Peer Community Journal

Improving human collective decision-making through animal and artificial intelligence

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Volume **1** (2021), article e59

https://doi.org/10.24072/pcjournal.31

Abstract

Whilst fundamental to human societies, collective decision-making such as voting systems can lead to non-efficient decisions, as past climate policies demonstrate. Current systems are harshly criticised for the way they consider voters needs and knowledge. Collective decision-making is central in human societies but also occurs in animal groups mostly when animals need to choose when and where to move. In these societies, animals balance between the needs of the group members and their own needs and rely on each individuals (partial) knowledge. We argue that non-human animals and humans share similar collective decision processes, among which are agenda-setting, deliberation and voting. Recent works in artificial intelligence have sought to improve decision-making in human groups, sometimes inspired by animals decision-making systems. We discuss here how our societies could benefit from recent advances in ethology and artificial intelligence to improve our collective decision-making system.

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Rethinking current voting systems

Collective decision-making processes such as **voting systems** are pillars of our Western societies (Arrow 1950; Bergson 1958; Riker, Ordeshook 1968; Enelow, Hinich 1989; Hinich, Munger 2008; Saari 2008). However, democratic choices may sometimes lead to non-efficient or non-representative decisions (see Glossary for definitions of **efficiency** and **representativeness**). This was the case with the election of François Hollande in 2012 (Baujard *et al.* 2014) and the election of Donald Trump in 2016 (Gunther *et al.* 2019). In the 2012 French presidential elections, François Hollande beat Nicolas Sarkozy and was elected with 51.62% of votes. However, these two candidates would have lost in a one-to-one vote to François Bayrou (a third candidate). In fact, Bayrou would have won one-to-one against any other candidate in this election and would therefore have been a Condorcet candidate (i.e. a candidate with a majority against any other candidate in a one-to-one vote). Nevertheless, voters' preferences for Bayrou were not strong enough to qualify him for the second round of elections in a two-round majority system (Van der Straeten *et al.* 2013). This example shows how the choice offered to the voters and the institutions governing that vote are perhaps as important as the way people vote. As illustrated by Donald Trump's victory over Hillary Clinton in the 2016 election, another issue affecting the legitimacy of voting results is the way in which citizens base their choice on media and news sources that were often unreliable and played on people's fears (Jotzo *et al.* 2018; Davenport, Landler 2019). In the long term, these biased choices lead to non-efficient decisions that have to be revised frequently. Besides, society and political parties have become more polarised on many issues, due to the massive use of social networks and influencers (Golub, Jackson 2010; Kurvers *et al.* 2020), while the political supply has not become more diverse. This combination of high polarisation and low political diversity results in a decrease in citizens' satisfaction with democracy (Hoerner, Hobolt 2019). In addition, Western democracies suffer more and more from low turnout rates (Kostelka, Blais 2021), which further weakens the political systems. It is therefore essential to find solutions that ensure citizens' support. The issues that may lead to dissatisfaction with elections or referendums can be summarised into three categories: 1. the voting systems and, more generally, the mechanisms used to aggregate preferences, 2. the needs and/or desires of citizens, and 3. the knowledge on which voters decide. Each of these categories could benefit from recent findings in animal and **artificial intelligence (AI)**.

Recent advances in political science

Political institutions are powerful organisations to articulate multi-level human societies and to produce decisions that affect large numbers of people. However, to achieve these two goals, most political institutions have excluded ordinary citizens from policy **agenda-setting** and deliberation, two fundamental yet underestimated aspects of collective decision-making (Landemore 2020). Even in representative democracies, ordinary citizens constitutionally have access only to the final choice, through their vote. In political science, voting generally refers to the choice of elected representatives by citizens. In most current cases, once the vote is over, the elected representatives become independent and are in no way bound to deliver their electoral promises: there is no recall option for the citizens. Over the years, two different types of disadvantages of voting have been reported. First, it is possible to question the capacity of the vote to represent society, based on the observation that, sociologically, elected officials differ greatly from ordinary citizens (Fox, Lawless 2005). However, other forms of representation are conceivable. For example, statistical research has developed random sampling techniques that are representative of the general population. While these **sortition** techniques are widely used for opinion polls, they are still not very popular for choosing representatives of civil society, although recent experiments in Iceland and France (to name but two) have taken place (Landemore 2020). Moreover, under certain conditions, it is possible to consider the **self-selection** of certain individuals as representative of a desire of similar individuals to take part in the public debate (Landemore 2020). Finally, liquid representation is a very recent concept in political science (Tullock 1967; Miller 1969) that implies (Blum, Zuber 2016): (i) direct voting on any issue, (ii) flexible proxy voting, (iii) meta proxy voting and (iv) possible instant recall by each original voter. The other major form of disadvantage of voting is that it focuses attention on the final choice, while other dimensions of power are also important to consider. For many political scientists,

representative democracy has come of age and should be either complemented or replaced by **deliberative democracy** or open democracy (Landemore 2020). Voting as currently envisaged does not allow citizens to access the political agenda-setting (Bachrach, Baratz 1962) or deliberation (List *et al.* 2013) to choose between different options. Yet, these different forms of political participation are increasingly recognised as crucial and, as we will see later, these two forms also exist in animal groups.

