Generating two-dimensional game maps with use of cellular automata

Michał Wolski

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Contents

Chapter 1

Introduction

During recent years, presence of computer games in human lives has increased. The demand for games has shown that playing games, both as a medium of expression and a means for entertainment, is a desirable form of activity. However, as the demand for games rises [1] and computer games become increasingly complex, demand for game content must also rise – game elements such as believable maps, textures, sound and models (among other types of content) are a necessary resource for production of games. Studies such as [Hen+13] show where the evidence for insufficiency of manual content creation may be found. In the study, authors point to work of Kelly and McCabe [KM07], Lefebvre and Neyret [LN03], Smelik et al. 2009 [Sme+09] and Iosup 2009 [Ios09] as sources which reveal game content production as a time-consuming and expensive endeavour.

Solving the inefficiency issue

Scientific surveys such as [Hen+13] and [Sme+09] show why investigating procedural generation is useful for the game industry, by providing examples of successful methods which can be used to generate content for games. Primary concerns which drive the interest in automated ways to create game content are the rising project costs and increasing development time.

In order to reduce the cost of game development, allow for greater replay value or provide a feeling of vastness to the game worlds that designers aim to create, procedural content generation techniques can provide an attractive solution to the problem of content creation. Surveys such as [Hen+13], [Tog+11] and [DC+11]

[1] The Interactive Software Federation of Europe compiles and publishes statistics which include frequency of gaming in European countries and show that demand for games is on the rise. `https://www.isfe.eu/industry-facts/statistics`

show what types of game content can be generated and are a good starting point for seeking methods of procedural generation.

Personal motivation

During two recent years, the author of this thesis took part in a small, after-hours independent game development project. Working with a group of friends, using Unreal Engine as a tool to develop a simple prototype of a game belonging to the *rogue-like* game genre. The project is still in development phase and finding a good method of map generation can potentially result in contribution of useful features.

1.1 Thesis structure

The overall structure of this thesis includes introduction followed by three chapters. The second chapter 2 serves as a study on possible mechanisms that could be used for procedural generation and specifically, for creation of 2D maps for games. The chapter 3 describes performed experiments, design and implementation of a solution to the problem. Chapter 4 summarizes the findings and concludes the thesis, followed by chapter 5 which lists full source code of the developed solution.

1.2 Objectives

This work focuses on automated creation of 2-dimensional game maps using a cellular automata approach. We aim to do so by generating small map tiles, which can be later merged into a bigger map. Such approach allows for a degree of control to the map designer - who may want to decide which tiles will be merged and at which locations in the map they will be present. Moreover, we could also allow for editing the tile before placing it in the map. An approach that integrates manual editing or parametrization of desired results with procedural generation techniques has been proposed before [Bid+10], [Sme+10], [Sme+11].

We focus on creation of maps for games, since literature shows map generation as an interesting area for experimentation, although personal motivation influenced the choice as well.

Beginning experimentation with flat maps on 2-dimensional plane avoids the complexity that may arise when dealing with higher dimensions.

We will investigate existing methods for procedural generation of game maps which resemble cave structures. Then, an approach that may be used for automated creation of such maps will be selected and examined with a focus on implementing a working map generator. Main points of focus for this project are as follows:

- research on procedural generation of maps
- selecting a promising approach to use
- designing a map generator program
- implementing the solution in a programming language of choice

TO DO: Objectives - is that all?

1.3 Thesis scope

TO DO: scope - what we will do, what we will not do. specific goals.

TO DO: scope - shortly: what could be done instead

1.4 Technology and tools

The following paragraphs summarize what tools were involved during the project of thesis preparation and performing the experiments.

1.4.1 Hardware

All experiments in this thesis have been performed using a laptop with an Intel x64 2.0 GHz multi-core processor, 16GB RAM and an *nVidia GeForce GTX 560M* graphics card.

1.4.2 Software

Development environment for the purposes of thesis experiments and writing has been set up under Windows 10 operating system with the following software installed:

- Visual Studio 2015 Community IDE
- CMake for Windows
- TeXstudio editor with MikTeX back-end
- Git version control system
- Notepad++
- UMLet open source modelling program
- TO DO: ...

Other configuration details include:

TO DO: environment variables, configuration specifics...

This thesis has been prepared with LaTeX system for document typesetting.

Programming languages

The program that allowed to carry out experiments in this thesis was implemented using the C++ programming language and compiled with MSVC++ 14.0 compiler, natively included in the VS2015 IDE.

