The Evolution of Cooperation: The Genetic Algorithm Applied to Three Normal-Form Games

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Abstract

The genetic algorithm with a fixed-length genome is applied to three normal-form games: Prisoner's Dilemma, Chicken, and Battle of the Sexes. The dynamics of the evolution of cooperation in these games are analyzed.

Games and Cooperation

In a two-player, normal form game, each of the two players simultaneously selects one of a set of possible moves (i.e. each player chooses his move without knowing what move the other player has chosen); the players are then given a score according to a payoff matrix (Figure 1; P1 indicates the score player one receives for a given combination of moves; P2 indicates the score player two receives).

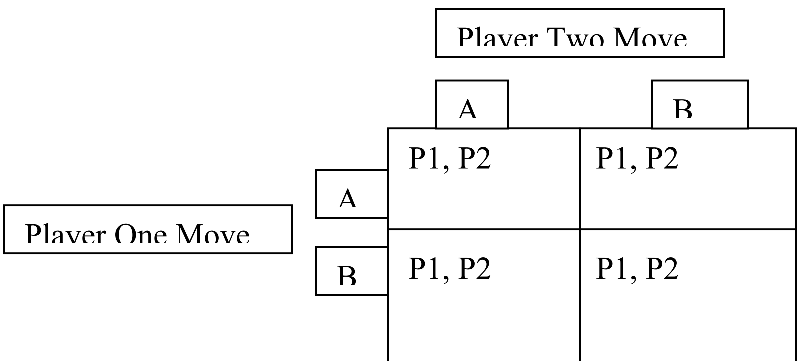


Figure 1 – A two-player, two-move normal-form game

Games of this type are typically used as a means of modeling strategic interactions between agents in economic, political, social, or other settings. By far the most well-studied game in such settings is the infamous Prisoner's Dilemma, the payoffs for which are as shown below. In this game, moving top (player one) or left (player two) is considered to be "cooperating"; the opposite move is "defecting". The dilemma arises because, no matter what move one's opponent makes, one's own score is always improved by defecting; on the other hand, mutual cooperation leads to a better score for both players than does mutual defection.

3,3	0,5
5,0	1,1

Prisoner's Dilemma

In a single, isolated game it is difficult to overcome the argument that defection is the "rational" choice. If the game is iterated, however, with the same two players facing each other repeatedly, the possibility of rewarding or punishing one's opponent for previous actions makes it reasonable to adopt a strategy other than constant defection. In particular, the strategy known as "tit-for-tat", in which a player cooperates initially and afterwards mimic's the opponent's last action, has been shown to perform well against a variety of other strategies (Axelrod).

The Genetic Algorithm and Cooperation in Games

There are two primary reasons why it is interesting to apply the genetic algorithm to evolving strategies for games such as Prisoner's Dilemma. For one thing, it may be possible to model the emergence of cooperative behavior in humans and other social animals, and to observe interesting population dynamics during this evolution. For another, it may be possible to evolve previously unknown strategies that perform better than existing ones, thus shedding light on the games themselves.

Previous Work

Much attention has been devoted to the study of Prisoner's Dilemma using the genetic algorithm. In particular, Lindgren studied the population dynamics of infinitely iterated Prisoner's Dilemma over a large number of generations, using a model in which noise was introduced to cause a player's actual move to differ with some probability from his chosen move (Lindgren 1991). Angeline studied the effect of modified forms of Prisoner's Dilemma in which the total payoff to the two players for cooperation/defection is higher than that of mutual cooperation; he observed the evolution of "non-mutual" cooperation in which the agents took turns cooperating and defecting (Angeline 1994). Beaufils *et al* describe a strategy called "gradual" which they claim outperforms tit-for-tat against a variety of competitors and attempt to improve on "gradual" by running the genetic algorithm with a genome consisting of values for specially chosen, intuitively understandable parameters.

Games Used in this Study

Aside from Prisoner's Dilemma, there are a variety of games with different payoffs creating different dilemmas and incentives. Colman describes several, including "Battle of the Sexes" and "Chicken", the payoffs matrices of which are shown below (Colman 1982). These two games, along with Prisoner's Dilemma, were used in this study.