Taking inspiration from animal collective decisions

Humans are not the only species that uses group processes to make important choices. These concepts also exist in other animal societies, in which voting systems are readily used, for instance to decide where to go (Fig. 1). In ethology, voting means that ''an animal communicates its individual preference with regard to the collective decision outcome'' (Conradt, Roper 2005), and the decision is a sign of an ''ecological rationality'' and intention, the effectiveness of which is assessed over long evolutionary periods. These voting processes are mostly used to decide about where and when to go for foraging or for resting. Of course, this does not mean that these species have the same mental states as humans but their behaviours suggest certain cognitive capabilities as degrees of theory of mind (Boureau *et al.* 2015; Bayne *et al.* 2019). Empirical studies supported by modelling are able to differentiate simple copying process from true voting decisions involving intentional communication and awareness of mental states of others (Sankey *et al.* 2021). Group decision-making is common in the animal kingdom, and has been documented in social insects (honeybees (Seeley 2010) or ants (Franks *et al.* 2003; Czaczkes *et al.* 2011; Buffin *et al.* 2012)), fish (Reebs 2000; Ward *et al.* 2011; Burns *et al.* 2012; Kao, Couzin 2014) and mammals (e.g. primates (Sueur, Deneubourg, *et al.* 2011; Strandburg-Peshkin *et al.* 2015), meerkats (Bousquet *et al.* 2011), African wild dogs (Walker *et al.* 2017), bison (Ramos *et al.* 2015) and deer (Conradt, Roper 2005)). We do not mean here that cognitive processes involved in animal collective decisions are similar to the ones in humans, they differ in degrees. However, animal and human processes are comparable, and this comparison may help to provide insight for the stewardship of human collective behaviour (Bak-Coleman *et al.* 2021). Living in groups brings many advantages but animals have to resolve conflicts of interest to maintain their cohesion and these advantages, through collective decisions. Research efforts largely have been directed in relatively stable and cohesive groups. Less well understood is how fission-fusion dynamics mediate the processes and outcomes of collective decision-making. However, collective decisions also happen in species with fission-fusion dynamics as shown in bison or hamadryas baboons and are based on similar concepts than the ones applied to cohesive groups (e.g. needs, information, social networks, see (Sueur, King, *et al.* 2011) for a review) but only partial consensus may apply. The difference between stable or cohesive groups and groups with fission-fusion dynamics also lies in the way individuals evaluate group membership: it is a common rule in animals that if the costs of being in the group outweighs the benefits, individuals will leave. It is this rule that partly sets an upper limit to the group sizes observed in animals: even in species living in stable groups, fissions are observed when a certain group size is reached (Ménard, Vallet 1993; Henzi *et al.* 1997; Okamoto, Matsumura 2001; Manno *et al.* 2007), without necessarily always understanding the underlying mechanisms. This could shed new light on the low turnout rates observed in elections in Western societies: the benefits of the electoral process for some citizens are too low, leading them to desert the ballot box.
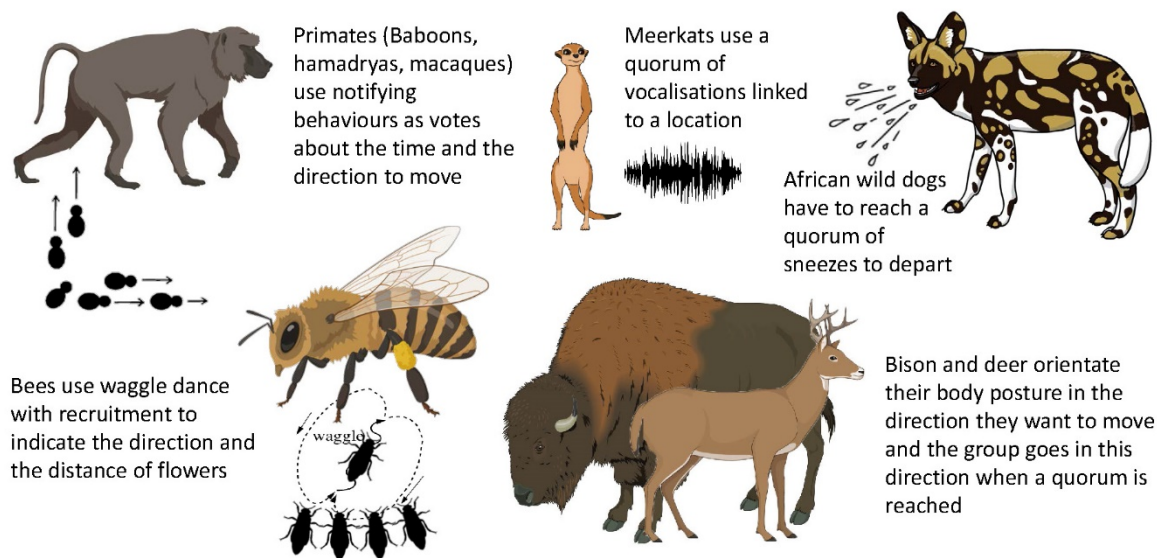
Figure 1: Species showing these different voting behaviours, specifically primates (Sueur, Deneubourg, *et al.* 2011; Strandburg-Peshkin *et al.* 2015), meerkats (Bousquet *et al.* 2011), African wild dogs (Walker *et al.* 2017), honeybees (Seeley 2010), bison (Ramos *et al.* 2015) and deer (Conradt, Roper 2005).

Animal decisions can be complex since they may involve many (up to thousands) individuals having different needs and information about a complex environment with high conflicts needing resolution and wrong decisions potentially leading to death. These conflicts of interests might be due to differential needs of individuals as in primate groups or due to private information about different sites as in swarming honeybees (Marshall 2011). Acquiring information is costly, which is why animals often rely on their groupmates to get informed (Duboscq *et al.* 2016). By signalling information and needs within the group, these social species engage in a sort of deliberation that can take into account the magnitude of each signal as a proxy for individual motivation (see the part "the needs of citizens" for more details). Over the course of successive collective decisions, the identities of the individuals sending signals of information or need vary, thus ensuring a rotation of the group members participating in the agenda-setting and in the deliberation. Most likely, due to stochastic phenomena in physiological processes or in information acquisition processes, the identities of the participants in each collective decision vary randomly, thus basing the selection mechanism on sortition rather than on election. Animal collective decisions are therefore based on mechanisms of sortition, agenda-setting and deliberation. Furthermore, these mechanisms have been selected over many generations to optimise the trade-off between speed and accuracy of the collective decision and to favour the fitness of individuals belonging to these groups. Although less studied from this perspective, animal groups with fission-fusion dynamics also use the same collective decision mechanisms as stable groups, with the additional possibility for each individual to choose the subgroup that best suits them. In some respects, this could be similar to liquid representation, although more research is needed to confirm this link.

In a nutshell, animal processes and issues such as agenda-setting, deliberation, majority rules, importance of minorities, uninformed individuals, source of information and misinformation are very similar to human processes and issues (Krause *et al.* 2010; Kao, Couzin 2014; Bak-Coleman *et al.* 2021). Therefore, because of the strong natural selection increasing the efficiency of animal systems, authors call for research on animal systems to improve the decision-making process in human societies, especially in link with AI (Mezza-Garcia 2013; Hassabis *et al.* 2017; Zador 2019; Aral, Eckles 2019; Dorigo *et al.* 2020): bioinspiration for AI may conduct to better understand and control AI behaviour (Rahwan *et al.* 2019).

Taking inspiration from AI

It is important and timely to ask how artificial intelligence and digital technologies can contribute to strengthening democracy. This link is not straightforward when we see (i) the development of AI applications in non-democratic countries (China, Russia, among others) (Fatima *et al.* 2021) and (ii) the little attention paid to the privacy of their users by the major firms in the sector (Durand 2020). AI can help shape more democratic human collective-decision systems in several ways, from the establishment of fair voting conditions to the integration of artificial voting agents. AI can influence decision-making of humans in different contexts (e.g. politics or dating) (Agudo, Matute 2021). A famous example is an experiment on voting behaviour during the 2010 congressional election in the U.S., using a sample of 61 million Facebook users (Bond *et al.* 2012). The results showed that Facebook messages influenced political self-expression and voting behaviour in millions of people. These results were subsequently replicated during the 2012 U.S. Presidential election (Jones *et al.* 2017). This example shows at the same time how much AI can be useful and very dangerous for democracies.

Humans benefit from a number of recent advances in AI to improve voting systems. The first example is an algorithm developed to counter electoral gerrymandering by creating electoral districts that are representative of the global population (Levin, Friedler 2019). By using an algorithm following a divide-and-conquer approach, it is possible to produce electoral districts' maps that maximise compactness (to ensure geographical continuity) and minimise population deviation (to ensure representativeness) (Levin, Friedler 2019). By following these two rules, the algorithm avoids gerrymandering, thus providing fairer voting conditions, particularly if all stakeholders participated in developing the rules and in evaluating the resulting maps. Another perspective is the integration of principles derived from collective animal processes into AI algorithms (Metcalf *et al.* 2019). By combining human and AI, the Artificial Swarm Intelligence algorithm (Metcalf *et al.* 2019) offers promising results: it performs better than humans-only and machine-only setups on a variety of tasks. The resulting increase in accuracy and acceptance of the collective decision is attributable to the direct involvement of humans in the decision process.

