Sex, Love, and Anger: on the evolutionary emergence of emotionally motivated gaming strategies

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Abstract: Emotions obviously play an important role in human behavior. This study seeks to determine why emotions may have evolved. It is speculated that one's genes seek to influence the individual beyond merely the construction of the individual's body at birth. Game theoretic methods have been employed, to search for Evolutionary Stable Strategies (ESSs) that would make it more likely for an individual to pass its genes on to subsequent generations. The Genetic Algorithm (GA) was used to search for evolutionary stable strategies, by evolving a population of competing strategies. Two different gaming scenarios have been considered: aggressive/aggressive-avoidance behavior and mating behavior. Results have been found that are consistent with human behavior. For instance, males and females formed relatively long-lasting relationships that fostered the development of offspring through the age of maturity. Promiscuous relationships also emerged, though favored much more heavily by males than by females. An important (and potentially new) result was found, linking the onset of female menopause to the dependence of infant survivability on the care of its mother.

Introduction and Overview

It appears to be relatively difficult for a person to control his emotions. If someone unexpectedly slugs you in the face you quite rightly become angry; if you meet an attractive male or female you might very well fall in love. But why become angry; why fall in love? It is our contention that anger, love and other emotions are evolved responses and provide an adaptive advantage to an individual. Emotions are your genes' mechanism to influence your behavior in ways that have been found, over evolutionary time, to be advantageous. This theory has been examined by running a series of games to determine if Evolutionary Stable Strategies (ESSs) emerge that are consistent with human behavior. While discovering strategies that are stable will not prove the theory (there is likely a learned component to emotions as well), it can at least point out why certain, emotionally influenced behaviors may be valuable to an individual.

Two game scenarios have been considered. The first one examines aggressive behavior to determine strategies that are advantageous to an individual when confronted by the threat of aggression. For example, it may not be a wise strategy to always turn your tail and run when threatened, because if you do, a bully can easily take advantage of you.

The second game examined is that of mating and subsequent reproduction. We are interested in answering questions such as, what sex should I choose for my child, how long should I stay married, and should I be promiscuous. Note that one doesn't get to choose the sex of a child, so strictly speaking emotions can't affect this "decision." But the genes do choose the sex of a child and fundamentally this study is about the evolution of genes.

It is traditional in game theoretic studies, for a set of strategies to be determined by an expert analyzing the system, and then a cost/benefit analysis performed to determine the evolutionary stable set of strategies. However, for anything other than the most simple of systems, no claim can be made that the original set of strategies was in any sense complete. It is a goal of this paper, especially with regards to the aggressive behavior game, to examine a more complete set of strategies to determine if initial determinations of ESSs (see, Dawkins 1976, pgs 67-76, for example) are in fact, evolutionary stable, or if they can be attacked by strategies not originally considered.

For both of the games examined, a population of randomly chosen strategies has been evolved using the Genetic Algorithm (GA) (Holland, 1975). Individuals receiving higher scores in competition with other individuals have a better chance of passing on their genes to subsequent generations. Discoveries of new strategies are obtained through the use of standard mutation and crossover operations. As the population evolves over successive generations, the highest scoring strategies tend to take over the population and a set of stable strategies should emerge after many generations of the genetic algorithm. But do stable strategies in fact emerge? Perhaps there is some detail in the randomness of the genetic algorithm that inhibits the discovery of an ESS. But if ESSs can be found with the genetic algorithm, then a statement can be made regarding the possibility of evolution affecting our emotions. Since the genetic algorithm is patterned after sexual reproduction in nature, then if the genetic algorithm can discover an ESS, then it is certainly possible that natural evolution can also learn an ESS. This would imply that there might be a component of our behavior that is an ESS, learned over the eons of evolutionary time. So the next time you get angry or fall in love, think back to the genes of your distant ancestor and wonder if perhaps your behavior is controlled, in part, by something your genes learned long ago.

Background

This study is motivated by scenarios discussed in, "The Selfish Gene," by Richard Dawkins (Dawkins 1976). In this book, Dawkins introduces game theoretic concepts and discusses several examples. Two are of interest here: 1. the gaming of aggressive behavior, in particular the dove-hawk strategy; and 2. issues related to sex determination. These two gaming studies are briefly discussed to provide a motivation for the work described in this paper.

