Game Theory Investigation

Overview

This investigation serves to test Game Theory when applied to the behaviour of individuals in a species of animals. Game theory is a mathematical theory for analysing situations in which parties make interdependent decisions, causing each player to consider the others' possible strategies when formulating their own. Game Theory postures that this will result in, if possible, the domination of an "evolutionarily stable strategy" (ESS), a strategy that cannot be bettered if most parties adopt it, as deviants will fall victim to selection. If an ESS is impossible, a stable ratio of available strategies where each party gains, or loses, an equal average amount will form. In this investigation, I will simulate one of Maynard Smith's simplest proposed examples of this.

A population consists of Hawks and Doves. Every 'turn', each member of the population confronts another, competing for some resource. A hawk's strategy is to always fight, whereas a dove will simply threaten. As such, a hawk will always scare away a dove, two hawks will always fight, the loser becoming seriously injured, and two doves will always waste time attempting to intimidate each other, but neither become injured. No individual can know whether another is a hawk or a dove. Different results will have different effects on an individual's 'score', representing their likelihood of gene survival. Negative results will reduce it, such as becoming seriously injured or wasting time, whilst winning a confrontation will increase the score. If an individual's score drops below a certain threshold, they are eliminated. The higher an individual's score, the more likely it is that the spaces left by eliminated parties will be filled by one of their type (hawk or dove).

Mathematically, Game Theory applies to ethology and the behaviour of individuals within a species. In this investigation, I will be ascertaining whether Game Theory applies in this hypothetical scenario, representing the behaviour of species in the real world by testing the mathematics experimentally.

Equipment

- Physical:
    - Laptop (for portability)
- Software:
    - Code Editor (VS Code)
    - Image creation software (paint)
- Modules:
    - Python
    - Pygame
    - Matplotlib
    - Numpy

Method

(Instead of outlining a real-world method, I will describe a program that can be built that models the dove hawk scenario)

- Create a population of a hard-coded size that will remain constant.
- Fill it with a random ratio of doves and hawks.
- Create a clock to regulate 'turns' in the game.
- Each turn that passes, create random pairs from the population and ascertain the results of the confrontation according to the aforementioned rules.
- Based on the results, increase or decrease a 'score' value attached to each individual.
- Check if any now have a score under the killing threshold and eliminate them if so.
- Optionally, eliminate a random but limited number of the older population to ensure the simulation remains mobile.
- Fill the empty spaces with new individuals, their type chosen randomly but weighted towards the type with the higher average score.
- Record the population ratios after each turn.

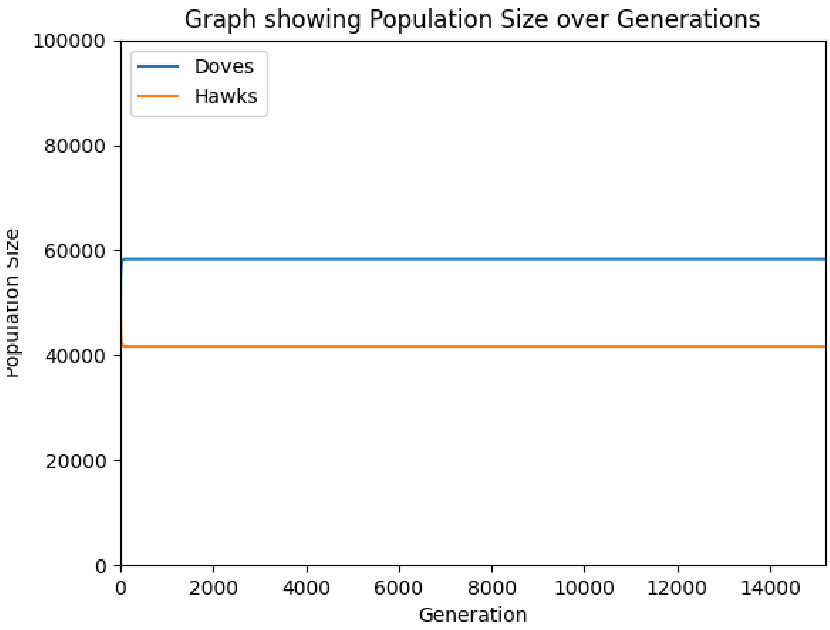
Hypothesis

If Game Theory applies to the behaviour of individuals in a species, then, if a large population of doves and hawks is simulated by this method overnight, then a stable, constant ratio will be reached as neither hawks' nor doves' strategies are examples of an ESS. Furthermore, if the scoring of the game is changed, the ratio will change along with it, but still no ESS will dominate.