3,3	1,4
4,1	0,0

Chicken

1,1	3,2
2,3	0,0

Battle of the Sexes

In Battle of the Sexes, we imagine two friends planning to go to a movie who have different preferences about which movie to see. The top/left move corresponds to going to one's preferred movie; the bottom/right move to going to the other player's preferred movie. Thus payoffs are higher when the two friends end up at the same movie, but, given that the friends go to a movie together (or separately), a higher payoff is given for seeing one's preferred movie. Unlike in Prisoner's Dilemma, the "defect" strategy (i.e. choosing one's own preferred movie) does not strictly dominate the "cooperate" strategy.

In Chicken, we imagine a contest in which the players are bearing down on one another (in tractors, say), and each must decide whether to swerve (top/left) or to continue straight ahead (bottom/right). A player wins the contest when the other player swerves first, but the worst outcome for both players happens when neither swerves and they collide.

Set-up of the Problem

I used a fixed-length genome that encoded, for each possible history less than or equal to a certain length, the move to be made by the individual. It should be noted that a history of length two consists of the opponent's last move and the player's last move. The tableau for this problem appears below.

For each of the three games I ran three trials, for accessible histories of length 2, 4, and 6. At each generation, each individual in the population played 75 consecutive games against each other individual; an individual's fitness was its average score in all of these games. I ran populations of 500 individuals for 500 generations, with a probability of crossover of 0.75 and a probability of mutation of 0.05.

Average fitness and best-of-generation fitness are plotted against generation for each of the three games for histories of length four and six; the plots appear as an appendix.

Tableau

Representation scheme:

Structure: fixed-length binary genome; length = 2^0 + 2^2 + ... + 2^hist_length each bit indicates which move to make given the corresponding history (or partial history, at the beginning of the game)

Fitness cases:

Round-robin tournament consisting of a run of 75 consecutive games against each of the other individuals in the population.

Fitness:

Average score received across all games in fitness cases.

Parameters:

population size = 500
num generations = 500
probability of crossover = 0.75
probability of mutation = 0.005

Termination criteria:

None. Run for all 500 generations regardless.

Result designation:

None. Compile statistics for entire population.

Analysis of Results

Individuals tended to converge quickly to the "cooperative" result. In Prisoner's Dilemma, there was an initial tendency towards defection, and thus a relatively low average score. However, this was eventually overcome in both runs by cooperation, with the average score per game converging to 3.

In Chicken, for both test runs, the average score converged to 3 per game very quickly, indicating that individuals soon adapted to swerve. Since there is not a dominant strategy, we did not observe an initial tendency towards non-cooperation like there was in Prisoner's Dilemma.

In Battle of the Sexes, the results are somewhat more difficult to interpret. The average per-game score seemed generally to converge to 2.25, suggesting a mixture of agreeing to see the same movie (alternately the player's first choice and his second choice) and insisting on seeing the first-choice movie alone. Towards the end of the length-4-history run, there was an upward trend in average score towards 2.5, suggesting consistent agreement to see the same movie, alternating between first-choice and second-choice.

In all cases the variance of the mean fitness was quite low, suggesting relatively homogeneous populations.

Conclusion and Suggestions for Further Work

This study has revealed the basic population dynamics of individuals evolving a strategy in the three games under study. It revealed that the absence of a dominant non-cooperative strategy in Chicken and Battle of the Sexes resulted in monotonic increases in average fitness over the course of the run, unlike the initial tendency towards defection in Prisoner's Dilemma.

The first step in future work would be to extend the study of these dynamics by executing repeated runs for more generations with larger populations and longer histories.

The second step would be to analyze the populations more closely to determine whether new and interesting strategies are emerging. In particular, it would be interesting to see how cooperation is coordinated in Battle of the Sexes, where "taking turns" seeing one's favorite and second-choice movies seems to emerge.

