# Effects of Conflict on Collective Movement Decision-Making

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## 1 Introduction

Collective movement is a necessary consequence of living and working in groups. However, conflicts of interest complicate collective movements. Individuals have differing needs, information, and cost to benefit ratios which introduces conflict into the decision-making process [1, 2, 8]. Conflict is very general phenomenon observed universally in evolutionary biology, but research efforts on its effects on collective movement models has primarily focused on navigation decisions [4] or on the benefits of different types of decision-making models [3], and not on the decisions involved in initiating collective movements. As such, the effects of conflict on the decision-making process are not well understood.

In the work discussed here, we present predictions on the effects of conflict on simulations using an extension of a model developed through observations of collective movement attempts in white-faced capuchin monkeys [7, 9], and was later confirmed in observations of sheep groups ranging in size from 2–8 members [10]. Our extension to the model allows for the inclusion of individual-specific conflict values that affect the rate at which individuals join an existing movement. Two types of conflict were simulated: an abstract concept of conflict with no specific cause and a more concrete concept of conflict using individual-specific preferred directions of movement and assertiveness values. Our simulations predict that there is no critical conflict value beyond which there is a drastic reduction in collective movement success. Furthermore, our simulations show that rarely will systems encounter higher than moderate levels of conflict.

## 2 Collective Movement Model

The collective movement model uses three rules to govern the decision-making process involved in starting collective movements [7, 9]. The first rule assumes that all individuals within the group can initiate a collective movement attempt with a rate of $1/\tau_o$. While this assumption may not hold for groups with dominant leaders, studies have shown that it is a viable assumption for egalitarian animal groups, such as the capuchin monkeys used in the model's development.

The second rule describes the rate at which followers join the collective movement attempt and is calculated by $1/\tau_r$. The time constant $\tau_r$ for the following rate is calculated by the following:

$$\tau_r = \alpha_f + \beta_f \frac{N - r}{r} \tag{1}$$

where $\alpha_f$ and $\beta_f$ are constants determined through direct observation, $N$ is the number of individuals in the group, and $r$ is the number of individuals following the initiator. As the number of individuals following the initiator increases, the rate at which individuals join the movement also increases.

Not all initiation attempts are successful as initiators often cancel and return to the group. The third rule calculates this cancellation rate by the following:

$$C_r = \frac{\alpha_c}{1 + (r/\gamma_c)^{\varepsilon_c}} \tag{2}$$

where $\alpha_c$, $\gamma_c$, and $\varepsilon_c$ are constants determined through direct observation, and $r$ is the number of individuals following the initiator. Simulations of the model include the implicit assumption that a successful collective movement requires all of the members of the group to participate, since there is a non-zero probability of canceling even if all but one member participates. While this is not necessarily the case in nature, cohesive collective movements are the primary objective of this work and, as such, incomplete movements are considered failures.

To investigate the effects of overemphasizing the rate at which individuals follow an initiator, Gautrais added an "over-following factor" $k$ to the following rate calculation of the collective movement model [7], as follows:

$$k_i \tau_r = k_i \left( \alpha_f + \beta_f \frac{N - r}{r} \right) \tag{3}$$

where $k_i$ is individual $i$'s over-following factor and the remaining variables are the same as before. While the original intent of $k$ was to increase the following rate, it can also be used to decrease the following rate if values between 0 and 1 are used[1]. Since this $k$ factor can be used to increase or decrease the rate and which an individual follows an initiator, it is an ideal means with which the effects of conflict can be incorporated into the model.

## 3 Numerical Implementation

In the first set of simulations, conflict was modeled as an abstract value in the interval $[0, 1]$. Since conflict wasn't discussed as a component of the collective movement model, we assumed that the capuchin monkeys on which the model was based experienced a moderate level of conflict. As such, a conflict value of $c = 0.5$ would produce a following factor $k$ of 1, which results in the original model's following rate. To ensure that values for $k$ were evenly distributed around 1, the following simple relationship between an individual $i$'s conflict value $c_i$ and the resulting following factor $k_i$ was used:

$$k_i = 2 \times (1 - c_i) \tag{4}$$

Two types of simulations were performed using this abstract concept of conflict. In the first type, all individuals in the group had the same level of conflict and are referred to as `ABSTRACT-SAME` simulations. While such a situation may not be realistic, it did afford an opportunity to directly evaluate the success of leaders in initiating collective movements. In the second type of simulation, conflict values for individuals in the group were randomly generated from a Gaussian distribution with a mean that varied with different treatments and a standard deviation of 0.1 and are referred to as `ABSTRACT-GAUSSIAN` simulations.

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[1] Gautrais added similar factors to the initiation and canceling rates [7], but only the following rate is of interest in the work presented here.