Aggressive-Behavior Game

Dawkins uses the aggressive-behavior game to introduce game theory. In the simplest version of this game, a population of individuals, playing either the dove or the hawk strategy, competes for a predetermined prize. The prize (payoff) is given to the winner of the game, based on the strategy of the two competing individuals. For example, if a hawk plays a dove, the hawk always wins and receives a payoff of 50 points while the dove receives nothing. If a hawk plays a hawk, the winner also receives 50 points, but the loser is penalized 100 points because of the possibility of becoming injured during the fight. If a dove plays a dove, the winner (determined probabilistically) receives 40 points (50 points for winning minus 10 points for wasting time) while the loser is penalized 10 points for wasting time playing the game. Individuals with high scores survive and pass their genes on to the next generation.

The outcome of the game is that there is an ESS for a population consisting of hawks and doves. In fact, with the payoffs discussed above, the ratio of doves to hawks in the population is 5 doves for every 7 hawks. The fact that doves can coexist with hawks, can be seen by considering the average payoff of –25 for an all-hawk population. A single dove can thrive in this environment, because its payoff is 0 (much better than –25) and the single dove passes its genes on to the next generation.

Another strategy is that of the retaliator. The retaliator initially poses as a dove, but conditionally switches to hawk behavior when it meets a hawk. The retaliator drives out both doves and hawks from the population and is an ESS on its own. Perhaps you have met a retaliator; this person is a pretty decent fellow, except that he will respond in kind, if attacked.

Mating Game

As described by Dawkins, this is a simple game. Consider a population of all females. In this instance you would most certainly want to choose to have male offspring, because male children will find an ample supply of mates and you will likely have more grandchildren, thus increasing your chances of passing on your genes to subsequent generations. A similar argument exists for producing female offspring in a population of all males. It turns out that the ESS for this game is for your genes to produce a combination of 50% female and 50% male offspring.

Methods

Both games utilize a modification of the GENESIS genetic algorithm software (Grefenstette, 1990), version 5.0. Standard mutation and crossover operations are used but fitness evaluation is modified. Individuals store information (for instance, the current sex of the individual) in their own separate data structures, which are initialized in an `initializeCompetition` function, applied at the beginning of each fitness evaluation cycle.

Fitness is evaluated in a `compete` function, that passes in the individual to be evaluated, along with another individual that is optionally used in a competition to determine fitness.

The major difference in these games and standard genetic algorithm runs, is that the fitness of an individual depends on population averages (for instance, the average number of females in the population), rather than solely determined by outside criteria. This allows for behavior to emerge from the population, without being specified at the beginning. Otherwise the genetic algorithm runs are fairly standard. An initial population of strategies is created randomly (in most cases) and the algorithm is run over successive generations until a stable population is discovered.

Aggressive-Behavior Game

A standard tableau for the aggressive-behavior runs is shown in Table 1. The primary complication is that of the gene structure shown in Table 2. The genome consists of 3 genes of 2 bits each. The first gene specifies the display tactics of the individual. For instance, if the first gene is "10" then the individual displays a dove face to the world, indicating that it may act as a dove (although it could, in fact, lie, or otherwise use a conditional strategy). The second and last genes are conditional. If the competitor displays as a hawk, then the second gene is used as the fighting strategy. Otherwise, if the competitor displays as a dove, the last gene is used. The payoffs for the game are shown in Table 3.

Consider the retaliator strategy "101110." This individual presents a dove face (first two bits are "10") and acts as a dove (last two bits are "10") if it meets another dove presenter. However, if the retaliator competes with a hawk presenter, it selects the hawk strategy (middle two bits are "11"). If a retaliator meets a true hawk ("111111") it receives, on average, –25 points (50 points if it wins, -100 points if it loses). If a retaliator meets a true dove ("101010") it receives, on average, 15 points (40 points if it wins and –10 if it loses).

The structure length for the aggressive-behavior game is only 6 bits for a total search space of only 64 (hardly a challenge for the GA, especially with a population size of 48). A relative large mutation rate (.005) was chosen because premature convergence (leading to a decrease in genetic variation) was sometimes seen in the population.

Table 1. Tableau for the aggressive-behavior game.

Objective:	To discover evolutionary stable strategies for aggression/aggression avoidance problems.
Representation scheme:	Structure = bit string K = 2 L = 6 Mapping from points in search space of the problem to structure in the population = 3 genes of 2 bits each (last two genes are conditioned on value of the first, see Table 2 for gene structure).
Fitness cases:	All other individuals in the population.
Fitness:	Average score (see Table 3) obtained by an individual competing with all other members of the population.
Parameters:	Population size M = 48 Crossover rate = 0.4 Mutation rate = 0.005
Termination criteria:	1000 generations.
Result designation:	The results are determined by examining the distribution of strategies in the population during and at the end of the run.