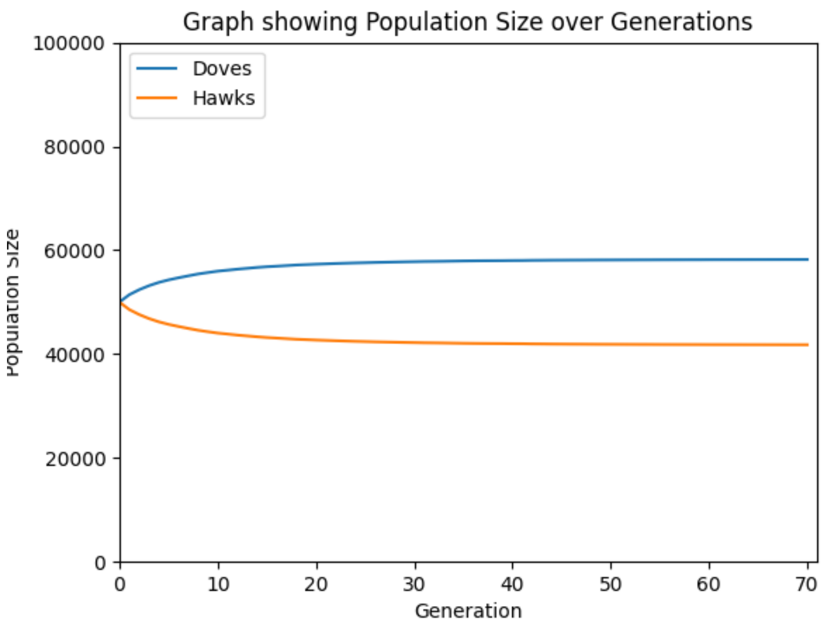
Prediction

Theoretically, the mathematics of Game Theory apply to the behaviour of individuals in a species, and here, experimentally, this will be reinforced. Game Theory will be observed in the simulation. This will be shown by a stable ratio between hawks and doves being reached, as neither strategy is an ESS; in a hawk population, a dove (which never gets injured) will flourish, and a single hawk in a dove population will win every fight and spread rapidly. The ratio will oscillate slightly with new, randomly created individuals, but will quickly correct itself; if there are more doves than in the stable ratio, the hawks will win more confrontations and rapidly grow, correcting this. If there are too many hawks, they will frequently be injured in fights and the uninjured doves will benefit, also correcting the imbalance. If scoring is changed, the ratio will also change as now either the doves' or the hawks' strategy is more successful, and vice versa, resulting in an increase in their numbers.

