68     12:1/0 = 0  
69     13:1/0 = 0  
70     14:1/0 = 0  
71     15:1/0 = 0  
72     16:1/0 = 0  
73     17:1/0 = 0  
74     18:1/0 = 0  
75     19:1/0 = 0  
76     20:1/0 = 0  
77     21:1/0 = 0  
78     22:1/0 = 0  
79     23:1/0 = 0  
80     24:1/0 = 0  
81     25:1/0 = 0  
82     26:1/0 = 0  
83     27:1/0 = 0  
84     28:1/0 = 0  
85     29:1/0 = 0  
86     30:1/0 = 0  
87     31:1/0 = 0  
88     32:1/0 = 0  
89     33:1/0 = 0  
90     34:1/0 = 0  
91     35:1/0 = 0  
92     36:1/0 = 0  
93     37:1/0 = 0  
94     38:1/0 = 0  
95     39:1/0 = 0  
96     40:1/0 = 0  
97     41:1/0 = 0

98     42:1/0 = 0  
99     43:1/0 = 0  
100    44:1/0 = 0  
101    45:1/0 = 0  
102    46:1/0 = 0  
103    47:1/0 = 0  
104    48:1/0 = 0  
105    0:2/0 = 0  
106    1:2/0 = 0  
107    2:2/0 = 0  
108    3:2/0 = 0  
109    4:2/0 = 0  
110    5:2/0 = 0  
111    6:2/0 = 0  
112    7:2/0 = 0  
113    8:2/0 = 0  
114    9:2/0 = 0  
115    10:2/0 = 0  
116    11:2/0 = 0  
117    12:2/0 = 0  
118    13:2/0 = 0  
119    14:2/0 = 0  
120    15:2/0 = 0  
121    16:2/0 = 0  
122    17:2/0 = 0  
123    18:2/0 = 0  
124    19:2/0 = 0  
125    20:2/0 = 0  
126    21:2/0 = 0  
127    22:2/0 = 0  
128    23:2/0 = 0  
129    24:2/0 = 0  
130    25:2/0 = 0

131	$26:2/0 = 0$
132	$27:2/0 = 0$
133	$28:2/0 = 0$
134	$29:2/0 = 0$
135	$30:2/0 = 0$
136	$31:2/0 = 0$
137	$32:2/0 = 0$
138	$33:2/0 = 0$
139	$34:2/0 = 0$
140	$35:2/0 = 0$
141	$36:2/0 = 0$
142	$37:2/0 = 0$
143	$38:2/0 = 0$
144	$39:2/0 = 0$
145	$40:2/0 = 0$
146	$41:2/0 = 0$
147	$42:2/0 = 0$
148	$43:2/0 = 0$
149	$44:2/0 = 0$
150	$45:2/0 = 0$
151	$46:2/0 = 0$
152	$47:2/0 = 0$
153	$48:2/0 = 0$
154	$0:3/0 = 0$
155	$1:3/0 = 0$
156	$2:3/0 = 0$
157	$3:3/0 = 0$
158	$4:3/0 = 0$
159	$5:3/0 = 0$
160	$6:3/0 = 0$
161	$7:3/0 = 0$
162	$8:3/0 = 0$
163	$9:3/0 = 0$

164    10:3/0 = 0  
165    11:3/0 = 0  
166    12:3/0 = 0  
167    13:3/0 = 0  
168    14:3/0 = 0  
169    15:3/0 = 0  
170    16:3/0 = 0  
171    17:3/0 = 0  
172    18:3/0 = 0  
173    19:3/0 = 0  
174    20:3/0 = 0  
175    21:3/0 = 0  
176    22:3/0 = 0  
177    23:3/0 = 0  
178    24:3/0 = 0  
179    25:3/0 = 0  
180    26:3/0 = 0  
181    27:3/0 = 0  
182    28:3/0 = 0  
183    29:3/0 = 0  
184    30:3/0 = 0  
185    31:3/0 = 0  
186    32:3/0 = 0  
187    33:3/0 = 0  
188    34:3/0 = 0  
189    35:3/0 = 0  
190    36:3/0 = 0  
191    37:3/0 = 0  
192    38:3/0 = 0  
193    39:3/0 = 0  
194    40:3/0 = 0  
195    41:3/0 = 0  
196    42:3/0 = 0

197      $43:3/0 = 0$   
198      $44:3/0 = 0$   
199      $45:3/0 = 0$   
200      $46:3/0 = 0$   
201      $47:3/0 = 0$   
202      $48:3/0 = 0$   
203      $0:4/0 = 0$   
204      $1:4/0 = 0$   
205      $2:4/0 = 0$   
206      $3:4/0 = 0$   
207      $4:4/0 = 0$   
208      $5:4/0 = 0$   
209      $6:4/0 = 0$   
210      $7:4/0 = 0$   
211      $8:4/0 = 0$   
212      $9:4/0 = 0$   
213      $10:4/0 = 0$   
214      $11:4/0 = 0$   
215      $12:4/0 = 0$   
216      $13:4/0 = 0$   
217      $14:4/0 = 0$   
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1055    19:21/0 = 0
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1062    26:21/0 = 0
1063    27:21/0 = 0
1064    28:21/0 = 0
1065    29:21/0 = 0
1066    30:21/0 = 0
1067    31:21/0 = 0
1068    32:21/0 = 0
1069    33:21/0 = 0
1070    34:21/0 = 0
1071    35:21/0 = 0
1072    36:21/0 = 0
1073    37:21/0 = 0
1074    38:21/0 = 0
1075    39:21/0 = 0
1076    40:21/0 = 0
1077    41:21/0 = 0
1078    42:21/0 = 0
1079    43:21/0 = 0
1080    44:21/0 = 0
1081    45:21/0 = 0
1082    46:21/0 = 0
1083    47:21/0 = 0
1084    48:21/0 = 0
1085
1086    [resource]
1087    sources/0 = SubResource("TileSetAtlasSource_qer06")

```

### C.2.13 LICENSE

```
1   This work is licensed under the Creative Commons Attribution-
    ShareAlike 4.0 International License. To view a copy of this
    license, visit http://creativecommons.org/licenses/by-sa/4.0/
    or send a letter to Creative Commons, PO Box 1866, Mountain
    View, CA 94042, USA.
```

## C.3 GD4VoronoiRPG

These are the source code listings for the Voronoi Cells implementation of the 2D tile-map RPG scenario in the Godot game engine. The link to the publicly available source code repository is here: <https://github.com/Zishan-Rahman/GD4VoronoiRPG>

### C.3.1 .gitattributes

```
1   # Normalize EOL for all files that Git considers text files.
2   * text=auto eol=lf
```

### C.3.2 .gitignore

```
1   # Godot 4+ specific ignores
2   .godot/
```

### C.3.3 project.godot

```
1   ; Engine configuration file.
2   ; It's best edited using the editor UI and not directly,
3   ; since the parameters that go here are not all obvious.
4   ;
```

```

5 ; Format:
6 ; [section] ; section goes between []
7 ; param=value ; assign values to parameters
8
9 config_version=5
10
11 [application]
12
13 config/name="Voronoi Cells"
14 run/main_scene="res://tile_map.tscn"
15 config/features=PackedStringArray("4.0", "Forward Plus")
16 config/icon="res://icon.svg"
17
18 [display]
19
20 window/size/viewport_height=640
21
22 [input]
23
24 reset_position={
25     "deadzone": 0.5,
26     "events": [Object(InputEventKey,"resource_local_to_scene":false,"
27         resource_name":"","device":-1,"window_id":0,"alt_pressed":false
28         ,"shift_pressed":false,"ctrl_pressed":false,"meta_pressed":
29         false,"pressed":false,"keycode":71,"physical_keycode":0,"
30         key_label":0,"unicode":103,"echo":false,"script":null)
31     , Object(InputEventMouseButton,"resource_local_to_scene":false,"
32         resource_name":"","device":-1,"window_id":0,"alt_pressed":false
33         ,"shift_pressed":false,"ctrl_pressed":false,"meta_pressed":
34         false,"button_mask":2,"position":Vector2(75, 12),"
35         global_position":Vector2(78, 44),"factor":1.0,"button_index
36         ":2,"pressed":true,"double_click":false,"script":null)
37 ]

```

```

29     }
30
31     [rendering]
32
33     environment/defaults/default_clear_color=Color(0, 0, 0, 1)

```

### C.3.4 tile\_map.tscn

