Hawk-Dove Tournament: A New Selection Technique for Genetic Algorithms Based on Evolutionary Game Theory

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Abstract - This paper presents a new selection method for Genetic Algorithms based upon the concepts of the Evolutionary Game Theory, enabling individuals to compete for available resources. Hence they have the possibility to alter their adaptability and as an effect, assume an influential role on the generation of offspring. The results of some simulations of this technique are presented and compared with other selection methods, like: Traditional Roulette, Tournament and Hawk-Dove Roulette (HDR).

Keywords: Genetic Algorithms, Evolutionary Game Theory, Hawk-Dove Game, Tournament Selection Method.

1 Introduction

Evolutionary Computation is an area that seeks inspiration on the optimization process established by Nature itself, known as Evolution. By bearing in mind the principle that, from a few chains of molecules, Nature was capable of creating complex beings that are able to understand and control their own existences, the simulation of this process and its adaptation to solving problems and optimizing their solutions can produce very satisfactory results \[1\].

In the Evolutionary Computation area, a highlight are the Genetic Algorithms (GA), which are grounded to the concepts of Genetics and Charles Darwin’s Natural Selection, modeling the biological operators of selection, crossover and mutation, thus enabling problem solving, function optimization and finding solutions with more adaptability (fitness) \[3\].

Despite the fact that there are still many aspects to be studied and fully comprehended, such as a high degree of randomness, which is completely against the Evolution’s principles, Genetic Algorithms are applicable to a wide array of knowledge domains with a significant amount of successful cases.

Considering this issue as a starting point, many researchers have proposed the aggregation of new biological variables (biologically plausible) to the canonical structure of the GAs, thus reducing its degree of randomness and achieving better results in shorter execution cycles \[4\].

Yet in a somehow inexpressive form, one of the techniques that have been employed to divert from this problem is the Evolutionary Game Theory, proposed by a biologist, John Maynard Smith (1920-2004), appealing to mathematical descriptions of the interaction among the individuals on the struggle to get natural resources \[5\].

The Evolutionary Game Theory defines the individuals (chromosomes) as active agents that can alter their fitness values through contest. So, effectively, the adaptability of individuals is no more calculated based only upon their genetic material. In the proposed approach, the calculation of this value relies also on phenotype (environment plus genotype), in a way much alike what happens in Nature.

This article presents the Evolutionary Game Theory, along with the GA Selection Operator, as a means to optimize the functioning of the GA itself. In order to attain this, a new selection method, named Hawk-Dove Tournament \[6\], is presented. In order to exemplify the application of this method, some results of tests for the Symmetric Traveling Salesman Problem (TSP) are described.

2 Genetic Algorithms

The Genetic Algorithms were developed by John Holland in the 1960’s and 1970’s, and became popular in the 1980’s, when one of his students, David Goldberg, applied the theory on the solution of a pipeline optimization problem \[3\].

The GA is defined in \[4\] as a method of moving from one population to another, with the aid of some kind of “Natural Selection” and also other genetic operators as mutation and crossover. The former substitutes a gene for an allele in a random manner, whereas in the latter process the chosen chromosomes exchange pieces, thus generating new possible solutions. The main process is repeated until a satisfactory solution is found.

Altogether, GAs are quite efficient search algorithms, as they implement in a primitive way some of the processes of natural evolution. They are strongly recommended for...
function optimization or pattern recognition and classification, since their structure permits an efficient search in a very big space of possible solutions [1].

Nowadays, despite the knowledge that GAs have absorbed other areas and besides that, are much closer to a biological simulation tool, the structure originally proposed by Holland is still valid, and is defended by many authors, and is called Canonical GA or Simple GA [7].

This canonical form consists in: generate, based on a model of the problem, a population of candidate solutions (chromosomes); evaluate the fitness of each individual solution, which can be understood as a probability of that solution generate new descendants, with its genetic material; then, apply the selection, crossover and mutation operators on the solutions, and repeat the process until a satisfactory result is found, or when a number of generations has been reached [3].

In [5] it is stated that the selection operation is highly connected to the value of the individuals’ chromosomes, most of the times using the fitness values to guide the choice of individuals that will transmit their material to the next generation. This makes the more qualified individuals go through the crossover operator more times, establishing a parallel with the Natural Selection process, presented by Charles Darwin in his “Origin of the Species”.

Several methods have been proposed to carry out the selection operator. The spotlight goes to the Roulette method, which relies upon a selection based on fitness, a traditional and easy to implement approach. The more recent Tournament method is widely considered to be more efficient, computationally – $O(n)$ – as much as to make possible a better exploration of the surface of search able solutions [8].

The Crossover Operator is the characteristic that makes GAs quite unique amongst other techniques, and is considered the most important of the genetic operators. Besides that, it is the first manner that a GA employs to explore the search surface within the genetic material (alleles) that is already on the individuals of the population, leading the GA to convergence of results [3].

