**Dissertation Literature Review**

**2.1 – Current Use of Procedural Generation in Games and Research**

**2.1.1 – Overview**

The first aim of this project was to research how procedurally generated content is currently being used successfully in games.

Using the Procedural Content Generation Wiki [[Link](http://pcg.wikidot.com/)], two games were highlighted that could provide some valuable insight into the current state of PCG in games:

* Minecraft
* Spelunky

This section will cover each of these games in more detail, highlighting their success, as well as how procedural generation affects the game, and which techniques were used.

There was also a research paper which seemed particularly interesting in the context of the project. It used a combination of Markov Chains and machine learning to create a model which can procedurally generate levels in the style of Super Mario Bros [Nintendo, 1985].

**2.1.2 - Infinite Mario Bros**

Infinite Mario Bros was a research project taken on by Sam Snodgrass and Santiago Ontañón [Sam Snodgrass, 2021], where the aim was to create a procedural level generation model, using a combination of machine learning and Markov Chains, to dynamically create levels for an infinite version of Nintendo’s Super Mario Bros [Nintendo, 1985]. To achieve this, they first assign each type of tile a letter, for example G for ground, P for pipes, etc., then feed this data into a machine learning algorithm to evaluate where in the level they most often occur, and how common they are throughout the levels. From here, the levels are then built tile-by-tile, by feeding this data into a Markov Chain to decide which tile should be placed at each point.

A key point which can be taken from this paper’s conclusions, and applied to the current project, is that the Markov Chains created levels which were unique and varied. Whilst all levels were using the same set of available tiles, each one had objects placed in varying locations with different combinations, making each level feel new.  This is important for the project because it shows how player engagement could be improved using Markov Chains. Players can get used to the limited number of tile *types;* however, they may get surprised by the variation of how they are used and combined through the level.

**2.1.3 - Minecraft**

Minecraft [Mojang Studio, 2009] is an open-world sandbox game that has become the Guinness World Record holder for the best-selling video game of all time [[Guiness World Records,](https://www.guinnessworldrecords.com/world-records/best-selling-video-game?os=0&ref=app#:~:text=The%20best-selling%20videogame%20of%20all%20time%20is%20Minecraft%2C,sales%20by%20publisher%20Microsoft%20on%2015%20October%202023) 2023]. In 2023, it officially reached over 300 million copies sold, and as of January 2025, it still has over 50 million players logging in every day [[Saisuman Revanker](https://www.sci-tech-today.com/stats/minecraft-statistics/" \t "_blank), 2025].

With such a vast number of live players almost 16 years after launch, Minecraft must have something to keep players constantly coming back and a huge part of this can be attributed to its virtually infinite combination of worlds. Each world in Minecraft is generated entirely using procedural generation, through a combination of Perlin Noise, Fractal Noise, and 3D noise [[Dawnosaur](https://dawnosaur.substack.com/p/how-minecraft-generates-worlds-you), 2023]. On top of this, like how this project’s levels are generated, Minecraft does its world generation across three different passes [[Alan Zucconi](https://www.alanzucconi.com/2022/06/05/minecraft-world-generation/), 2023]. In the first pass, a “biome map” is generated, which dictates how each section of the world is generated. For example, mountain biomes will allow the world to be generated up to a higher altitude, whilst a desert or forest biome may keep the world at a lower altitude. The next pass then covers the biomes in an appropriate material, such as stone for the mountains and sand for the deserts, then grass for the forests. The third pass then goes back over the world and removes ground from specific areas to create caves or ravines, whilst the fourth and final pass decorates the world with structures.

Through these techniques, the game can generate approximately 18 quintillion unique world combinations [[Minecraft Wiki](https://minecraft.wiki/w/World_generation)]. Overall, Minecraft portrays a fitting example of how a game can use procedural generation to its advantage and allow players to replay the game multiple times over, causing it to retain popularity many years after release.

