Find Stable Solutions to the Richardson Equation

CSE 589: Bioinspired Computing

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ABSTRACT

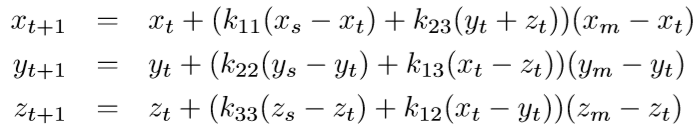
KEYWORDS

Genetic Algorithms, Richardson Equation, normalization, mutation, crossover, selection

1. Introduction

Lewis Fry Richardson expressed an idea that the push and pull of arms spending was indicative of the outbreak of war. Therefore, he developed a system of differential equations that could estimate the probability of two countries engaging in war according to their arms expenditures and other fiscal constraints, thus known as the Richardson Arms Race Model. This model has been widely adopted to two country systems, but is there a reason it could not be adjusted to multiple countries? For the purpose of this assignment, the Richardson Equation was updated to reflect the introduction of a third country that can contribute to the outbreak of war. This iteration more accurately reflects the advanced international economy of the world today (USA, Russia, and China, for example). In this version, three two weaker countries become allies, and pool their resources against the dominant country.

This model can exhibit some strange behaviors. First, there is the possibility of a shift in alliance. This would be the result of one of the weaker countries overtaking the dominant country, thus causing a new alliance between the new set of weaker countries. Secondly, instability within the nations can present itself in the form of a runaway arms race in which the countries continue to increase their spending on arms over each time step. Ideally, the countries would find a scenario in which the spending remains constant and shifts in alliance no longer occur. This would be considered as arms control and the steady state proposed in the Richardson Equation.

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**Eq1.** Richardson model expressed in three differential equations

However, there are 12 parameters that can be adjusted in this equation, so it can be difficult to manually determine how these values can be set such that we can achieve states of arms control between the three countries. To do this, a genetic algorithm can be created to produce the possible parameterizations.

2. Methodology

The genetic algorithm was implemented Python 3 without the use of genetic algorithm libraries. The parameters for this GA are all real numbers between 0 and 1.

 The GA is designed to create a variable size population with random initial parameters, perform crossover between individuals, mutate individuals, and perform a selection tournament to pick the fittest individuals. By performing crossover and mutations during each iteration of the genetic algorithm, the search space is continuously explored and genetic diversity is increased, thus leading to more fit generations over time.  These actions are performed over multiple generations with the goal of increasing the fitness of the overall population over time.

To perform mutation, one value for the individual is randomly chosen. This value is then increased or decreased by 5% of its current value. Now, the values must be in between 0 and 1, so if the mutation was to increase or decrease the value above or below these thresholds, mutation would be limited and the value would be kept within this predefined range. There is a variable mutation rate that can limit the number of mutations in a generation.

Crossover switches one value from two randomly selected individuals in the population. There is a variable crossover rate to limit the number of crossovers performed in a generation. The crossover is done with replacement. Thus an individual can be crossed over with another individual more than once.

The selection tournament is a one versus one selection tournament with replacement, thus allowing for an individual to be added to the next population more than once. The fitter of the two individuals is selected. The fitness of these individuals is calculated using a fitness function. An individual is more fit if the current arms spending between the dominant country and the two allied countries is close to 0.

3. Representation

The values for the GA are being represented using Python objects. The lowest level object is a Country(). Each country holds each of their four unique parameters that are randomly assigned, mutated, and crossed over. Along with this, each country holds its current arms spending and whether or not it is the current dominant country. A country has the ability to take in all of the above parameters for the purpose of debugging possible parameterization.

The Richardson() object simulates a single individual within the GA population. Each Richardson contains three countries, x, y, and z. Along with these three countries, it contains its fitness and mutation rate. The Richardson class can take all of these as parameters, again for debugging purpose, but by default it uses a static method to randomly create the three countries and assigns it fitness to -1. The mutation rate must be passed into each Richardson object. Its publicly available functions are to mutate and to perform fitness calculations. Mutation is performed as described in the previous section. To perform fitness calculations, Eq. 1 is performed dynamically depending on which country is currently dominant. After the spending is calculated, the countries are reassessed and a new dominant country is assigned if one of the allied countries has started to outspend the dominant country. Once any possible reassignments are complete, Eq. 2 is performed and assigns the fitness for the individual.