```

1     [gd_scene load_steps=7 format=3 uid="uid://d6lxn73sfbh1w"]
2
3     [ext_resource type="Texture2D" uid="uid://cpign73sfbsrt" path="res
        ://monochrome_packed.png" id="1_o183d"]
4     [ext_resource type="Script" path="res://tile_map.gd" id="2_lf4lw"]
5     [ext_resource type="PackedScene" uid="uid://cau5jgogdnf53" path="
        res://accept_dialog.tscn" id="3_y08lj"]
6     [ext_resource type="PackedScene" uid="uid://b5q8ovcigrvyr" path="
        res://win_dialog.tscn" id="4_fkys0"]
7
8     [sub_resource type="TileSetAtlasSource" id="
        TileSetAtlasSource_6h0bd"]
9     texture = ExtResource("1_o183d")
10    0:0/0 = 0
11    1:0/0 = 0
12    2:0/0 = 0
13    3:0/0 = 0
14    4:0/0 = 0
15    5:0/0 = 0
16    6:0/0 = 0
17    7:0/0 = 0
18    8:0/0 = 0
19    9:0/0 = 0
20    10:0/0 = 0

```

21 11:0/0 = 0  
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965     24:19/0 = 0  
966     25:19/0 = 0  
967     26:19/0 = 0  
968     27:19/0 = 0  
969     28:19/0 = 0  
970     29:19/0 = 0  
971     30:19/0 = 0  
972     31:19/0 = 0  
973     32:19/0 = 0  
974     33:19/0 = 0  
975     34:19/0 = 0  
976     35:19/0 = 0  
977     36:19/0 = 0

978 37:19/0 = 0  
979 38:19/0 = 0  
980 39:19/0 = 0  
981 40:19/0 = 0  
982 41:19/0 = 0  
983 42:19/0 = 0  
984 43:19/0 = 0  
985 44:19/0 = 0  
986 45:19/0 = 0  
987 46:19/0 = 0  
988 47:19/0 = 0  
989 48:19/0 = 0  
990 0:20/0 = 0  
991 1:20/0 = 0  
992 2:20/0 = 0  
993 3:20/0 = 0  
994 4:20/0 = 0  
995 5:20/0 = 0  
996 6:20/0 = 0  
997 7:20/0 = 0  
998 8:20/0 = 0  
999 9:20/0 = 0  
1000 10:20/0 = 0  
1001 11:20/0 = 0  
1002 12:20/0 = 0  
1003 13:20/0 = 0  
1004 14:20/0 = 0  
1005 15:20/0 = 0  
1006 16:20/0 = 0  
1007 17:20/0 = 0  
1008 18:20/0 = 0  
1009 19:20/0 = 0  
1010 20:20/0 = 0

1011	$21:20/0 = 0$
1012	$22:20/0 = 0$
1013	$23:20/0 = 0$
1014	$24:20/0 = 0$
1015	$25:20/0 = 0$
1016	$26:20/0 = 0$
1017	$27:20/0 = 0$
1018	$28:20/0 = 0$
1019	$29:20/0 = 0$
1020	$30:20/0 = 0$
1021	$31:20/0 = 0$
1022	$32:20/0 = 0$
1023	$33:20/0 = 0$
1024	$34:20/0 = 0$
1025	$35:20/0 = 0$
1026	$36:20/0 = 0$
1027	$37:20/0 = 0$
1028	$38:20/0 = 0$
1029	$39:20/0 = 0$
1030	$40:20/0 = 0$
1031	$41:20/0 = 0$
1032	$42:20/0 = 0$
1033	$43:20/0 = 0$
1034	$44:20/0 = 0$
1035	$45:20/0 = 0$
1036	$46:20/0 = 0$
1037	$47:20/0 = 0$
1038	$48:20/0 = 0$
1039	$0:21/0 = 0$
1040	$1:21/0 = 0$
1041	$2:21/0 = 0$
1042	$3:21/0 = 0$
1043	$4:21/0 = 0$

1044	$5:21/0 = 0$
1045	$6:21/0 = 0$
1046	$7:21/0 = 0$
1047	$8:21/0 = 0$
1048	$9:21/0 = 0$
1049	$10:21/0 = 0$
1050	$11:21/0 = 0$
1051	$12:21/0 = 0$
1052	$13:21/0 = 0$
1053	$14:21/0 = 0$
1054	$15:21/0 = 0$
1055	$16:21/0 = 0$
1056	$17:21/0 = 0$
1057	$18:21/0 = 0$
1058	$19:21/0 = 0$
1059	$20:21/0 = 0$
1060	$21:21/0 = 0$
1061	$22:21/0 = 0$
1062	$23:21/0 = 0$
1063	$24:21/0 = 0$
1064	$25:21/0 = 0$
1065	$26:21/0 = 0$
1066	$27:21/0 = 0$
1067	$28:21/0 = 0$
1068	$29:21/0 = 0$
1069	$30:21/0 = 0$
1070	$31:21/0 = 0$
1071	$32:21/0 = 0$
1072	$33:21/0 = 0$
1073	$34:21/0 = 0$
1074	$35:21/0 = 0$
1075	$36:21/0 = 0$
1076	$37:21/0 = 0$

```

1077 38:21/0 = 0
1078 39:21/0 = 0
1079 40:21/0 = 0
1080 41:21/0 = 0
1081 42:21/0 = 0
1082 43:21/0 = 0
1083 44:21/0 = 0
1084 45:21/0 = 0
1085 46:21/0 = 0
1086 47:21/0 = 0
1087 48:21/0 = 0
1088
1089 [sub_resource type="TileSet" id="TileSet_3drs5"]
1090 sources/0 = SubResource("TileSetAtlasSource_6h0bd")
1091
1092 [node name="TileMap" type="TileMap"]
1093 tile_set = SubResource("TileSet_3drs5")
1094 format = 2
1095 script = ExtResource("2_lf4lw")
1096
1097 [node name="AcceptDialog" parent="." instance=ExtResource("3_y08lj"
    )]
1098
1099 [node name="WinDialog" parent="." instance=ExtResource("4_fkys0")]

```

### C.3.5 tile\_map.gd

```

1 extends TileMap
2
3 const buildings: Array[Vector2i] = [
4     Vector2i(0, 19),
5     Vector2i(1, 19),

```

```

6      Vector2i(2, 19),
7      Vector2i(3, 19),
8      Vector2i(4, 19),
9      Vector2i(5, 19),
10     Vector2i(6, 19),
11     Vector2i(7, 19),
12     Vector2i(8, 20),
13     Vector2i(0, 20),
14     Vector2i(1, 20),
15     Vector2i(2, 20),
16     Vector2i(3, 20),
17     Vector2i(4, 20),
18     Vector2i(5, 20),
19     Vector2i(6, 20),
20     Vector2i(7, 20),
21     Vector2i(8, 20),
22     Vector2i(0, 21),
23     Vector2i(1, 21),
24     Vector2i(2, 21),
25     Vector2i(3, 21),
26     Vector2i(4, 21),
27     Vector2i(5, 21),
28     Vector2i(6, 21),
29     Vector2i(7, 21),
30     Vector2i(8, 21)
31 ]
32 const trees: Array[Vector2i] = [
33     Vector2i(0,1),
34     Vector2i(1,1),
35     Vector2i(2,1),
36     Vector2i(3,1),
37     Vector2i(4,1),
38     Vector2i(5,1),

```

```

39     Vector2i(6,1),
40     Vector2i(7,1),
41     Vector2i(0,2),
42     Vector2i(1,2),
43     Vector2i(2,2),
44     Vector2i(3,2),
45     Vector2i(4,2)
46 ]
47 const PLAYER_SPRITE: Vector2i = Vector2i(24, 7)
48 var player_placement_cell: Vector2i
49 const rings: Array[Vector2i] = [
50     Vector2i(43, 6),
51     Vector2i(44, 6),
52     Vector2i(45, 6),
53     Vector2i(46, 6)
54 ]
55 var ring_placement_cell: Vector2i
56
57 var points: Array[Dictionary] = []
58 const EUCLIDEAN: String = "Euclidean distance"
59 const MANHATTAN: String = "Manhattan distance"
60 ## Determines whether or not the Euclidean or Manhattan distance
    formula is used for calculation of the deltas between points
    within Voronoi cells.
61 @export_enum(EUCLIDEAN, MANHATTAN) var distance: String = MANHATTAN
62 ## Determines the number of points randomly picked from at the
    start. Therefore, it also determines the number of cells in our
    Voronoi tessellation.
63 @export_range(15, 40, 1) var random_starting_points: int = 20
64 var x_tile_range: int = ProjectSettings.get_setting("display/window
    /size/viewport_width") / tile_set.tile_size.x
65 var y_tile_range: int = ProjectSettings.get_setting("display/window
    /size/viewport_height") / tile_set.tile_size.y

```



```

66
67 # Called when the node enters the scene tree for the first time.
68 func _ready() -> void:
69     randomize()
70     var start_time: float = Time.get_ticks_msec()
71     define_points(random_starting_points)
72     paint_points()
73     place_player()
74     place_ring()
75     var new_time: float = Time.get_ticks_msec() - start_time
76     print("Time taken: " + str(new_time) + "ms")
77     $AcceptDialog.dialog_text = "You're a hollow Golem who seeks the
        ultimate treasure; a ring that's got something on top of it
        . It's somewhere in this large village and barely visible to
        your naked eyes, which took us " + str(new_time) + "
        milliseconds to generate (" + str(new_time / 1000.0) + "
        seconds), but you'll stop at nothing to get what you want.
        You can chow down every tree and fauna that stands in your
        way of the ring, but your Achilles heel is any bricks and
        mortar, which WILL make you stop at your tracks. Since it's
        easy to get lost in here, we'll tell you that you're in
        position " + str(player_placement_cell) + " in this big
        village of size " + str(Vector2i(x_tile_range, y_tile_range)
        ) + ". It's also easy to get stuck here, so either press the
        G key or right click to teleport somewhere else where there
        is fauna (or even the ring!!), because this game actually
        WANTS you to win it. Ultimately, though, it is YOUR job to
        find the ring, so are you ready to attain the treasure that
        is rightfully yours?!"
78     $AcceptDialog.visible = true
79     $AcceptDialog.confirmed.connect(_on_AcceptDialog_closed)
80     $AcceptDialog.canceled.connect(_on_AcceptDialog_closed)
81     $WinDialog.confirmed.connect(_on_WinDialog_confirmed)

```