Table 2. Gene structure for the aggressive-behavior game.

Initial, "display as" gene	bits 1-2	11 = hawk, 10 = dove, 0* = resigner
Conditional hawk gene	bits 3-4	
Conditional dove gene	bits 5-6	

Table 3. Payoffs for the aggressive-behavior game.

Fight (hawk strategy) and win	50
Fight (hawk strategy) and lose	-100
Display (dove strategy) and win	40
Display (dove strategy) and lose	-10
Resign (resigner strategy)	0

Mating Game

A standard tableau for the mating studies is shown in Table 4, with specific details regarding the gene structure in Table 5. The gene structure is relatively complicated with two general-purpose genes at the beginning of the genome selecting for death (at a specified age) and the sex of the offspring. The conditional male genes come next, selecting for the desired length of marriage and for promiscuity. The female genes follow, also containing the marriage length and promiscuity genes, as well as a gene selecting the age of menopause onset.

Table 4. Tableau for the mating game.

Objective:	To discover evolutionary stable strategies for mating behavior.
Representation scheme:	Structure = bit string $K = 2$ $L = 22$ Mapping from points in search space of the problem to structure in the population = 7 genes (first 2 are general followed by sex specific genes, see Table 5).
Fitness cases:	All other individuals in the population.
Fitness:	Number of potential grandchildren = (# myMaleChildren / # allMaleChildren) * (# allFemaleChildren - # myFemaleChildren) + # myFemaleChildren
Parameters:	Population size $M = 128$ Crossover rate = 0.7 Mutation rate = 0.001 Individual lifetime = 32 years Age of maturity = 16 years Maximum number of marriage attempts = 5 Probability of child death if no father (per year) = 0.04 Probability of child death if no mother (per year) = 0.5 Death gene application age = 50 years (i.e., normally not activated)
Termination criteria:	1000 generations.
Result designation:	The results are determined by examining the distribution of strategies in the population during and at the end of the run.

Table 5. Gene structure for the mating game.

Fatal gene	bit 1	Individual dies at a specified age if on (‘1’ = on).
Sex determination gene	bits 2-5	Probability of having a male child (‘0000’ = 0.0, ‘1111’ = 1.0, and other values in between).
Male marriage length gene	bits 6-10	Desired length of marriage (integer from 0 to 31 years).
Male promiscuity gene	bit 11	Male is promiscuous if on (‘1’ is on).
Female marriage length gene	bits 12-16	Desired length of marriage (integer from 0 to 31 years).
Female promiscuity gene	bit 17	Female is promiscuous if on (‘1’ is on).
Female menopause gene	18-22	Age of menopause onset (integer from 0 to 31 years).

The algorithm for mate selection is fairly complicated. Females are allowed to chose their mates based on a cooperatively agreed upon marriage length. A female chooses the first male she finds that seeks the same marriage length as her own. Otherwise, she chooses the male seeking the nearest marriage length to her own. Once a mate is chosen, the couple enters the birthing cycle, where a child is born (one per year) and each child is subsequently raised to maturity (16 years). There is a distinct probability that a child may not reach maturity, if both parents are not present to care for the child (a marriage may end before maturity or one or both parents may die). If the father deserts the child (for the entire 16 years to maturity), the child has roughly a 50% probability of surviving. Offspring of females that desert their children are penalized much more heavily (see Table 4). Up to 5 marriage are permitted, but individuals are penalized a year of life for each marriage over the first (this assumes that it takes some time to negotiate a marriage contract).

Promiscuous behavior (children born outside of marriage) is allowed between male and females if the promiscuity gene is turned on. It is assumed that fathers refuse to support children born in promiscuous relationships. Both mothers and fathers are penalized for entering these temporary relationships, because the child may die before maturity. Each individual is given an opportunity for a promiscuous relationship, both before marriage and then each year during marriage. Promiscuous mates are chosen at random from the population of the opposite sex.

Fitness is proportional to the number of potential grandchildren an individual may ultimately produce. An individual's fitness is roughly proportional to the number of female children plus the number of male children the individual has. A male child in a population of females is worth more that a female child, because it can potentially sire children with all of the available females. So for fitness evaluations, the number of male children is scaled by the number of available females (not including sisters), divided by the number of males in the overall child population (see Table 5).

Results

Aggressive-Behavior Game

Figure 1. Distribution of hawk and dove strategies in a population of only hawks and doves.

