CA Simulator Report: Project 1

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Introduction:

In this project I simulated 40 iterations of a 1-D cellular automata and carefully recorded the results. I used a Java program written by a previous student (provided by professor) that created a randomly generated transition table, which was then used to calculate the parameters for a cellular automaton: lambda (λ), entropy (H), lambda_t (λ_t)and H_t (H_t). The goal of this project was to find correlations between Class IV behavior and calculations of the characteristics of the simulated CA's from each iteration.

Overview of Methods:

As stated above, I performed these simulations with distributed Java code written by a former student (denoted as author 'a1flecke'). For each iteration of his code, a new CA simulator instance is generated (for each new experiment – number is determined by way of user input) and his simulate() function is called. It is in this simulate() function where the heavy lifting is done: The rule table is generated with random integers which are used to calculate lambda, lambda_t, H, and H_t. The functions for calculating the parameters are called here, along with writing the output to the MasterExperiment.csv file and the generation of images.

Once I ran the program for 40 experiments, I analyzed the images and classified them (with an observation) in the MasterExperiment.csv file. I then generated graphs comparing Class vs. [parameter] and created a separate .csv for Class IV classifications only. Here, I used formulas to calculate average, standard deviation, skewness, median, and variance. After further examination, I discarded median and variance from the calculation table (left in .csv for reference) due to the other parameters painting a much better picture of the data.

Calculations:

	Class IV	Calculations		
Parameter	**Lambda**	**Lambda_t**	**H**	**H_t**
Average	0.6637778	0.62606838	1.87457	1.971874
Standard Deviation	0.177639	0.14496658	0.226958	0.227451
Skewness	0.2612626	-0.0221039	0.000338	-0.72647

After simulating 40 experiments and calculating key statistics, I concluded that entropy (H) acts as the best indicator of Class IV behavior. Even though the standard deviations for entropy and totalistic entropy are greater than lambda and totalistic lambda as shown in the table above; they are a lower proportion of their respective averages (means). For example:

$$\frac{Standard\ Derivation(lambda)}{Average(lambda)} = \frac{0.177639}{0.6637778} = 26.7\%$$

$$\frac{Standard\ Deviation(entropy)}{Average(entropy)} = \frac{0.226958}{1.87457} = 12.1\%$$

Hence, the data set is significantly closer to each other (clustered) than lambda. The value is the same for their totalistic values as well. It is worth noting, however, that around 70% of Class IV classifications had lambda values in the range of [0.44, 0.76], which fits nicely with the notion that since a lambda value near 0 would be in the ordered realm and a value near 1 would be chaotic. Since the Edge of Chaos is somewhere in between 0 and 1, these values do fit well. Despite this, I was looking for more clustering when it came time to identify the most reliable value, which is why I decided on entropy. Additionally, I added skewness to my calculations. This was to get an insight into how the parameters were distributed with their respective averages as the reference of point. The symmetry of entropy (near 0 skewness) combined with its comparatively low standard deviation creates a great illustration of its closer data set when compared to lambda.

Graphs:

I generated these graphs in Excel. Below each graph is a brief note of interpretation for the data.