A third approach that requires a democratic debate makes it technically possible for citizens to be represented by avatars reflecting the preferences of each voter rather than by politicians (Perez 2020). Technically, it will soon be possible to create intelligent e-democracy bots that can infer the political preferences of their associated human voter. Such bots could then be allowed to participate in voting processes on the voter's behalf (Perez 2020). For example, these bots could use Natural Language Processing (NLP) to copy the opinion expressed by the politician deemed closest to the voter's position. This controversial topic could allow citizens to express themselves on a wide range of issues. Yet this same technique could reinforce vote manipulation or the abandonment of political life by voters by delegating the expression of their opinions to a bot. When faced with electoral choices, voters sometimes find it difficult to distinguish or rank the positions of different political offers on various issues. Analyses by NLP make it easier to compare the contents of political programmes (Merz *et al.* 2016). This tool provides a more quantitative representation of political programmes, or an easier means to trace the evolution of a party's positions on a specific topic over time. This leverage could be used to improve the trade-offs among parties between rounds or in combination with **evaluative voting** (Baujard *et al.* 2014). In addition, techniques based on distance analyses between the positions of stakeholders in successive rounds of deliberation can identify individuals or clusters that refuse to move towards a consensus (Ding *et al.* 2020). Once these individuals or clusters have been identified, their weight in the next round of deliberation could, for example, be penalised (Ding *et al.* 2020). Democratically, this could make sense because participants in a preference aggregation process who refuse to change their position in response to other stakeholders indicate that they are not prepared to seek consensus among reasonable perspectives (Landemore, Page 2015). Without such a penalisation, small minorities could gain veto power blocking any progress.

AI techniques, such as data mining (Duan *et al.* 2019) and synthetic data generation (El Emam *et al.* 2020; Rankin *et al.* 2020), will also be useful in producing consistent, unbiased and privacy-protecting data (Lane 2020). This last point underlines the importance of the acceptability of AI by the public. While AI is generally viewed positively by the media (Fast, Horvitz 2016), significant concerns about data protection (Lane 2020) and human employment have recently emerged. Thus, resistance to AI is stronger among those least inclined to innovation and most sensitive to data privacy (Lobera *et al.* 2020). Finally, AI is very good at identifying patterns in data, but far less good at predicting complex social outcomes, perhaps because

such outcomes are inherently unpredictable (due to the inevitable reduction of real complexity in algorithms and to the ability of living beings to react very differently to subtle changes in their environment) (Jensen 2021).

The different systems used to aggregate individual preferences

Different systems can be used to aggregate individual preferences, ranging from how proportional they are (i.e. how the final choice represents the votes) and bearing in mind that heterogeneous preferences and beliefs hinder conflict resolution. A parliament selecting the proportion of deputies based exactly on the votes for each party is statistically representative of the political preferences in the population, but one selecting the deputies based only on the majority voting is not. Moreover, the voting systems may change the final result according to how preferences of voters are taken into account (see the section "the needs of citizens"). Human political systems range from authoritarian regimes to full democracies, depending on the distribution of weights for each individual in society (Fig. 2). Authoritarian regimes are more likely to emerge and sustain themselves if the despots manage to secure a relative advantage in fighting ability both in humans and in animals (Hemelrijk 1999; Summers 2005). This fighting advantage may be due to individual traits (strength, personality) but not only. Securing alliances is important to keep the power (Chapais 1995; Waal 2007), which gives prior access to resources as food (King *et al.* 2008), reproduction (Hodge, Manica, Flower, Clutton-Brock 2008; Wroblewski *et al.* 2009), safe places (Schein, Fohrman 1955) but also to leadership (Kindleberger 1981; Peterson R.O. *et al.* 2002; Sueur, MacIntosh, *et al.* 2013). In democracies, the most commonly used representation system is the voting system with **majority voting**, for instance the first-past-the-post rule. Whilst animals do not elect presidents (but see (Waal 2007) to choose the dominant male in an animal society), they use democratic (equally shared consensus) or semi-democratic (partially shared consensus with some individuals having higher decision weights) systems in their everyday life (Conradt, Roper 2003, 2005; List 2004; Sueur, Petit 2008; Seeley 2010). Non-human animals do not have the sophisticated language capacity of humans but this does not mean that they cannot deliberate and negotiate over different alternatives and vote for them (Conradt, Roper 2003; List 2004; Sueur, Deneubourg, *et al.* 2011; Pennisi, Giallongo 2018). Recent empirical studies have shown that the decision-making of social species happens through the adoption of symbolic systems for consensus construction (vocalisations, movements of intentions, notifying behaviours, and dances) (King, Sueur 2011).