```

82     $WinDialog.canceled.connect(_on_WinDialog_canceled)
83     get_tree().paused = true
84
85     func _on_WinDialog_confirmed() -> void:
86         get_tree().reload_current_scene()
87
88     func _on_WinDialog_canceled() -> void:
89         get_tree().quit()
90
91     func _on_AcceptDialog_closed() -> void:
92         $AcceptDialog.visible = false
93         get_tree().paused = false
94
95     func _get_random_placement_cell() -> Vector2i:
96         return Vector2i(randi() % x_tile_range, randi() % y_tile_range)
97
98     func place_player() -> void:
99         player_placement_cell = _get_random_placement_cell()
100        while buildings.has(get_cell_atlas_coords(0,
101            player_placement_cell)) or player_placement_cell ==
102            ring_placement_cell:
103
104            player_placement_cell = _get_random_placement_cell()
105        set_cell(0, player_placement_cell, 0, PLAYER_SPRITE)
106
107    func place_ring() -> void:
108        ring_placement_cell = _get_random_placement_cell()
109        while buildings.has(get_cell_atlas_coords(0, ring_placement_cell
110            )) or ring_placement_cell == player_placement_cell:
111            ring_placement_cell = _get_random_placement_cell()
112        set_cell(0, ring_placement_cell, 0, rings.pick_random())
113
114    func _is_not_out_of_bounds(cell: Vector2i) -> bool:
115        return cell.x >= 0 and cell.x < x_tile_range and cell.y >= 0 and

```

```

        cell.y < y_tile_range
112
113 func _physics_process(_delta) -> void:
114     var previous_cell: Vector2i = player_placement_cell
115     var direction: Vector2i = Vector2i.ZERO
116     if Input.is_action_pressed("ui_up"): direction = Vector2i.UP
117     elif Input.is_action_pressed("ui_down"): direction = Vector2i.
        DOWN
118     elif Input.is_action_pressed("ui_left"): direction = Vector2i.
        LEFT
119     elif Input.is_action_pressed("ui_right"): direction = Vector2i.
        RIGHT
120     elif Input.is_action_just_pressed("reset_position"): # Respawn
        player in a different part of the map
121     player_placement_cell = _get_random_placement_cell()
122     while buildings.has(get_cell_atlas_coords(0,
        player_placement_cell)): # This time, since we're not
        STARTING the game, we don't care whether or not the
        player magically lands on the ring
123     player_placement_cell = _get_random_placement_cell()
124     set_cell(0, player_placement_cell, 0, PLAYER_SPRITE)
125     set_cell(0, previous_cell, 0) # replace the previous sprite
126     _win_game_if_won()
127     return
128     var new_placement_cell: Vector2i = player_placement_cell +
        direction
129     if (not get_used_cells(0).has(new_placement_cell) or trees.has(
        get_cell_atlas_coords(0, new_placement_cell)) or
        new_placement_cell == ring_placement_cell) and
        _is_not_out_of_bounds(new_placement_cell):
130     player_placement_cell = new_placement_cell
131     set_cell(0, previous_cell, 0) # deletes contents of previous
        cell (atlas_coords = Vector2i(-1, -1))

```

```

132         set_cell(0, player_placement_cell, 0, PLAYER_SPRITE)
133         _win_game_if_won()
134
135     func _win_game_if_won() -> void:
136         if player_placement_cell == ring_placement_cell:
137             $WinDialog.visible = true
138             get_tree().paused = true
139
140     # ALGORITHM BEGINS HERE
141
142     # Used as inspiration: http://pcg.wikidot.com/pcg-algorithm:voronoi
143     # -diagram
144     # (brute-force implementation in JavaScript, here adapted to
145     # GDScript)
146
147     func paint_points() -> void:
148         for point in points:
149             set_cell(0, Vector2(point["x"], point["y"]), 0, point["type"]
150                 ])
151             for citizen in point["citizens"]:
152                 if _is_in_bounds(point["x"], citizen["dx"], point["y"],
153                     citizen["dy"]):
154                     set_cell(0, Vector2(point["x"] + citizen["dx"], point["
155                         y"] + citizen["dy"]), 0, point["type"])
156
157     func _is_in_bounds(x: int, dx: int, y: int, dy: int) -> bool:
158         return x + dx >= 0 and x + dx < x_tile_range and y + dy >= 0 and
159             y + dy < y_tile_range
160
161     func _squared(x: int) -> int:
162         return x ** 2
163
164     func calculate_points_delta(x: int, y: int, p: int) -> float:

```

```

159     if distance == EUCLIDEAN:
160         return sqrt(_squared(points[p]["x"] - x) + _squared(points[p]
161             ["y"] - y))
162
163     return abs(points[p]["x"] - x) + abs(points[p]["y"] - y)
164
165 func define_points(num_points: int) -> void:
166     var types: Array[Vector2i] = trees.duplicate()
167     types.append_array(buildings)
168     for i in range(num_points):
169         var x: int = randi_range(0, x_tile_range)
170         var y: int = randi_range(0, y_tile_range)
171         var type: Vector2i = types.pick_random()
172         types.erase(type)
173         points.append(
174             {
175                 "type": type,
176                 "x": x,
177                 "y": y,
178                 "citizens": []
179             }
180         )
181     for x in range(x_tile_range):
182         for y in range(y_tile_range):
183             var lowest_delta: Dictionary = {
184                 "point_id": 0,
185                 "delta": x_tile_range * y_tile_range
186             }
187             for p in range(len(points)):
188                 var delta: float = calculate_points_delta(x, y, p)
189                 if delta < lowest_delta["delta"]:
190                     lowest_delta = {
191                         "point_id": p,
192                         "delta": delta

```

```

191         }
192         var active_point: Dictionary = points[lowest_delta["
            point_id"]]
193         var dx: int = x - active_point["x"]
194         var dy: int = y - active_point["y"]
195         active_point["citizens"].append(
196             {
197                 "dx": dx,
198                 "dy": dy
199             }
200         )

```

### C.3.6 accept\_dialog.tscn

```

1  [gd_scene format=3 uid="uid://cau5jgogdnf53"]
2
3  [node name="AcceptDialog" type="AcceptDialog"]
4  title = "Tree-Munching Time!"
5  position = Vector2i(326, 100)
6  size = Vector2i(500, 421)
7  mouse_passthrough = true
8  ok_button_text = "Bring it on!"
9  dialog_text = "You're a hollow Golem who seeks the ultimate
    treasure; a ring that's got something on top of it. It's
    somewhere in this large village and barely visible to your
    naked eyes, but you'll stop at nothing to get what you want.
    You can chow down every tree and fauna that stands in your way
    of the ring, but your Achilles heel is any bricks and mortar,
    which will make you stop at your tracks. Are you ready to
    attain your treasure?w Golem in a black-and-white world, in
    search for your most desired treasure. It's a ring with
    something on top of it. And you'll stop at nothing to get what

```

```

    you want. You can chow down every tree and fauna that stands in
    your way of the ring, but your Achilles heel is any bricks and
    mortar, which will make you stop at your tracks. Are you ready
    to attain the treasure that is rightfully yours?!"
10  dialog_autowrap = true

```

### C.3.7 win\_dialog.tscn

```

1  [gd_scene format=3 uid="uid://b5q8ovcigrvyr"]
2
3  [node name="WinDialog" type="ConfirmationDialog"]
4  title = "You Found the Treasure!"
5  position = Vector2i(326, 100)
6  size = Vector2i(500, 421)
7  mouse_passthrough = true
8  ok_button_text = "Get Me a New Village"
9  dialog_text = "You found your treasure! Well done, you!"
10
11  Would you like to travel to a new village in the hopes of finding
    another ring? Or would you like to take your treasure home now?
    "
12  dialog_autowrap = true
13  cancel_button_text = "Get Me Out of Here"

```

### C.3.8 icon.svg.import

```

1  [remap]
2
3  importer="texture"
4  type="CompressedTexture2D"
5  uid="uid://du4v6taw8ssax"

```

```

6   path="res://.godot/imported/icon.svg-218
    a8f2b3041327d8a5756f3a245f83b.ctex"
7   metadata={
8     "vram_texture": false
9   }
10
11   [deps]
12
13   source_file="res://icon.svg"
14   dest_files=["res://.godot/imported/icon.svg-218
    a8f2b3041327d8a5756f3a245f83b.ctex"]
15
16   [params]
17
18   compress/mode=0
19   compress/high_quality=false
20   compress/lossy_quality=0.7
21   compress/hdr_compression=1
22   compress/normal_map=0
23   compress/channel_pack=0
24   mipmaps/generate=false
25   mipmaps/limit=-1
26   roughness/mode=0
27   roughness/src_normal=""
28   process/fix_alpha_border=true
29   process/premult_alpha=false
30   process/normal_map_invert_y=false
31   process/hdr_as_srgb=false
32   process/hdr_clamp_exposure=false
33   process/size_limit=0
34   detect_3d/compress_to=1
35   svg/scale=1.0
36   editor/scale_with_editor_scale=false

```



```
37 editor/convert_colors_with_editor_theme=false
```

### C.3.9 monochrome\_packed.png.import

```
1  [remap]
2
3  importer="texture"
4  type="CompressedTexture2D"
5  uid="uid://cpign73sfbsrt"
6  path="res://.godot/imported/monochrome_packed.png-6
    b9bd1c64dd50f72acd3afd14d1ac34f.ctex"
7  metadata={
8    "vram_texture": false
9  }
10
11  [deps]
12
13  source_file="res://monochrome_packed.png"
14  dest_files=["res://.godot/imported/monochrome_packed.png-6
    b9bd1c64dd50f72acd3afd14d1ac34f.ctex"]
15
16  [params]
17
18  compress/mode=0
19  compress/high_quality=false
20  compress/lossy_quality=0.7
21  compress/hdr_compression=1
22  compress/normal_map=0
23  compress/channel_pack=0
24  mipmaps/generate=false
25  mipmaps/limit=-1
26  roughness/mode=0
```