Bibliography

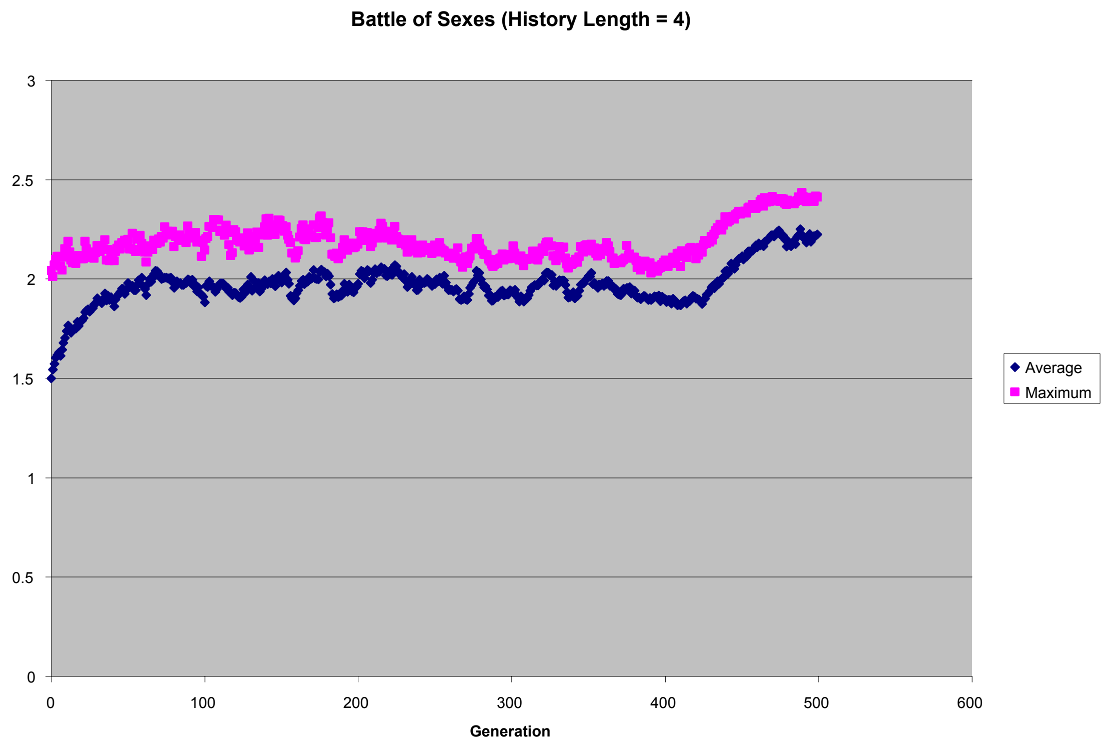
Angeline, Peter J. "An Alternate Interpretation of the Iterated Prisoner's Dilemma and the Evolution of Non-Mutual Cooperation." In *Artificial Life IV: Proceedings of the 4th International Workshop on the Synthesis and Simulation of Living Systems.* Rodney A. Brooks and Pattie Maes, eds. Cambridge: MIT Press, 1994.

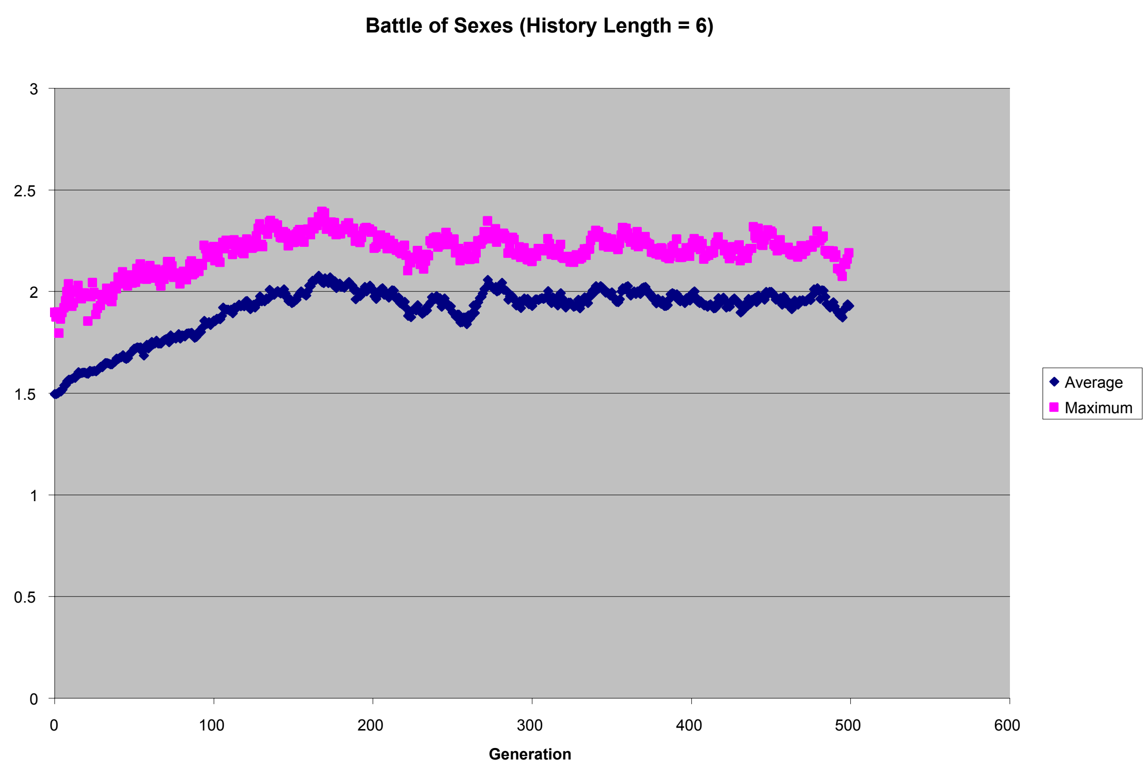
Axelrod, Robert. *The Evolution of Cooperation*. New York: Basic Books, 1984.