Cases (for instance the first-past-the-post rule) where one alternative is chosen until it is more popular than another, whatever small the difference of evidence for the two alternatives may be are said to derive from the **Race Model** and were proved to be non-efficient compared to the **Drift-Diffusion Model** (DDM), described at the individual (i.e. brain) level or the collective level both in humans and animals (Bogacz 2007; Pirrone *et al.* 2014; Ratcliff *et al.* 2016; Tavares *et al.* 2017). The DDM stipulates that the differences between two alternatives have to reach a threshold and this model, operating in brain and collective decision processes, is far more efficient than the race model (Marshall *et al.* 2009; Pelé, Sueur 2013). It is adaptive in urgent situations where decision speed is favoured over accuracy (Pelé, Sueur 2013; Pirrone *et al.* 2014). In ants, in emergency situations, individuals decrease their **quorum** threshold and the quality of a future nest in profit of the decision time, whilst they take time and choose the best nest in normal conditions by increasing the quorum threshold, which indicates a DDM (Franks *et al.* 2003; Marshall *et al.* 2009). This use of different quorums could help to generalise the **Condorcet's jury theorem** to a wider range of **decision ecologies** (Marshall *et al.* 2019). In decision ecology, individuals are prone to two different types of errors: false positives and false negatives. Yet, in its simplest form, the Condorcet theorem assumes that both errors are identical. When this assumption is relaxed (when the probability of a false positive differs from the probability of a false negative), it can be shown that majority voting becomes non representative and should be replaced by sub- or supermajority quorums depending on the conditions (Marshall *et al.* 2019). Sometimes, in humans, instead of choosing one of the two alternatives with a small majority, a compromise can be found thanks to a new alternative satisfying a greater majority. This phenomenon has been coined the **median voter theorem**.
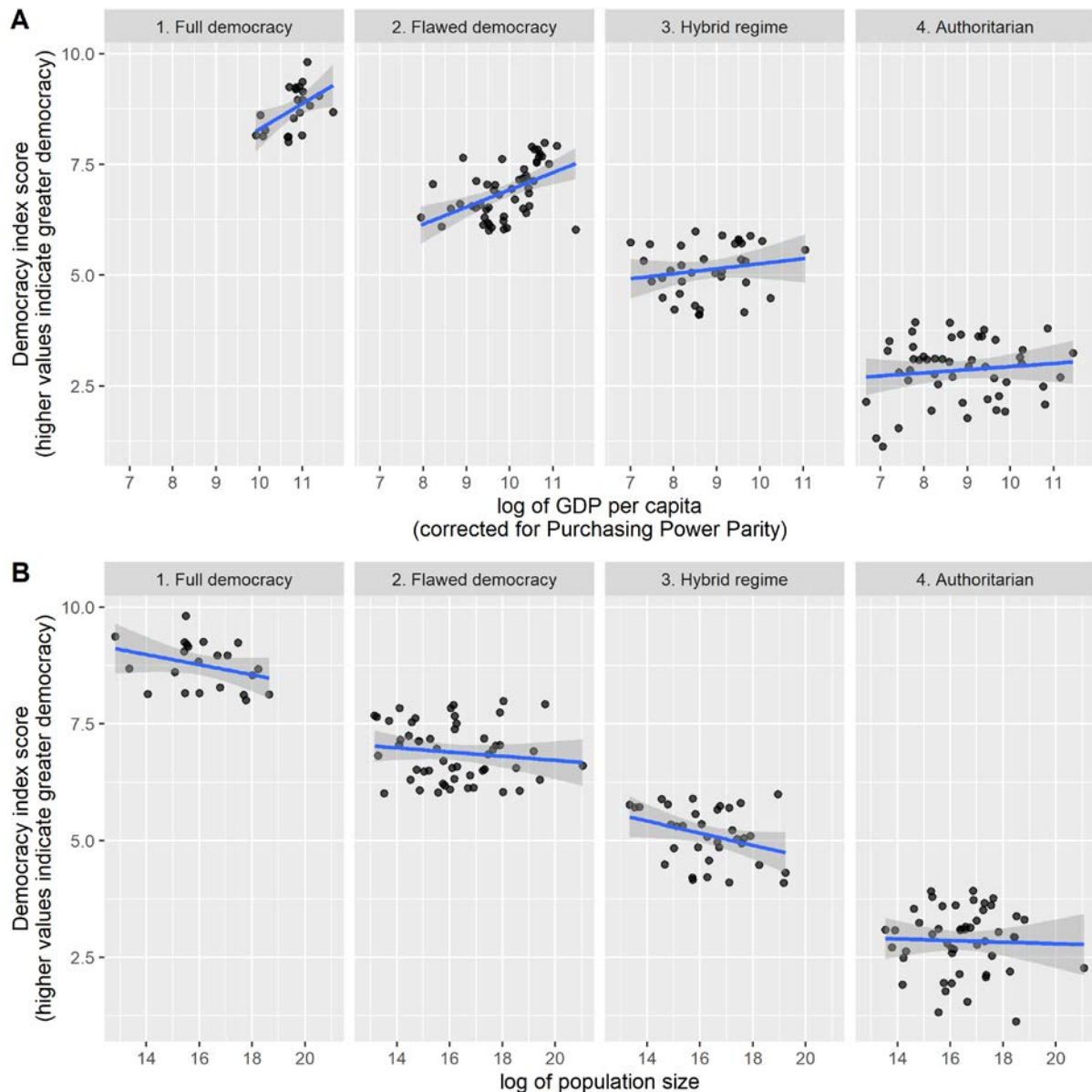
Figure 2: Relationship of the Democracy Index Score (DIS) (each point represents a country) with the logarithm of the country's Growth Domestic Product per capita, corrected for purchasing power parity (A) and the logarithm of the country's population size (B). Within each regime type, a higher democracy index is more likely when GDP per capita is high (LMM: 0.19 ± 0.06, t = 2.990, p < 0.01) (Fig. 1A). There is also a tendency for countries with smaller populations to be more democratic (LMM: -0.08 ± 0.05, t = -1.692, p = 0.09) (Fig. 1B). The analysis takes into account the overall regime type of the country by adding this variable as a random effect in the model. Data come from the following websites: Democracy Index (https://www.eiu.com/topic/democracy-index), GDP (https://data.worldbank.org/indicator/NY.GDP.PCAP.PP.CD) and population size (https://en.wikipedia.org/wiki/List_of_countries_and_dependencies_by_population). Data and analyses script are available at Zenodo. http://doi.org/10.5281/zenodo.4703733

Current voting systems could also be improved by creating small, independent groups of randomly selected voters before deliberation and voting. In this context (called mini-publics), the deliberation phase is crucial to reduce the partisanship bias observed in other voting methods. If a large crowd (in which a meaningful deliberation cannot take place because of its size (Landemore 2020)) is structured into such mini-publics, deliberation and social influence within groups improve the crowd's collective accuracy (Navajas *et al.* 2018): averaging consensus decisions is then significantly more accurate than aggregating

the initial independent opinions. Such settings have proved to provide better and more robust collective decisions in a variety of contexts (Navajas *et al.* 2018; Almaatouq *et al.* 2020; Kurvers *et al.* 2021). This may also be where fission-fusion groups could have an evolutionary advantage over stable groups: for instance, for the same number of individuals over a territory, fission-fusion subgroups may more effectively collect resources than one stable group. However, this hypothesis still needs to be tested empirically.