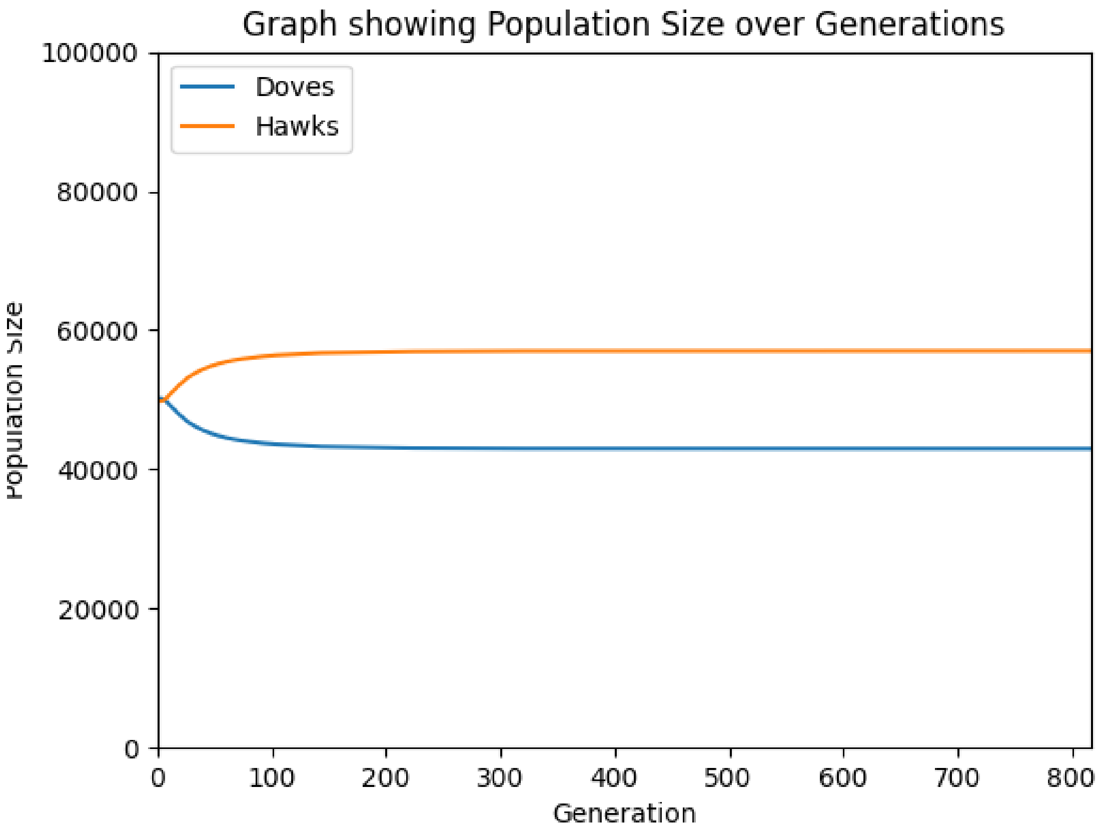
Results



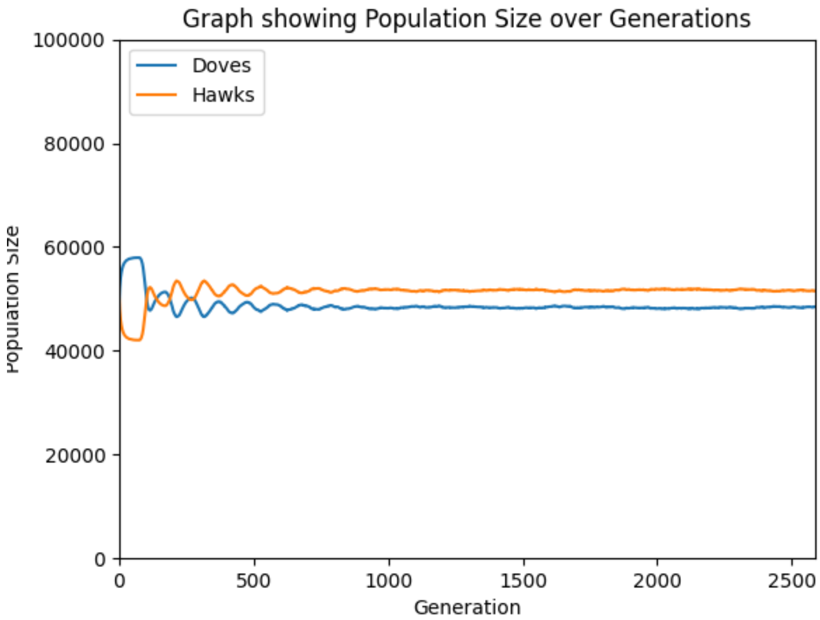
1 First Simulation



2Close-up of first generations of first simulation



3Close-up of first generations of second simulation with different weights



4Simulation with random death chances

Conclusion

Game Theory does apply to the behaviour of individuals in a population, both in this simulation and in nature. Within only around 15 generations, the initially balanced, equal populations of doves and hawks rebalanced to form a stable ratio of 5/12 doves to 7/12 hawks, maintaining this for the entire rest of the simulation of 15,000 generations. Once this ratio had been reached, rampant eliminations entirely ceased as stability had been reached, causing both hawks and doves to experience maximised (in this case positive) average score turnouts, preventing any from dropping below the killing threshold. Neither strategy dominated as neither is an ESS, so the population remained split. The theoretical ratio predicted by Richard Dawkins for my initial score weightings was 7/12 doves to 5/12 hawks, exactly matching my findings. When the scoring for the doves and hawks was changed to favour the hawks, a different ratio of 113/200 hawks to 87/200 doves (56.5% hawks, 44.5% doves) formed, reflecting a new balance of success between the two strategies.