Beaufils, Bruno, Jean-Paul Delahaye and Philippe Mathieu. "Our Meeting With Gradual: A *Good* Strategy for the Iterated Prisoner's Dilemma." In *Artificial Life V: Proceedings of the 5th International Workshop on the Synthesis and Simulation of Living Systems.* Christopher G. Langton and Katsunori Shimohara, eds. Cambridge: MIT Press, 1997.

Colman, Andrew. *Game Theory and Experimental Games: The Study of Strategic Interaction.* New York: Pergamon Press, 1982.

Lindgren, Kristian. "Evolutionary Phenomena in Simple Dynamics." In *Artificial Life II*. C.G. Langton, C. Taylor, J.D. Farmer, and S. Rasmussen, eds. Addison-Wesley, 1991.


Battle of Sexes (History Length = 4)
3
2.5
2
1.5
1
0.5
0
0
100
200
300
400
500
600
Generation
Average
Maximum


Battle of Sexes (History Length = 6)
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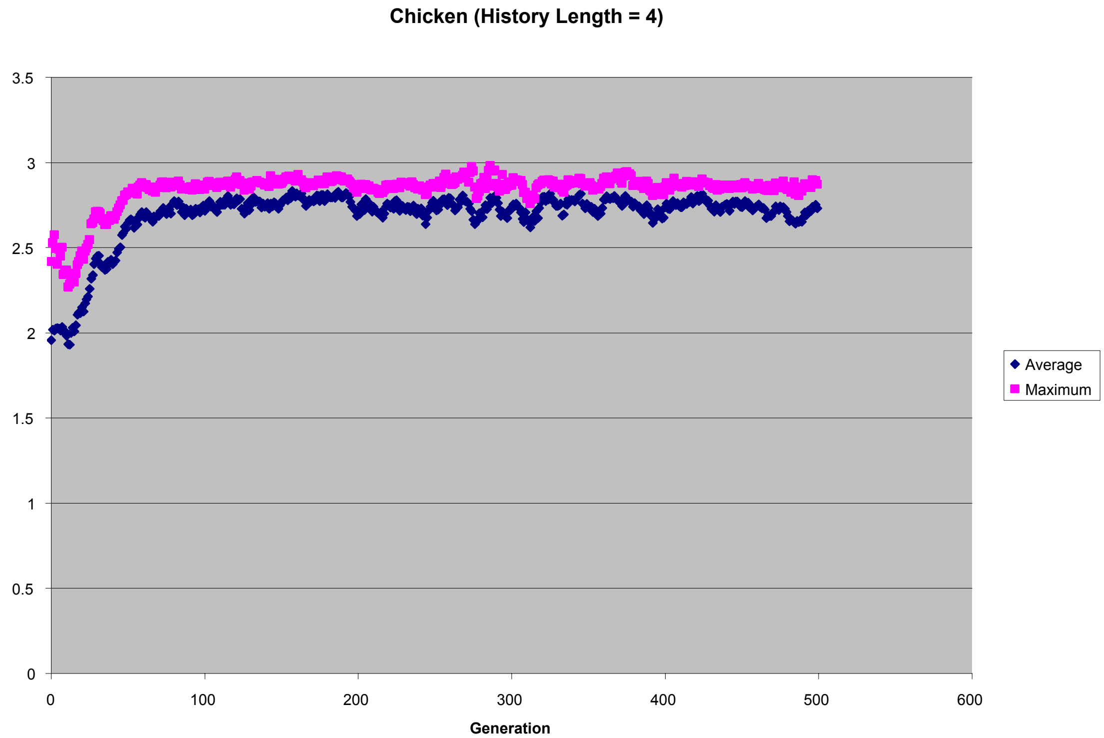
2.5
2
1.5
1
0.5
0
0
100
200
300
400
500
600
Generation
Average
Maximum