In animals, the spectrum of weight distributions for individual preferences is also quite broad. Animals have different needs according to their physiological status, different knowledge about their environment, and different personality types (Wolf, Weissing 2012). These variables may have synergetic effects to determine which individuals will emerge as a leader (Bousquet *et al.* 2017). Some species can be classified as despotic, particularly when there is a large difference in resource-holding potential within a group (King *et al.* 2008). In other species, some group members have a greater weight in group decisions, especially when these individuals possess a greater knowledge of the environment that can benefit all group members as in elephants (McComb *et al.* 2011), bonobos (Tokuyama, Furuichi 2017) or killer whales (Brent *et al.* 2015). Still, mechanisms are at work to allow most if not all group members to express their preferences. One such mechanism is to attain a specific number of individuals (a quorum) notifying a preference. For example, African buffalo (Prins 1996), wild dogs (Walker *et al.* 2017), hamadryas baboons (Kummer 1968) or Tonkean macaques (Sueur *et al.* 2010) are reported to use body orientation to vote and indicate their preferred direction to achieve a consensus on travel direction, while golden shiners (Herbert-Read *et al.* 2011; Katz *et al.* 2011) or goats (Sankey *et al.* 2021) achieve consensus of direction by responding to the movement cues of their neighbours. In voting processes, long negotiation processes happen during the collective decision to reach a quorum showing implication of theory of mind, particularly described in primates (Kummer 1968; Sueur, Deneubourg, *et al.* 2011; Strandburg-Peshkin *et al.* 2015). Generally, a voting process to reach a quorum in animals is divided in four steps (Fig. 3): initially, all animals are resting or grazing ❶; then, some individuals stand up and indicate with their body posture or intentional movements their willingness to move in a specific direction ❷; then, group members enter in a negotiation (or deliberation) process where some individuals try to influence others ❸; eventually, all individuals move in the same direction according to the majority choice ❹. Once this quorum is reached, the probability of deciding for the proposed alternative sharply shifts, leading to a group consensus. However, supermajority quorums could be used by a minority to maintain the status quo, without aiming at finding a consensus. As already mentioned, such an attitude could be identified by detection algorithms of non-cooperative behaviour, which could then reduce the weight of this uncooperative minority in the calculation of the consensus degree (Ding *et al.* 2020). A functionally similar mechanism is present in bees searching for new nests: scouts that indicate a potential nest decrease the intensity of their dance each time they return to the hive, causing scouts that found a poorer quality nest to stop dancing faster (Seeley 2003). Quorum decisions are used to manage competing needs and information in order to decrease decision errors (Sumpter, Pratt 2009; Marshall *et al.* 2019). This solution to a collective problem can work without needing high cognitive capacities: much of these collective decisions are the result of relatively simple interaction patterns among group members but not only. Sometimes very high cognitive capacities are involved, but this does not change the implication of self-organised rules. Self-organisation principles also rule collective decisions in species with high cognitive abilities as primates (Sueur, Deneubourg 2011). In this context, group size does not influence behavioural or communication processes involved in the collective processes, the system just switches from global to local communication, which means that group members do not have a full perception of what happens in the group, but they do not need it to decide, as local perception is sufficient (Sueur, King, *et al.* 2011). Voting systems in bees, macaques or bison are not so different even if species differ in social organisation or cognitive capacities. In such 'self-organising systems', multiple individuals following simple rules can produce complex collective behaviours without requiring high abilities at the individual level (Couzin *et al.* 2005; Marshall *et al.* 2009), which is of great relevance for AI systems used in voting systems.
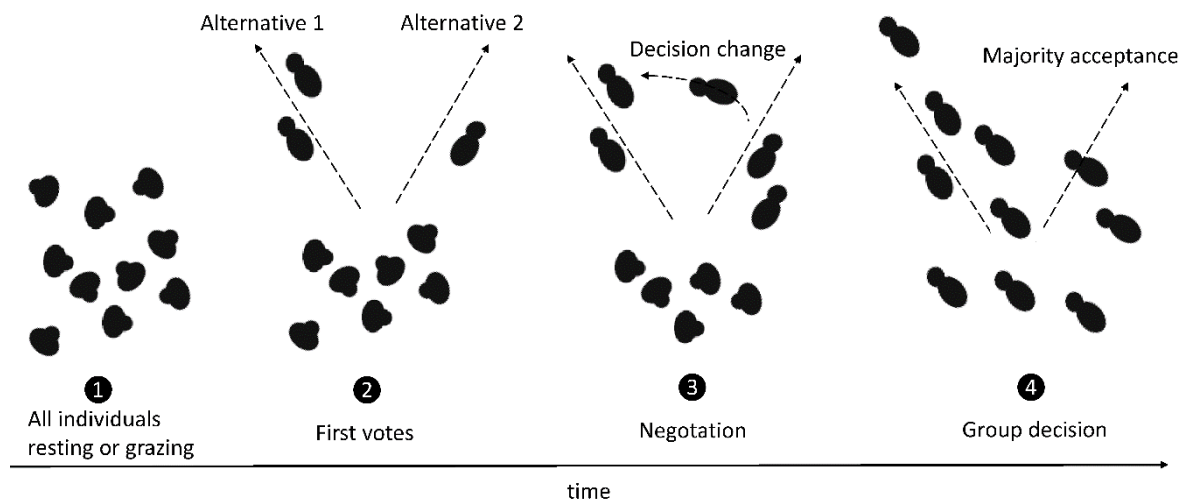
Figure 3: Steps of a voting process in animals

Overall, many studies confirmed that the DDM with a quorum threshold seems to be more efficient than simple majority voting. Another difference between collective decisions in humans and non-human animals is that the latter do not elect representatives like humans do, but decide together throughout the day, as a **participatory democracy**. Besides, non-human animals typically take decisions for short-term aims (those that will occur within minutes or hours after the decision). There are many multilevel animal societies in which some individuals have more influence than others at different organisation levels. Importantly, having a greater weight in the decision does not mean that they are the sole decision makers. This looks like the participatory democracy (or shared consensus) that many human citizens request today and seems to be more efficient than a monopolised leadership (unshared consensus). For instance, in Switzerland, there are seven Councillors who are indirectly representative of the population but the citizens are invited to vote on various issues several times a year, which can be done by mail. So, this system can also work for large sample size and AI can help to pool these votes and avoid errors. However, the consensus type also depends on the population homogeneity in terms of needs and knowledge (Conradt, Roper 2003; Sueur 2012). How to take into account different needs and different knowledge of citizens is of matter and will be developed in the next sections.

The needs of citizens

Decision makers within a group vary in terms of needs, goals and preferences. Therefore, choosing an alternative generally only satisfies individuals who vote for this alternative. Arrow's impossibility theorem stipulates that there is no way to always aggregate all individual choices within one voting system. However, when within-group choices become more aligned, as in emergency or wars, more cohesive or coercive systems may become more acceptable. The current COVID-19 sanitary situation leads us, for example, to accept coercive decisions such as lockdowns and closures of establishments that are not accepted in other situations. Previous theoretical studies worked on this homogeneity concept (Conradt, Roper 2003; Sueur 2012): when animals or humans all have the same needs, there is no issue about preferences pooling and a single leader system is more viable as all individuals are satisfied and the decisions are taken more rapidly than those made using democratic systems, which require participants to vote. This is an auto-emergent dictatorship (Sueur 2012). Collective decision-making in the non-human animal world cannot escape the notion of dominance. However, true despotic societies are rare in animal societies, as they are typically not evolutionarily stable due to the diversity of group members (Sueur 2012). Aggressive and coercive leaders are strongly disfavoured (Smith *et al.* 2016). It is clear that this system is not viable when group members differ in their physiological and social needs and preferences. Moreover, models, confirmed by empirical data (King *et al.* 2008), show that the system collapses if the despot disappears, and a wrong decision taken by the despot may have strong negative consequences for all individuals (Conradt, Roper 2003; Hooper *et al.* 2010; Sueur 2012). Conradt and Roper's model (Conradt,

