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Game Theory, the Hawk-Dove Game and its Applications in Species Survival

Introduction to Game Theory

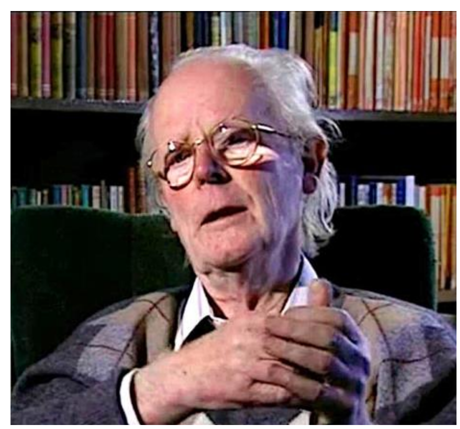
What is Game Theory?

Hungarian American mathematician John von Newmann is commonly considered as the father of game theory.

Source: Wikimedia foundation

Game theory is a mathematical framework in applied mathematics used to analyze situations in which agents, called players, make interdependent decisions. Classical game theory was founded in 1944 by mathematician John von Newmann, in his 1928 paper *On the Theory of Games of Strategy*. Game theory studies how players make decisions, how they affect each other, and how these effects determine the outcome, or, payoff, for each participant. It can be argued that game theory is essentially the science of strategy in a system with rational players. Using game theory, real-world situations can be applied to a mathematical system. [Investopedia, n.d.]. In spite of being a relatively new field of mathematics, game theory is used extensively in a broad spectrum of fields, such as economics, politics, computer science and, in this case, evolutionary biology.

An Introduction to Evolutionary Game Theory



John Maynard Smith FRS pioneered the use of the Hawk-Dove game in evolutionary game theory.

Source: Wikimedia foundation

Evolutionary game theory is the application of classical mathematical game theory to biological contexts. It rose from the realization that the behaviors that organisms use to survive can be classified as strategies, or decisions on individual games. [Britannica, n.d.].

Evolutionary game theory was first developed by British polymath Ronald Fisher in his paper *The Genetic Theory of Natural Selection,* which attempted to explain why the sex ratio is approximately equal in many species even though the male never mates. However, the main breakthrough came with British biologist John Maynard Smith, who pioneered the modelling of evolutionary games, most notably the Hawk-Dove game. [R. Dawkins, *The Selfish Gene,* 1976].

‘Chicken’ and the Hawk-Dove Game

An Introduction to Chicken and the Hawk-Dove Game

The chicken game in game theory, otherwise known as the hawk-dove game when applied in evolutionary biology, is a mathematical model for conflict between two players. In principle, the chicken game represents a scenario in which players try to taunt one other into surrendering. Surrendering is avoided, as it comes at a price that varies depending on the context. The loser is nicknamed the ‘chicken,’ hence the name of the model.

The two strategies explored in the Hawk-Dove Game are quite similar, and are listed below [R.Dawkins, 1976]:

1. **Hawk:** An aggressive strategy in which the individual tries to cause conflict over a resource until the opponent has retreated or both players are injured.
2. **Dove:** A more peaceful strategy in which the individual relies on intimidation to win but surrenders if conflict is caused.

Rules:

1. If two hawks, they fight until one is injured or killed.
2. If a hawk and a dove meet, the dove is intimidated and thus surrenders, therefore losing. The hawk wins without a fight.
3. If two doves meet, they share the resource.
4. Winning is preferred over a tie.
5. A tie is preferred over losing.

V represents the value of the contested resource and *C* represents the cost of the fight. For the sake of the model, it is always assumed that value *‘V’* costs less than the cost of the fight *‘C’* ($C > V > 0$). [J.Maynard, 2004]. In a payoff matrix, if two individuals with the same strategy meet, the resource is split equally as an average value.

In essence, the Hawk-Dove Game is an anti-coordination game, wherein it is beneficial for both players to make different choices. Two mixed-strategy Nash equilibria are created, meaning that when a Hawk and a Dove meet, neither can benefit by changing their strategy.

