Creative Technologies Project: Procedural city generation on a pre-existing height map

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Research Report

Abstract

This report summarises the research completed as a precursor to the development of Forge, with the goal of creating a user friendly but powerful urban environment generation tool. The research will not only highlight several different methods of procedural generation and evaluate them as relevant avenues to explore in the project, but it will also give clarity to strictures applied to real urban planning scenarios which will enable the final product to more closely reflect realistic civilisations.

Keywords: Procedural Generation, Wave Function Collapse, L-Systems, Terrain, Software Design, Urban Development, Architecture,

1. Introduction

The game development process is intensive, and without proper planning can easily run over budget. The use of procedural generation in game design, and by extension environmental design, can help with the multifarious aspects of game development; thus facilitating cost reduction (Tanya Short and Tarn Adams, 2017).

'Forge' will be a Unity development tool that allows for the procedural generation of urban environments that conform to constricting variables in order to produce a city layout specific to a developer's wishes. The formation of the cities will integrate with uploaded terrain data and mould itself to the landscape, as well as being able to replicate real world architectural and city planning decisions.

The aims of this research was to investigate different facets of procedural generation and help build an understanding of how settlement restrictions might impact a cities growth. These investigations will form the basis of Forge's creation, and will help answer the following:

- What current issues exist with traditional manual level design?
- What method(s) of procedural generation are best suited to city and environment generation?
- How might a societies overall wealth or abundance of resources affect the evolution of its civilisation?

The research will use level design as its primary context, however there are many other potential applications for this project that lie outside the games industry. The ability to quickly generate urban environments could be used for hypothetical military training, emergency service drills, or real city and infrastructure planning if given height maps that more closely resemble a real world location.

2. Research methods

Primary research was collected in both a qualitative and quantitative way. A focus group was set up with 5 current Games Technology students, on 2 separate occasions. The meetings were held at a University conference room on days where all students were free and without imminent deadline pressure in order to try and avoid a hurried or insincere response. The students were selected to have different strengths to one another, as to avoid a biased response to the questions asked. The purpose of this focus group was to gain an understanding of the general attitude towards level design and to help identify its shortcomings, so that the development of Forge can be steered towards trying to mitigate the problems.

Quantitative research was carried out in the form of a multiple choice survey question. The question "When designing a level, what is the biggest barrier to development?" was distributed to 3 different groups of students from different universities across the country.

Group A – UWE
Group B – Southampton Solent
Group C – University of Sussex

The purpose of this question was to support the findings from the focus group with a larger sample size to increase validity. Moreover, covering different areas of the country helps to eliminate the chance of an anomalous result generated by an individual course's content being shifted towards one aspect of the development pipeline.

The main issue of this primary research collection is that the questions and focus groups were aimed at relatively inexperienced students and not industry professionals. There were also issues with sourcing enough individuals to compile a reliable set of data.

Secondary research was also gathered to explore different avenues of procedural generation, and evaluate them for relevancy to the project. It was also vital to research city planning, and the different variables that play a part in how a city evolves over time so that considerations could be made for the generator. Several journals, books, and research papers were gathered to achieve this goal.

3. Research findings

-See Appendix B for focus group notes

After collecting the results from the quantitative survey into Table 1 and Figure 1, it is clear that the time constraints of a deadline often means that properly completed level design is overlooked. This is also confirmed by Participant C (2019) in the November focus group meeting saying that they would want a city generator to be quick and easy to use so that it would save time rather than just trying to manually build an environment. The generation must be fast, and the chosen method(s) must therefore also be so.

Barrier to development	A	B	C	Total
Time Constraints	20	8	12	40
Lack of Creativity	7	3	2	12
Technical Knowhow	3	0	1	4
Other	2	1	1	4

Table 1: Results of the Barrier to development survey question sent to 3 groups and totalled.

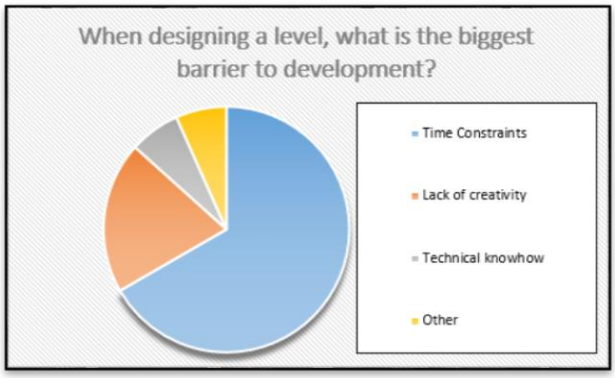

Figure 1: Pie chart showing the proportion of responses from Table 1.

Evidence of Early Settlement in later design

With exception to a small minority, cities are not planned from conceptualisation to be Metropolis'. They would have started out historically as little villages or towns that developed over time around a particular infrastructure, natural resource, or defendable location (Arnaud Emilien et al., 2015).

A lot of these restrictive values could play a part in how Forge is allowed to develop cities. Arnaud Emilien et al. (2015) discuss a cost analysis that their generator must complete before stepping forward in the generation. If the village is poor, then the road generation could favour a cost effective, but inefficient road pattern that might take longer for a citizen to get from A to B, whereas a richer village might be able to afford bridges or tunnels to bypass difficult terrain, making their flow of 'traffic' more systematic.