Chicken (History Length = 4)
3.5
3
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2
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0
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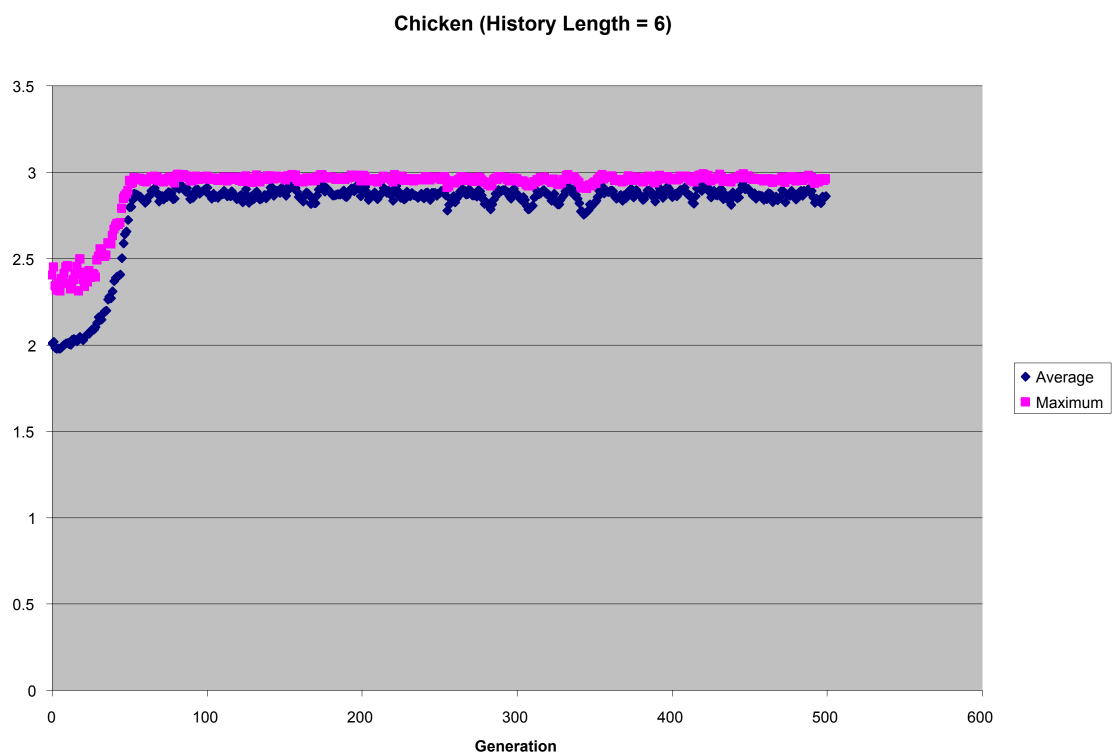
Generation
Average
Maximum


