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COSC 527 Biology-Inspired Computing
February 10, 2023

Classifying Cellular Automata

Introduction

This lab explores the behavior of cellular automata and aims to find patterns for classifying these cellular systems. Specifically, this lab researches a single dimensional cellular system. The classification system used in this paper identifies class I as systems that converge to a homogenous state, class II represents states with clear repeating patterns, class III as systems exhibiting unpredictable chaotic systems, and class IV as systems that exhibit some of the chaotic behavior of class III along with some interesting patterns that are created and destroyed. Class IV is the system of most interest for this experiment. In total, the experiment yielded 42 class IV systems out of 390. The classification was done manually by inspecting a graph of the cells over time. The experiment was run 30 times with a random seed to generate a cellular system whose behavior is defined by a random 12 digit number. The number is a rule that dictates how cells transition between states. After the initial generation, each experiment will iterate 12 times to set a random digit in the rule to 0, so that by the end all states will map to the quiescent state.

To quantify the behavior of the cellular system, this lab uses Langston's lambda and entropy. The lambda is essentially the probability a cell will not map to 0, while entropy is a measure of how significant it is for a state to occur. The totalistic lambda and entropy are noted as λ_t and H_t respectively while the lambda and entropy for the complete transition table are λ and H. The fifth parameter calculated, noted as zeta, is a calculation of the percent of cells in the experiment that are not in the quiescent state. This parameter was chosen because it seemed systems without complex behavior such as class I and II are likely to have a large amount of cells in the quiescent state, while class III and IV will have close to no quiescent cells.