Libraries

The implementation uses following libraries:

- Dear ImGui, by Omar Cornut - to easily build an Immediate Mode user interface. Project homepage: `https://github.com/ocornut/imgui`
- GLFW 3.2.1 library - to create an OpenGL context and have direct access to texture functions. Project homepage: `http://www.glfw.org/`
- TO DO: ...

1.4.3 Other tools

Design patterns

TO DO: list used design patters, if any. Singleton? Command? Factory?

1.5 Related work (?)

TO DO: think what could be included here

Chapter 2

Research on 2D map generation methods

2.1 Definitions

Before we start planning a solution to the problem of map generation, we must first define what we mean by maps. As stated in chapter 1, our context does not deal with projections of 3D objects onto a plane, like the fields of geography and cartography do [Sny93]. Our goal is simply to generate planar maps.

Map

what is a map?

Generation

what generation means?

TO DO: 2d map types?

2.2 Automation - reduction in development time and cost

TO DO: write about PCG in general, short

TO DO: PCG types of content

TO DO: PCG methods

TO DO: focus on maps

2.3 Existing solutions for 2D map generation

In scientific surveys on PCG methods, we find approaches to map generation employed in the past. As listed by Hendrikx et al. [Hen+13],

TO DO: list map procgen methods

TO DO: HOW it was done until now? options?

TO DO: ref survey with table of 2d dungeon gen

2.3.1 Cellular automata

A cellular automaton is a simulation in which every object in a mathematically defined space is being updated at every step of a simulation. Historically, cellular automata and their properties have been studied since the time of first electronic computers [Sar00]. One of the most complete sources on cellular automata is a book summarizing research on CA carried out by Stephen Wolfram since 1980s [Wol02], where a classification of cellular automata is shown along with examples for each kind of CA.

Specifically, 2-dimensional automata operate on a grid of cells with arbitrary discrete dimensions. Each cell in the grid has neighbours, which may be relevant to the simulation rules. Depending on the type of rules which are used by a particular CA, a different type of cell neighbourhood may be used. To present this concept concisely, a short list of definitions follows.

Cell A cell is simply one unit positioned in CA simulation space. Cells have state, which can be simple - for example, a binary digit, an integer - or more complicated - a real number with constraints, a complex number, or other.

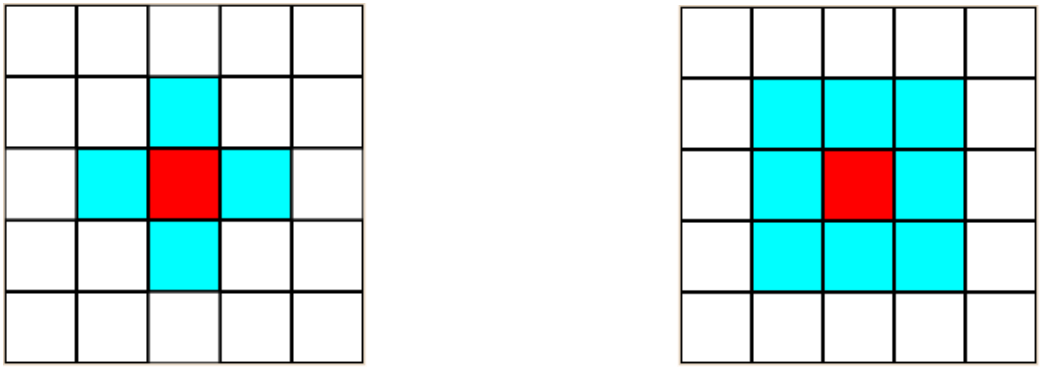
Cell neighborhood In a context of a 2D square grid of cells, neighbourhood is a collection of nearest cells to the selected one.

Moore's neighbourhood Moore neighbourhood includes the cell and its immediate neighbours - one to the north, south, east and west of the cell, as shown in figure 2.1.

Von Neumann neighbourhood Von Neumann neighbourhood includes 8 closest neighbours of the cell - immediate and diagonal, as shown in figure 2.1.

Other types of neighborhood It is possible to imagine other types of cell neighbourhoods, possibly including more cell rings around a cell or only a se-

lection of them arranged in a custom pattern. Those cases are beyond the scope of this thesis.



(a) *Moore neighborhood* ***(b)*** *Von Neumann neighborhood*

Figure 2.1: *Two basic types of cell neighborhood*

There is a...