```

27  roughness/src_normal=""
28  process/fix_alpha_border=true
29  process/premult_alpha=false
30  process/normal_map_invert_y=false
31  process/hdr_as_srgb=false
32  process/hdr_clamp_exposure=false
33  process/size_limit=0
34  detect_3d/compress_to=1

```

### C.3.10 LICENSE

```

1  This work is licensed under the Creative Commons Attribution-
    ShareAlike 4.0 International License. To view a copy of this
    license, visit http://creativecommons.org/licenses/by-sa/4.0/
    or send a letter to Creative Commons, PO Box 1866, Mountain
    View, CA 94042, USA.

```

## C.4 GD4PoissonRPG

These are the source code listings for the Poisson Disk Sampling implementation of the 2D tile-map RPG scenario in the Godot game engine. The link to the publicly available source code repository is here: <https://github.com/Zishan-Rahman/GD4PoissonRPG>

### C.4.1 .gitattributes

```

1  # Normalize EOL for all files that Git considers text files.
2  * text=auto eol=lf

```

### C.4.2 .gitignore

```
1  # Godot 4+ specific ignores
2  .godot/
```

### C.4.3 project.godot

```
1  ; Engine configuration file.
2  ; It's best edited using the editor UI and not directly,
3  ; since the parameters that go here are not all obvious.
4  ;
5  ; Format:
6  ;   [section] ; section goes between []
7  ;   param=value ; assign values to parameters
8
9  config_version=5
10
11  [application]
12
13  config/name="Poisson Sampling Project"
14  run/main_scene="res://tile_map.tscn"
15  config/features=PackedStringArray("4.0", "Forward Plus")
16  config/icon="res://icon.svg"
17
18  [display]
19
20  window/size/viewport_height=640
21
22  [rendering]
23
24  environment/defaults/default_clear_color=Color(0, 0, 0, 1)
```

### C.4.4 tile\_map.tscn

```

1  [gd_scene load_steps=7 format=3 uid="uid://f2kv7fett7"]
2
3  [ext_resource type="Texture2D" uid="uid://c3bpsm4r8t504" path="res
    ://monochrome_packed.png" id="1_uucm3"]
4  [ext_resource type="Script" path="res://tile_map.gd" id="2_iyhvf"]
5  [ext_resource type="PackedScene" uid="uid://cau5jgogdnf53" path="
    res://accept_dialog.tscn" id="3_bk3rg"]
6  [ext_resource type="PackedScene" uid="uid://b5q8ovcigrvyr" path="
    res://win_dialog.tscn" id="4_4hdc7"]
7
8  [sub_resource type="TileSetAtlasSource" id="
    TileSetAtlasSource_j4usm"]
9  texture = ExtResource("1_uucm3")
10 0:0/0 = 0
11 1:0/0 = 0
12 2:0/0 = 0
13 3:0/0 = 0
14 4:0/0 = 0
15 5:0/0 = 0
16 6:0/0 = 0
17 7:0/0 = 0
18 8:0/0 = 0
19 9:0/0 = 0
20 10:0/0 = 0
21 11:0/0 = 0
22 12:0/0 = 0
23 13:0/0 = 0
24 14:0/0 = 0
25 15:0/0 = 0
26 16:0/0 = 0
27 17:0/0 = 0
28 18:0/0 = 0
29 19:0/0 = 0

```

30 20:0/0 = 0  
31 21:0/0 = 0  
32 22:0/0 = 0  
33 23:0/0 = 0  
34 24:0/0 = 0  
35 25:0/0 = 0  
36 26:0/0 = 0  
37 27:0/0 = 0  
38 28:0/0 = 0  
39 29:0/0 = 0  
40 30:0/0 = 0  
41 31:0/0 = 0  
42 32:0/0 = 0  
43 33:0/0 = 0  
44 34:0/0 = 0  
45 35:0/0 = 0  
46 36:0/0 = 0  
47 37:0/0 = 0  
48 38:0/0 = 0  
49 39:0/0 = 0  
50 40:0/0 = 0  
51 41:0/0 = 0  
52 42:0/0 = 0  
53 43:0/0 = 0  
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1086 47:21/0 = 0
1087 48:21/0 = 0
1088
1089 [sub_resource type="TileSet" id="TileSet_8pb5m"]
1090 sources/0 = SubResource("TileSetAtlasSource_j4usm")
1091
1092 [node name="TileMap" type="TileMap"]
1093 tile_set = SubResource("TileSet_8pb5m")
1094 format = 2
1095 script = ExtResource("2_iyhvf")
1096
1097 [node name="AcceptDialog" parent="." instance=ExtResource("3_bk3rg"
    )]
1098
1099 [node name="WinDialog" parent="." instance=ExtResource("4_4hdc7")]

```

#### C.4.5 tile\_map.gd

```

1  extends TileMap
2
3  const buildings: Array[Vector2i] = [
4      Vector2i(0, 19),
5      Vector2i(1, 19),
6      Vector2i(2, 19),
7      Vector2i(3, 19),
8      Vector2i(4, 19),
9      Vector2i(5, 19),
10     Vector2i(6, 19),
11     Vector2i(7, 19),
12     Vector2i(8, 20),
13     Vector2i(0, 20),
14     Vector2i(1, 20),

```

```

15     Vector2i(2, 20),
16     Vector2i(3, 20),
17     Vector2i(4, 20),
18     Vector2i(5, 20),
19     Vector2i(6, 20),
20     Vector2i(7, 20),
21     Vector2i(8, 20),
22     Vector2i(0, 21),
23     Vector2i(1, 21),
24     Vector2i(2, 21),
25     Vector2i(3, 21),
26     Vector2i(4, 21),
27     Vector2i(5, 21),
28     Vector2i(6, 21),
29     Vector2i(7, 21),
30     Vector2i(8, 21)
31 ]
32 const trees: Array[Vector2i] = [
33     Vector2i(0,1),
34     Vector2i(1,1),
35     Vector2i(2,1),
36     Vector2i(3,1),
37     Vector2i(4,1),
38     Vector2i(5,1),
39     Vector2i(6,1),
40     Vector2i(7,1),
41     Vector2i(0,2),
42     Vector2i(1,2),
43     Vector2i(2,2),
44     Vector2i(3,2),
45     Vector2i(4,2)
46 ]
47 const PLAYER_SPRITE: Vector2i = Vector2i(24, 7)

```

```

48  var player_placement_cell: Vector2i
49  const rings: Array[Vector2i] = [
50      Vector2i(43, 6),
51      Vector2i(44, 6),
52      Vector2i(45, 6),
53      Vector2i(46, 6)
54  ]
55  var ring_placement_cell: Vector2i
56
57  var x_tile_range: int = ProjectSettings.get_setting("display/window
    /size/viewport_width") / tile_set.tile_size.x
58  var y_tile_range: int = ProjectSettings.get_setting("display/window
    /size/viewport_height") / tile_set.tile_size.y
59
60  var cell_points: Array[Vector2]
61  ## The probability that a building gets painted at a cell in lieu
    of a tree. The higher this probability, the more likely a
    building tile gets painted instead of a tree tile.
62  @export_range(0.0, 1.0) var paint_building_probability: float =
    0.125
63  ## The radius value used to measure distances between points for
    the algorithm. The longer the radius, the further apart points
    are during the algorithm's processing, and the further apart
    painted cells are in the game.
64  @export_range(0.5, 2.5) var point_radius: float = 1.0
65  ## The size of the region in which the algorithm is performed. Set
    to the "default" tile map size (72, 40) in the script, shown as
    (0, 0) in the Godot editor. Can be changed to use a smaller
    region for the algorithm itself, of course resulting in less
    cells covered within the boundaries set for this game, though
    the algorithm will perform faster due to less cells being
    checked.
66  @export var region_size: Vector2 = Vector2(x_tile_range,

```

```

        y_tile_range)
67  ## The maximum number of times a cell is checked before it is
    ignored. A cell can be accepted and painted on before this
    maximum number is reached. The higher this value, the more
    times a cell is checked, therefore the higher the algorithm's
    processing time.
68  @export_range(1, 50, 1) var rejection_samples: int = 8
69
70  # Called when the node enters the scene tree for the first time.
71  func _ready():
72      randomize()
73      var start_time: float = Time.get_ticks_msec()
74      cell_points = generate_points(point_radius, region_size,
        rejection_samples)
75      paint_points()
76      place_player()
77      place_ring()
78      var new_time: float = Time.get_ticks_msec() - start_time
79      print("Time taken: " + str(new_time) + "ms")
80      $AcceptDialog.dialog_text = "You're a hollow Golem who seeks the
        ultimate treasure; a ring that's got something on top of it
        . It's somewhere in this large village and barely visible to
        your naked eyes, which took us " + str(new_time) + "
        milliseconds to generate (" + str(new_time / 1000.0) + "
        seconds), but you'll stop at nothing to get what you want.
        You can chow down every tree and fauna that stands in your
        way of the ring, but your Achilles heel is any bricks and
        mortar, which WILL make you stop at your tracks. Since it's
        easy to get lost in here, we'll tell you that you're in
        position " + str(player_placement_cell) + " in this big
        village of size " + str(Vector2i(x_tile_range, y_tile_range)
        ) + ". However, it is YOUR job to find the ring, so are you
        ready to attain the treasure that is rightfully yours?!"