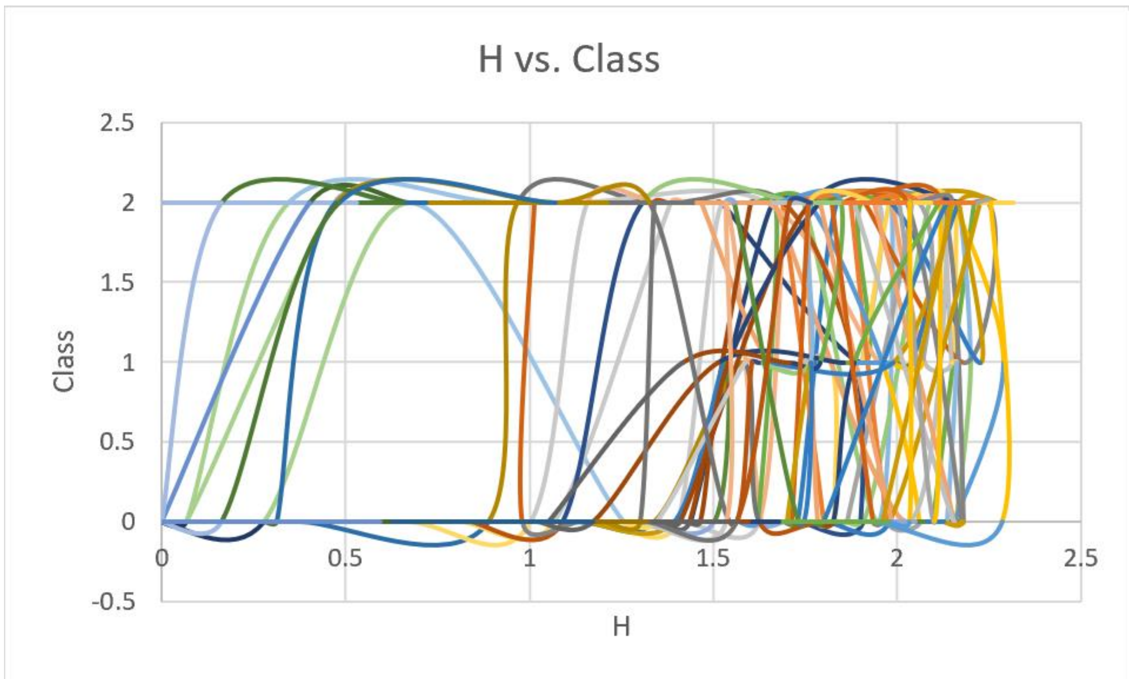


Figure 1: Note the clustering of entropy numbers for Class I and II around the 1.7-2.25 range, with Class III in the 1.5-2.15, and Class IV averaging almost directly in between them. See Figure 2 for better reading.