A simple test of the aggressive-behavior game can be obtained if only hawk and dove strategies are allowed (other strategies are heavily penalized). The results of this test are shown in Figure 1, where hawks initially dominate the population (by design), but doves rapidly grow by generation 20 to be roughly 5/12 of the population, exactly as predicted by theory (Dawkins 1976). Dawkins also finds that the retaliator strategy (display as a dove, hawk if hawk opponent, dove if dove opponent) is an ESS in a population of hawks, doves and bullies (display as hawk, dove if hawk opponent, hawk if dove opponent). Results from runs allowing only this population mix also show the retaliator emerging as an ESS. Thus, it appears that the aggressive-behavior game using the GA for population evolution functions correctly.

Figure 2. Distribution of dominant strategies in the aggressive-behavior game.

Results from the aggressive-behavior game are shown in Figure 2. In this figure, four dominant strategies are shown: the hawk, the bully and the retaliator, along with a new strategy, the dove-faker (display as dove, hawk if hawk opponent, hawk if dove opponent). Other strategies are proportionally smaller in number and are not shown. Notice the clear pattern of two distinct sets of ESSs. One ESS is the combination of the retaliator and dove-faker strategies (from generation 50 to 200) and the other is the hawk and bully strategies (from generation 200 to 400). Examination of the results beyond 400 generations (not shown in the figure) shows additional jumps between the two sets of ESSs.

Careful examination of the two ESSs in Figure 2 shows basically the same hawk and dove behavior as seen in Figure 1. For example, the dove-faker entices the retaliator into its conditional dove strategy and then plays the hawk. Thus, the retaliators (playing the dove role) are roughly 5/12 of the population, as doves were in Figure 1.

The phase changes seen in Figure 2 are facilitated by additional strategies (not shown in the figure). For example, the transition near generation 200 is facilitated by the retaliator-hunter strategy (display as dove, dove if hawk opponent, hawk if dove opponent). In a population of retaliators and dove-fakers, the retaliator-hunter plays the hawk role and wins all competitions with retaliators. A more detailed examination of the distribution of strategies than is shown in Figure 2, shows that retaliator-hunters slowly build up in number to around 10 at generation 207. At this point a hawk (previously extinct) is created by a mutation. The hawk strategy wins against the retaliator-hunter, as the retaliator-hunter plays the dove role to the hawk. Thus, in simplistic terms, what is occurring is a transfer of energy from the retaliator population, to the retaliator-hunter population, and then finally to the hawk population. The end result is that the retaliator population dwindles in numbers until driven extinct. At this point the retaliator-hunter is driven extinct by the retaliator and bully strategies and the phase change is complete.

Figure 3. Results of the mating game showing the percentage of males in the population.

Mating Game

Dawkins predicts that the ESS for the ratio of males to females in a population is 50%. This is exactly what is seen to occur in Figure 3. To make sure that this is not a statistical fluke several tests were run. In one test, the sexual distribution function was weighted to give females the advantage, on average. In others, the distribution of probabilities actually chosen by the second gene after 1000 generations was examined for several different random seeds. In all cases, the results show that individuals are making a decision on the sex of their children and they chose roughly half females and half males, as predicted.

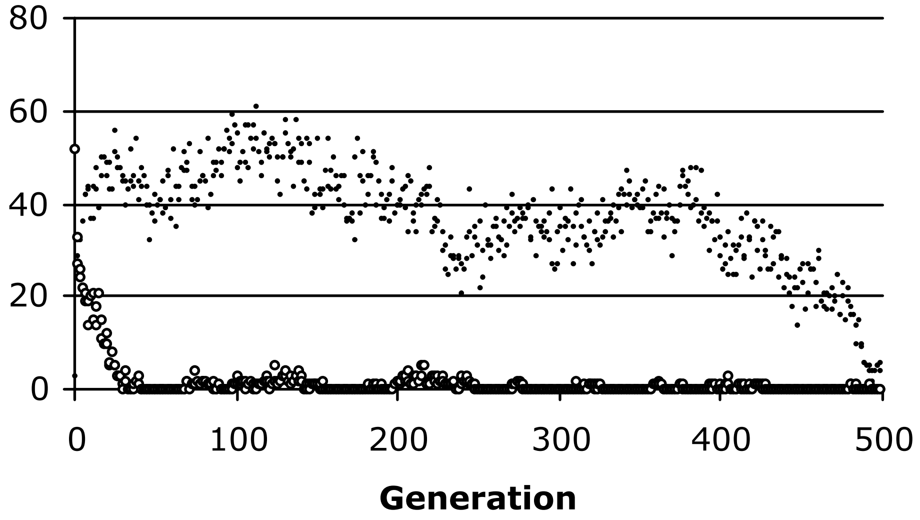

Figure 4. Results of the mating game showing the number of promiscuous males and females in the population.