Roper 2003) indicates that democratic decisions can evolve when groups have a heterogeneous composition, but the higher the heterogeneity, the harsher the conflicts and the more unlikely the conflict resolution. From an evolutionary perspective, animal societies have managed to resolve these conflicts of interest by giving all members the opportunity to participate in daily decisions (i.e. to have a say in agenda-setting) but to different extents. Although dominant individuals can take the role of leader in African wild dogs (Walker *et al.* 2017), meerkats (Bousquet *et al.* 2011) and baboons (King *et al.* 2008), they do not have the exclusive right to decide, but simply a greater weight in the decision (King, Sueur 2011). The alternating of leadership roles among animals can ensure the expression of individual needs (Bousquet, Manser 2011). In this way, voters maintain the leadership purposefully, which implicitly downplays the social and environmental conditions underlying egalitarianism (Van Vugt *et al.* 2008; King 2010). Indeed, true egalitarianism may lead to a very long decision time or even to an absence of consensus. Even if the needs of group members are different, leadership allows a better group coordination but does not permit other members to express their intentions. Indeed, in larger human and non-human groups, group members may willingly give leaders greater leeway to make decisions, in view of the functional benefits of leader-follower relationships in such contexts (Smith *et al.* 2016). For a fully functioning democracy, some researchers in political science favour a switch from participatory democracy to deliberative democracy (Dryzek *et al.* 2019; Landemore 2020). In deliberative human democracies, it is crucial to allow every citizen to express themselves freely, with a seamless interface between this public space and the empowered space (Dryzek, Stevenson 2011) and to have an equal right to participate in the public debate, even outside of the electoral process (Landemore 2020). For instance, the European Commission regularly launches public consultations to which all stakeholders, including unions or NGOs, can contribute.

In animal groups, leadership can respect the needs of different individuals in a number of ways. First, the generality dimension of leadership allows it to be split into various sub-domains (Smith *et al.* 2016). For example, dominant meerkat individuals fight fiercely to secure a disproportionate share of the reproductive output (Hodge, Manica, Flower, Clutton-Brock 2008), but are much less assertive when the group has to take decisions about changes in daily activities (Bousquet, Manser 2011; Bousquet *et al.* 2011; Gall *et al.* 2017). Second, the alternating of leadership roles among group members can ensure the expression of individual needs and leadership. Indeed, studies in sticklebacks (Harcourt *et al.* 2010) and meerkats (Bousquet, Manser 2011) show that individuals with conflicting information take turns in leading the group to their respective favourite location. Another issue with leadership is that it does not safeguard against profiteers becoming leaders. Humans elect people who propose an electoral platform but who may want to be leaders for their personal gain and not for the public good. Leaders can be described as individuals who have a disproportionate level of influence and decision-making power within their communities, and can distort social relationships to their advantage (Conradt, Roper 2005; Bourjade, Sueur 2010; King 2010). Even in non-human animals, leaders shape social dynamics through policing (Flack *et al.* 2006) or by embodying culturally appropriate behaviour (Canteloup *et al.* 2020). In return, leaders are often rewarded with privileges (Flack *et al.* 2006; King *et al.* 2008). Hence, leadership itself is a frequently contested resource that individuals compete to obtain and/or maintain. This issue may concern humans (Riker 1986) and some vertebrates with theory of mind (see a discussion about Machiavellian intelligence in primates (Whiten, Byrne 1997)), but is absent in species such as ants. Machiavellian Intelligence also applies in the context of strategic votes, which is quite difficult to measure in animals even if studies on private versus social information may give some cues about decision-making processes (Czaczkes *et al.* 2011). Are human leaders alpha individuals in a dominance hierarchy (Smith *et al.* 2016)? When we look at presidents or monarchs, this appears to be quite plausible. Work in psychology showed that dominant appearance traits are chosen by voters in absence of more political information (Alexander, Andersen 1993; Olivola, Todorov 2010). Current knowledge in animal and artificial decision-making can help our societies improve their public decision-making systems and can provide insight about institutional and electoral design to select the most appropriate candidates for the offices.

The knowledge on which citizens base their decisions

Knowledge is important to decide which alternative to vote for. Whilst there is a huge work on this domain in political science (Brown 2009; Collins *et al.* 2020), only a few scholars grasped the potential contribution of animal studies to this field (Conradt, List 2009; Krause *et al.* 2010). Humans and non-human

animals have two ways to access information: learning by themselves and/or learning from others (Czaczkes *et al.* 2011; Duboscq *et al.* 2016). The most obvious constraint on majority rules for questions having a correct answer is that the majority of informants the group relies on need to be right (Marshall *et al.* 2019; Mercier, Morin 2019). In eusocial insects, groups seem to identify the best information: even though very few individuals actually possess relevant information regarding the decision at hand, decisions are still efficient with a mix between private and social information (Czaczkes *et al.* 2011). In many cases, individuals check and compare their private and social information before making a decision. Yet we currently observe in human societies many fake news or misinformation voluntarily spread to influence votes for representatives (Golub, Jackson 2010; Kurvers *et al.* 2020). Misinformation is a clear threat to private and social learning as they drive the majority toward a non-efficient decision that is beneficial to the group of manipulators. Many AI algorithms try to identify fake news, particularly during election periods (Gunther *et al.* 2019; KAPLAN 2020; Ozbay, Alatas 2020).

To comply with the Condorcet theorem, votes should be independent from each other. However, the heavy reliance on social information in humans is at odds with this assumption. Therefore, trusting others may have consequences at the individual level (Giraldeau *et al.* 2002), but also at the group level. At the individual level, this is what Amartya Sen called the 'capability to vote': although it is good to vote, it is better when one has the knowledge to vote well (Sen 2009), meaning to be sure to have all the information for each alternative in order to make a choice representative of one's needs. At the group level, the sum of knowledge leads to the emergence of the 'wisdom of crowds' for humans and 'swarm intelligence' for non-human animals (Krause *et al.* 2010; Nagy *et al.* 2020), both of which sometimes fail (Giraldeau *et al.* 2002; Chamley 2004; Kao, Couzin 2014). As already mentioned, several vote-pooling mechanisms can efficiently improve outcome accuracy, both when voters cannot communicate (Almaatouq *et al.* 2020; Kurvers *et al.* 2021) and when communication is allowed (Navajas *et al.* 2018). Theoretical and empirical works suggest that collective decisions can be more accurate than individual decisions. However, homogeneity of individual traits may lead to non-efficient collective decisions (Jolles *et al.* 2020) as group members all search for or have the same information and needs reinforcing the probability to take wrong decisions, whilst diversity of individual traits conducts to diversity of information and diversity of alternatives. In fish, social insects, birds and humans, two or more individuals independently collect information that is processed through social interactions, providing a solution to a cognitive problem that is not available to single individuals (Krause *et al.* 2010). Different studies have attempted to identify who should be trusted and which decision is the best when faced with the choice between one expert and ten non-experts. Collective decisions are almost always preferred to individual ones (Katsikopoulos, King 2010; Kurvers *et al.* 2016). However, it is not necessary to know who has the best information as the combination of individual behaviours and social interactions lead to the emergence of effective systems (Couzin *et al.* 2005).

Importantly, two phenomena may prevent individuals or algorithms from correctly assessing a situation: misinformation (or lack of information) and biases. Currently, fake news and misinformation appear to be on the rise and poses a threat to democracy, particularly when elected politicians and activist groups interact to relay such news (Tollefson 2021). This type of misinformation could be mitigated by providing citizens with a better understanding of how to differentiate between fake and real news. However, sometimes, fake news can also convince well-informed people through other cognitive mechanisms (confirmation bias, desirability bias (Lazer *et al.* 2018)). In such cases, algorithms relying on advanced AI can detect fake news from real information in social media posts (Ozbay, Alatas 2020) or in video speeches (Kaur *et al.* 2020) and can propose, as Twitter, to consider reading a link before sharing it or warn about specific content (violent, unsure). This better identification also comes from research on animal and human communication, particularly facial expressions (Lisetti, Schiano 2000; Crivelli, Fridlund 2018).