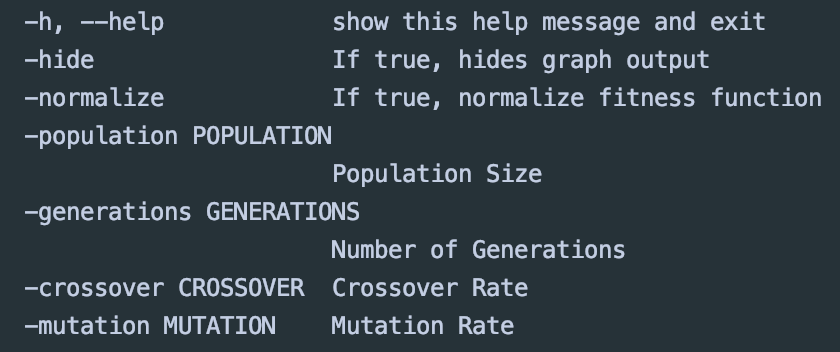
The GeneticAlgorithm() object contains all the information needed to perform the entire GA as the name suggests. There are four required parameters for the GA: population size, crossover rate, mutation rate, and a normalization flag (this flag will be addressed later). Upon initialization, the GA creates a population of Richardson objects according to its parameterization. It has one publicly available function, which is to iterate the population. This function performs crossover, mutation, selection tournament, and historical tracking, in this order. Mutation and crossover have been described in detail in previous sections.

However, there is a small caveat when performing the selection tournament. When adding the fitter individual to the next generation, a deep copy for that individual is sent and not the individual itself. A deep copy will create a new object with the same attributes as the original. If a deep copy is not used, then the new generation will have multiple references to the same individual in the population. This means, without the deep copy, if one individual is crossed over then that change is reflected everywhere that object is reflected in the population. This could cause individuals to be mutated or crossed over significantly more than intended.

Once the selection tournament is performed, the GA object performs some additional calculations to track the best global solutions and the average fitness of the population for each generation. With these objects in place, the GA can be run quite easily for a variable number of generations to observe how performance changes.

4. Parameterization

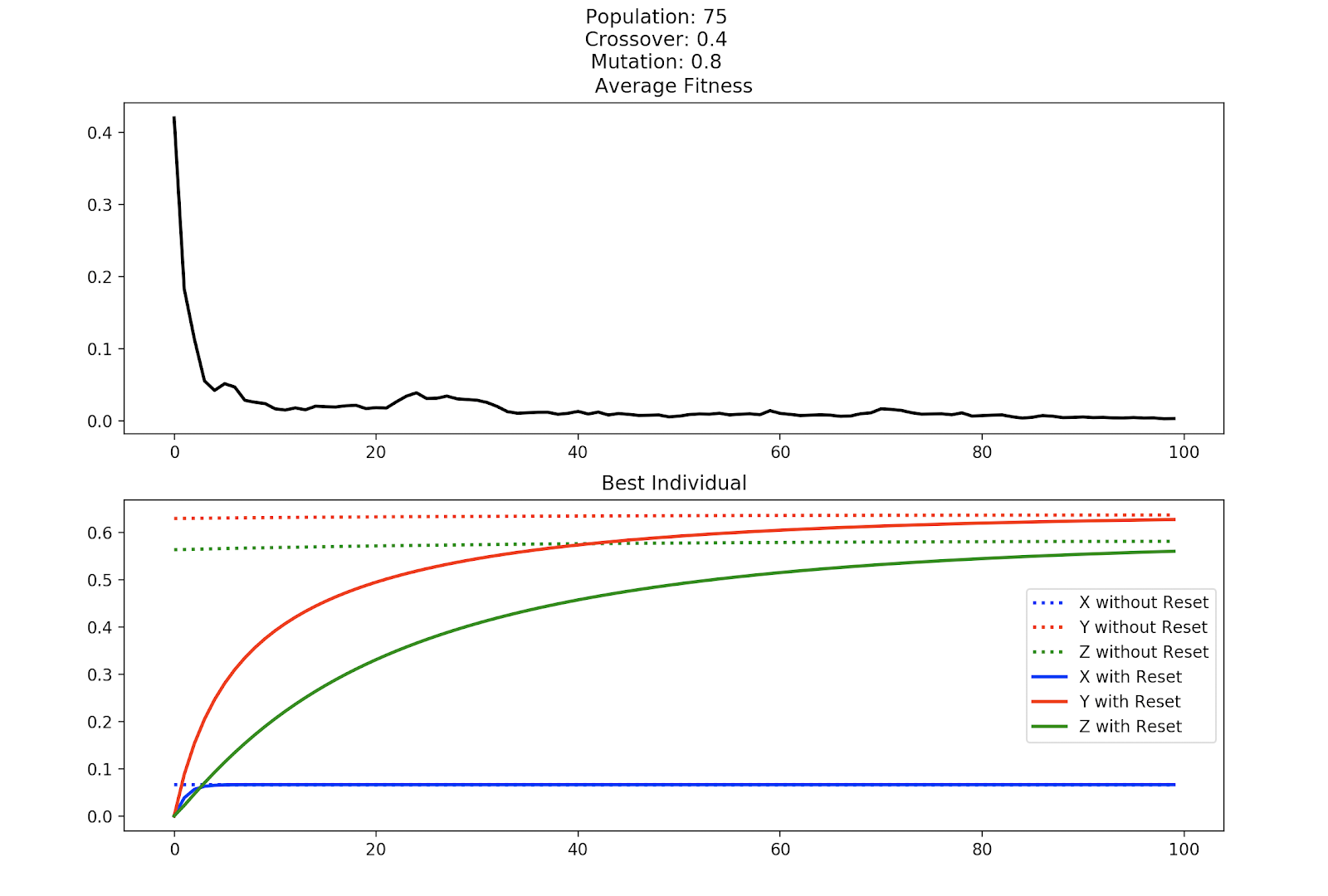
Because the final GeneticAlgorithm() object takes in 5 parameters, these are the 5 values that can be adjusted from run to run. These values can be adjusted with command line arguments to allow for quick parameter adjustments without having to touch the source code. Below are the parameters that can be adjusted at the command line. A full detailed list of ways to run the code can be found in the README.md



