Uninformed Individuals Promote Democratic Consensus in Animal Groups

Iain D. Couzin,† Christos C. Ioannou,‡ Güven Demirel,‡ Thilo Gross,‡ Colin J. Torney,† Andrew Hartnett,† Larissa Conradt,§ Simon A. Levin,‡ Naomi E. Leonard

Conflict among group members is common when making collective decisions, yet failure to achieve consensus can be costly. Under these circumstances individuals may be susceptible to manipulation by a strongly opinionated, or extremist, minority. It has previously been argued, for humans and animals, that social groups containing individuals who are uninformed, or exhibit weak preferences, are particularly vulnerable to such manipulative agents. Here, we use theory and experiment to demonstrate that, for a wide range of conditions, a strongly opinionated minority can dictate group choice, but the presence of uninformed individuals spontaneously inhibits this process, returning control to the numerical majority. Our results emphasize the role of uninformed individuals in achieving democratic consensus amid internal group conflict and information constraints.

Social organisms must often achieve a consensus to obtain the benefits of group living and to avoid the costs of decision (1–12). In some societies, notably those of eusocial insects, making consensus decisions is often a unitary, conflict-free process because the close relatedness among individuals means that they typically share preferences (11). However, in other social animals, such as schooling fish, flocking birds, herding ungulates, and humans, individual group members may be of low relatedness; thus, self-interest can play an important role in group decisions. Reaching a consensus decision, therefore, is dependent on individuals resolving complex conflicts of interest (1, 2, 13, 14).

There are several means of achieving group consensus. In some cases, decisions made by one or only a small proportion of the group dictate the behavior of the entire group (4, 6, 13, 14). Therefore, a minority, or even a single individual, has the potential to control or exploit the majority, achieving substantial gains at the expense of other group members (6, 9, 10, 14). In contrast, consensus can also be reached through democratic means, with fair representation and an outcome determined by a plurality. Democratic decisions tend to be more moderate, minimizing group consensus costs, particularly in large animal groups (3). However, in the absence of established procedures such as voting (8), it is unclear how equal representation is enforced.

Consequently, for both human societies (1, 2, 6, 9, 10, 14) and group living animals (6, 13), it has been argued that group decisions can be subject to manipulation by a self-interested and opinionated minority. In particular, previous work suggests that groups containing individuals who are uninformed, or naive, about the decision being made are particularly vulnerable to such manipulation (2, 9, 10, 13). Under this view, uninformed individuals destabilize the capacity for collective intelligence in groups (10, 14), with poorly informed individuals potentially facilitating the establishment of extremist opinions in populations (9, 14).

Here, we address the question of whether and, if so, under which conditions a self interested and strongly opinionated minority can exert its influence on group movement decisions. We show that uninformed individuals (defined as those who lack a preference or are uninformed about the features on which the collective decision is being made) play a central role in achieving democratic consensus.

We use a spatially explicit computational model of animal groups (15) that makes minimal assumptions regarding the capabilities of individual group members; they are assumed to avoid collisions with others and otherwise exhibit the capacity to be attracted toward, and to align direction of travel with, near neighbors (5, 16). We investigate the case of consensus decision making regarding a choice to move to one of two discrete targets in space (thus, the options are mutually exclusive).

The direction and strength of an individual’s preference are encoded in a vector term ω (directed toward the individual’s preferred target). Higher scalar values of ω (equivalent to the length of the ω vector, |ω|) represent a greater conviction in, or strength of, individual preference to move in the direction of the target and, thus, also represent greater intransigence to social influence (5). We explore the case where there are two subpopulations within the group N1 and N2, respectively that have different preferred targets. Because we are interested in determining whether a minority can exploit a majority, we set N1 > N2 for the simulation. The strengths of the preference of the numerical majority and minority are represented by their respective ω values, ω1 and ω2. See (15) for details.

If the strength of the majority preference (ω1) is equal to or stronger than the minority preference (ω2), the group has a high probability of reaching the majority preferred target (Fig. 1A) (5). Yet increasing ω2 (beyond ω1) can result

![Image](https://dx.doi.org/10.1126/science.1210280)
in the minority gaining control and eventually dictating group outcome (Fig. 1A and fig. S1). If some individuals do not have relevant prior information or are only weakly biased, however, as is likely in many animal groups (3, 6, 12), then groups can be considered to have a third subpopulation of N3 individuals with α3 = 0. Now when α2 is in the range where the minority dictates the group outcome for N3 = 0, adding uninformed individuals tends to return control spontaneously to the numerical majority (Fig. 1B) (α2, 0.4, 0.42). As N3 increases, this effect reaches a maximum and then begins to slowly diminish. Eventually, noise dominates and uninformed individuals neither amplify a weak numerical majority nor lend substantial support to the minority.

To determine whether these results can be generalized, we developed reduced, analytically tractable versions of the above model. The first, modified from (17), represents individuals as nodes on a network with interindividual communication represented by a dynamically changing edge topology. A second (increasingly minimalist) approach considers a convention game of self-reinforcing normative opinion dynamics (18). These simplified models are nonspatial and consider discrete (binary) opinions, yet incorporate key features of the spatial model: (i) Individuals adopt, probabilistically, the opinion they perceive to be that of the local majority (this results in positive feedback reinforcing the pre-existing dominant opinion and, consequently, rapid non-linear transitions from disordered to ordered consensus states). (ii) The strength of individual preference manifests as intransigence during interactions with others.