**2.1.4 – Spelunky**

Spelunky is a 2D platformer that uses procedural generation to define its’ level layouts. Unlike Minecraft [Mojang Studios, 2009] however, the game is not entirely random. Each level is a four-by-four grid, and each section of this grid contains a pre-made template, created by level designers. Since each section has around 8-16 templates [[TinySubversions](https://tinysubversions.com/spelunkyGen2/" \t "_blank)], this means there are at least 8^16 (280 trillion) level layouts, based on terrain alone. On top of this, the game then parses back over the level and checks for any “probabilistic” tiles in the room, which are tiles that can be replaced with several other blocks. This means there are even more than 280 trillion layouts, so it is entirely possible for players to play the game many times without repeating levels.

Whilst this generation may not provide the colossal number of layouts Minecraft can, it does give much more input to level designers. This is an excellent example of PCG not only because of its replayability but also because it helps to solve an issue mentioned in the introduction of this paper, where level designers are under more pressure to create a huge influx of levels to keep players engaged. By combining handmade level templates with the procedural generation which stitches them together randomly, the levels have a more personal touch, keep development time down by taking pressure off the level designers, and still give players the replayability value that can drastically increase the value-for-money aspect of the game.

**2.2. – Procedural Generation Techniques**

**2.2.1 – Overview**

After researching the many procedural generation techniques and algorithms available, Perlin Noise and Markov chains were deemed to be the best options in the context of the project.

One technique which was considered, but later removed from the project plan, was Wave Function Collapse (WFC). It was replaced with Markov Chains because the after research, it was found that Markov Chains are significantly more computationally efficient than WFC. WFC also relies on tighter constraints, whereas Markov Chains can return a wider range of outputs, making them more suitable for level variation.

Before starting the implementation of the level generator, some criteria were laid out to decide what would outline a successful level:

* The terrain of each level should be unique enough that a player could replay the game multiple times without encountering two levels that felt too similar. This can be achieved with the effective use of Perlin Noise.
* Each level must have enemies and collectibles placed randomly throughout to encourage the player to explore or find alternative routes. This can be achieved using Markov Chains.
* Each level must have at least one path which guarantees the player can reach the end goal and win the level. This can be achieved by setting rules and constraints for the level generator scripts.
* Players should have the ability to edit parameters that will customize how future levels are generated, allowing them to see how the procedural generation can lead to a variety of level types.

**2.2.2 – Perlin Noise**

Perlin Noise is a procedural generation technique that was first introduced and used by Ken Perlin in 1985 [[Ken Perlin](https://dl.acm.org/doi/pdf/10.1145/325165.325247), 1985]. The development of the noise function began because Perlin wanted to find a more efficient way of creating realistic textures to be applied to models in CGI. As Perlin mentioned in his research, many of the procedural generation techniques at the time required combining multiple individual functions, which required rewriting, recompiling, and rerunning the program until the desired effect was generated. Perlin found this to be “cumbersome” [Ken Perlin, 1985, Introduction], therefore he created his program, which would generate a black-and-white noise map and then manipulate the values at each point to correspond to different values on the final texture. Perlin outlines in his paper that he developed functions to convert these values to colours, normal, and heights.

Whilst the original intended use of Perlin Noise centred around graphical textures, game developers have since adapted many of these functions to create terrain in their video games. A prominent example of a game that brilliantly utilizes Perlin Noise is Minecraft [Mojang Studios, 2009], and it is fair to assume that much of the game’s success can be attributed to the infinite world generation created partly using this technique. Minecraft’s ground layer is largely generated from a Perlin Noise map, however due to the gradual gradients being one of the characteristics of a Perlin Noise map, the developers did not deem this to create unique enough terrain for an infinite world, therefore they layered multiple maps on top of each other which were combined to make one more significantly unique map [Dawnosaur, 2023]. The height of each block of the world is then scaled according to the grayscale value of the corresponding pixel on the map, like how Perlin created the “Stucco Donut” in his paper [Ken Perlin, 1985, A Pixel Stream Editing Language]. For example, a darker pixel would place blocks up to the upper limit of the world, whereas a white pixel would move towards the lower constraint.

Perlin Noise is a good technique to be used in this project as Perlin designed it to be as computationally efficient as possible. By mapping the height value of points throughout the level to the grayscale value of the noise map, the level generator can effectively adapt Minecraft’s generation technique to be used in the context of a 2D platformer.