TO DO:

Every CA simulation also consists of rules which drive the process of cell evolution to its next stage.

TO DO: ca basics - game of life

TO DO: using CA for simulations

TO DO: using CA for generation of content

2.3.2 Generative grammars

TO DO: What is it? Is relevant to maps? Can we use it? Why?

2.3.3 L-systems

TO DO: What is it? Is relevant to maps? Can we use it? Why?

2.3.4 ...

TO DO: What is it? Is relevant to maps? Can we use it? Why?

2.3.5 ...

TO DO: What is it? Is relevant to maps? Can we use it? Why?

2.4 Choosing a method of generation

In order to effectively judge the value that a working map generator may bring to a game development project, we need to consider what characteristics should be evaluated. First, a useful generator must be effective at map generation.

TO DO: how to measure effectiveness? time of map generation, map shape, desirable map features?

Another point to consider is how easy to use such generator can be. Game designers may ultimately decide to use manual methods of map creation if the method of map generation requires too much effort to include in their project.

TO DO: how to measure such ease of use? accessibility?

The third aspect of choice what a generation method could be used is to consider how much value it brings to the designer versus what development costs it can reduce.

TO DO: how to measure cost?

The following subsections describe how each of the mentioned aspects can influence the choice of a generation method.

2.4.1 Effectiveness

TO DO: study on generation time

TO DO: desired characteristics of generated content?

2.4.2 Accessibility

TO DO: study on what makes generation easy to include in game development projects

TO DO: integrating manual editing AND procgen

2.4.3 Cost

TO DO: examples of development costs - human resources, machine resources

TO DO: which of these costs can be reduced by PCG

2.5 Chosen approach: cellular automata for 2D map generation

One of possible proposed approaches is the work of L. Johnson, G. Yannakakis and J. Togelius from IT University of Copenhagen [JYT10].

Authors describe rules of a cellular automaton which are able to transform a tile filled initially with random distribution of cells into a tile which has interesting properties for a map designer.

TO DO: authors describe a process - 1 random image 2 apply CA steps as in article cave gen 3 merge tiles, result: maps!

TO DO: short paragraph on the choice of CA for game maps

TO DO: why we chose CA for mapgen?

TO DO: what are pros and cons of such choice?

Chapter 3

Generating and visualizing maps - proposed solution

To describe the developed solution concisely, this chapter consists of five sections: definition of required features, design of simple CA simulation and map generator models, followed by implementing them in C++ programming language, experiments and finally, tests.

3.1 Analysis of requirements for a map generator

Having gathered the abstract constructs needed to build a CA map generator in chapter 2, we may proceed to state the requirements formally. In the following sections, we will:

- define features required of a map generator program to automate creating maps,
- state the desired properties of such generator,
- discover to what constraints such program may be required to conform.

3.1.1 Functional requirements

First, we must define the desired functions which a useful map generator must provide to its user. Since we have selected an approach to map generation based on cellular automata in chapter 2, we have to include simulation of CA states. As described in [JYT10], our approach consists of generating a random image, which after several transformations performed by CA rules becomes structured

with island-like features. Such image can then be used as a tile for larger maps. Showing each step of image transformation could be useful to the designer, allowing them to control what kind of generated tiles will be chosen to compose the map.

Another potentially useful feature would be manual editing of tiles before they are placed in the map, which would allow for an even greater degree of control over tile contents. Further expansion of such feature could be to provide the designer with tools to make their own rules for tile generation, while also allowing them to define types of single cells composing the tile.

Finally, a map generator without a mechanism for saving the work done by a designer would certainly not be a useful tool. Such program needs a way to export generated maps to a file format that later can be used by a game engine of choice, possibly with procedures written by other programmers.

To summarize desired functions of a map generator program, a list follows:

1. The program must implement a cellular automaton to generate map tiles
2. The program must show generation stages graphically
3. The program must allow building maps from components (tiles)
4. The program may allow manual editing of map tiles
5. The program should have a mechanism for exporting generated maps
6. TO DO: expand desired functions

3.1.2 Non-functional requirements

TO DO: nf-req intro

1. The program must have a user interface that allows to change generation parameters easily
2. Generation parameters must be logically grouped and ordered to avoid user confusion
3. The program must be responsive to user input and avoid crashing.
4. TO DO:

3.1.3 Constraints

1. Map tile generation time must not exceed 5 seconds.
2. User interface elements must not invoke non-existent mechanisms.
3.

3.2 Design

3.2.1 Data structures and persistence

TO DO: how do we store data?