5. Experimental Design

Once a GA runs for the specified amount of generations, a way to assess the results had to be produced. A visualization was created to observe any patterns that might have manifested in the final results. The first was a fitness curve to show average fitness across each generation in the GA.

The next was to study how the best individual’s parameters performed over time.  The individual that produced the highest fitness was taken from the population and simulated again with its countries parameters and x0,y0,z0=xt,yt,zt where *t* is the number of generations simulated. These same parameters were used again but initial spending was set to 0, x0,y0,z0=0. This was done to compare how would perform according to the initial state given in the assignment. These calculation were recorded for number of generations ran by the GA, giving the Richardson Equation enough time to accurately observe its expected results vs its actual results.



Here is a standard output from the GA. The first visualization shows how the average fitness for the GA converges towards 0, which is ideal. There are some perturbations in the average fitness that can be attributed to the GA mutating and performing crossover to promote genetic diversity and to increase the search space. The second visualization shows the best individual and its counties’ spending over time. The dotted lines assume initial conditions x0, y0, z0=xt, yt, zt. The solid lines assume initial conditions x0, y0, z0=0. The faster the actual results can simulate arms control, the better the final solution is. Root-mean-square deviation (RMSD or RMSE) is used to measure how the expected model behaves (x0, y0, z0=xt, yt, zt) vs. how the actual conditions behave (x0, y0, z0=0). RMSD can thus be used to determine how the fitness and spending of the actual function compare to that of the expected function. A low RMSD indicates the differences between the actual and expected values are small. RMSD can be calculated for fitness as well as for the countries’ average spending. RMSD for fitness is a measure of how consistent the fitness is over time. RMDS for the countries is a measure of how fast the countries converge to their expected arms control point.

However, when running ad hoc experiments to observe how parameters could impact performance, the best individuals were typically spending an extremely limited amount on arms. This would result in them having incredibly low fitness, but their RMSD measures would be disproportionately higher, meaning their parameters did not actually perform well. These individuals rise to the top because of how the fitness function promotes extremely low spending on arms. Consider xi, yi, zi=.01, .005, .004. Using Eq. 2, this fitness, F, is 0.01. Now consider xi, yi, zi=.1, .05, .045. This tuple would produce F=0.05, a fitness 5 times worse than the previous. However, if the two fitness were normalized, the latter is better than former by a factor of two. So while, the second could have relatively a more stable solution, the current fitness function does not promote its results.

To address this problem faced in the fitness function, the ability to normalize the fitness function was proposed. (Adjusting the fitness function might have been out of scope for this project, but normalizing the fitness function did provide much better results) By standardizing the fitness function, low scale results are evaluated fairly against the larger spending results. When enabled with the normalization flag mentioned in section 3, the fitness function is updated to Eq. 3, eliminating the problem addressed in the paragraph above. With Eq. 3, xi, yi, zi=.01, .005, .004 would produce F=0.2 and xi, yi, zi=.1, .05, .045 would produce F=0.0909, accurately reflecting that the latter is closer to arms control. To further support normalization of the results, the normalized root-mean-square deviation (NRMSD) was utilized to evaluate the results.

F=|xn-(yn+zn)|/(xn-min(yn,zn))

Eq. 3 Normalized fitness function

F=RMSD/(ymax-ymin)

Eq. 4 NRMSD, where y is either fitness or country spending

Experiments were designed to study how population size, number of generations, mutation rate, crossover rate, and normalization of the fitness function would impact impact the average fitness of the GA, the best individual fitness produced by the GA, the country NRMSD, and the fitness NRMSD. Each set of parameters was ran 10 times, and the average across all the runs were recorded. In terms of evaluating the best individual, the standard deviation was also recorded for the country NRMSD and fitness NRMSD.