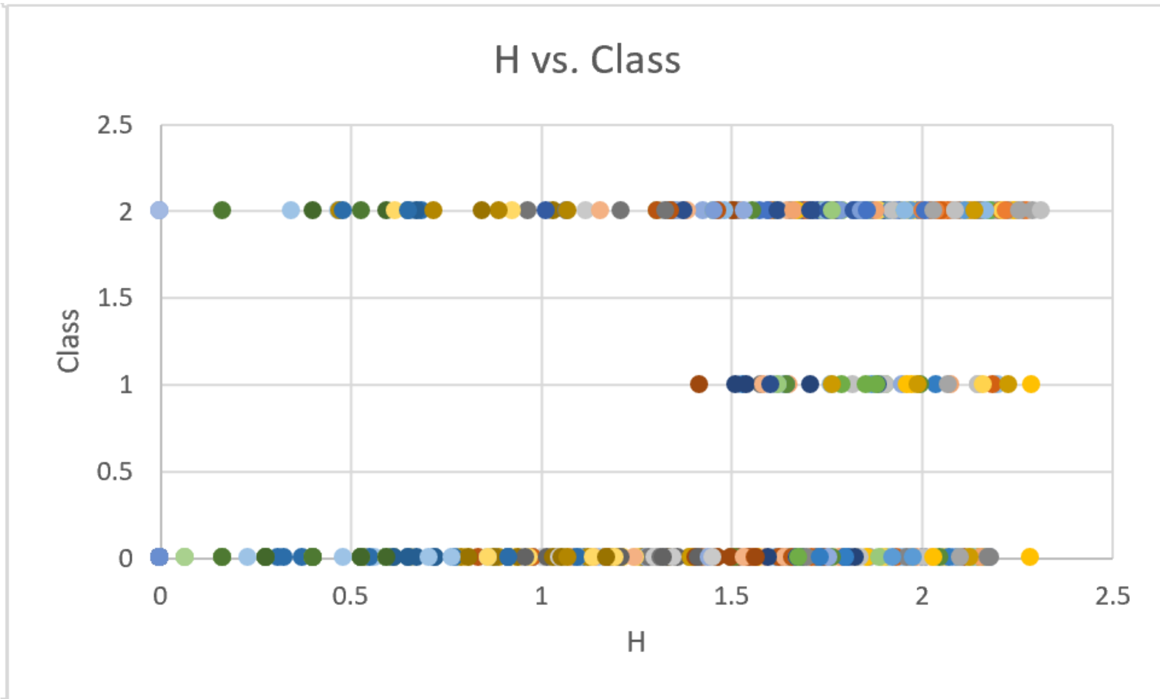


Figure 2: As mentioned at Figure 1, the Class IV here is averaging an entropy of 1.87 and a near perfect (.00038) skewness. The skewness is interesting to me because it shows how the entropy wound up to be a near symmetrical data set around the mean.

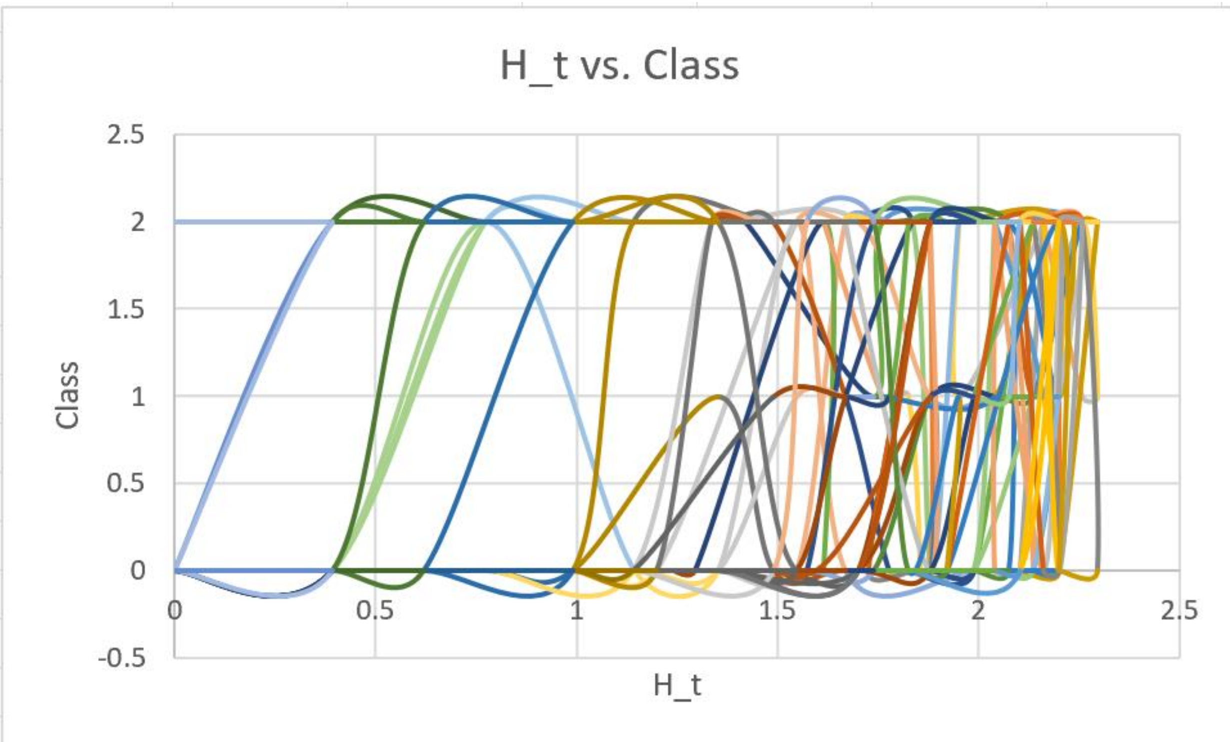


Figure 3: Note the general clusters for Classes I, II, and III for totalistic entropy are in the same general area. Class IV is a bit more un-even here.