TO DO: diagrams of cell, board

TO DO: exporting data from generator?

TO DO: how designers can get a complete map model?

3.2.2 Application logic

TO DO: how a generator will work

TO DO: behavior diagrams

3.2.3 User interface

TO DO: OpenGL immediate mode paradigm

TO DO: imgui immediate mode user interface library

TO DO: diagram of texture class, used by Component MapGen, uses OpenGL

TO DO: mention Bret Victor talks - why we choose Immediate Mode

3.3 Basic cellular automata simulations

Having chosen cellular automata as a method for generating maps, we need to have a clear idea about how to approach building a program that could simulate a cellular automaton. One of the helpful resources on the topic of building cellular automata simulations is chapter 7 in Nature of Code, a book by Daniel Shiffman [Shi12], where we can find a short tutorial to build our first CA simulation. There,

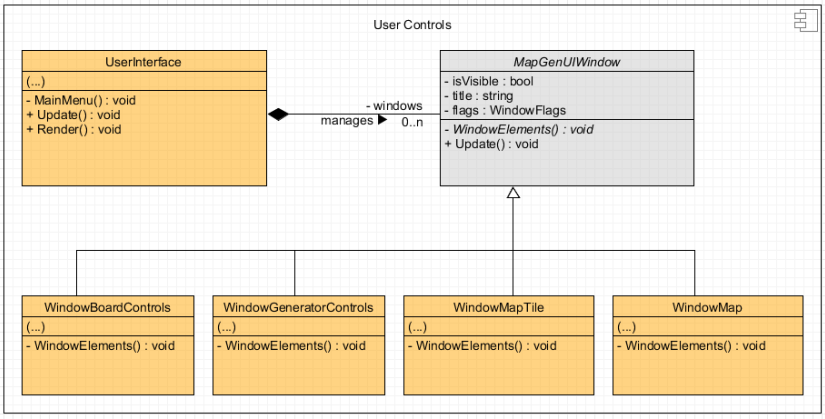


Figure 3.1: *Example model of classes to be used to construct user interface in the map generator program*

author describes elementary concepts needed to construct a basic CA, explains how to implement a working simulation and provides helpful exercises. The tutorial is quite useful as a guide, since examples presented in New Kind of Science [Wol02] are implemented in the Wolfram language and would require familiarity with it. As stated in Nature of Code [Shi12], a 2-dimensional CA would need the following key elements to be simulated:

- Cell state - every cell has a state updated on each simulation step,
- Grid - a space on which cells are placed,
- Neighbourhood - each cell needs to know the state of its neighbours to update its state.

In order to represent the cells of an automaton, a primitive data type is sufficient. However, we could design a class which will act as a collection of cells and provide additional utility to its user. Figure 3.2 presents an example model of a class that would encapsulate a collection of cell states while also preserving information about the board on which those cells are placed.

We can also assign a number to each cell

TO DO: why?

as shown in table 3.1.

Such abstraction creates an easy to use interface for further development and is also sufficient to access the values of neighbors to the selected cell. However, in some CA simulations summing the values of cells in neighbourhood is a common

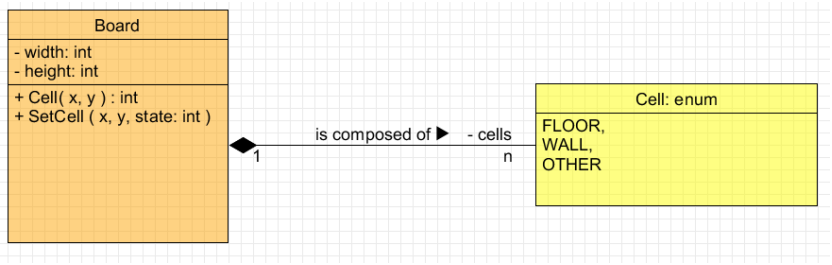


Figure 3.2: *A possible model of a Board Class which holds cell states in its block of memory and lets its user change their states*

0	1	2
7	S	3
6	5	4

Table 3.1: *Cell neighbours, numbered. S denotes selected cell. Cells marked with odd numbers are members of Moore neighborhood of selected cell and all numbered cells are members of Von Neumann neighbourhood of it.*

operation, so we can include variations of it for convenience. Similarly, a method to translate cell states into texture points would be welcome, since we may possibly need a way to display the state of CA board on screen. Adding those elements to our abstraction yields a class presented on figure 3.3.