The mathematical model of the Hawk-Dove game has been a subject of extensive research in game theory. All possible results of the game can be displayed in a payoff matrix, as is shown in Figure 1 (a visual representation of all possible outcomes):

For easier visualization, arbitrarily numerical values can be assigned to *V* and *C*, as is shown in Figure 2:

	Hawk	Dove
Hawk	*(V-C)/2, (V-C)/2,*	*0, V*
Dove	*V, 0*	*V/2, V/2*

Figure 1: a payoff matrix of the Hawk-Dove Game

	Hawk	Dove
Hawk	*-150, -150*	*1500, 0*
Dove	*0, 1500*	*750, 750*

V = *1500*

C = *1800*

Figure 2: a payoff matrix of the Hawk-Dove Game, with assigned values for *V* and *C*

In some versions of the Hawk-Dove game, an extra penalty is added for time wasted. This can be made into another payoff matrix, this time with the variable '*T*' representing the penalty, as is shown in Figure 3:

	Hawk	Dove
Hawk	*-150, -150*	*1500, -200*
Dove	*-200, 1500*	*750, 750*

V = *1500*

C = *1800*

T = *-200*

Figure 3: a payoff matrix of the Hawk-Dove Game, with assigned values for *V, C* and *T.*

In this scenario, when a Hawk and a Dove meet, the Dove leaves with a penalty of 200 (0 – 200).

An Analysis of the Hawk-Dove Game

Using the example created above, one can begin an analysis of the Hawk-Dove game, eventually leading to a method with which one can calculate the ideal ratio of Hawks to Doves in a population. The first thing that one should notice that it is not an Evolutionary Stable Strategy (ESS) for a population to consists completely of Hawks or Doves. A population completely consisting of Hawks is susceptible to a mutant strain of Doves. As can be seen from Figure 2, Hawks, on average, incur a penalty of 150 every time they fight. Doves, however, being pacifists, incur no penalty (0 > - 150). Therefore, the population of doves is likely to increase. On the other end of the spectrum, a population consisting completely of Doves is susceptible to mutant Hawk strains. Since the payoff for the Hawk for each interaction it has with a Dove is 1500, it puts the Hawk at a great advantage over the Doves (1500 > 750). Given the above statements, it is reasonable to assume that the ratio of Hawks to Doves is likely to oscillate, though an equilibrium can be expected to be reached eventually. [R. Dawkins, 1976]

Given this information, a method for calculating the stable equilibrium between the Hawk and Dove populations can be created.

Let the proportion of Hawks in a population be p, and the proportion of doves be $p – 1$.

Thus, the average payoff of Hawks (H) can be calculated as:

$$H = p \times \frac{(V-C)}{2} + V(1-p)$$

Therefore, the average payoff of Doves (D) can be calculated as:

$$D = \frac{V}{2} \times (1-p)$$

The condition that a ratio in a population of Hawks and Doves must fulfill to achieve equilibrium is:

$$p \times \frac{(V-C)}{2} + V(1-p) = \frac{V}{2} \times (1-p)$$

or, the average payoffs must balance each other out. Simplified, the equation is reduced to:

$$p = \frac{V}{C}$$

As an example, the values from Figure 2 can be substituted:

$$p = \frac{1500}{1800}$$

$$p = \frac{5}{6}$$

Therefore, the ideal ratio between the number of Hawks and Doves in a population is 5:1.

Real-life Examples of the Hawk-Dove Game

A population of Gouldian finches was once found to exhibit the phenomenon of the Hawk-Dove game. The population was split into 'hawks,' the rarer, more aggressive red-headed variety which comprised of approximately 30% of the population and 'doves,' the more common black headed variety which took up the remaining 70%. [Cornell University, n.d.] Once a payoff matrix was calculated with approximated assigned values given for contended resources, it was found that the ideal ratio of Hawks to Doves was 3:7.

Figure 4: As can be seen in the above image, Gouldian finches can be classified based on head colour, which are correlated with them being a Hawk or a Dove.

Source: Environmental Justice Australia

In a real-life social experiment conducted on 45 students [R. Yang. Xishan School], it was found that the ratio of four different groups could be predicted based by researchers.