Nowadays, humans are connected to many other people directly or indirectly through Facebook and other social media, people who they know as friends or family members or who they do not know but with whom they share similar interests. These connections form a social network which can be embedded into the real and the virtual world. Since the development of these social media, the number of relationships a human has increased, thus reducing the six degrees of separation (Milgram 1967) to three and half (Edunov *et al.* 2016). However, this booming of relationships may lead to different decision biases. Specific connections in social networks may lead information that is considered untrue by the majority to be

excessively over-trusted by voters who only have access to these connections. This social effect, called the 'majority illusion', is derived from the 'friendship paradox'. It leads individuals to systematically overestimate the prevalence of a piece of information, manipulating evidences in the DDM, which may accelerate the spread of fake news and the ultimate choice of an unsuitable alternative (Lerman *et al.* 2016; Jackson 2019). Such so-called 'small world' networks (Milgram 1967) lead to partial views of the world. To our knowledge, only one study has shown this effect in non-human animals (Pasquaretta *et al.* 2016). This is maybe the most difficult issue to control when trying to take individual and collective decisions.

Future perspectives about using animal and artificial intelligence

Human social adaptations evolved in the context of small hunter-gatherer groups solving local problems through vocalisations and gestures. Now humans face complex challenges from pandemics to climate change and communicate on dispersed networks connected by digital technologies and social media (Bak-Coleman *et al.* 2021). We are not ready for this, cognitively speaking, facing numerous biases, but decentralised systems exist in animal societies and we can use their decision-making processes via AI to increase the efficiency of our collective decisions (Bak-Coleman *et al.* 2021). Moreover, AI can also help to predict and understand how people make decisions even at large scale (Peterson *et al.* 2021). Then a strong link in the future research, between human collective decisions, AI and animal behaviour has to be made.

Numerous instances, such as policies on climate change, show that majority voting may lead to non-efficient collective decisions. We identified several research frameworks that could enhance the effectiveness of human collective-decision system:

1. Animal studies have shown that collective rules evolve to achieve efficient decisions. Many of these results inspired AI to help reach better democratic decisions. Continuing to think about a diffusion model with an appropriate difference threshold between alternatives and with an appropriate quorum (Bogacz 2007; Marshall *et al.* 2009) would increase effectiveness of human systems. We have to create systems in which minorities can attempt different strategies that search through the solution space. We need to "rethink democracy" not as an all-or-nothing system (Bollen, Jackman 1989), with always opposite alternatives where one wins and one loses but to build integrative solutions leading to unified societies as defined in deliberative or open democracies (Landemore 2020). As Seeley says in Honeybee Democracy (Seeley 2010), "It often pays a group to *argue* things carefully through to find the best solution to a tough problem" (p. 2). This is where applying the DDM might be useful to balance between accuracy and speed of the collective decision.

2. A second aim would be to increase participatory and deliberative democracy and AI helping it. The frequencies and the weights of decisions of each member in non-human animal groups or in small human groups are much higher than those observed in large human societies, as these groups decide on a daily basis: non-human animals or hunter-gatherers appear to hold referendums every day. A more participatory democracy in large human societies resembling those we observe in animal societies could result in greater satisfaction of citizens but also more efficient decisions due to a greater accumulation of knowledge (Katsikopoulos, King 2010; Czaczkes *et al.* 2011). Indeed, from our animal roots, the current decrease in voter turnout is not surprising, because current voting systems prevent ordinary citizens from participating in agenda-setting and deliberation phases, two important facets of animal collective decision-making. Agenda-setting should therefore be given back to citizens, for instance via sortition-based assemblies or mini-publics (Landemore 2020).

3. Third, we need to better understand how our connections affect the quality of information we get and as a consequence the efficiency of our decisions. The digital age and the rise of social media have accelerated changes to our social systems, with poorly understood functional consequences. We can gain a better picture of how our individual or collective decisions are constructed through the study of the real or imaginative links we make between the information provided by TV, social networks, social media and influential people (Kao, Couzin 2014). As humans we tend to think that we have control over our decisions and knowledge, but recent events in elections have shown this to be untrue. Collective behaviour reveals how large-scale higher-order properties of the group feedback to influence individual behaviour, which in turn can influence the behaviour of the group, and so on. Many voting processes are self-organized in the

animal kingdom and we should admit that this is also the case in humans (Sumpter, Pratt 2009; Kao, Couzin 2014).

Concluding remarks

Identifying these animal collective solutions shaped by selection over millions of years and implementing them into AI algorithms devoted to democracy is likely to increase the stability of our political systems in achieving larger consensus and reducing polarisation. However, AI can also be dangerous (Lazer *et al.* 2018; Kaur *et al.* 2020) and several scientists appeal to more and more develop the research field in AI ethics (Miorandi *et al.* 2014; Jobin *et al.* 2019; Hagendorff 2020). More research on efficient collective decisions in algorithms and animals has to be done focusing on the outcomes and their effectiveness. Indeed, humans are limited by their cognitive capacities, some biases and their mental dimensions, leading to higher polarisation of societies and mental block to think about new voting systems. As animals do not think as we do, behavioural experiments on multiple species and modelling can help to get out of these human dimensions, and to find new ones (De Waal 2016; Meijer 2019). This could improve humanity and yield novel bioinspired technologies.

Glossary

Agenda-setting: Ability to participate in the definition of the issues and/or options open to a vote.

Artificial intelligence: Set of algorithms and processes enabling artificial agents to perceive their environment or to process data in order to respond in an optimised way to a given problem.

Condorcet's jury theorem: The Condorcet's jury Theorem implies that the choice made by a group using the majority voting rule will be better than the individual choices of the members of that group, provided that the members of the group have more than a 1 in 2 chance of being correct. One of its postulates is that individuals can only make one type of mistake, which is not always true.

Condorcet winner criterion: The Condorcet criterion for a voting system is that it chooses the beats-all winner when one exists.

Decision ecology: Concept encompassing all dimensions influencing decision-making. It takes the types of error individuals do as the starting point for understanding decision-making and suggests that decisions need to be understood within their context.

Deliberative democracy: Form of democracy in which deliberation and negotiation are central to decision-making. It adopts elements of both consensus decision-making and majority rule.

Drift-Diffusion Model: The DDM stipulates that a choice should be made as soon as the difference between the evidence (information) supporting the winning alternative (drift 1) and the evidence supporting the losing alternative (drift 2) exceeds a threshold. The DDM implements a test called the sequential probability ratio test which optimises the speed of decision-making for a required accuracy.