These models capture the same qualitative collective features as the spatial model (15). Figure 2A shows the presence of a sharp transition from a minority to majority controlled outcome in the network model as the density of uninformed individuals is increased. Analysis reveals the dynamical nature of this transition (Fig. 2B) (15), as well as the large range of parameter space in which a minority preferred outcome switches to a majority preferred outcome if sufficient uninformed individuals are present (white region in Fig. 2C).

In all models, an entrenched minority is capable of exerting substantial influence by biasing the perceived consensus. Because they exhibit little intransigence or intrinsic bias, however, uninformed individuals will lend support to, and tend to amplify, a numerical advantage (even a slight one). If sufficiently numerous, they reduce the effect of intransigence and inhibit the capacity for the minority to take hold, thus returning control to the numerical majority. Consequently, even a small change in the number of uninformed individuals can dramatically alter the outcome of consensus decisions (Figs. 1B and 2A and figs. S7A and S8) (15). We emphasize that this process will tend to inhibit any strong minority preference, regardless of the intrinsic quality or value of that view. We conjecture that this phenomenon may be found in seemingly disparate systems that share these common features outlined above (15).

Our theoretical studies make a primary testable prediction: Uninformed individuals should inhibit the influence of a strongly opinionated minority, returning control to the numerical majority. To test this prediction, we conducted experiments with golden shiners (Notemigonus crysoleucas) (Fig. 3A, inset), a strongly schooling species of freshwater fish (19). We trained two subpopulations of individuals (representing either N1 or N2) to have preferences to move from a starting location toward either a blue target or a yellow target (Fig. 3B and figs. S3 and S4) (15). Under our experimental conditions, shiners exhibited a spontaneous preexisting bias toward the yellow target (15, 20), evident in both training (figs. S10 and S11) and testing (see results, below). Consequently, we did not need to...
employ different training regimes to create a
difference in the strength of preference between
our two trained subpopulations (13). A third (N3)
subpopulation was left untrained.

Because our theoretical predictions do not
depend on the absolute number of N1 individuals
(fig. S2), and due to the time consuming nature
of training and constraints related to obtaining
enough fish for replication, we set N1 6 and
N2 5 fish (as in Fig. 1). Our simulations also
predict a large effect for a relatively small number
of naïve individuals (Fig. 1B); thus, we set N3
0, 5, or 10. When N2 fish are trained to the yellow
(biased) target and all individuals exhibit a
preference (N3 0), the minority N2 dictates the
consensus achieved, even though the fish trained
to the blue target are more numerous. However,
when untrained individuals are present, they
increasingly return control to the numerical ma-
jority N1 (Fig. 3A) [generalized linear model
(GLM); likelihood ratio test (LRT)1,52 5.60, P
0.018]. A snapshot from a trial is shown in Fig.
3B. We also performed experiments in which
individuals with the stronger preference were
also in the numerical majority (N1 trained to the
yellow target). As expected (13), the majority
was more likely to win (72% of trials overall),
and the presence of uninformed individuals had
no effect (12, 16, and 11 of 18 replicates for N3
0, 5, and 10, respectively; GLM; LRT1,52 0.14,
P 0.71).

Our work provides evidence that uninformed
individuals play an important role in consensus
decision making: By enforcing equal representa-
tion of preferences in a group, they promote a
democratic outcome. This provides a new under-
standing of how informational status influences
consensus decisions and why consensus decision
making may be so widespread in nature (4). Fur-
thermore, these results suggest a principle that
may extend to self organized decisions among hu-
man agents.

References and Notes
1. K. Arrow, Social Choices and Individual Values (Yale Univ.
2. J. M. Buchanan, G. Tullock, The Calculus of Consent:
Logical Foundations of Constitutional Democracy
(Liberty Fund, Indianapolis, IN, 1958).
(2005).
433, 513 (2005).
19, R911 (2009).
7. J. Krause, G. D. Ruxton, Living in Groups (Oxford Univ.
8. J. Mansbridge, Beyond Adversary Democracy (The Univ.
and the Theory of Groups (Harvard Univ. Press,
Cambridge, MA, 1971).
10. W. Riker, Liberalism Against Populism: A Confrontation
Between the Theory of Democracy and the Theory of
11. T. D. Seeley, Honeybee Democracy (Princeton Univ. Press,
Princeton, NJ, 2010).
12. A. J. Ward, J. E. Herbert Read, D. J. T. Sumpter, J. Krause,
173, 304 (2009).
15. Materials and methods are available as supporting
material on Science Online.
16. Y. Katz, K. Tunstam, C. C. Ioannou, C. Huepe, I. D. Couzin,
073022 (2011).
18. H. P. Young, Individual Strategy and Social Structure: An
Evolutionary Theory of Institutions (Princeton Univ. Press,
100, 108702 (2008).

Acknowledgments: We thank H. Li, L. Petzold, J. Maehlis,
A. Kolpas, Y. Katz, and A. Kao for help with CUDA and the
Couzin lab for discussions. This work was supported by NSF
grant PHY 0848755, the Searle Scholars Program, Office of
Naval Research grant N00014 09 1 0055, and
The Royal Society. I.D.C. devised the study and performed
and analyzed the spatial simulations, C.C.I. performed and
analyzed the fish experiments, and G.D. and T.G. performed
the adaptive networks model and C.J.T. the convention model.
All authors participated in some aspects of model formulation
and analysis. I.D.C. wrote the paper with input from all
authors. Data and code freely available at http://icouzin.
princeton.edu/uninformed individuals promote democratic
consensus in animal groups.