A Cellular Automata Approach to Population Modeling

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Abstract

This project provides an agent-based model of the effects of temperature on population growth and change using a 2D cellular automata algorithm to predict behavior. The purpose of this project is to demonstrate how the behavior of a group is dependent on the interactions between individual group members, and to show that a cellular automata approach is valid in modling ecosystem behavior. It will model a system in which temperature and population changes have mutual effects on one another. The use of cellular automata as agents has not been thoroughly explored, and it is hoped that this research will be useful to researchers in the field of computer modeling as well as that of ecosystems science.

Keywords: cellular automata, population modeling, 2D Life, agent-based modeling, temperature

1 Introduction

1.1 Cellular automata

Cellular automata (CA) are in fact a very basic form of artificial intelligence. In a CA program, a set of "cells" is created on a grid, and the behavior of each cell is determined by the states of its neighboring cells. Cells "know" their own states ("alive" or "dead"), the states of neighboring cells, and the rule that determines their behavior. These simple parameters, when applied over a large number of cells, create often surprising and complex patterns. In the past, CA have had several mathematical and computer science applications, but researchers have begun to see their viability in the field of agent-based modeling.

1.2 Life

The “Life” collection of automata rules is based on the idea that survival of individuals in a population requires an adequate number of neighbors; that an individual can die due either to loneliness or overcrowding, and that an individual is only born when a “family” of individuals is already present. In Life models, the appearance of the grid changes at the end of each turn. The best Life models use rules which create lifelike behavior.

1.3 Purpose

The purpose of this project is to model the behavior of a population using a cellular automata approach as well as to demonstrate that cellular automata can be used in population modeling. The model will observe the affects of temperature on the population and vice versa, in a manner similar to the DaisyWorld simulation in ecosystems science.

For this model, the rule 14/3 was chosen because it causes cells to grow and move in a pattern resembling the spread of a species; cells begin localized and become more widespread. The use of the 14/3 rule suggests two types of individuals: “antisocial” (survives with 1 neighbor) and “social” (survives with 4 neighbors). This adds a degree of complexity to the model.

2 Background

2.1 CA Modeling

The field of cellular automata modeling is relatively new to computer science. Some work is being done to determine the usefulness of cellular automata in modeling the growth of cities, the spread of a rumor, the spread of an invasive species[3], and the spread and suppression of forest fires[4]. Cellular automata are useful in modeling because they describe the behavior of groups based on the interactions of individuals, which can produce surprising, realistic, and unique results.

2.2 NetLogo

The language used in this project is NetLogo, an extension of the Java language, created by Uri Wilensky. Specifically, this project is written in NetLogo 4.0.3. In addition to the ability to view the interactions of cells in "real time" in NetLogo's graphics window, NetLogo also provides charts and graphs. By observing both the behavior of individual cells in the graphics window and the changes in population and temperature as shown by graphs and charts, the project's performance can be verified and results can be observed.

3 Development

3.1 First Quarter

The first quarter version of the program correctly runs the cellular automata rule 14/3 (live cells with 1 or 4 neighbors survive the turn, dead cells with exactly 3 neighbors are born in the next turn) and allows the user to select the initial population density. It also graphs the percentage of live versus dead cells and provides population counts.

In test runs, the percentage and population of live cells are monitored. Variations occur due to the introduced variable of initial population density and the individual behavior of cells, which changes based on the random placement of cells on the grid. The nature of cellular modeling produces slightly different results with each run.

3.2 Second Quarter

The second quarter version of the program builds from the first quarter version and adds the factor of temperature. After an initial temperature is selected, temperature varies linearly with the changes in population (that is, the difference between the current population and the population at the end of the previous generation).

During a test run, monitors display the population count (number of live cells), temperature in degrees Fahrenheit, and percentage filled of the grid (ratio of live to dead cells in the grid). Two graphs display the changes in temperature (in Celsius) and population over time. The user may also use the add and remove walls buttons to draw walls around the cells, separating a section of the population from the larger group. These walls cannot be crossed by cells and are considered 'dead' by the cells but are unable to become alive at the next generation.

3.3 Further Development

This model is very basic, having only two parameters, and could be shaped into part of a larger program using a cellular automata population and showing its interactions with various factors in its environment such as nutrients and predators. Also, the model is not very specific; if modified to fit real-world data it could potentially model specific populations and their response to environmental changes. For instance, it could be used to model the spread of a virus, or the growth of a bacteria.

The main project focus for third quarter will be porting this program to Java. In Java, it will be easier to give certain traits to individual cells, allowing for more variation and exploration of population behavior including the spread of disease through a population.

Another possible extension would be trying the same model as a 3D cellular automata model using a "block" of cells which respond to temperature changes in their environment, showing diffusion through the block.

4 Results and Discussion

4.1 Results

The program correctly runs the cellular automata rule 14/3 (live cells with 1 or 4 neighbors survive the turn, dead cells with exactly 3 neighbors are born in the next turn) and allows the user to select the initial population density. It also graphs the percentage of live versus dead cells and provides population counts. Initial densities which are too low or too high result in small, isolated groups of individuals; the ideal initial density (shown above), in which the population grows more or less steadily outward, is about 55 percent.

With default settings (temperature of 21 degrees Celsius, population density of 55 percent), that the population eventually dies off. This may provide a (highly simplified) explanation for the phenomenon of global warming. This result is not always produced if the initial parameters are changed. The amount of time after which the population takes a sharp decline varies from run to run due to the nature of cellular automata to produce heterogeneous results. However, the trend remains the same.

When walls are added, isolated groups that are very small immediately die out, whereas larger isolated groups live longer. However, when the walls are added and even after they are removed, the rest of the population of cells avoids the isolated segments of the population and grows away from the walls.

4.2 Discussion and Conclusion

This project aims to model the behavior of a population based on the interactions between individuals using a cellular automata approach, in which the state of each individual at the end of a turn or generation depends on the states of its neighbors. By using the 14/3 rule, it creates a population which, under ideal conditions, grows and expands outward. This behavior realistically imitates the growth of a population of organisms. When additional factors are added, this project should demonstrate that cellular automata are valid for use in modeling the behavior of populations.

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