Crossover generally consists in an exchange of pieces (parts) of chromosomes between the individuals selected as parents, so that theoretically more adapted individuals are created as a result of this process. Some methods of applying this operator are: 1-point crossover, 2-point crossover and partial mapping (PMX) [9].

According to [3], the mutation operator is the second method a GA has to explore the problem’s search surface. It can introduce an allele that was absent from the population, avoiding a premature convergence and thus “escaping” from local optima.

The mutation operation makes small changes on the population, replacing the contents of a gene by an element of the alphabet of alleles randomly and with a small probability for each gene [1].

The next section presents the most important concepts about the Evolutionary Game Theory, specifically the Hawk-Dove Game.

3 The Hawk-Dove Game

Humans, animals and generally all living beings take part in games, ranging from a simple chess match to maneuvers in international politics, from quarrels to conquer the opposite sex to competition between two big companies that want to gain control of a specific market.

Game Theory can be defined as the formal description of the conflicting interests among participants. These have at their disposal a string of options to choose from. They make choices, aiming for the best strategy, and the aggregate of choices made by all participants determines the results obtained by each of them [10].

The formal study of what is today known as Game Theory is a relatively recent field, and had a high practical applicability in several grounds. It has evolved from a tool for mathematical analysis to guide improvements to revolutionize paradigms of areas such as Economy and Evolutionary Biology [10].

In this context there is a particular class, Evolutionary Games, coming from the works of John Maynard Smith e G. R. Price (1973) who, working independently, rediscovered the concept of Nash Equilibrium, calling it Evolutionary Stable Strategy – ESS [11].

The line between Game Theory and Evolutionary Game Theory is drawn in [5] by asserting that on the latter the participants (players) are biologically or socially conditioned, while on the former the game is analyzed as if all players were completely rational and knew all the rules of the game and the preferences of their opponents.

In [11], some Evolutionary Games are proposed, Hawk-Dove amongst them, modeling the contention between animals for a resource with a given value (V). To obtain this resource means an increase of the Darwin’s adaptability (fitness), and the loss does not imply in any decrease of the adaptability that the individual already possesses.

The resource can be associated to several biological factors, the search for food, sexual competition, the struggle for shelter, and many more. The increase in the adaptability directly reflects on the amount of expected offspring, i.e. the individual that gets the resource gets the ability to generate a greater amount of descendants, while the expected offspring
to the individual that loses the dispute remains the same as before it [11].

In the game proposed by [11], each player (individual) may assume two different strategies (behaviors): Hawk, non-cooperative, which fights for the resource until it is hurt or the opponent runs away, so characterized by aggressive behavior; Dove, cooperative, which is meek and never participates in physical quarrels with an opponent, opting to compete through exhibition and always running away if an aggressive opponent (Hawk) is met.

Based upon this characterization, [11] proposes the following payoff table for this game:

This table should be read considering the player as one line; the opponent is one column; the expected value for the player is shown in the crossing between line and column. The following situations may be observed:

Table 1. Payoff table for Hawk-Dove game

<table>
<thead>
<tr>
<th></th>
<th>Hawk</th>
<th>Dove</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hawk</td>
<td>$\frac{V-C}{2}$</td>
<td>$V$</td>
</tr>
<tr>
<td>Dove</td>
<td>0</td>
<td>$\frac{V}{2}$</td>
</tr>
</tbody>
</table>

*Hawk vs. Hawk:* in this contest both participants have equal probabilities of getting hurt and have its fitness reduced at a cost (C) or obtaining the resource (V) and increase its fitness;

*Hawk vs. Dove (or Dove vs. Hawk):* the Dove competitor does not suffer any change in its fitness; the Hawk competitor sees its fitness increase by the prize value (V);

*Dove vs. Dove:* the prize is shared between both individuals, and each fitness is increased by V/2.

4 **Hawk-Dove Tournament (HDT)**

This method is based on the recent proposal for applying the Evolutionary Game Theory on Genetic Algorithms, especially its Selection Operator, according to the Hawk-Dove Roulette (HDR) method, proposed by [5].

Both HDR and HDT rely on the fact that most selection methods consider the chromosome’s fitness is directly linked to its genotype. In this case, to increase fitness and try to obtain a better chance of transmitting its genetic material, a chromosome would need to change its genotype, something that, under the GA’s optics, results in a different individual, as this is born with its fitness defined on genotypic level.

These methods aim at guaranteeing a higher probability for the chromosomes to transfer their genetic code, acting also at phenotypic level. So the individuals compete in a moment of the generation prior to the selection, in an attempt to enhance their fitness. A consequence is a better control of the selective pressure, such as a premature convergence is avoided and local optima are prevented.