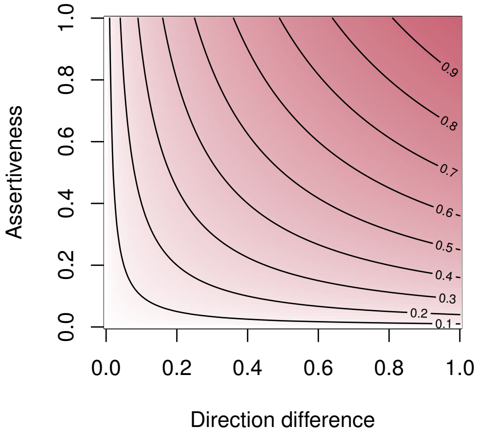
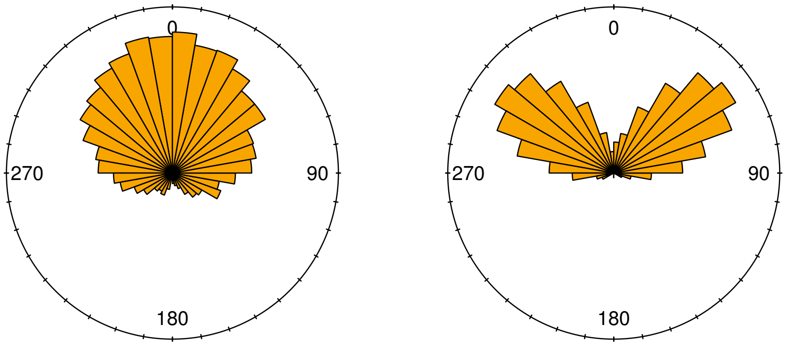


Figure 1: Conflict is calculated as the combination of an individual's assertiveness and the difference between the individual's preferred direction of movement and the direction of movement of the initiator (see Equation 5).



(a) Single Group (b) Two Subgroups

Figure 2: Sample distributions of an individual's preferred direction of movement for a group size of 90 are shown for `CONCRETE-SINGLE` simulations (see Figure 2(a)) and `CONCRETE-MULTIPLE` simulations (see Figure 2(b)).

In the second set of simulations, a more realistic concept of conflict similar to other work in the field [5] was used. Conflict was defined of as a product of the combination of an individual's assertiveness and the difference between the individual's preferred direction of movement and the initiator's preferred direction of movement, as follows:

$$c_i = a_i^{0.5} \times |d_i - d_I|^{0.5} \tag{5}$$

where $a_i$ was individual $i$'s assertiveness, $d_i$ was the individual's preferred direction, $d_I$ was the initiator's preferred direction, and $c_i$ was the resulting conflict value for individual $i$. An individual's assertiveness fell in the interval $[0, 1]$ with 0 being low assertiveness and 1 being high assertiveness. Preferred directions were normalized to the interval $[-1, 1]$. As a result, the difference in preferred directions also fell in the interval $[0, 1]$. Figure 1 shows the resulting conflict value for each assertiveness and direction difference combination.

For this concrete concept of conflict, two types of simulations were performed. In the first type, the preferred directions of movement for individuals in the group were randomly generated from a Gaussian distribution with a mean of 0 and a standard

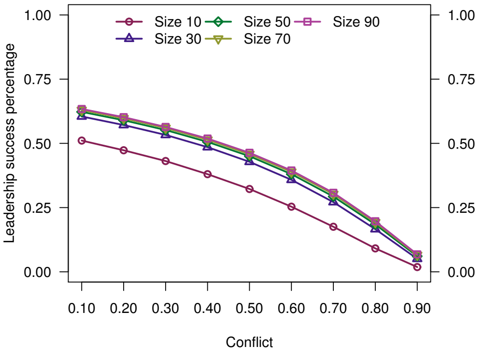


Figure 3: The mean leadership success percentage for `ABSTRACT-SAME` simulations.

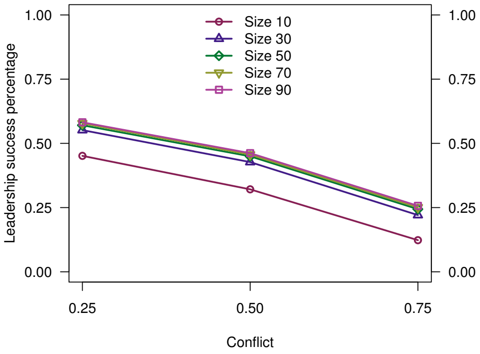


Figure 4: The mean leadership success percentage for `ABSTRACT-GAUSSIAN` simulations.

deviation that varied with different treatments (see Figure 2(a) for an example) and are referred to as `CONCRETE-SINGLE` simulations. In the second type, the individuals in the group were divided into two subgroups and then assigned a preferred direction of movement randomly generated from a Gaussian distribution with a mean value specific to its subgroup (see Figure 2(b)) and are referred to as `CONCRETE-MULTIPLE` simulations. This allowed for an opportunity to evaluate how the difference in the preferred direction between the subgroups affected the success of collective movement initiators in each subgroup. In each of these two simulation types, an individual's assertiveness was randomly generated from a Gaussian distribution with a mean of 0.5 and a standard deviation of 0.1.