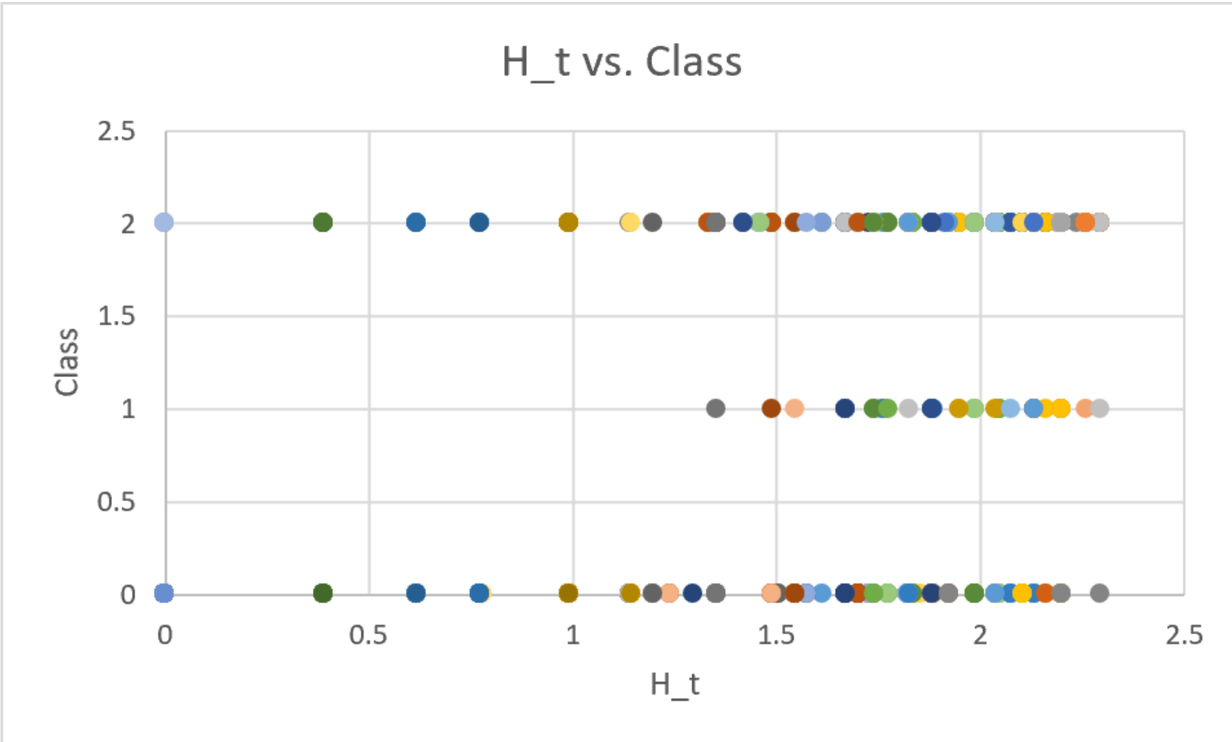


Figure 4: See Figure 3 description.