Both selection methods (HDR and HDT) are divided chronologically and structurally into two parts: firstly the individuals play the Hawk-Dove game; then the selection method itself takes place, Roulette or Tournament, according to the chosen method.

The game is divided into several matches (configurable parameter), involving two participants which are randomly selected amongst the population. Their fitness values are altered, increased or decreased, according to their behavior:

*Hawk vs. Hawk:* the gain of fitness for both individuals is measured by the cost of the contention (C) and prize (resource) value (V), according to the formula $\frac{1}{2}(V-C)$. If the cost for getting hurt is higher than the prize value, the individuals will suffer a decrease in fitness;

*Hawk vs. Dove (or Dove vs. Hawk):* the Dove competitor does not suffer any change in its fitness; the Hawk competitor sees its fitness increase by the prize value (V);

*Dove vs. Dove:* the prize is shared between both individuals, and each fitness is increased by V/2.

The Hawk-Dove Tournament method states that, after the game, the selection takes place based on the approach defined by [1]: two individuals are chosen from the population randomly, and the one with the higher fitness “wins” the contest and is chosen as one of the possible parents. This process is repeated until the expected number of parents is reached. The algorithm for this method is described as:

1. Generate initial population;
2. Evaluate each individual of the initial population;
3. Repeat until m generations:
   3.1. Repeat until x contests:
      3.1.1. Select two individuals randomly;
      3.1.2. Obtain the behavior of each individual;
      3.1.3. Alter the fitness of the individuals according to their behaviors, and the payoff table;
   3.2. Repeat until p parents are obtained:
      3.2.1. Select two individuals randomly;
      3.2.2. Compare the fitness values of the individuals;
      3.2.3. Select the individual with the higher fitness value and store on the mating pool;
3.3. Repeat until the number of descendants (offspring) is equal to the desired amount (% of crossover)
3.3.1. Select two individuals randomly from the mating pool;
3.3.2. Perform the crossover operation for the individuals selected on the previous step;
3.3.3. Perform the mutation operation on the offspring individuals generated on the previous step;
3.3.4. Evaluate the offspring individuals;
4. Substitute the individuals of the population by the individuals (offspring) generated on the crossover step;
5. The individual with the best fitness is the solution to the problem.

5 Simulations and Results

In order to evaluate these proposals, a testing tool was developed and the Symmetrical Traveling Salesman Problem (STSP) applied to the road distances among the 26 Brazilian capitals was used as a case study [12].

The results of these simulations are shown at table 2.

Table 2. Results of simulations

<table>
<thead>
<tr>
<th>Method</th>
<th>Worst Distance (km)</th>
<th>Best Distance (km)</th>
<th>Average Distance (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roulette</td>
<td>20696</td>
<td>26170</td>
<td>27432.19</td>
</tr>
<tr>
<td>Tournament</td>
<td>83960</td>
<td>28215</td>
<td>30613.04</td>
</tr>
<tr>
<td>HDR [C,V] = [20,30]</td>
<td>82008</td>
<td>20113</td>
<td>22502.81</td>
</tr>
<tr>
<td>HDR [C,V] = [30,20]</td>
<td>83561</td>
<td>21594</td>
<td>23108.86</td>
</tr>
<tr>
<td>HDT [C,V] = [20,30]</td>
<td>82505</td>
<td>24820</td>
<td>30870.89</td>
</tr>
<tr>
<td>HDT [C,V] = [30,20]</td>
<td>83062</td>
<td>22840</td>
<td>25752.64</td>
</tr>
</tbody>
</table>

The simulations demonstrate a substantial improvement on the results, compared to traditional methods that do not involve Evolutionary Games, even though the HDR method got to the best solution with 20113.

In traditional methods, from the moment that the algorithm converges to a local minimum, it is unlikely that the GA will evolve again. With the application of the Hawk-Dove game, as can be seen in figure 1, after a considerable initial evolution, a slight variation can be observed on the left graph, and a big one on the right graph, a clear display of the capacity of the technique to escape from local optima.

6 Final Remarks

The applicability of Game Theory to optimize the Genetic Algorithms is an area yet to be more studied and developed. Combinations of selection methods with games open a wide field of possibilities that need to be explored, considering the amount of games and selection methods available. The use of HDT in mating pools for interaction of individuals on parallel genetic algorithms is a step forward considered to be studied.

The Hawk-Dove Tournament method applied to the solving of the Symmetric Traveling Salesman Problem for the 26 Brazilian capitals demonstrated to be quite efficient compared to the traditional Roulette and Tournament methods, getting to find best solutions by enabling individuals to work also at phenotypic level. The capacity to escape from local optima is a desirable feature as well, demonstrating the power of using this technique as a selection method.

7 References