Interestingly, when random chance death was introduced, this trend was not detected, replaced by large oscillations between dove and hawk dominance giving way into a slightly oscillating ratio of around 48.3% hawks to 51.7% doves. This was due to the frequent disturbance of the ratio, and the natural drive to return to it, leading to a slowly stabilising balance.

Evaluation

This investigation was very successful, yielding results identical to my prediction. The results are highly reliable due to the very large sample sizes made possible by my choice to simulate the scenario (population of 100,000 over 15,000 generations). However, this volume of generations was not needed as the patterns demonstrated were clearly shown within only a few hundred, the rest serving only as assurance that the trend would continue. Furthermore, the results were very clear, with no anomalies or unexpected results. A trend was formed, and the simulation did not deviate on any reading.

A possible way to develop the investigation would be to classify the type continuously instead of only allowing hawk (always fight) and dove (never fight). Different population members would have varying chances of fighting in any encounter. A highly interesting ratio or an ESS could result from this. Furthermore, the idea of mutation could be introduced, with a very small, random chance for each individual's fighting chance to be randomised every turn, leading to variation within the species and trends towards the most successful strategy being observed. It would be interesting to investigate whether an ESS would dominate, a ratio would be reached, or this would lead to the population constantly varying, creating either random trends or some pattern or repeated oscillation being detected.

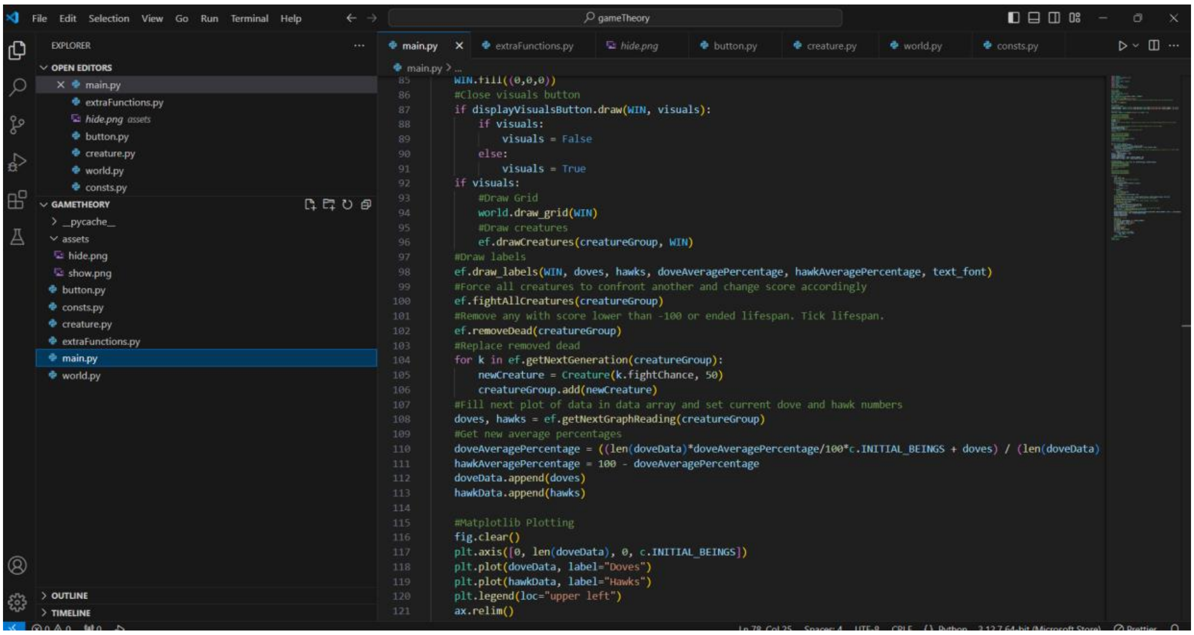
I did experiment with this while developing the investigation, however I decided to limit it to hawks and doves, as Maynard's simpler scenario, excluding strategies such as the “bully” or “retaliator”, is sufficient for representing a species. A continuous divide of the species would also have been much more difficult to graph, and therefore the pivotal population trends more complicated to read or detect.

