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The Evaluations of Optimisations of The Wave Function Collapse Algorithm In Procedural Generation

GDEV60001 GAMES DEVELOPMENT PROJECT

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# Abstract

***An overview of the project***

This is a summary of the whole report’s contents. Readers may decide whether to read the whole report based on the abstract and therefore it should provide enough information for them to understand what the dissertation is about, including the results of the investigation.

The abstract is written last, even though it is presented at the beginning. It should describe the work that has been carried out, not the work that will be carried out.

# Introduction

Procedural Generation Content(PCG) plays a pivotal role in modern game development, offering unique and varied experiences through each playthrough through generation of terrain, maps and assets(PCG Survey). Central to this innovation are algorithms that are highly optimised for efficiency. Among these, the Wave Function Collapse (WFC) algorithm, inspired by quantum mechanics and developed by Maxim Gumin(WFC GitHub) in 2016, stands out for its unique approach to generating coherent and diverse patterns from a limited set of inputted rules. (N-WFC)Despite its potential, the WFC algorithm's application has been largely theoretical due to its computational demands, particularly its inherent serial processing limitation. This dissertation explores the optimization of the WFC algorithm by transitioning from a single-threaded to a multi-threaded, parallelized process, enhancing efficiency and scalability. The WFC optimization strategies I will be discussing will be:

Nested WFC: This approach divides the grid into smaller, manageable regions that can be processed in parallel, increasing efficiency by allowing multiple regions to be worked on simultaneously(N-WFC).

Stitched WFC(S-WFC): Here, the grid is split into separate, smaller regions that are processed individually in parallel and then stitched together with a different version of the WFC algorithm, ensuring continuity and coherence across the entire grid even allowing for more personalisation.

Repeated WFC: This optimisation method develops the idea of the tile sets, and developing the already inputted tile set into larger more built up tile sets then using in a larger scale tile set.

By addressing these challenges, this work aims to transition WFC a lesser used method to a practical tool used in many procedural generations’ games, unlocking new possibilities for procedural content generation within larger scales to create diversity and custom experience even allowing for a plugin of this is widely used in simple to larger scale games.

# Aims and Objectives

## Aims

The primary aim of this dissertation is to critically evaluate the performance of a standard implementation of the Wave Function Collapse (WFC) algorithm and to assess the effectiveness of three specific optimizations—chunking, stitching, and nested WFC—in improving its scalability, efficiency, memory usage, and the quality of procedural generation in game development contexts.

## Objectives

### Evaluate the Base WFC Algorithm:

* Objective 1.1: Conduct and evaluate a standard 3D WFC algorithm to establish benchmarks for speed, memory usage, scalability, and output reproducibility.
* Objective 1.2: Identify limitations and then areas for improvement in the base algorithm that can be addressed through optimization.

### Develop Optimization Strategies:

* Objective 2.1: Design and implement the chunking optimization to divide the processing grid into smaller, manageable regions that can be executed in parallel, aiming to enhance processing speed and scalability.
* Objective 2.2: Design and implement the stitching optimization by processing separate, smaller regions in parallel and then combining them, focusing on improving scalability while maintaining output coherence and continuity.
* Objective 2.3: Design and implement the nested WFC optimization using a hierarchical approach to generate larger grids or rule sets, aiming to increase the efficiency and versatility of the algorithm.

### Evaluate the Optimizations:

* Objective 3.1: Assess the impact of each optimization strategy on the processing speed of the WFC algorithm, comparing it to the benchmarks established for the base algorithm.
* Objective 3.2: Measure the memory usage of each optimised algorithm to determine improvements over the base algorithm.
* Objective 3.3: Evaluate the scalability of each optimization by testing their performance in generating content of varying sizes and complexities.
* Objective 3.4: Analyse the fidelity of the outputs produced by the optimised algorithms compared to the base algorithm, focusing on reproducibility and the maintaining of visual and structural coherence between algorithms.

# Literature Review

***How are other people doing it?***

This section will inform the reader of the current thinking in your specific topic. It will place your research in context and show how you are building upon previous knowledge and any areas of contention should be highlighted. This section might also include information about which data bases you used, which search terms, etc. Ensure you cite your sources of information within the text and add an accurate reference list at the end of your work.  
  
PCG Intro:  
  
WFC Intro:  
  
PCG Survey:  
  
WFC GitHub(break down):  
  
N-WFC Intro:  
  
S-WFC Intro:  
  
Parallel Computing Intro:

# Research Methodologies

***How will you carry out your investigation?***

This section is important because if you undertake inappropriate methodology your results and findings will be disputed. The reader needs to know what you did to find out information so they can make a judgement about the suitability of your methodology.

In this section, you state what you have done to achieve your aims, what you did to find the information you need, and, why you did it.

The methodology section can include.

* Research paradigm used, in other words, the type of research you used and why.
* Sample Strategy - if you are using one you should provide a full explanation of who you used in your sample and why.
* Materials and equipment used.

Justify your decisions by referencing back to best practice.

# Results and Findings

***What have you found out?***

Sometimes this section can be merged with discussion and analysis

It tells the reader what you have found out from your investigation. It is objective; there is no interpretation of results in this section (that comes in the discussion). It objectively states the findings of your research. If you have done primary research this is where you present your findings. You may include tables and graphs, but also need to explain the results in words. Any raw data should be included as an appendix.

# Discussion and Analysis

***How has the project gone?***

This covers the interpretation of the findings, evaluation of the significance of the findings and a general discussion of the investigation. What do your findings mean? In this section you should consider questions such as:

* What has your investigation shown?
* Did it achieve its objectives?
* What theory/literature does it support or contradict?
* What are the most plausible explanations of your findings?
* Are there any possible criticisms of the investigation?

The discussion should also:

* Build on the material in the introduction and literature review
* Evaluate the adequacy of your methodology
* Suggest design features that may have affected the results
* Include whether the results would be different under different conditions

# Conclusion

***What conclusions have been reached?***

What has your investigation led you to conclude?

A conclusion:

* Demonstrates that you have achieved what you set out to do
* It provides the reader with a sense of closure on the topic

It might be worth going back to the aims and objectives or your introduction and making sure your conclusion is in line with what you said you would be doing.

# Recommendations

***What would you do in the future?***

Use your findings and analysis to make recommendations. You may recommend that further investigation is undertaken if you realise that there were gaps in your methodology or anomalies in your findings. Alternatively, you may advise that some actions be considered.

# References

Hendrikx, M., Meijer, S., Van Der Velden, J. and Iosup, A., 2013. Procedural content generation for games: A survey. *ACM Transactions on Multimedia Computing, Communications, and Applications (TOMM)*, *9*(1), pp.1-22.

# Appendices

Appendices is information referred to in the main document. It is not included in the word count.

Do not put results here: only the raw data should be presented in an appendix. Other materials that may be included in an appendix includes, for example, blank questionnaires, copy of written tests used.

Remember do not include anything in an appendix that has not been referred to in the text.

## Appendix 1 – xxx