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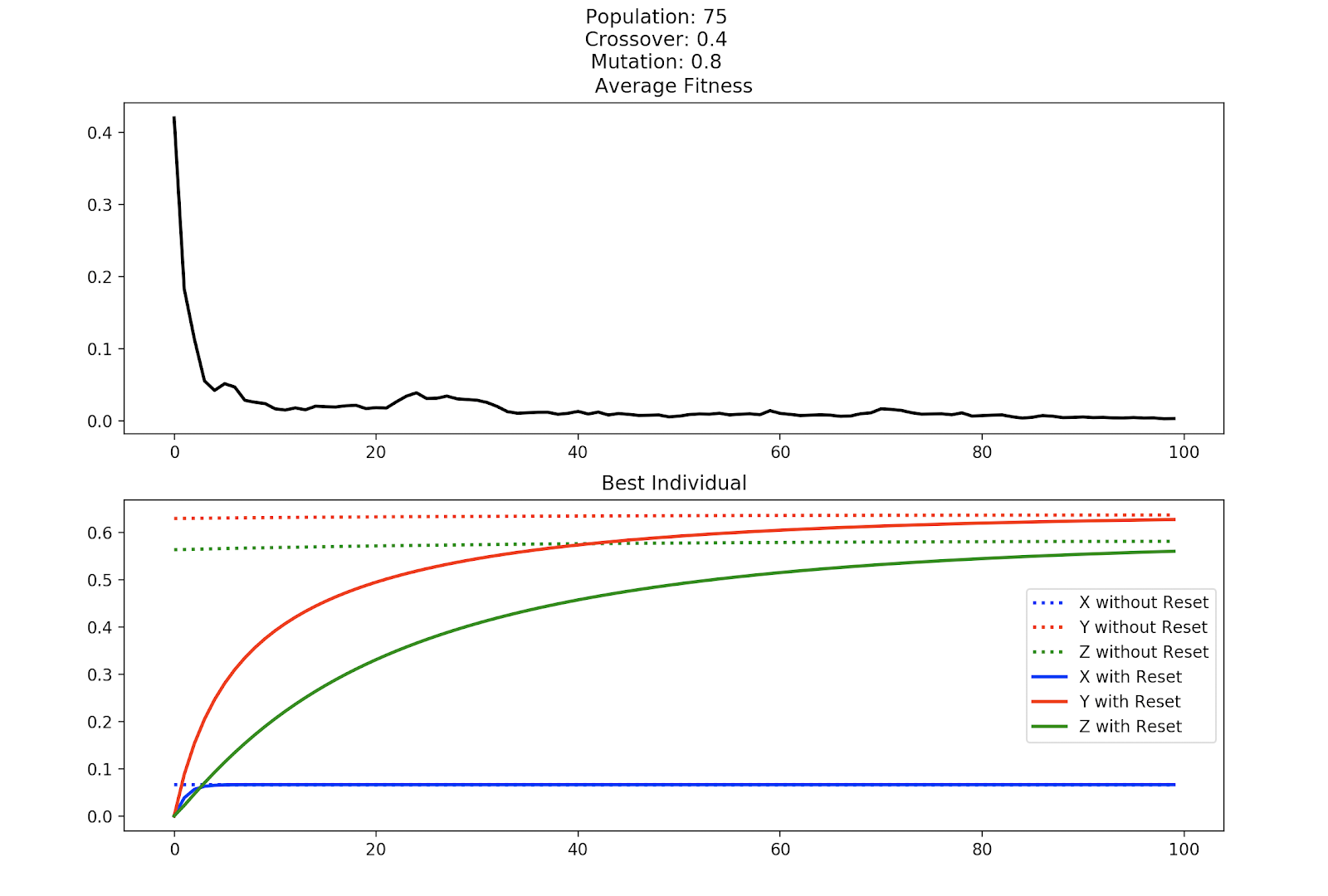


Figure 1: Here is a standard output from the GA. The first visualization shows how the average fitness for the GA converges towards 0, which is ideal. There are some perturbations in the average fitness that can be attributed to the GA mutating and performing crossover to promote genetic diversity and to increase the search space. The second visualization shows the best individual and its counties’ spending over time. The dotted lines show the countries expected behavior given the parameters found by the GA. The solid lines show how those parameters behave over time with the initial conditions x0,y0,z0=0. The faster the actual results can simulate arms control, the better the final solution is.

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5. Conclusion

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1. In a Word 2013/2016 document, insert a picture.
2. Right click on the inserted picture and select the **Format Picture** option.
3. In the settings at the right side of the window, click on the "Layout & Properties" icon (3rd option).
4. Expand **Alt Txt** option.
5. In the "Title:" and "Description:" text boxes, type the text you want to represent the picture, and then click "Close".

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