A Dynamic Individual Memory Results in Better Probability of Consensus in Animal Collectives

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1 Introduction

In information-based decision making, individuals in a group primarily depends on the non-social information (information of the environment gathered directly by its sensors) and social information (behaviour of other individuals). Having Both information is essential to reduce the uncertainty and forms a group to reduce the risk. Individuals often rely on consensus decisions because of an opposing minority which might provoke separation.

A lot of decision-making models used Bayesian decision theory, when applied to animal behaviour, assumes that the individual has a prior opinion of the possible states of the options [1] One such model is introduced by Arganda et al. Individual observer options build their opinion about those options and then use social information to update their knowledge/beliefs about those options and make their decision. In nature, individuals do not get the luxury to observe all possible options before making a final decision. For example, an individual has to decide which new nest site or resting place to choose. But in some instances, it only has social information about new sites or past information about new sites that might be outdated. Not knowing personally about the new site at the time of decision makes it hard to build an opinion about options,In this study, we implemented a modified version of Arganda et al. (2012)[2] incorporating a dynamic individual memory component to it which results in better consensus over possible options to tacked these problems.

2 Methods / Model

Arganda's Model

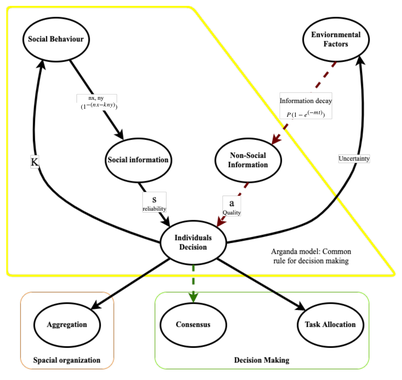
$$P(x \text{ is good}) = \frac{1}{1 + as^{-\left(n_x - kn_y\right)}}$$

New Model

$$P(x \text{ is good}) = \frac{1}{1 + (a - p(1 - e^{-mt}))s^{-\left(n_x - kn_y\right)}}$$

a = Quality of non-social information
s = Reliability of social information
n_x, n_y = Number of individuals that chose option x and y respectively
k = Relative impact of options
p = Memory, the point until which the quality of non-social information can decrease
m = Decay rate, rate at which information outdates over time.

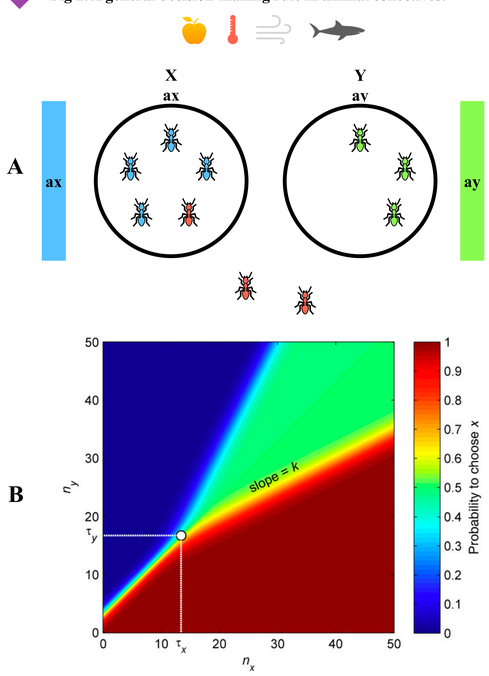
Higher the number of individuals that chose option x, n_X, the higher the probability that option x is good for the deciding individual, and more so the higher the reliability s of the information from the individuals that already chose x. However, each individual that chooses y decreases the probability that x is a good option. Parameter k measures the relative impact of these two opposing effects. Individuals need to decide based on the estimated probabilities When p=0 it behaves as general Arganda's model.



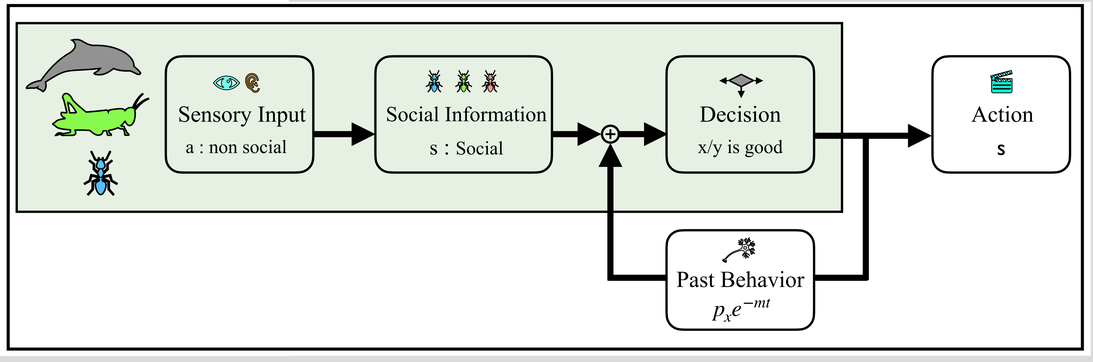
Directed Graphs of the model

3 Environment

Fig 1. A general decision-making rule in animal collectives.