Chicken (History Length = 6)
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3
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2
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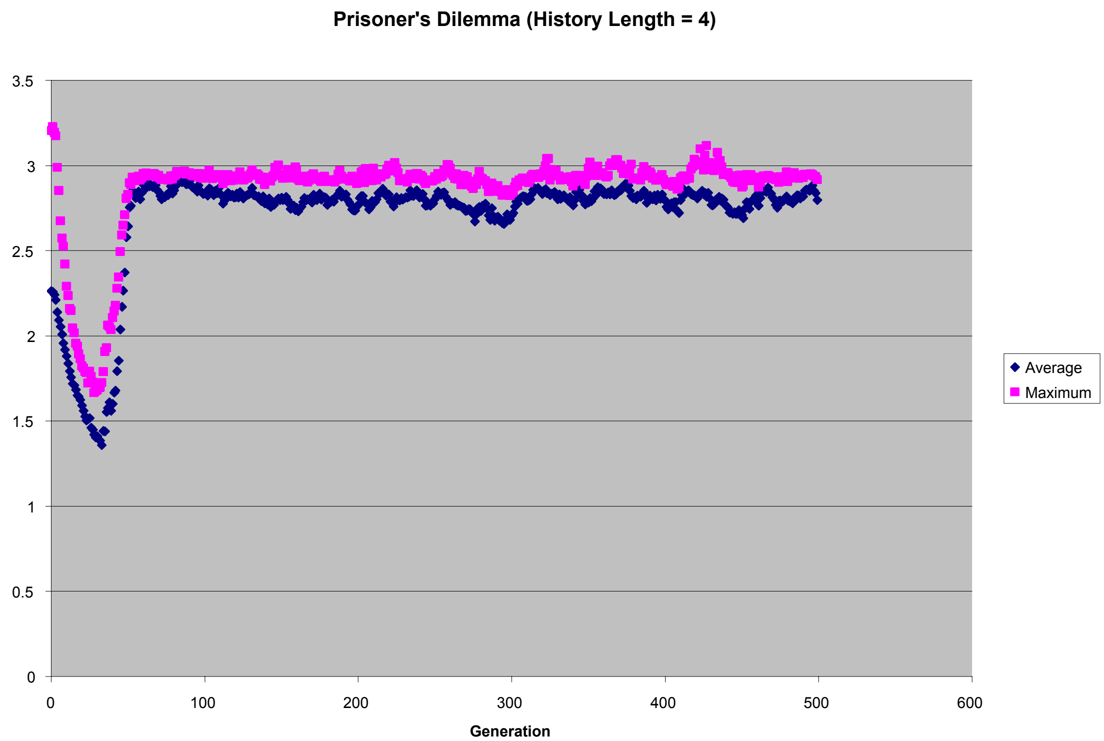
Generation
Average
Maximum


Prisoner's Dilemma (History Length = 4)
3.5
3
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500
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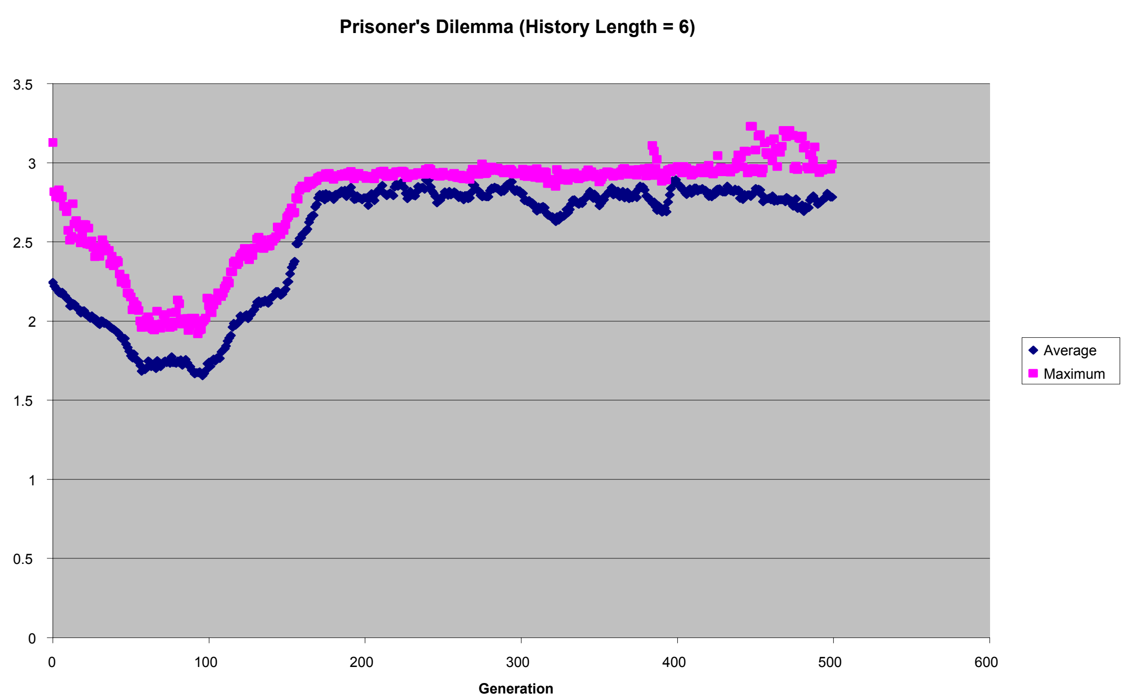
Generation
Average
Maximum


Prisoner's Dilemma (History Length = 6)
3.5
3
2.5
2
1.5
1
0.5
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0
100
200
300
400
500
600
Generation
Average
Maximum