Overall, this was a very successful investigation that very reliably proved my prediction to be correct.

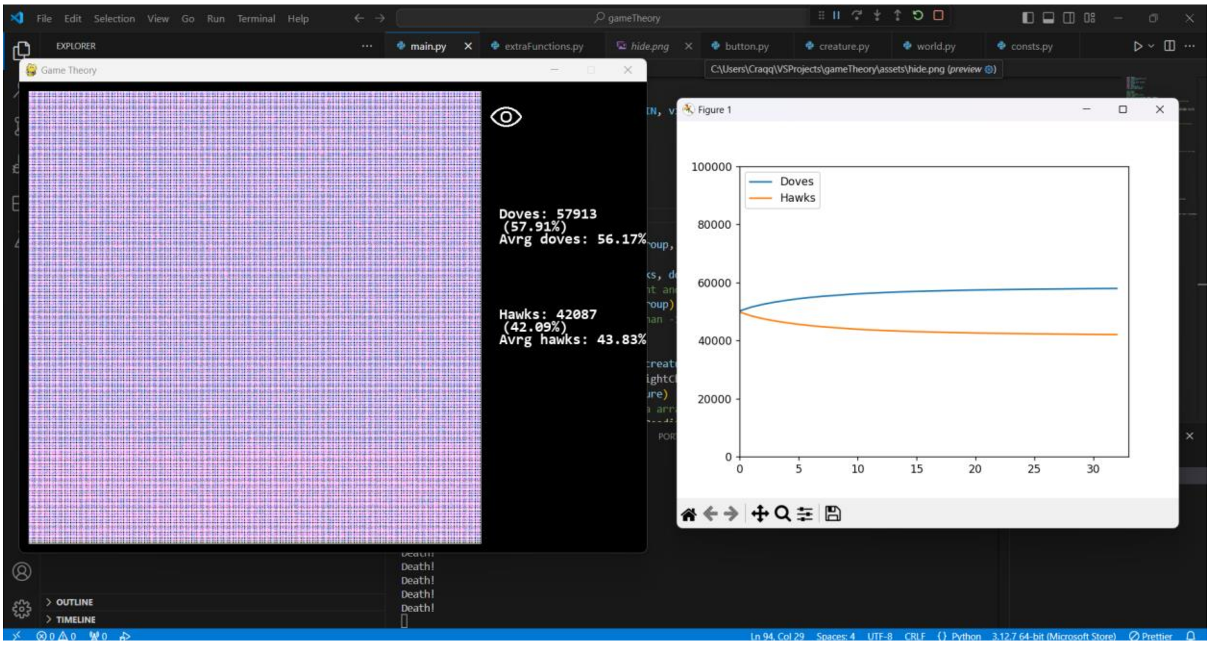
Attributions

- John von Neumann and Oskar Morgenstern for conceiving Game Theory.
- J Maynard Smith for connecting Game Theory with ethology.
- Richard Dawkins for, through his book ‘The Selfish Gene’, educating me in Game Theory and ethology. Also, for definitions and explanations, and for inspiring me to undertake this investigation after his description of it in the book.
- Britannica for information gathering.