The rate of promiscuous relationships can be seen in Figure 4. At the start, the promiscuous gene is randomly distributed in the population and roughly half the males and females have the gene. However, females rapidly learn that being promiscuous is not in their best interest, because males do not help with raising offspring and there is an increased probability of the child dying before maturity. By generation 50, the promiscuity gene is driven to extinction in the female population and only appears in the female population from time to time due to random mutations. Males, on the other hand, rapidly pick up the promiscuous gene, because it tends to increase the total number of their children. After generation 150, the male promiscuity gene is no longer actively selected for (there are too few promiscuous females to mate with), and it slowly dies out (purely by chance as other runs show it persisting through generation 500).

Examination of the gene selecting for marriage length shows it tends to be strongly peaked at single values. Four runs were examined with different initial random seeds and the dominant lengths of marriage were 22, 19, 19, and 22 years. These lengths are all longer than the time it takes for a child to reach maturity (16 years).

Several runs were made, each time varying the time of onset of the fatal gene. It was found that the fatal gene was almost always off, except for a small window of time near the end of the life expectancy of an individual as an adult (32 years). Even then the percentage of population with the gene turned on was relatively low (less than 15% at 31 years). This is another indication that the game is working correctly, as the GA has discovered that it is a good strategy to live as long as possible.

Several additional runs were also made, this time varying the random seed to examine the distribution of the ages chosen for the onset of female menopause. Menopause primarily occurs after the age of 22 and is roughly evenly distributed through the age range of 22 to 31 years. Thus, menopause onset was chosen to occur, in many cases, significantly before the female dies. A surprising result was found by decreasing the probability that a child will die when disserted by its mother. When this probability (see Table 4) was lowered to 0.4 (the same value as that for a deadbeat dad), the age for menopause onset jumped to 31, allowing females to effectively bear children until they die.

Discussion of Results

Aggressive-Behavior Game

It is interesting to note that the retaliator strategy is not an ESS by itself, as suggested by Dawkins (Dawkins 1776). It is an ESS only in combination with the dove-faker strategy. Even then the retaliator strategy can be attacked by the hawk-bully combination, when aided by the retaliator-hunter strategy. So indeed, one of the major purposes of this investigation has been born out. An evaluation of simple strategies by analytic means is useful for developing an understanding of a game theoretic situation, but reality can be more complex than simple strategies and the resultant outcomes may indicate. Certainly, in this case, an exhaustive search of the full range of possible strategies contained in the 6-bit genome led to a discovery of interesting new strategies and combinations of strategies.

However, a word of caution should be given regarding these results. First, it is not clear that the 6-bit genome fairly plays the strategies described by Dawkins. Dawkins describes the retaliator as playing hawk against hawk competitors and dove against dove competitors. A subtle difference in the retaliator strategy employed here is that it first displays as a dove, discovers how the opponent displays, and then conditionally responds to the opponents display, not how the opponent actually plays. This implies that a strategy can lie as to its true intentions, as the dove-faker strategy does (it displays as a dove but plays all hawk). Since Dawkins discusses the role of lying by individual strategies, it is felt that the 6-bit genome is an adequate representation of the simple aggressive-behavior game.

In reality, lying or posturing plays an import role in games of international conflict. In games of conflict between nations possessing nuclear weapons, it is the nation that can threaten the most convincingly that wins, since no “sane” nation will actually use nuclear weapons [Powell 2002]. For a too-real example, consider the massing of armies at the border between India and Pakistan in May of 2002. So the posturing phase of the 6-bit genome is probably a workable solution for describing reality in a simple strategy game.

How close does this strategy game come to describing human behavior? Well, certainly humans do have strong emotions that give guidance to our ultimate behavior, emotions such as fear, hate, and anger. Fear is consistent with the dove strategy in that it leads to a backing away from conflict. Anger is consistent with supporting a retaliator strategy to help overcome the fear of becoming hurt in a conflict. A deeply seated feeling of hate might support a hawk individual, one who is willing fight to the death. In addition, the results of this study show a much more complicated evolutionary mix of strategies than does the description of Dawkins.