A table of variables could be filled in prior to Forge's activation that dictate arbitrary values of population wealth, soil fertility, abundance of water, health of residents, the climate of the region etc. A formula could be constructed that would output a total budget for the generator to make candidates with, and that would allow a developer to more accurately produce a village to the context of their design.

Voronoi Diagrams

Voronoi diagrams can be used for a variety of effects when creating procedural textures and crucially they can be executed quickly at run time (Jacob Olsen, 2004). They represent a partitioned plane that resembles a cell structure, and in the context of procedural generation are mainly used for terrain and landscape generation.

A series of locations are placed on a map and represented as points. Those points then radiate outwards until it collides with the emission of another point, leaving a wall in between that is equidistant to both of its parents. In city planning, this could have a multitude of applications, such as designating districts of buildings, or creating local catchment zones for schools. (Melbourne School Zones, 2017).

Wave Function Collapse

Wave Function Collapse (WFC) is a procedural generation algorithm. It is inspired by quantum mechanics' wave functions, where an unobserved state allows for all states to be possible, and observations constraints the possibilities (Møller et al., 2019). The algorithm has 2 implementations; a tiled model, and the overlapping model. The tiled model uses a rule document that declares legal adjacencies for neighbouring tile placements, whereas the overlapping model breaks an input pattern up into chunks and propagates from there.

For the purposes of Forge, the tiled model appears to be superior for creating road networks due to the generation rules being so dependent on the placement of other roads, buildings, and geological features. It does come with the drawback of operating on a grid based system, which makes the outcome look robotic and unnatural, unless irregular quadrilateral grids are created using Noise (Møller et al., 2019).

City Road Patterns

Parish & Müller (2001) highlight the importance of creating road patterns that fit a certain architectural style. Most real cities display a number of road patterns due to historical growth and different phases of city creation. Depending on what the user of Forge aims to create, they should be able to choose between these styles. An evaluation of the different zones of the City shown in the book by C. Focas (1998) reveals that urban environments with high population densities tend towards a raster pattern (Figure 2). The book also highlights that cities can be polycentric, and this was a consideration raised in the December focus group by Participant D (2019); a city could have 2 or more focal points. This should also be an important consideration when planning the settings menu for the generator.

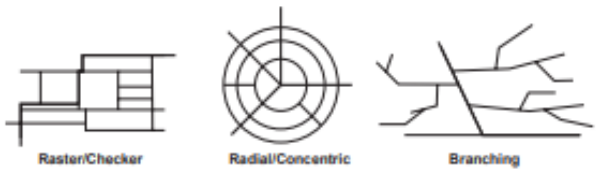

Figure 2: Examples of different city road patterns (Parish & Müller, 2001)

The paper by Parish & Müller (2001) also refers to a 4th pattern type, which is particularly

relevant to Forge. In Figure 3, 2 separate 2D reference images on the left describe the elevation of the terrain and the street map for the environment respectively. These are then multiplied together and cast down onto the landscape to create a street map on elevated geometry, which is precisely the kind of interaction Forge needs in order to discern impassable terrain such as steep mountains and bodies of water and discount them from the generation.

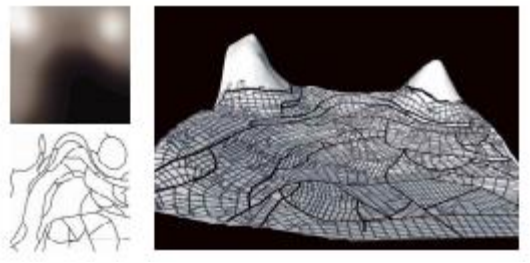

Figure 3: Elevation and highway map (left) being multiplied to create the model (right) using the 'San Francisco' rule (Parish & Müller, 2001)

Furthermore, there may be eventualities where the user would wish to incorporate 2 of these city road patterns into 1 urban environment. Figure 4 details a similar process to that shown in Figure 3, where 2 parameter values are summed up and weighted according to the value in the input image grey scale map (Parish & Müller, 2001).

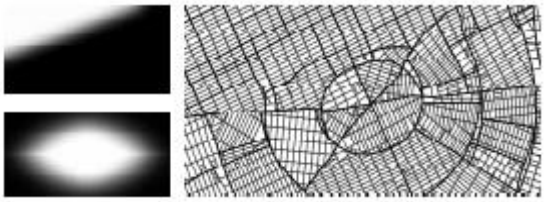

Figure 4: 2 City Road Patterns are blended into 1 start location, using a raster and radial/concentric parameter grey scale maps (Parish & Müller, 2001)

4. Conclusion and recommendations

There are a near infinite amount of ways that the generator can be improved upon to accommodate for different strands of urban planning, with particular emphasis to those variable settings that would allow a generator economy to be formulated. This would really diversify the output from the tool, and truly help in reducing the amount of time taken on level design by not forcing large teams of developers to make something equivalent by hand.

Wave Function Collapse seems to be an ideal choice to base the main chunk of generation code, as it allows modules to be placed with strict rules in place, which would complement the economy settings.

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Appendix A: Project Log

https://gamedevelopment676677755.wordpress.com/2019/10/14/ctp-progress-log/

Appendix B: Further Documentation

Link to focus group Minutes

https://gamedevelopment676677755.wordpress.com/2019/11/05/minutes-for-ctp-focus-group-4-11-19/
https://gamedevelopment676677755.wordpress.com/2019/12/05/minutes-for-focus-group-3-12-19/