```



```

81     $AcceptDialog.visible = true
82     $AcceptDialog.confirmed.connect(_on_AcceptDialog_closed)
83     $AcceptDialog.canceled.connect(_on_AcceptDialog_closed)
84     $WinDialog.confirmed.connect(_on_WinDialog_confirmed)
85     $WinDialog.canceled.connect(_on_WinDialog_canceled)
86     get_tree().paused = true
87
88     func _on_WinDialog_confirmed() -> void:
89         get_tree().reload_current_scene()
90
91     func _on_WinDialog_canceled() -> void:
92         get_tree().quit()
93
94     func _on_AcceptDialog_closed() -> void:
95         $AcceptDialog.visible = false
96         get_tree().paused = false
97
98     func paint_points() -> void:
99         for point in cell_points:
100             var cell_point: Vector2i = Vector2i(roundi(point.x), roundi(
                point.y))
101             if randf() < paint_building_probability:
102                 set_cell(0, cell_point, 0, buildings.pick_random())
103             else:
104                 set_cell(0, cell_point, 0, trees.pick_random())
105
106     func _get_random_placement_cell() -> Vector2i:
107         return Vector2i(randi() % x_tile_range, randi() % y_tile_range)
108
109     func place_player() -> void:
110         player_placement_cell = _get_random_placement_cell()
111         while get_used_cells(0).has(player_placement_cell):
112             player_placement_cell = _get_random_placement_cell()

```

```

113     set_cell(0, player_placement_cell, 0, PLAYER_SPRITE)
114
115     func place_ring() -> void:
116         ring_placement_cell = _get_random_placement_cell()
117         while get_used_cells(0).has(ring_placement_cell):
118             ring_placement_cell = _get_random_placement_cell()
119         set_cell(0, ring_placement_cell, 0, rings.pick_random())
120
121     func _is_not_out_of_bounds(cell: Vector2i) -> bool:
122         return cell.x >= 0 and cell.x < x_tile_range and cell.y >= 0 and
            cell.y < y_tile_range
123
124     func _physics_process(_delta) -> void:
125         var previous_cell: Vector2i = player_placement_cell
126         var direction: Vector2i = Vector2i.ZERO
127         if Input.is_action_pressed("ui_up"): direction = Vector2i.UP
128         elif Input.is_action_pressed("ui_down"): direction = Vector2i.
            DOWN
129         elif Input.is_action_pressed("ui_left"): direction = Vector2i.
            LEFT
130         elif Input.is_action_pressed("ui_right"): direction = Vector2i.
            RIGHT
131         var new_placement_cell: Vector2i = player_placement_cell +
            direction
132         if (not get_used_cells(0).has(new_placement_cell) or trees.has(
            get_cell_atlas_coords(0, new_placement_cell)) or
            new_placement_cell == ring_placement_cell) and
            _is_not_out_of_bounds(new_placement_cell):
133             player_placement_cell = new_placement_cell
134             set_cell(0, previous_cell, 0) # deletes contents of previous
                cell (atlas_coords = Vector2i(-1, -1))
135             set_cell(0, player_placement_cell, 0, PLAYER_SPRITE)
136             if player_placement_cell == ring_placement_cell:

```

```

137         $WinDialog.visible = true
138         get_tree().paused = true
139
140     # ALGORITHM BEGINS HERE
141
142     func generate_points(radius: float, sample_region_size: Vector2,
        number_of_samples_before_rejection: int = 30) -> Array[Vector2
        ]:
143         var cell_size: float = radius / sqrt(2)
144         var grid: Array[Array] = []
145         var points: Array[Vector2] = []
146         var spawn_points: Array[Vector2] = []
147         var grid_x_axis_size: int = ceili(sample_region_size.x/cell_size
            )
148         var grid_y_axis_size: int = ceili(sample_region_size.y/cell_size
            )
149
150         for i in range(grid_x_axis_size):
151             grid.append([])
152             for j in range(grid_y_axis_size):
153                 grid[i].append(0)
154
155         spawn_points.append(sample_region_size/2)
156
157         while spawn_points.size() > 0:
158             var spawn_index: int = randi_range(0, spawn_points.size() -
                1)
159             var spawn_centre: Vector2 = spawn_points[spawn_index]
160             var candidate_accepted: bool = false
161
162             for i in range(number_of_samples_before_rejection):
163                 var angle: float = randf() * TAU # TAU = PI * 2
164                 var direction: Vector2 = Vector2(sin(angle), cos(angle))

```

```

165         var candidate: Vector2 = spawn_centre + direction *
            randf_range(radius, 2 * radius)
166         if is_valid(candidate, sample_region_size, cell_size,
            radius, points, grid, grid_x_axis_size,
            grid_y_axis_size):
167             points.append(candidate)
168             spawn_points.append(candidate)
169             grid[int(candidate.x/cell_size)][int(candidate.y/
                cell_size)] = len(points)
170             candidate_accepted = true
171             break
172
173         if not candidate_accepted:
174             spawn_points.remove_at(spawn_index)
175
176     return points
177
178 func is_valid(candidate: Vector2, sample_region_size: Vector2,
    cell_size: float, radius: float, points: Array[Vector2], grid:
    Array[Array], grid_x_axis_size: int, grid_y_axis_size: int) ->
    bool:
179     if candidate.x >= 0 and candidate.x < sample_region_size.x and
        candidate.y >= 0 and candidate.y < sample_region_size.y:
180         var cell_x: int = roundi(candidate.x / cell_size)
181         var cell_y: int = roundi(candidate.y / cell_size)
182         var search_start_x: int = max(0, cell_x - 2)
183         var search_end_x: int = min(cell_x + 2, grid_x_axis_size - 1)
184         var search_start_y: int = max(0, cell_y - 2)
185         var search_end_y: int = min(cell_y + 2, grid_y_axis_size - 1)
186         for x in range(search_start_x, search_end_x):
187             for y in range(search_start_y, search_end_y):
188                 var point_index: int = grid[x][y] - 1
189                 if point_index != -1:

```

```

190         var distance: float = (candidate - points[
                point_index]).length_squared()
191         if distance < radius:
192             return false
193         return true
194     return false

```

#### C.4.6 accept\_dialog.tscn

```

1  [gd_scene format=3 uid="uid://cau5jgogdnf53"]
2
3  [node name="AcceptDialog" type="AcceptDialog"]
4  title = "Tree-Munching Time!"
5  position = Vector2i(326, 100)
6  size = Vector2i(500, 421)
7  mouse_passthrough = true
8  ok_button_text = "Bring it on!"
9  dialog_text = "You're a hollow Golem who seeks the ultimate
    treasure; a ring that's got something on top of it. It's
    somewhere in this large village and barely visible to your
    naked eyes, but you'll stop at nothing to get what you want.
    You can chow down every tree and fauna that stands in your way
    of the ring, but your Achilles heel is any bricks and mortar,
    which will make you stop at your tracks. Are you ready to
    attain your treasure?w Golem in a black-and-white world, in
    search for your most desired treasure. It's a ring with
    something on top of it. And you'll stop at nothing to get what
    you want. You can chow down every tree and fauna that stands in
    your way of the ring, but your Achilles heel is any bricks and
    mortar, which will make you stop at your tracks. Are you ready
    to attain the treasure that is rightfully yours?!"
10 dialog_autowrap = true

```

### C.4.7 win\_dialog.tscn

```
1  [gd_scene format=3 uid="uid://b5q8ovcigrvyr"]
2
3  [node name="WinDialog" type="ConfirmationDialog"]
4  title = "You Found the Treasure!"
5  position = Vector2i(326, 100)
6  size = Vector2i(500, 421)
7  mouse_passthrough = true
8  ok_button_text = "Get Me a New Village"
9  dialog_text = "You found your treasure! Well done, you!"
10
11  Would you like to travel to a new village in the hopes of finding
    another ring? Or would you like to take your treasure home now?
    "
12  dialog_autowrap = true
13  cancel_button_text = "Get Me Out of Here"
```

### C.4.8 icon.svg.import

```
1  [remap]
2
3  importer="texture"
4  type="CompressedTexture2D"
5  uid="uid://uotfe6soknht"
6  path="res://.godot/imported/icon.svg-218
    a8f2b3041327d8a5756f3a245f83b.ctex"
7  metadata={
8  "vram_texture": false
9  }
10
11  [deps]
```

```

12
13     source_file="res://icon.svg"
14     dest_files=["res://.godot/imported/icon.svg-218
        a8f2b3041327d8a5756f3a245f83b.ctex"]
15
16     [params]
17
18     compress/mode=0
19     compress/high_quality=false
20     compress/lossy_quality=0.7
21     compress/hdr_compression=1
22     compress/normal_map=0
23     compress/channel_pack=0
24     mipmaps/generate=false
25     mipmaps/limit=-1
26     roughness/mode=0
27     roughness/src_normal=""
28     process/fix_alpha_border=true
29     process/premult_alpha=false
30     process/normal_map_invert_y=false
31     process/hdr_as_srgb=false
32     process/hdr_clamp_exposure=false
33     process/size_limit=0
34     detect_3d/compress_to=1
35     svg/scale=1.0
36     editor/scale_with_editor_scale=false
37     editor/convert_colors_with_editor_theme=false