(A) Decision making between two sites when nx and ny animals have already chosen sites x and y, respectively.
(B) The probability of choosing x in the general rule equation plotted as a function of the animals that have already chosen between the two sites, nx, and ny.



4 Results

Fig2 A. Fraction of population forming consensus on binary options

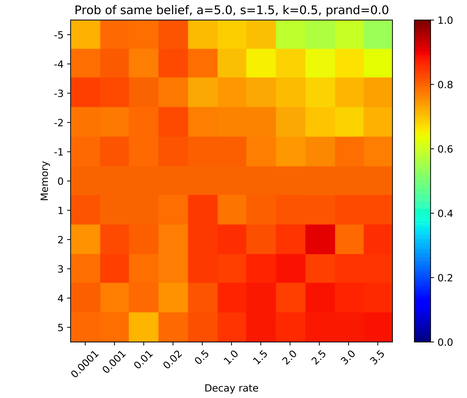
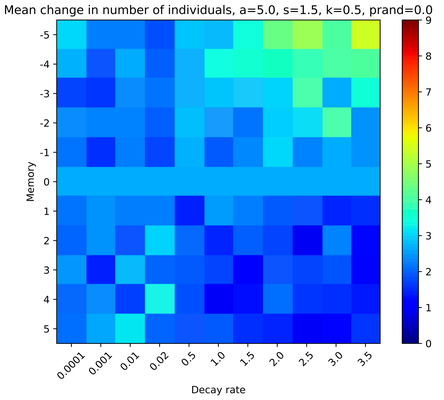


Fig2 B. Mean change in number of individual (number of individuals changing their option at final run)



a= 5.0, s = 1.5, k=0.5, prand = 0, x axis: memory(P) = the point until which the non-social information can decrease, decay rate(m)= rate at which information outdates over time. (memory and decay new parameters added in the model formulation to account for information loss over time)

Fig3. Evolution of individuals decisions over time for different P and m values(memory, decay), a= 5.0, s = 1.5, k=0.5, prand = 0

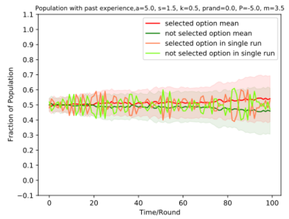


Fig3 A. P = -5.0, m = 3.5

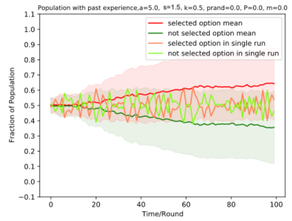


Fig3 B. P = 0.0, m = 0.0 (without past information)

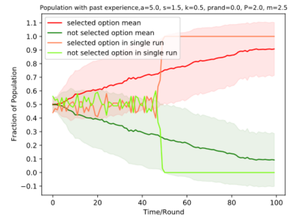


Fig3 C. P = 2.0, m = 2.5

x axis: fraction of population(0-1) = fraction of population choosing same option , y axis: rounds of decision making, 1 round is 1 time steps. red line indicates mean of population at wining option(selected option), green line indicates mean of population at losing option at each time step for 100 iterations.

5 Conclusions

- Dynamic individual memory component increase the probability of consensus of population over possible options as compared to normal Arganda's model
- As time progress less number of individuals changes their opinions and more number of individuals preferred single option for longer amount of time.
- Larger decay rate results in more fraction of population choosing one option over other in binary model.

6 References

[1]McNamara, J. M., Green, R. F., & Olsson, O. (2006). Bayes' theorem and its applications in animal behaviour. Oikos, 112(2), 243-251. https://doi.org/10.1111/j.0030-1299.2006.14228.x

[2]Arganda, S., Pérez-Escudero, A., & de Polavieja, G. G. (2012). A common rule for decision making in animal collectives across species. *Proceedings of the National Academy of Sciences*, *109*(50), 20508–20513. https://doi.org/10.1073/pnas.1210664109