Mating Game

This strategy game clearly tracks the 50% ratio of males to females in the human population. No amount of twiddling with free parameters changed this result. In all of the evolutionary runs, the sex ratio quickly converged to 50%, after a few initial transient fluctuations. While the sex ratio is not determined by emotion, these results are consistent with the conclusion that our genes control this ratio and that the sex ratio is the value it is because 50% is an evolutionary stable strategy.

The results regarding promiscuous relationships also seem to track human behavior. While no hard data is given to support this conclusion, it is proposed that more males seek to engage in promiscuous behavior than do females. Certainly, there exists more employment for female prostitutes than for heterosexual male prostitutes.

Somewhat surprising then, it was found that marriage contracts tended to be relatively long, a few years longer than the age of maturity (16 years) for children. Given the difference in promiscuous behavior between males and females, it might have been expected for males to seek shorter-term commitments than do females. So why is there not a difference? Well, males were allowed to father additional children outside of marriage, to increase their net production, so there was no real advantage (at least until the promiscuous female population went extinct) for males to seek zero year marriage contracts (effectively becoming promiscuous, although it is noted that this possibility, unfortunately, was not actually allowed by the mating algorithm).

However, there is a deeper reason for long term contracts to be sought for by the male population (and for the distribution of contract lengths to be strongly peaked at a single value). There are clear advantages to the female in long-term contracts and the males must cooperate with the females to form a marriage. It is proposed that this is a clear signature of emergent cooperative behavior. Females seek long-term relationships, males must cooperate with the females to agree on the term of the relationship, and the actual length of the contract that emerges is discovered jointly by the entire population. So the cooperatively determined length of the marriage contract tends to be the same throughout the population (but the actual length that emerges varies from run to run). This is reminiscent of the cooperation needed to evolve joint communication signals between males and females to enhance mating opportunities as reported by Werner and Dyer (Werner 1990).

So why do we die? The fatal gene is always off at younger ages, but sometimes it is on very near the enforced death of an individual at 32 years of age. Of course if the fatal gene is expressed at a very early age, the population will go extinct, so there is high selection pressure on finding a “cure” for fatal genes with an early onset. However, this is not true for fatal genes with a late onset, especially if the onset occurs after the childbearing age (menopause). As stated, this is essentially the theory for death as outlined by Dawkins. While the results of this study are consistent with this theory, they are only weakly so, as only a few individuals in the population actually have this gene, even at an onset age of 31.

A potential link between the child-rearing tactics of a female and the age of menopause has been found. Normally there is a high probability that a child will die if uncared for by its mother. Thus, there is no advantage for a female to have children late in life because the children will tend to die anyway. Therefore, there is no reason for the female to extend the age of menopause. However, if it is likely that a child will survive the death of its mother, then there is an advantage given to females who can extend the age of childbearing. This is exactly the trend of the results found in the test runs related to menopause age. It appears that menopause in females may be related to an increased commitment by females (relative to males) to care for their young until they reach maturity. This may be a new conclusion (although an exhaustive literature search has not been done to make this determination).

Conclusion

Consider the amount of resources that humans expend thinking about sex. Love and romance are everywhere. It is in our books, in our music, and in our movies. Therefore, it is not a reach to suggest that emotions deeply influence human behavior. Certainly, no one can claim that love and the strong emotional bond of a parent to its child is not a contributing factor in human behavior. What is not so obvious is the reason why one may feel anger or why does one falls in love.

The results of this study support the theory that emotions have evolved to influence human behavior in a manner that is consistent with evolutionary stable strategies. We may feel anger because anger leads to a retaliator strategy that is an ESS. We may feel love and we may bond strongly with our children, because these emotions act to increase the probability that we will act in ways to increase the likelihood that we will have children, and that we will form relationships (like marriage), that increase the probability that our children will survive to pass on our genes.

Future Work

There is a lot that can be done to improve on this study. Probably, the most important task would be to do a more thorough statistical analysis, especially, considering that the genetic algorithm is probabilistic and that the results for a given run depend on the initial random seed. It would be valuable to compare the results of an improved statistical analysis, with population studies in humans, to more carefully compare gaming strategies with observed human behavior.

It would also be fruitful to expand the study so that the full range of primate mating behavior could be addressed. The primates display a wonderfully broad range of mating behaviors. What conditions might lead to different ESSs evolved by the primates and what can this tell us about how our behavior evolved?

On a more technical nature, it is suggested that tournament selection more closely represents the spirit of gaming than does roulette wheel selection based on fitness, as used here.

Acknowledgements

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