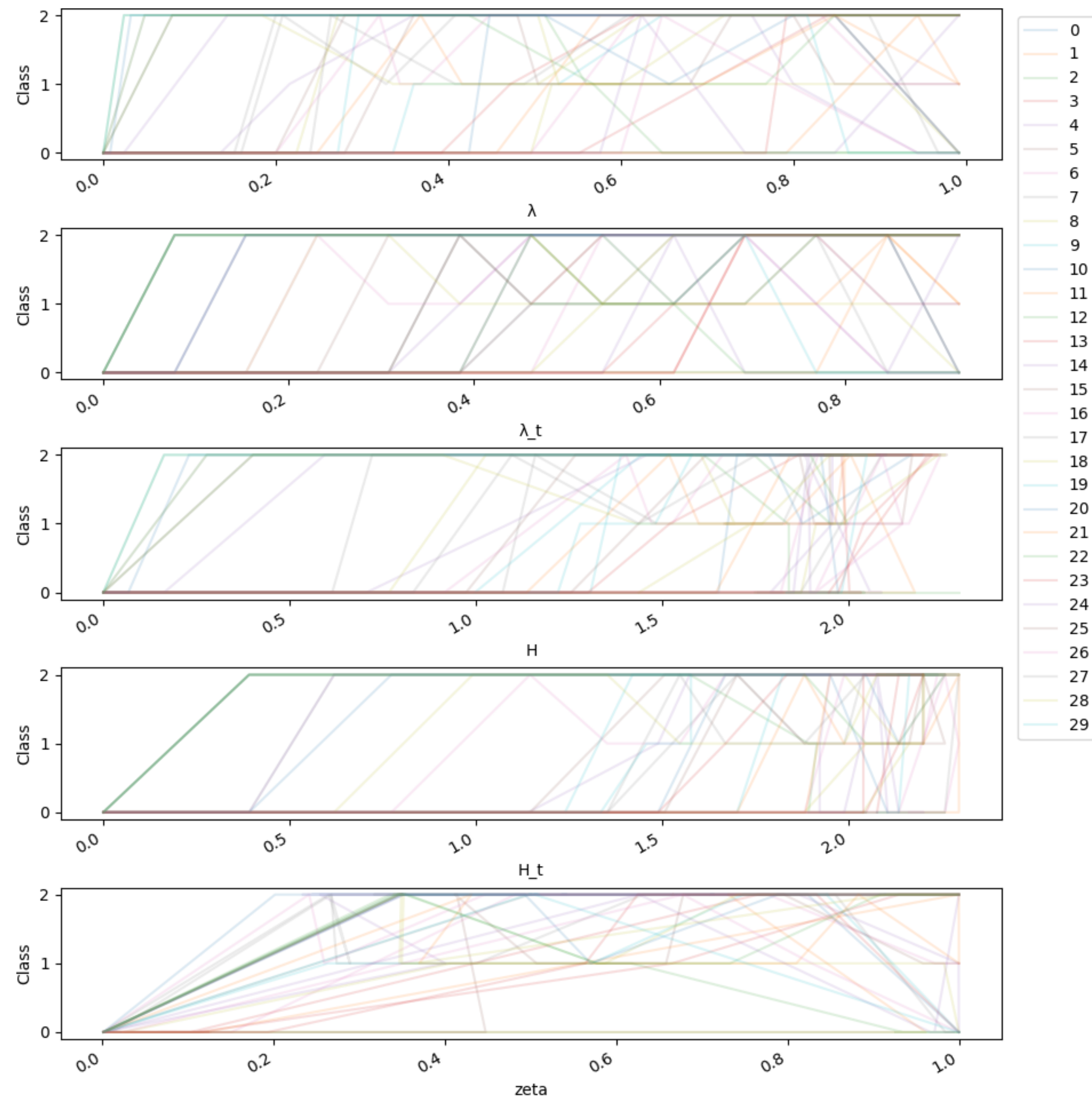
Calculations

The raw experimental data may be found in the MasterExperiment.csv file. The following average and standard deviations of the parameters were computed across all experiments for any experiment iteration that was perceived as having class IV behavior.

	Average	Standard deviation
λ	0.610286	0.20526
λ_t	0.622711	0.163673
H	1.772243	0.248806
H_t	1.967073	0.26041
zeta	0.600732	0.26041

Of the five parameters, the totalistic lambda had the lowest standard deviation. Meanwhile, zeta and the totalistic entropy tied for the highest. Because standard deviation is a measure of variability, class IV systems would be more likely to have similar totalistic lambda values.

While the totalistic lambda may vary less within class IV systems, the other parameters may also help reinforce a conclusion on what systems exhibit class IV behavior. To get a better idea of how the parameters might indicate class IV behavior, the researcher created the graphs below relating the parameter values to the behavior class for each experiment. Each line represents a different experiment numbered from 0 to 29. The graph represents class I and II behavior as 0, class IV behavior as 1, and class III behavior as 2.



To better show overlapping values, the plots have a degree of transparency. For the entropy and totalistic entropy graphs, it appears that systems changed classes more often at higher values. Class IV behavior was also more common at higher entropy and totalistic entropy values. The lambda and totalistic lambda graphs show a more even spread of all classes, though there were less class I and II instances at higher values and less classes III and IV at lower values. Since the lambda values decreased at a predictable rate, most experiments changed states around similar steps. The zeta graph showed that most class III and IV behavior happened towards the middle, which makes sense since more cells that are quiescent indicate restrictive rules.

Analysis

Overall, class IV behavior was more common at a totalistic lambda value 0.622, a lambda value of 0.61, an entropy value of around 1.77, a totalistic entropy of 1.96 and a zeta value of 0.601, as supported by the graphs and the averages table. For both entropies, class IV tended to occur within 0.25 of the average values. For the lambda values, experiments were more likely to to move from a complex class to a chaotic class. The totalistic lambda shows class IV behavior is likely between a value of 0.45 and 0.70, while the other lambda was likely to have class IV appear in the value range of 0.4 and 0.8, though there was also a group of complex behavior between 0.85 and 1. Based on the zeta graph, the experiments that were chaotic or complex were very unlikely to change to a simple state unless the quiescent states made up less than 20% of the board. Additionally, of the systems that had 100% or nearly 100% quiescent states, and most of those changed directly to chaotic or complex.

The plots correlate with the standards and averages calculated earlier. Given the lighter graph of lambda in the class IV region, it seems to be a relatively poor estimate of class IV behavior. For further exploration, it would be interesting to feed these features into a machine learning algorithm to see how well the classification would perform.

While conducting the experiment, it seemed common that classes tended to occur in groups. This observation is supported by the graph of the lambda function. Class IV behavior tended to appear when chaotic regions did not crowd the whole board, and when there was enough complexity in the rule to allow patterns. One anomaly to this was in experiment 4, the class was first found in step two and didn't reappear until step seven. The second class 4 did not seem to be able to make patterns through the empty "holes" of the quiescent state and instead made patterns through the triangle pattern that is common for higher steps. Another anomaly was a class I that appeared at step two of experiment twenty four. The experiment started as class III then went to II then I then back again through II and III. I also noted that a couple simple systems started with complex behavior, such as experiment 11, step 4, then patterns collided and the complex behavior resulted in a continuous pattern that spread to the whole board.