```

#### C.4.9 monochrome\_packed.png.import

```

1     [remap]
2

```

```

3  importer="texture"
4  type="CompressedTexture2D"
5  uid="uid://c3bpsm4r8t504"
6  path="res://.godot/imported/monochrome_packed.png-6
    b9bd1c64dd50f72acd3afd14d1ac34f.ctex"
7  metadata={
8  "vram_texture": false
9  }
10
11  [deps]
12
13  source_file="res://monochrome_packed.png"
14  dest_files=["res://.godot/imported/monochrome_packed.png-6
    b9bd1c64dd50f72acd3afd14d1ac34f.ctex"]
15
16  [params]
17
18  compress/mode=0
19  compress/high_quality=false
20  compress/lossy_quality=0.7
21  compress/hdr_compression=1
22  compress/normal_map=0
23  compress/channel_pack=0
24  mipmaps/generate=false
25  mipmaps/limit=-1
26  roughness/mode=0
27  roughness/src_normal=""
28  process/fix_alpha_border=true
29  process/premult_alpha=false
30  process/normal_map_invert_y=false
31  process/hdr_as_srgb=false
32  process/hdr_clamp_exposure=false
33  process/size_limit=0

```



```
34 detect_3d/compress_to=1
```

#### C.4.10 LICENSE

```
1 This work is licensed under the Creative Commons Attribution-
  ShareAlike 4.0 International License. To view a copy of this
  license, visit http://creativecommons.org/licenses/by-sa/4.0/
  or send a letter to Creative Commons, PO Box 1866, Mountain
  View, CA 94042, USA.
```

### C.5 GD4NoiseRPG

These are the source code listings for the Perlin/Simplex Noise implementation of the 2D tile-map RPG scenario in the Godot game engine. The link to the publicly available source code repository is here: <https://github.com/Zishan-Rahman/GD4NoiseRPG>

#### C.5.1 .gitattributes

```
1 # Normalize EOL for all files that Git considers text files.
2 * text=auto eol=lf
```

#### C.5.2 .gitignore

```
1 # Godot 4+ specific ignores
2 .godot/
```

#### C.5.3 project.godot

```
1 ; Engine configuration file.
```

```

2   ; It's best edited using the editor UI and not directly,
3   ; since the parameters that go here are not all obvious.
4   ;
5   ; Format:
6   ;   [section] ; section goes between []
7   ;   param=value ; assign values to parameters
8
9   config_version=5
10
11  [application]
12
13  config/name="Noise Demo"
14  run/main_scene="res://tile_map.tscn"
15  config/features=PackedStringArray("4.0", "Forward Plus")
16  config/icon="res://icon.svg"
17
18  [display]
19
20  window/size/viewport_height=640
21
22  [rendering]
23
24  environment/defaults/default_clear_color=Color(0, 0, 0, 1)

```

#### C.5.4 tile\_map.tscn

```

1  [gd_scene load_steps=7 format=3 uid="uid://d4jdcavluwx6s"]
2
3  [ext_resource type="Texture2D" uid="uid://m662wwd4prmn" path="res
      ://monochrome_packed.png" id="1_ld7xx"]
4  [ext_resource type="Script" path="res://tile_map.gd" id="2_o1dn1"]
5  [ext_resource type="PackedScene" uid="uid://cau5jgogdnf53" path="

```

```

    res://accept_dialog.tscn" id="3_e0ur6"]
6  [ext_resource type="PackedScene" uid="uid://b5q8ovcigrvyr" path="
    res://win_dialog.tscn" id="4_ecfaa"]
7
8  [sub_resource type="TileSetAtlasSource" id="
    TileSetAtlasSource_1e80b"]
9  texture = ExtResource("1_ld7xx")
10  0:0/0 = 0
11  1:0/0 = 0
12  2:0/0 = 0
13  3:0/0 = 0
14  4:0/0 = 0
15  5:0/0 = 0
16  6:0/0 = 0
17  7:0/0 = 0
18  8:0/0 = 0
19  9:0/0 = 0
20  10:0/0 = 0
21  11:0/0 = 0
22  12:0/0 = 0
23  13:0/0 = 0
24  14:0/0 = 0
25  15:0/0 = 0
26  16:0/0 = 0
27  17:0/0 = 0
28  18:0/0 = 0
29  19:0/0 = 0
30  20:0/0 = 0
31  21:0/0 = 0
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```

36    26:0/0 = 0  
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52    42:0/0 = 0  
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57    47:0/0 = 0  
58    48:0/0 = 0  
59    0:1/0 = 0  
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311	$7:6/0 = 0$
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313	$9:6/0 = 0$
314	$10:6/0 = 0$
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328	$24:6/0 = 0$
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352     48:6/0 = 0  
353     0:7/0 = 0  
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364     11:7/0 = 0  
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366 13:7/0 = 0  
367 14:7/0 = 0  
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369 16:7/0 = 0  
370 17:7/0 = 0  
371 18:7/0 = 0  
372 19:7/0 = 0  
373 20:7/0 = 0  
374 21:7/0 = 0  
375 22:7/0 = 0  
376 23:7/0 = 0  
377 24:7/0 = 0  
378 25:7/0 = 0  
379 26:7/0 = 0  
380 27:7/0 = 0  
381 28:7/0 = 0  
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1018	$28:20/0 = 0$
1019	$29:20/0 = 0$
1020	$30:20/0 = 0$
1021	$31:20/0 = 0$
1022	$32:20/0 = 0$
1023	$33:20/0 = 0$
1024	$34:20/0 = 0$
1025	$35:20/0 = 0$

1026	$36:20/0 = 0$
1027	$37:20/0 = 0$
1028	$38:20/0 = 0$
1029	$39:20/0 = 0$
1030	$40:20/0 = 0$
1031	$41:20/0 = 0$
1032	$42:20/0 = 0$
1033	$43:20/0 = 0$
1034	$44:20/0 = 0$
1035	$45:20/0 = 0$
1036	$46:20/0 = 0$
1037	$47:20/0 = 0$
1038	$48:20/0 = 0$
1039	$0:21/0 = 0$
1040	$1:21/0 = 0$
1041	$2:21/0 = 0$
1042	$3:21/0 = 0$
1043	$4:21/0 = 0$
1044	$5:21/0 = 0$
1045	$6:21/0 = 0$
1046	$7:21/0 = 0$
1047	$8:21/0 = 0$
1048	$9:21/0 = 0$
1049	$10:21/0 = 0$
1050	$11:21/0 = 0$
1051	$12:21/0 = 0$
1052	$13:21/0 = 0$
1053	$14:21/0 = 0$
1054	$15:21/0 = 0$
1055	$16:21/0 = 0$
1056	$17:21/0 = 0$
1057	$18:21/0 = 0$
1058	$19:21/0 = 0$

```

1059    20:21/0 = 0
1060    21:21/0 = 0
1061    22:21/0 = 0
1062    23:21/0 = 0
1063    24:21/0 = 0
1064    25:21/0 = 0
1065    26:21/0 = 0
1066    27:21/0 = 0
1067    28:21/0 = 0
1068    29:21/0 = 0
1069    30:21/0 = 0
1070    31:21/0 = 0
1071    32:21/0 = 0
1072    33:21/0 = 0
1073    34:21/0 = 0
1074    35:21/0 = 0
1075    36:21/0 = 0
1076    37:21/0 = 0
1077    38:21/0 = 0
1078    39:21/0 = 0
1079    40:21/0 = 0
1080    41:21/0 = 0
1081    42:21/0 = 0
1082    43:21/0 = 0
1083    44:21/0 = 0
1084    45:21/0 = 0
1085    46:21/0 = 0
1086    47:21/0 = 0
1087    48:21/0 = 0
1088
1089    [sub_resource type="TileSet" id="TileSet_qtrb6"]
1090    sources/0 = SubResource("TileSetAtlasSource_1e80b")
1091

```

```

1092 [node name="TileMap" type="TileMap"]
1093 texture_filter = 1
1094 tile_set = SubResource("TileSet_qtrb6")
1095 format = 2
1096 script = ExtResource("2_o1dn1")
1097
1098 [node name="AcceptDialog" parent="." instance=ExtResource("3_e0ur6"
    )]
1099
1100 [node name="WinDialog" parent="." instance=ExtResource("4_ecfaa")]
1101 title = "You Found the Treasure!"

```

### C.5.5 tile\_map.gd

```

1  extends TileMap
2
3  const buildings: Array[Vector2i] = [
4      Vector2i(0, 19),
5      Vector2i(1, 19),
6      Vector2i(2, 19),
7      Vector2i(3, 19),
8      Vector2i(4, 19),
9      Vector2i(5, 19),
10     Vector2i(6, 19),
11     Vector2i(7, 19),
12     Vector2i(8, 20),
13     Vector2i(0, 20),
14     Vector2i(1, 20),
15     Vector2i(2, 20),
16     Vector2i(3, 20),
17     Vector2i(4, 20),
18     Vector2i(5, 20),

```

```

19     Vector2i(6, 20),
20     Vector2i(7, 20),
21     Vector2i(8, 20),
22     Vector2i(0, 21),
23     Vector2i(1, 21),
24     Vector2i(2, 21),
25     Vector2i(3, 21),
26     Vector2i(4, 21),
27     Vector2i(5, 21),
28     Vector2i(6, 21),
29     Vector2i(7, 21),
30     Vector2i(8, 21)
31 ]
32 const trees: Array[Vector2i] = [
33     Vector2i(0,1),
34     Vector2i(1,1),
35     Vector2i(2,1),
36     Vector2i(3,1),
37     Vector2i(4,1),
38     Vector2i(5,1),
39     Vector2i(6,1),
40     Vector2i(7,1),
41     Vector2i(0,2),
42     Vector2i(1,2),
43     Vector2i(2,2),
44     Vector2i(3,2),
45     Vector2i(4,2)
46 ]
47 const PLAYER_SPRITE: Vector2i = Vector2i(24, 7)
48 var player_placement_cell: Vector2i
49 const rings: Array[Vector2i] = [
50     Vector2i(43, 6),
51     Vector2i(44, 6),

```