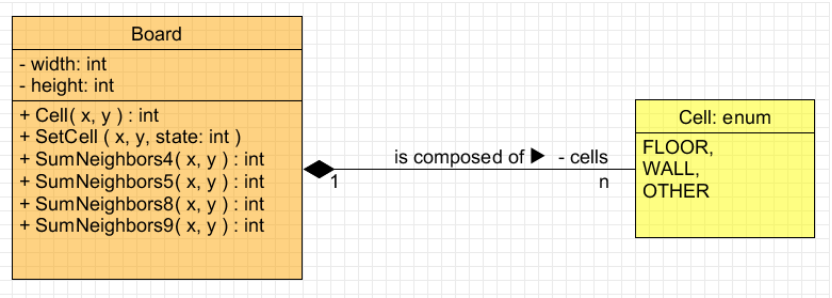


Figure 3.3: *Revised Board abstraction - added methods for neighbor sums and translation of cell states to texels*

TO DO: add neighbor methods to board2

TO DO: result of what it all does?

At this point, we could also observe a common property of cellular automata - whenever cell states need to change (the simulation moves to a later step), the state change is applied to every cell in the grid before simulation step ends [Wol84]

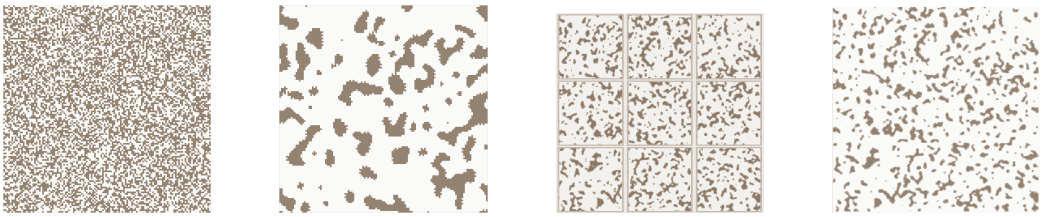
and cells do not need to be updated in sequence if only all cells will be changed before the next step. Hence, cell state updates could be applied in parallel to reduce the time needed to compute the simulation step. One way to do so would be to apply the findings presented by Reno Fourie in his thesis about applying CUDA technology to reduce time to compute next state of the board in case of 2-dimensional cellular automata [Fou15].

TO DO: what else to include?

TO DO: more on CA, 2dim CA?

3.4 Generating maps with CA

Since the goal of this work is not to just implement a working cellular automaton simulation, we need to find a way to generate maps using CA simulation.



(a) *Step 1 - random noise*

(b) *Step 2 - generated tile*

(c) *Step 3 - tiles in a grid*

(d) *Step 4 - complete map*

Figure 3.4: *Four stages of map construction*

3.5 Implementation

TO DO: describe how it all works now, with object diagrams

TO DO: refer to code itself

3.6 Tests

3.6.1 Performance test

3.7 Deployment (?)

Chapter 4

Conclusions

4.1 Evaluation of results

4.1.1 Effectiveness

4.1.2 Accessibility

4.1.3 Cost

4.2 Perspectives for usage

TO DO: map generator will be used in game project codenamed 'UW'

4.3 Further work

Chapter 5

Full source code

This chapter includes the full source code of the developed application, for reference and persistence (in case when digital versions are lost).

```
\lstinputlisting{../main.cpp}
\lstinputlisting{../Board.h}
\lstinputlisting{../Map.h}
\lstinputlisting{../Ruleset.h}
\lstinputlisting{../TextureAtlas.h}
\lstinputlisting{../TileGenerator.h}
\lstinputlisting{../UserInterface_MapGenerator.h}
\lstinputlisting{../Window_Base.h}
\lstinputlisting{../WindowBoardControls.h}
\lstinputlisting{../WindowBoardImage.h}
\lstinputlisting{../WindowGeneratorControls.h}
\lstinputlisting{../WindowMapTileGrid.h}
```

TO DO: remove verbatim to include listings: 30 pages a4paper

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List of Figures

List of Tables

List of abbreviations and acronyms

The following terms, abbreviations and acronyms have been used in the thesis.

CA Cellular Automaton. A simulation consisting of cell objects.

PCG Procedural Content Generation. An automated process of creation.

TO DO: (?)

Attachments

1. List of To Do Notes
2. TO DO: include thesis defence documents
3. TO DO: ?
4. TO DO: ?
5. TO DO: ?

list of todos - remove this before submitting thesis

Todo list