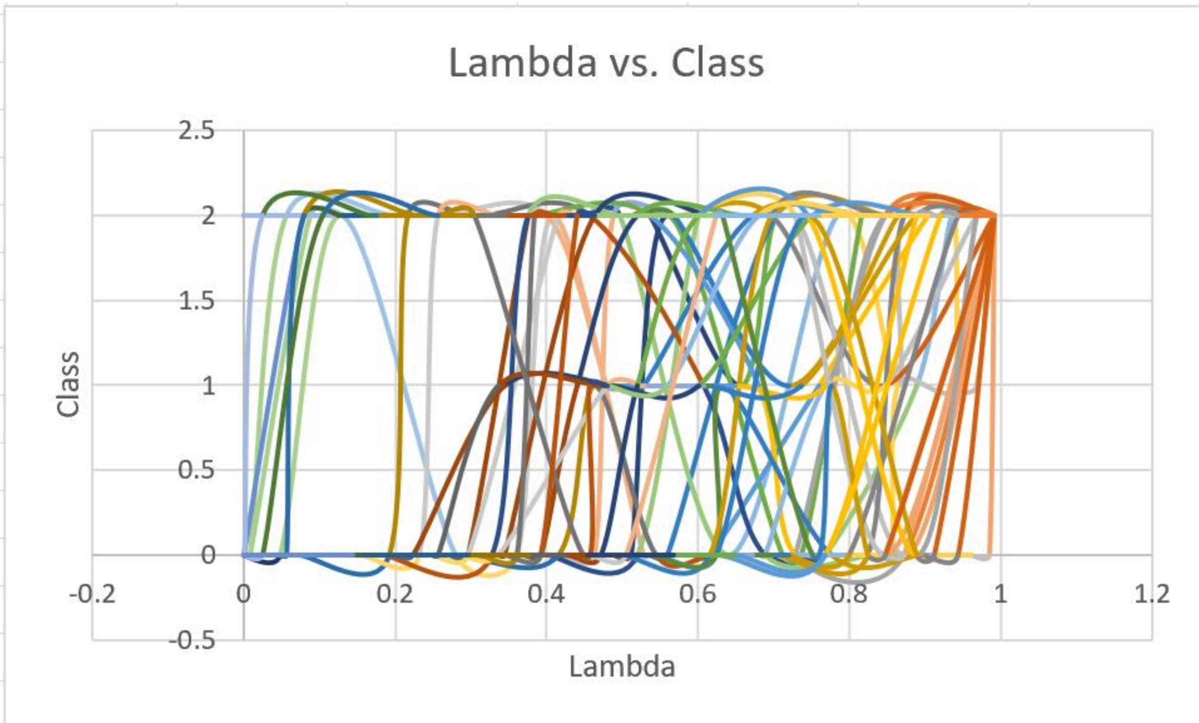


Figure 5: Lambda I found very interesting, since the approximately 70% of Class IV classification had lambda's between 0.44 and 0.76. Since a lambda of 0 gives the ordered realm and a lambda of 1 would be chaotic, this could be a great indication of a general range for the Edge of Chaos.