```

52     Vector2i(45, 6),
53     Vector2i(46, 6)
54 ]
55 var ring_placement_cell: Vector2i
56
57 var noise: FastNoiseLite
58 ## Defines the type of noise generation algorithm to use. Equates
    to the noise_type property in FastNoiseLite.
59 @export_enum("Perlin", "Simplex", "Simplex Smooth", "Value", "Value
    Cubic") var noise_type: String = "Simplex Smooth"
60 ## Defines the type of method used to combine octaves of a noise
    image into a fractal. Directly equates to the FractalType enum
    in FastNoiseLite.
61 @export var fractal_type: FastNoiseLite.FractalType
62 ## Defines the function used to calculate the distance between the
    nearest/second-nearest point(s). Directly equates to the
    CellularDistanceFunction enum in FastNoiseLite.
63 @export var cellular_distance_type: FastNoiseLite.
    CellularDistanceFunction
64 ### Defines the number of noise octaves to use in the generated
    image.
65 #@export_range(1, 10, 1) var octaves: int = 5
66 ## Defines the frequency of the generated noise, the higher the
    frequency, the rougher and more granular the noise.
67 @export_range(0.0, 1.0) var noise_frequency: float = 0.894
68
69 ## Defines the upper limit to set for painting a tree tile on a
    specific noise pixel. If the value returned by the get_noise_2d
    method (in FastNoiseLite) is smaller than this, then it gets
    painted.
70 @export_range(-1.0, 1.0) var tree_cap: float = -0.048
71 ## Defines the upper limit to set for painting a building tile on a
    specific noise pixel. If the value returned by the

```

```

    get_noise_2d method (in FastNoiseLite) is smaller than this,
    then it gets painted. If the value of building_cap is smaller
    than tree_cap, then decide whether or not to paint a building
    cell there with building_overtakes_tree.
72 @export_range(-1.0, 1.0) var building_cap: float = -0.252
73 ## Only used when building_cap is smaller than tree_cap. Determines
    the probability that a building tile would be painted in a
    cell where a tree tile was, or could be, also painted. Whether
    or not the cell actually is painted over is decided on
    computation time.
74 @export_range(0.0, 0.5) var building_overtakes_tree: float = 0.12
75 var x_tile_range: int = ProjectSettings.get_setting("display/window
    /size/viewport_width") / tile_set.tile_size.x
76 var y_tile_range: int = ProjectSettings.get_setting("display/window
    /size/viewport_height") / tile_set.tile_size.y
77
78 # Called when the node enters the scene tree for the first time.
79 func _ready() -> void:
80     randomize()
81     var start_time: float = Time.get_ticks_msec()
82     set_noise()
83     paint_tiles()
84     place_player()
85     place_ring()
86     var new_time: float = Time.get_ticks_msec() - start_time
87     print("Time taken: " + str(new_time) + "ms")
88     $AcceptDialog.dialog_text = "You're a hollow Golem who seeks the
        ultimate treasure; a ring that's got something on top of it
        . It's somewhere in this large village and barely visible to
        your naked eyes, which took us " + str(new_time) + "
        milliseconds to generate (" + str(new_time / 1000.0) + "
        seconds), but you'll stop at nothing to get what you want.
        You can chow down every tree and fauna that stands in your

```

```

way of the ring, but your Achilles heel is any bricks and
mortar, which WILL make you stop at your tracks. Since it's
easy to get lost in here, we'll tell you that you're in
position " + str(player_placement_cell) + " in this big
village of size " + str(Vector2i(x_tile_range, y_tile_range)
) + ". However, it is YOUR job to find the ring, so are you
ready to attain the treasure that is rightfully yours?!"

89     $AcceptDialog.visible = true
90     $AcceptDialog.confirmed.connect(_on_AcceptDialog_closed)
91     $AcceptDialog.canceled.connect(_on_AcceptDialog_closed)
92     $WinDialog.confirmed.connect(_on_WinDialog_confirmed)
93     $WinDialog.canceled.connect(_on_WinDialog_canceled)
94     get_tree().paused = true
95
96     func _on_WinDialog_confirmed() -> void:
97         get_tree().reload_current_scene()
98
99     func _on_WinDialog_canceled() -> void:
100         get_tree().quit()
101
102     func _on_AcceptDialog_closed() -> void:
103         $AcceptDialog.visible = false
104         get_tree().paused = false
105
106     func _get_random_placement_cell() -> Vector2i:
107         return Vector2i(randi() % x_tile_range, randi() % y_tile_range)
108
109     func place_player() -> void:
110         player_placement_cell = _get_random_placement_cell()
111         while get_used_cells(0).has(player_placement_cell):
112             player_placement_cell = _get_random_placement_cell()
113         set_cell(0, player_placement_cell, 0, PLAYER_SPRITE)
114

```



```

115 func place_ring() -> void:
116     ring_placement_cell = _get_random_placement_cell()
117     while get_used_cells(0).has(ring_placement_cell):
118         ring_placement_cell = _get_random_placement_cell()
119     set_cell(0, ring_placement_cell, 0, rings.pick_random())
120
121 func _is_not_out_of_bounds(cell: Vector2i) -> bool:
122     return cell.x >= 0 and cell.x < x_tile_range and cell.y >= 0 and
        cell.y < y_tile_range
123
124 func _physics_process(_delta: float) -> void:
125     var previous_cell: Vector2i = player_placement_cell
126     var direction: Vector2i = Vector2i.ZERO
127     if Input.is_action_pressed("ui_up"): direction = Vector2i.UP
128     elif Input.is_action_pressed("ui_down"): direction = Vector2i.
        DOWN
129     elif Input.is_action_pressed("ui_left"): direction = Vector2i.
        LEFT
130     elif Input.is_action_pressed("ui_right"): direction = Vector2i.
        RIGHT
131     var new_placement_cell: Vector2i = player_placement_cell +
        direction
132     if (not get_used_cells(0).has(new_placement_cell) or trees.has(
        get_cell_atlas_coords(0, new_placement_cell)) or
        new_placement_cell == ring_placement_cell) and
        _is_not_out_of_bounds(new_placement_cell):
133         player_placement_cell = new_placement_cell
134         set_cell(0, previous_cell, 0) # deletes contents of previous
            cell (atlas_coords = Vector2i(-1, -1))
135         set_cell(0, player_placement_cell, 0, PLAYER_SPRITE)
136         if player_placement_cell == ring_placement_cell:
137             $WinDialog.visible = true
138             get_tree().paused = true

```

```

139
140 # ALGORITHM BEGINS HERE
141
142 func _get_noise_type() -> int:
143     match noise_type:
144         "Perlin": return 3
145         "Simplex": return 0
146         "Value": return 5
147         "Value Cubic": return 4
148         _: return 1 # Return Simplex Smooth by default
149
150 func set_noise() -> void:
151     noise = FastNoiseLite.new()
152     noise.frequency = noise_frequency
153     noise.noise_type = _get_noise_type() as FastNoiseLite.NoiseType
154     noise.fractal_type = fractal_type
155     noise.cellular_distance_function = cellular_distance_type
156     # noise.fractal_octaves = octaves
157     noise.seed = randi()
158
159 # I took inspiration from a Godot 3.1 tutorial: https://youtu.be/SBDs8hbs43w
160 # However, no code was taken or adapted in any way, shape or form.
161
162 func paint_tiles() -> void:
163     for x in range(x_tile_range):
164         for y in range(y_tile_range):
165             var noise_point: float = noise.get_noise_2d(x * tile_set.
                tile_size.x, y * tile_set.tile_size.y)
166             if noise_point < tree_cap and not get_used_cells(0).has(
                Vector2i(x, y)):
167                 set_cell(0, Vector2i(x, y), 0, trees.pick_random())
168             if ((building_cap <= tree_cap and randf() <

```

```

        building_overtakes_tree) or (building_cap > tree_cap
        and noise_point < building_cap)) and not
        get_used_cells(0).has(Vector2i(x, y)):
169         set_cell(0, Vector2i(x, y), 0, buildings.pick_random())

```

### C.5.6 accept\_dialog.tscn

```

1  [gd_scene format=3 uid="uid://cau5jgogdnf53"]
2
3  [node name="AcceptDialog" type="AcceptDialog"]
4  title = "Tree-Munching Time!"
5  position = Vector2i(326, 100)
6  size = Vector2i(500, 421)
7  mouse_passthrough = true
8  ok_button_text = "Bring it on!"
9  dialog_text = "You're a hollow Golem who seeks the ultimate
        treasure; a ring that's got something on top of it. It's
        somewhere in this large village and barely visible to your
        naked eyes, but you'll stop at nothing to get what you want.
        You can chow down every tree and fauna that stands in your way
        of the ring, but your Achilles heel is any bricks and mortar,
        which will make you stop at your tracks. Are you ready to
        attain your treasure?w Golem in a black-and-white world, in
        search for your most desired treasure. It's a ring with
        something on top of it. And you'll stop at nothing to get what
        you want. You can chow down every tree and fauna that stands in
        your way of the ring, but your Achilles heel is any bricks and
        mortar, which will make you stop at your tracks. Are you ready
        to attain the treasure that is rightfully yours?!"
10 dialog_autowrap = true

```

### C.5.7 win\_dialog.tscn