Applications of Evolutionary Game Theory and the Hawk-Dove Game in Species Survival

Applications of evolutionary game theory

Game theory has a myriad of applications in evolutionary biology. For instance, the evolutionary game theory (EGT) can be used to predict the behaviors, or, strategies used by animals, thus furthering study about organisms. For instance, in Etosha National Park, Namibia, it was found that it is considered evolutionarily viable for lionesses to hunt in groups of 3 to 4 (Figure 5). [Pacheco.M, Jan 2009]. This is considered as a strategy that lionesses can implement, which helps research in fields related to them.

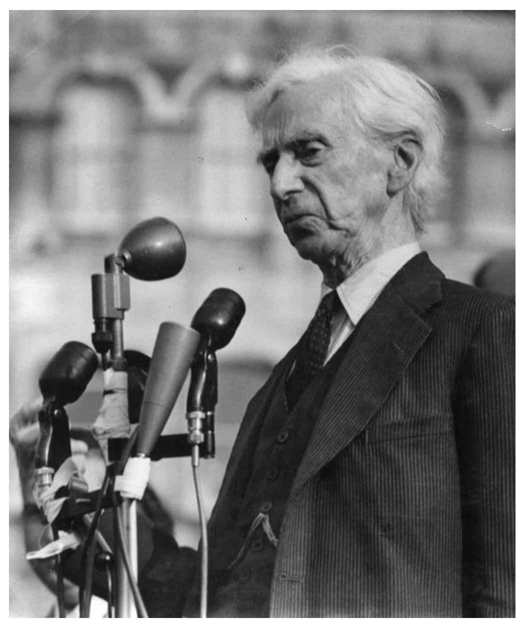
Figure 5: Lionesses are commonly seen hunting in groups of 3 or 4. This proves that it is an evolutionarily stable strategy (ESS).

Source: Restova

Evolutionary game theory can also be used to study the creation and evolution of human social norms, traditions and societal conventions. This can be loosely tied to the Hawk-Dove theory, as some cultures can be more aggressive than others, thus giving them an advantage over pacifist cultures. This increases the probability that their norms and traditions persist [Molleman et al., 2014, Herold and Kuzmics, 2020, Perepelitsa, 2021].

Applications of 'Chicken' and the Hawk-Dove Game

For greater simplification, the real-life applications of the Hawk-Dove game can be put in the same category as those in the broader category, the chicken game. Here, it is assumed that the term 'species survival' also applies to human survival, as humans are also a species of animal.



Controversial British mathematician Bertrand Russell was a notable spokesperson against the use of nuclear weapons in conflict, as is seen in the Russell-Einstein manifesto that highlighted the dangers of such weapons.

Source: Wikimedia foundation

British mathematician Bertrand Russel has famously compared the Chicken game to nuclear brinkmanship, saying that:

"*Since the nuclear stalemate became apparent, the governments of East and West have adopted the policy that… calls 'brinkmanship'. This is a policy adapted from a sport… called 'Chicken!' …it will come to be felt that loss of face is more dreadful than nuclear annihilation. When that moment comes, the statesmen of both sides will plunge the world into destruction.*"

Additionally, the Hawk-Dove game can be compared to economic competitions and political campaigns, with more aggressive players being called ‘Hawks’ and pacifists being called ‘Doves’.[Britannica, n.d.].

The Hawk-Dove game can also be used in animal conservation, such as by helping humans understand interspecies and intraspecies competition and helping with habitat management in areas with endangered animals (by achieving an equilibrium between the Hawks, humans, and Doves, threatened animals).

Conclusion: Game theory, the Hawk-Dove Game and Their Relevance to Species Survival

In conclusion, evolutionary game theory and the Hawk-Dove game are excellent tools when studying and enforcing species survival. They help people understand the relationships between species and provide insight onto how existing species coexist and conflict with each other. In terms of species survival, it can help humans conserve species, especially when studying the equilibrium between Hawks and Doves. In a constantly changing world, novel tools such as game theory, its evolutionary branch and the Hawk-Dove game are vital for societal progress and environmental conservation, no matter if they are targeted towards animals or humans. At the end of the day, man and beast are essentially the same. The destruction of one likely leads to the destruction of the other, and the link between them is impossible to break, whether one likes it or not.

Final word count: 1635

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