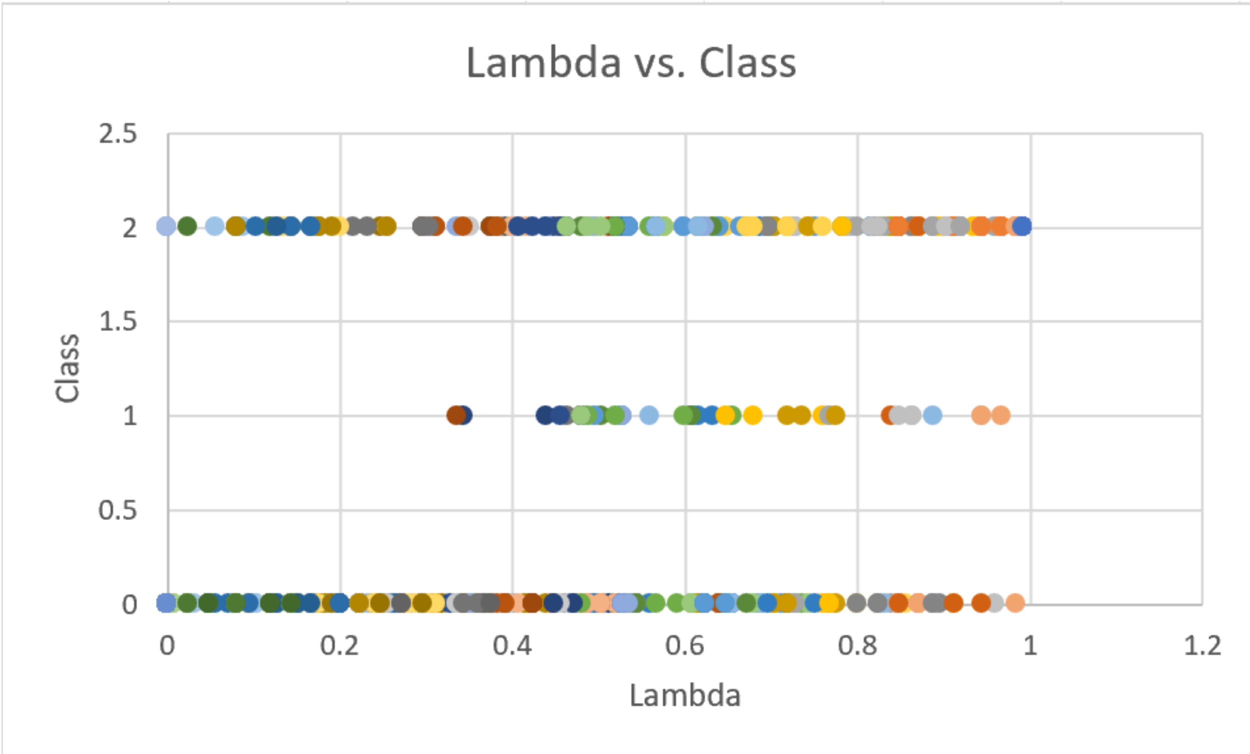


Figure 6: Note the lambda values between 0.44 and 0.76 for Class IV classifications.

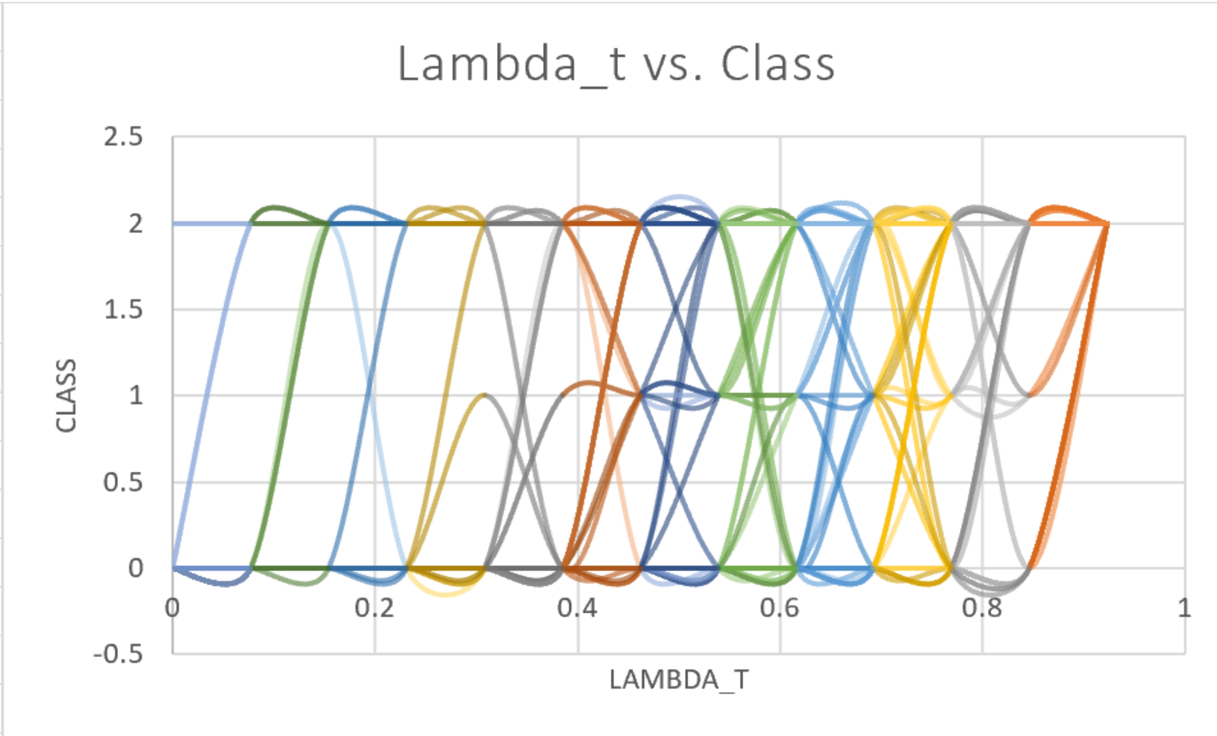


Figure 7: Note the significant overlap between iterations.