A summary of the pros and cons of using Perlin Noise are as follows:

Pros:

* Perlin Noise was designed with efficiency and simplicity in mind, which will help to lower loading times when levels are being created, as well as allowing minor changes to be made which will help achieve desired effects on each level’s terrain.
* Perlin Noise generates softer, more gradual terrain which can be used to create smaller changes in height throughout the level to help prevent impassable walls or slowing down the pace of the level.’
* There has been a significant volume of research surrounding Perlin Noise, and therefore strong documentation, as well as the Unity Editor (being used for the project) including some functions dedicated to getting a Perlin Noise generator started quickly.

Cons:

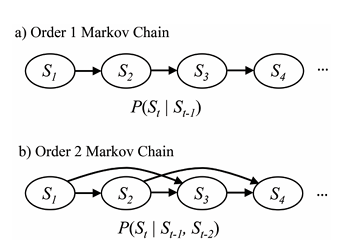
* Perlin Noise maps may sometimes “cluster,” creating areas of the same colour, which can result in extended areas of flat ground, however, this can be negated with secondary passes to add other objects to these areas.
* Perlin Noise maps may start to tile on larger maps, however since the levels in the project will be small, this is not expected to present any issues.

**2.2.3 – Finite Markov Chains**

Markov Chains were created by Andrey Markov during his research on the theories of probability in 1906 [[Eugene Seneta](https://citeseerx.ist.psu.edu/document?repid=rep1&type=pdf&doi=4c6bb41637a6438f22eb190d014a01cd0b0a7162), 2006]. The Markov Chain is a structure made of multiple states, where each state may have one or more transitions, but all transition probabilities must sum to one [J.R Norris, 1997]. In practice, this means the chain should never get stuck in one state and will always move forward, however, it also has the chance to have a different outcome each time.

This can be extremely useful in procedural generation since the transition chance of each state can be edited dynamically based on events in the world. This could, for example, mean as a world creates a larger ocean, the chance of creating an island will increase, meaning it is more likely to move from a “water” state to a “ground” state.

There is a key distinction to be made between the two different types of Markov Chains: a standard-order Markov Chain has no memory of its’ past states, meaning the decision of whether it should progress to the next state relies purely on parameters in the current state. A second-order Markov Chain, however, considers the current state as well as the state before, then uses a cumulative chance to choose its’ next state. This can improve the accuracy of the chain, but also increases the computational resources required as it must keep previous state results in memory.



[Sam Snodgrass, 2014].

In the project, standard order Markov Chains are used, since each should result in a true or false result, for example: deciding whether ground should be placed, whether ground should be destroyed to make a gap and deciding whether an enemy should be placed. A second-order Markov may have been more suitable if the project included biomes, for example it could have a state which checks the ground height, and a state which checks the current biome, then a combination of these chances could decide which biome it moves to next.

A summary of the pros and cons of using Markov Chains (standard-order) are as follows:

Pros:

* Markov Chains are very efficient since they do not need to retain any memory of past states, and each state is treated as its own decision. This stays in line with keeping the level generation fast to keep the pace of the game going and preventing players from being stuck on loading screens.
* Markov Chains allow for implementing rules and constraints, which allows the developers to decide how levels should look. This could, for example, prevent too many enemies from being spawned as the number of enemies could be passed as a parameter into the Markov Chain to decrease the chance based on how many are in the level.

Cons:

* Without appropriate parameter planning and restrictions, the Markov Chains will sometimes return the same result many times in a row, which can lead to long and repetitive sections in the level. This can be solved by thoroughly testing the generator and ensuring the levels are generated as intended.
* When there are too many states to be decided through, this can sometimes slow down and reduce the efficiency of Markov Chains, however, this will not affect the project since there are not too many decisions to be made.

**2.2.4 – Summary**

After careful consideration and extensive research into the many procedural generation techniques available, the techniques being used in the project will be:

* Perlin Noise.
* Standard-order Markov Chains.

The next section will go into detail about how these techniques were adapted for use in the project.