```
1  [gd_scene format=3 uid="uid://b5q8ovcigrvyr"]
2
3  [node name="WinDialog" type="ConfirmationDialog"]
4  title = "Tree-Munching Time!"
5  position = Vector2i(326, 100)
6  size = Vector2i(500, 421)
7  mouse_passthrough = true
8  ok_button_text = "Get Me a New Village"
9  dialog_text = "You found your treasure! Well done, you!"
10
11  Would you like to travel to a new village in the hopes of finding
    another ring? Or would you like to take your treasure home now?
    "
12  dialog_autowrap = true
13  cancel_button_text = "Get Me Out of Here"
```

### C.5.8 icon.svg.import

```
1  [remap]
2
3  importer="texture"
4  type="CompressedTexture2D"
5  uid="uid://crgf6ascxsdt0"
6  path="res://.godot/imported/icon.svg-218
    a8f2b3041327d8a5756f3a245f83b.ctex"
7  metadata={
8  "vram_texture": false
9  }
10
11  [deps]
```

```

12
13   source_file="res://icon.svg"
14   dest_files=["res://.godot/imported/icon.svg-218
           a8f2b3041327d8a5756f3a245f83b.ctex"]
15
16   [params]
17
18   compress/mode=0
19   compress/high_quality=false
20   compress/lossy_quality=0.7
21   compress/hdr_compression=1
22   compress/normal_map=0
23   compress/channel_pack=0
24   mipmaps/generate=false
25   mipmaps/limit=-1
26   roughness/mode=0
27   roughness/src_normal=""
28   process/fix_alpha_border=true
29   process/premult_alpha=false
30   process/normal_map_invert_y=false
31   process/hdr_as_srgb=false
32   process/hdr_clamp_exposure=false
33   process/size_limit=0
34   detect_3d/compress_to=1
35   svg/scale=1.0
36   editor/scale_with_editor_scale=false
37   editor/convert_colors_with_editor_theme=false

```

### C.5.9 monochrome\_packed.png.import

```

1   [remap]
2

```

```

3  importer="texture"
4  type="CompressedTexture2D"
5  uid="uid://m662wwd4prmn"
6  path="res://.godot/imported/monochrome_packed.png-6
    b9bd1c64dd50f72acd3afd14d1ac34f.ctex"
7  metadata={
8  "vram_texture": false
9  }
10
11  [deps]
12
13  source_file="res://monochrome_packed.png"
14  dest_files=["res://.godot/imported/monochrome_packed.png-6
    b9bd1c64dd50f72acd3afd14d1ac34f.ctex"]
15
16  [params]
17
18  compress/mode=0
19  compress/high_quality=false
20  compress/lossy_quality=0.7
21  compress/hdr_compression=1
22  compress/normal_map=0
23  compress/channel_pack=0
24  mipmaps/generate=false
25  mipmaps/limit=-1
26  roughness/mode=0
27  roughness/src_normal=""
28  process/fix_alpha_border=true
29  process/premult_alpha=false
30  process/normal_map_invert_y=false
31  process/hdr_as_srgb=false
32  process/hdr_clamp_exposure=false
33  process/size_limit=0

```

```
34 detect_3d/compress_to=1
```

### C.5.10 LICENSE

```
1 This work is licensed under the Creative Commons Attribution-
  ShareAlike 4.0 International License. To view a copy of this
  license, visit http://creativecommons.org/licenses/by-sa/4.0/
  or send a letter to Creative Commons, PO Box 1866, Mountain
  View, CA 94042, USA.
```

## C.6 LSystemGrammarDemo

These are the source code listings for the L-System demonstration used to generate the screenshots in Figures 3.1, 3.2, 3.3 and 3.4 (in the report body). The link to the publicly available source code repository is here: <https://github.com/Zishan-Rahman/LSystemGrammarDemo>

### C.6.1 .gitattributes

```
1 # Normalize EOL for all files that Git considers text files.
2 * text=auto eol=lf
```

### C.6.2 .gitignore

```
1 # Godot 4+ specific ignores
2 .godot/
```

### C.6.3 project.godot

```
1 ; Engine configuration file.
```

```

2   ; It's best edited using the editor UI and not directly,
3   ; since the parameters that go here are not all obvious.
4   ;
5   ; Format:
6   ;   [section] ; section goes between []
7   ;   param=value ; assign values to parameters
8
9   config_version=5
10
11  [application]
12
13  config/name="LSystemGrammarDemo"
14  run/main_scene="res://DemoNode.tscn"
15  config/features=PackedStringArray("4.0")
16
17  [display]
18
19  window/stretch/mode="canvas_items"
20  window/stretch/aspect="expand"
21
22  [gui]
23
24  common/drop_mouse_on_gui_input_disabled=true
25
26  [physics]
27
28  common/enable_pause_aware_picking=true

```

#### C.6.4 DemoNode.tscn

```

1   [gd_scene load_steps=2 format=3 uid="uid://bu380we4od0ln"]
2

```



```

3  [ext_resource type="Script" path="res://DemoNode.gd" id="1"]
4
5  [node name="DemoNode" type="Node"]
6  script = ExtResource("1")
7  choices = "deterministic"
8
9  [node name="Timer" type="Timer" parent="."]
10
11 [node name="TextLabel" type="Label" parent="."]
12 offset_right = 1152.0
13 offset_bottom = 23.0
14 autowrap_mode = 3
15
16 [connection signal="timeout" from="Timer" to="." method="
    _on_Timer_timeout"]

```

### C.6.5 DemoNode.gd

```

1  extends Node
2
3  # Basic: https://youtu.be/feNVBEPXAcE?t=77 (L = +)
4  # Choices: http://paulbourke.net/fractals/lsys/
5  # Deterministic: https://ww1.biologie.uni-hamburg.de/b-online/
    e28_3/lsys.html#DOL-system
6
7  ## Allows you to decide which ruleset to use. See the script file
    for the sources of said rulesets.
8  @export_enum("basic", "choices", "deterministic") var choices:
    String = "choices"
9  var axiom: String
10 @onready var string: String
11 @onready var timer = $Timer

```

```

12  @onready var label = $TextLabel
13  @onready var rules: Array[Dictionary]
14
15  func set_values() -> void:
16      match choices:
17          "basic":
18              rules = [
19                  {
20                      "from": "F",
21                      "to": "F+F"
22                  }
23              ]
24              axiom = "F+"
25          "choices":
26              rules = [
27                  {
28                      "from": "F",
29                      "to": "F+--FFFF+F+-FF"
30                  }
31              ]
32              axiom = "F+F+F+F"
33          "deterministic":
34              rules = [
35                  {
36                      "from": "a",
37                      "to": "ab"
38                  },
39                  {
40                      "from": "b",
41                      "to": "a"
42                  }
43              ]
44              axiom = "b"

```

```

45
46 func _ready() -> void:
47     set_values()
48     string = axiom
49     label.size.x = get_viewport().size.x
50     label.text = string
51     print(len(string))
52     timer.start()
53
54 # Thanks to Alexander Gillberg (Codat) for inspiration
55 # https://youtu.be/eY9XkJERiG0
56 # Code adapted with his permission
57 func get_new_replacement(character: String) -> String:
58     for rule in rules:
59         if rule["from"] == character:
60             return rule["to"]
61     return ""
62
63 func _on_Timer_timeout() -> void:
64     # Thanks to Alexander Gillberg (Codat) for inspiration
65     # https://youtu.be/eY9XkJERiG0
66     # Code adapted with his permission
67     var new_string: String = ""
68     for character in string:
69         new_string += get_new_replacement(character)
70     string = new_string
71     label.text = string
72     print(len(string))

```

### C.6.6 icon.svg.import

```

1 [remap]

```

```

2
3   importer="texture"
4   type="CompressedTexture2D"
5   uid="uid://cwnnuqmejj04q"
6   path="res://.godot/imported/icon.svg-218
      a8f2b3041327d8a5756f3a245f83b.ctex"
7   metadata={
8     "vram_texture": false
9   }
10
11   [deps]
12
13   source_file="res://icon.svg"
14   dest_files=["res://.godot/imported/icon.svg-218
      a8f2b3041327d8a5756f3a245f83b.ctex"]
15
16   [params]
17
18   compress/mode=0
19   compress/high_quality=false
20   compress/lossy_quality=0.7
21   compress/hdr_compression=1
22   compress/normal_map=0
23   compress/channel_pack=0
24   mipmaps/generate=false
25   mipmaps/limit=-1
26   roughness/mode=0
27   roughness/src_normal=""
28   process/fix_alpha_border=true
29   process/premult_alpha=false
30   process/normal_map_invert_y=false
31   process/hdr_as_srgb=false
32   process/hdr_clamp_exposure=false

```

```
33 process/size_limit=0
34 detect_3d/compress_to=1
35 svg/scale=1.0
36 editor/scale_with_editor_scale=false
37 editor/convert_colors_with_editor_theme=false
```

### C.6.7 LICENSE

```
1 This work is licensed under the Creative Commons Attribution-
  ShareAlike 4.0 International License. To view a copy of this
  license, visit http://creativecommons.org/licenses/by-sa/4.0/
  or send a letter to Creative Commons, PO Box 1866, Mountain
  View, CA 94042, USA.
```