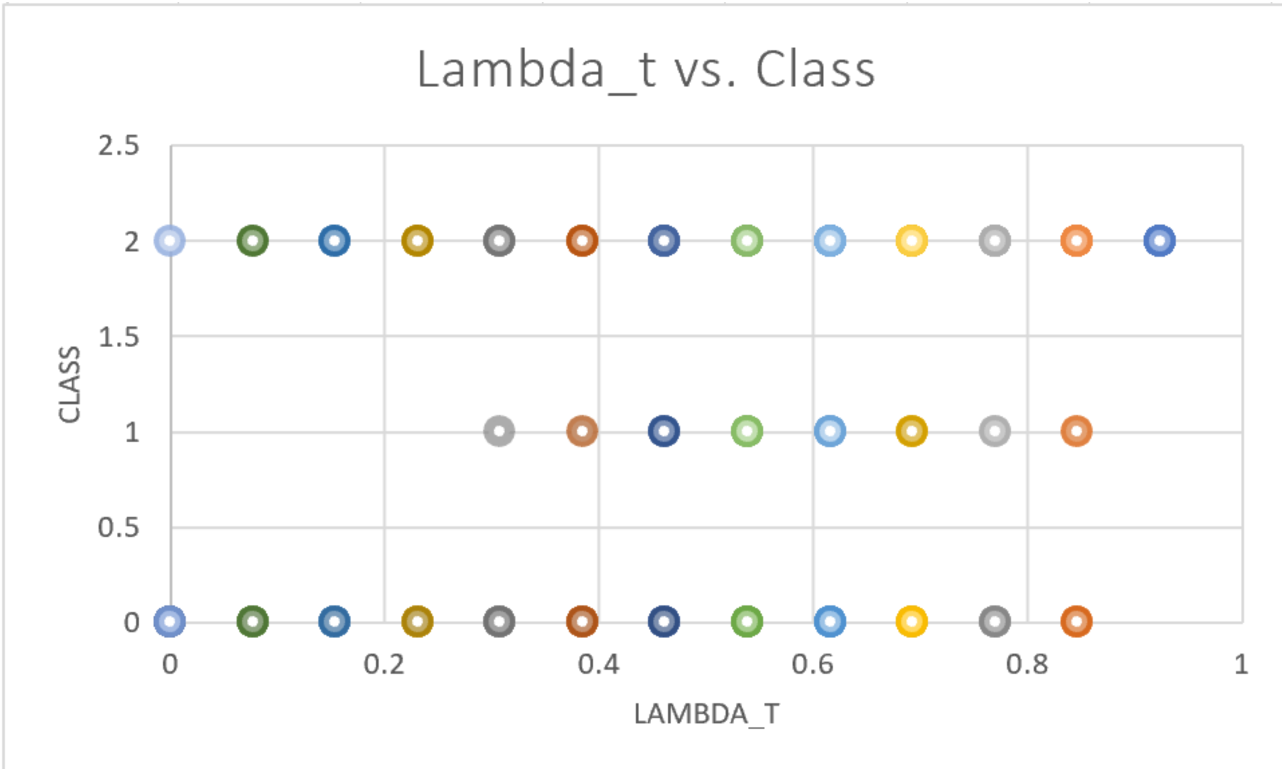


Figure 8: See Figure 7.

Discussion and Analysis:

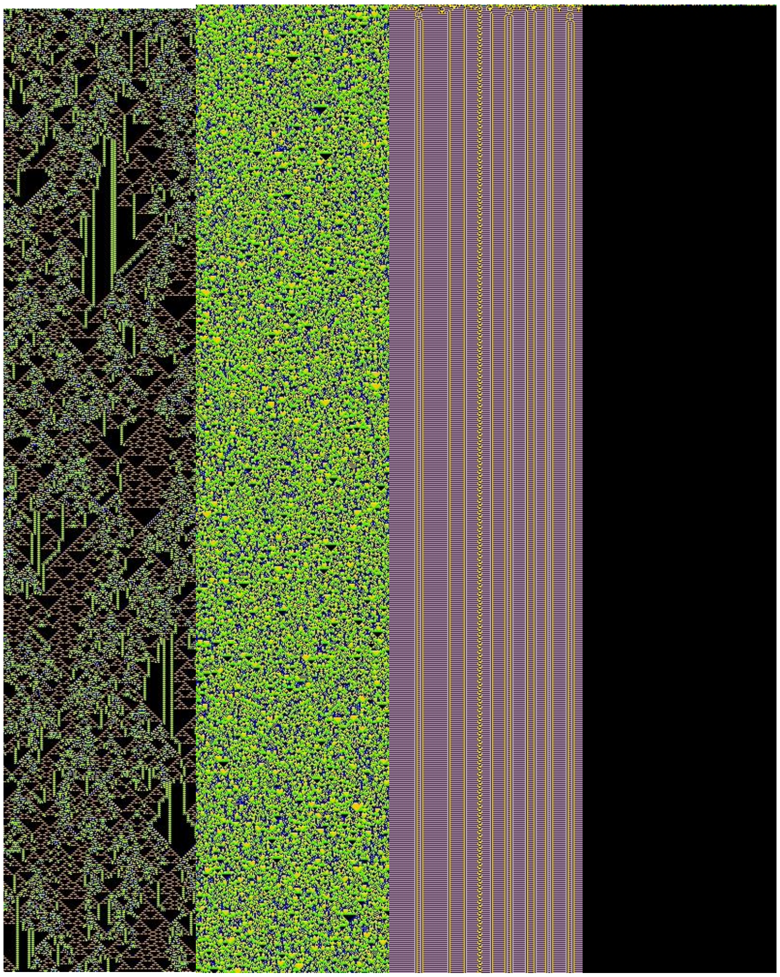
To begin my discussion and analysis I would like to start with a few conclusions about the lambda and lambda_t values. After running 40 experiments, I found that Class I and II behavior correlated with lower lambda values, Class III behavior correlated with higher lambda values, and Class IV values were somewhat in between. Given further thought, this makes sense. Class I is established as a stable state, while Class II displays simple periodic behaviors and many times oscillates. Therefore, it is no surprise these have lower lambda values as they are closer to the ordered realm. Class III, on the other hand, is more chaotic and therefore has higher lambda values in the chaotic realm. Lastly, Class IV lies somewhere in-between these by the Edge of Chaos, and it is no surprise that its lambda value averaged 0.663. Lambda_t was less telling, as there was significant overlap in values.

As for the entropy values, H and H_t, they tended to be much more clustered for Class IV behavior than for Classes I, II, or III. Though there was significant clustering for Classes I, II, and III around the values Class IV were distributed, they had a significantly greater range of values (and other points of clustering, for that matter). This anomaly could be explained by the sheer number of experiments performed and the significantly greater numbers of Class I, II, and III classifications than for Class IV. Nonetheless, Class IV tended to have higher H and H_t values when compared to the other classes. Another anomaly I felt compelled to explain is the distribution of values for entropy and lambda. As mentioned above, the ranges Classes I, II, and II for these values were much greater than a Class IV. Despite this, the higher entropies should have meant more Class IV at the higher values and less of the other Classes. This might be explained by the rule table in the simulator only having thirteen rules and five states, which would mean less variability and more repetition.

In general, Class IV behavior resulted in entropies approximately between 1.6 and 2.2, totalistic entropies approximately between 1.7 and 2.3 (so slightly higher than normal H), lambda values generally between 0.44 and 0.76 (there was a small cluster around 0.85), and totalistic lambda values evenly distributed between 0.3 and 0.85.

Examples of Class Behavior:

To conclude this paper, I thought it best to include examples of Class behavior and gives a relatively non-technical description of each. These images were generated in the experiments conducted and explained above.



Class IV Class III Class II Class I

Class IV behavior here shows overlapping patterns and 'stalactites' in between many of the holes. Despite this, the pattern still seems to flow smoothly, and more orderly than in a chaotic state. Class III behavior is shown above with general chaos: the CA is evolving chaotically and seemingly without order. Class II is shown here in cyclic and periodic fashion, which is typical of its Class. Additionally, it contains oscillating strands. The Class I here is in a solid state, which means it has approached a fixed point and will not endure any further changes.