The time of each event was calculated as a random number drawn from an exponential distribution using the appropriate rate. As such, the simulations use continuous time events, and not discrete time. For each conflict configuration, group sizes from 10 to 90 individuals were evaluated. The original model was only evaluated with a group size of 10, but other work has shown that the success of collective movement initiations increases as the group size is increased, with diminishing effects beyond a group size of 100 [6]. Fifty different evaluations were performed for each group size, each with a different random seed. A single evaluation consisted of $2,000 \times N$ collective movement simulations, where $N$ was the group size. All individuals had approximately the same number of initiation attempts as the initiation rates for all individuals were the same. The cancellation rate was also the same for every individual. The base following rate was the same for every individual, but was modified by the individual's conflict value $c_i$, using the model's $k$ variable (see Section 2). The model parameters used were the same as those used in the original model [7, 9].

# 4 Results & Analysis

Figure 3 shows the predicted mean leadership success percentage in collective movement initiations across 50 evaluations for each conflict value and group size combination for `ABSTRACT-SAME` simulations. All success percentages were statistically significantly different from one another with $p << 0.0001$ due to very small standard deviations. However, evaluations for group sizes of 50, 70, and 90 differed by less than 5% for each conflict value. As expected, as conflict increased, the success rate of collective movement initiations decreased. However, these results do not indicate that there is a critical conflict value at which there is a drastic reduction in initiation success.

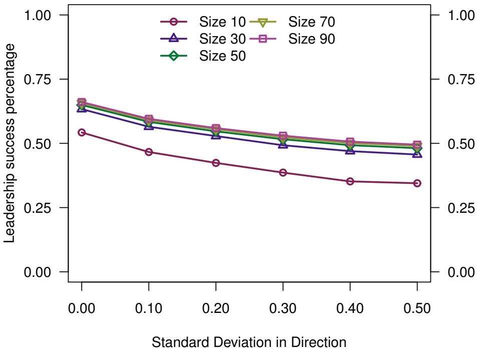


Figure 5: The mean leadership success percentage for `CONCRETE-SINGLE` simulations.

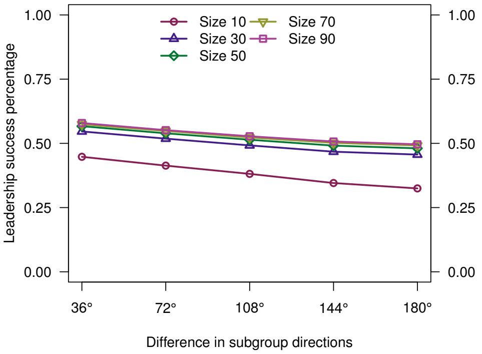


Figure 6: The mean leadership success percentage for `CONCRETE-MULTIPLE` simulations.

Figure 4 shows the predicted mean leadership success percentage in collective movement initiations across 50 evaluations for each mean conflict value and group size combination in `ABSTRACT-GAUSSIAN` simulations. All success percentages were statistically significantly different from one another with $p < 0.01$. Again, there is no indication that there is a critical conflict value at which there is a drastic reduction in initiation success. Furthermore, the mean predicted leadership success percentages from both `ABSTRACT-SAME` and `ABSTRACT-GAUSSIAN` simulations are consistent with one another, but the `ABSTRACT-GAUSSIAN` simulations have a higher standard deviation, which would be expected. This indicates that the variations in conflict in the `ABSTRACT-GAUSSIAN` simulations balance out (i.e., the effects of individuals with higher than average conflict are countered by the effects of individuals with lower than average conflict).

Figures 5 and 6 shows the predicted mean leadership success percentage in collective movement initiations across 50 evaluations for each group size combination in `CONCRETE-SINGLE` and `CONCRETE-MULTIPLE` simulations, respectively. Analysis indicates that the predictions for both the `CONCRETE-SINGLE` simulations with a high standard deviation in preferred direction and `CONCRETE-MULTIPLE` simulations in which the two subgroups differed in their preferred direction by 180° are comparable to those of the `ABSTRACT-SAME` and `ABSTRACT-GAUSSIAN` simulations with a conflict value of 0.50. Since the difference in preferred direction cannot be any larger, this indicates that, using this model of conflict, systems will rarely encounter higher than moderate levels of conflict.

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