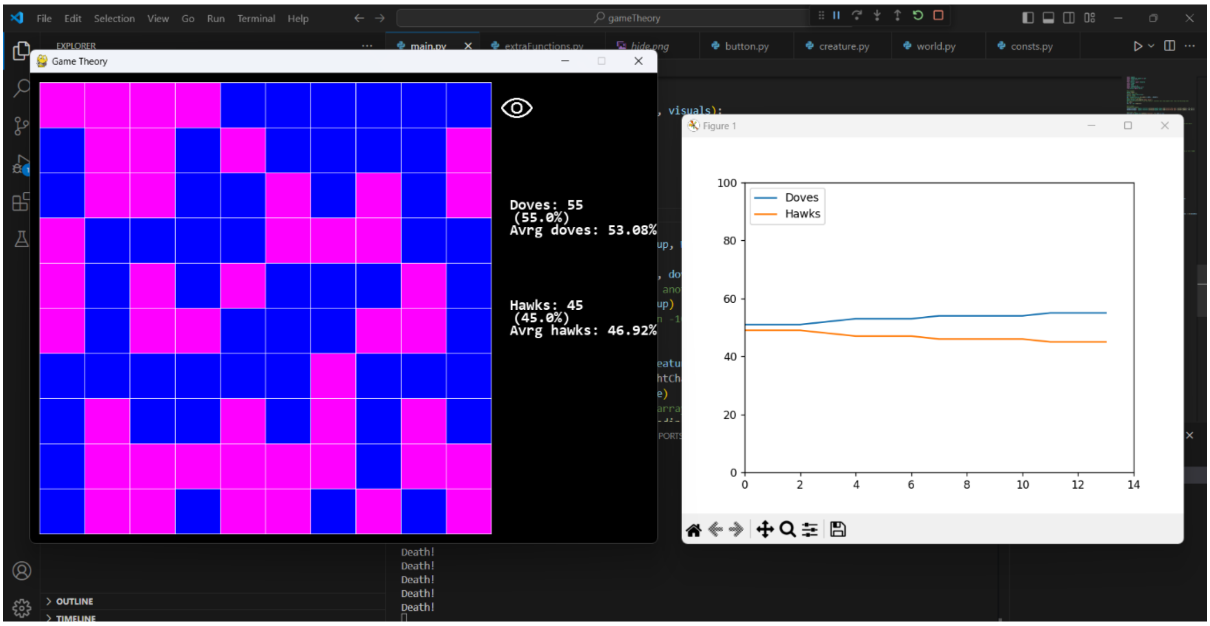
Media



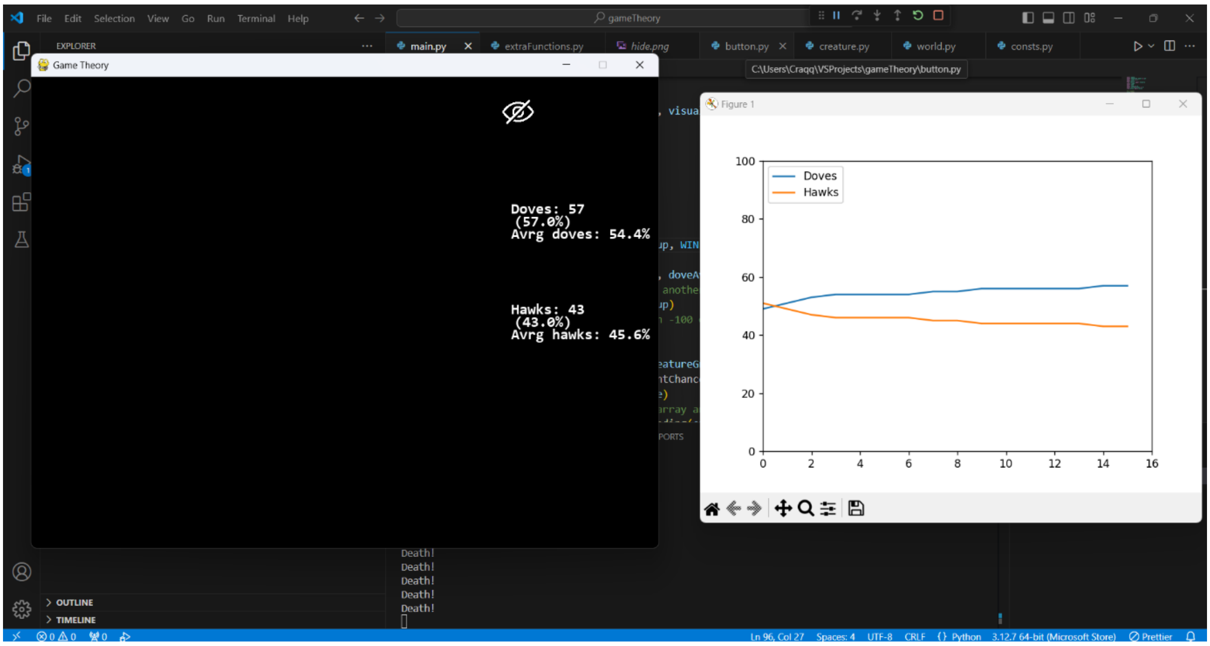
5Snippet of Simulation Code



6Simulation Running with Display



7Simulation Running with Smaller Sample Size



8Simulation Running with Display Disabled (to save processing power when simulating overnight)