Efficiency: In the context of voting, efficiency relies on a decision that maximises the difference between the benefits and the costs. These benefits and costs can be measured in two ways: first, the time to take a decision, which can increase costs if it is too long; second the representativeness of the decision. Usually, there is a trade-off between the decision time and the representativeness. This trade-off reflects the decision efficiency (Pelé, Sueur 2013; Sueur, King, *et al.* 2013). Time to take a decision often reflects the quantity of information or evidence one can get to take a decision. A short decision time indicates low quantity and quality of information conducting to higher probability of wrong decision. With efficient decisions, the divide between competing participants is likely to decrease and such decisions are therefore more likely to be implemented for longer periods of time (List *et al.* 2013; Dryzek *et al.* 2019). As a corollary, efficient decisions are generally more representative of the diversity of the group (Dryzek *et al.* 2019).

Evaluative voting: Each alternative open to voting can be evaluated independently by each voter. The scale for evaluating alternatives may vary.

Majority voting: A decision is taken as soon as a number of votes equals to (N/2) + 1 of the N votes cast.

Median voter theorem: Proposition relating to direct ranked preference voting put forward by Duncan Black (Black 1948). It states that if opinions are distributed along a one-dimensional spectrum, then any voting method which satisfies the **Condorcet winner criterion** will produce a winner close to the median voter.

Participatory democracy: Participatory democracy tends to advocate more involved forms of citizen participation and greater political representation than representative democracy.

Quorum: Minimum number of group members necessary to observe a drastic change in group behaviour or to validate a group decision. Majority voting is a special case of quorum. Fifty percent for a quorum makes sense when only two alternatives are proposed, which is rare in animal societies as researchers count all animals even those which do not have opinions. Fifty percent majority is present in humans but removing individuals with no opinion. If we consider individuals who do not vote or do white vote, the majority does not reach 50%. For instance, if only 60% of the population vote, then the real quorum is 30% (60%*50%). Sub-majority quorums refer to cases where the collective decision is taken as soon as a threshold of less than 50% is reached. Symmetrically, super-majority quorums refer to cases where the collective decision is taken as soon as a threshold of more than 50% is reached.

Race Model: The Race Model stipulates that a choice should be made as soon as the evidence supporting the winning alternative exceeds a threshold.

Representativeness: State or quality of a decision to be representative of the group or individual needs according to the level we consider (group or individual).

Self-selection: Selection mechanism relying on individuals selecting themselves to influence collective decisions; in humans, self-selection is present in all candidates for elections or participants in a demonstration; in non-human animals, self-selection is present when individuals produce signals that are evaluated during the voting process.

Sortition: Selection mechanism relying on a (stratified) random sampling of participants; in humans, sortition is a recognised method for producing interpretable opinion polls.

Voting system: Mechanism by which individual preferences are pooled together in order to reach a group decision.

Data accessibility

Data are available online: http://doi.org/10.5281/zenodo.4703733

Acknowledgements

Conflict of interest disclosure

The authors declare no competing interests. Cédric Sueur is one of the PCI Network Sci recommenders

References

Agudo U, Matute H (2021) The influence of algorithms on political and dating decisions. PLOS ONE, 16, e0249454. https://doi.org/10.1371/journal.pone.0249454

Alexander D, Andersen K (1993) Gender as a Factor in the Attribution of Leadership Traits. Political Research Quarterly, 46, 527-545. https://doi.org/10.1177/106591299304600305

Almaatouq A, Noriega-Campero A, Alotaibi A, Krafft P, Moussaid M, Pentland A (2020) Adaptive social networks promote the wisdom of crowds. Proceedings of the national academy of sciences of the United States of America, 117, 11379-113686. https://doi.org/10.1073/pnas.1917687117

Aral S, Eckles D (2019) Protecting elections from social media manipulation. Science, 365, 858-861. https://doi.org/10.1126/science.aaw8243

Arrow KJ (1950) A difficulty in the concept of social welfare. Journal of political economy, 58, 328-346. https://doi.org/10.1086/256963

Bachrach P, Baratz MS (1962) Two faces of power. American political science review, 56, 947-952. https://doi.org/10.2307/1952796

Bak-Coleman JB, Alfano M, Barfuss W, Bergstrom CT, Centeno MA, Couzin ID, Donges JF, Galesic M, Gersick AS, Jacquet J, Kao AB, Moran RE, Romanczuk P, Rubenstein DI, Tombak KJ, Bavel JJV, Weber EU (2021) Stewardship of global collective behavior. Proceedings of the National Academy of Sciences, 118. https://doi.org/10.1073/pnas.2025764118

Baujard A, Igersheim H, Lebon I, Gavrel F, Laslier J-F (2014) Who's favored by evaluative voting? An experiment conducted during the 2012 French presidential election. Electoral studies, 34, 131-145. https://doi.org/10.1016/j.electstud.2013.11.003

Bayne T, Brainard D, Byrne RW, Chittka L, Clayton N, Heyes C, Mather J, Ölveczky B, Shadlen M, Suddendorf T (2019) What is cognition? Current Biology, 29, R608-R615. https://doi.org/10.1016/j.cub.2019.05.044

Bergson A (1958) An Economic Theory of Democracy. New York. Harper & Row, 310 p.

Black D (1948) On the rationale of group decision-making. Journal of political economy, 56, 23-34. https://doi.org/10.1086/256633

Blum C, Zuber CI (2016) Liquid democracy: potentials, problems, and perspectives. Journal of political philosophy, 24, 162-182. https://doi.org/10.1111/jopp.12065

Bogacz R (2007) Optimal decision-making theories: linking neurobiology with behaviour. Trends in cognitive sciences, 11, 118-125. https://doi.org/10.1016/j.tics.2006.12.006

Bollen KA, Jackman RW (1989) Democracy, stability, and dichotomies. American Sociological Review, 612-621. https://doi.org/10.2307/2095882

Bond RM, Fariss CJ, Jones JJ, Kramer ADI, Marlow C, Settle JE, Fowler JH (2012) A 61-million-person experiment in social influence and political mobilization. Nature, 489, 295-298. https://doi.org/10.1038/nature11421

Boureau Y-L, Sokol-Hessner P, Daw ND (2015) Deciding How To Decide: Self-Control and Meta-Decision Making. Trends in Cognitive Sciences, 19, 700-710. https://doi.org/10.1016/j.tics.2015.08.013

Bourjade M, Sueur C (2010) Shared or unshared consensus for collective movement? Towards methodological concerns. Behavioural processes, 84, 648-652. https://doi.org/10.1016/j.beproc.2010.02.027

Bousquet CAH, Ahr N, Sueur C, Petit O (2017) Determinants of leadership in groups of female mallards. Behaviour, 154, 467-507. https://doi.org/doi.org/10.1163/1568539X-00003431

Bousquet CAH, Manser MB (2011) Resolution of experimentally induced symmetrical conflicts of interest in meerkats. Animal behaviour, 81, 1101-1107. https://doi.org/10.1016/j.anbehav.2011.02.030

Bousquet CAH, Sumpter DJT, Manser MB (2011) Moving calls: a vocal mechanism underlying quorum decisions in cohesive groups. Proceedings of the Royal Society of London B, 278, 1482-1488. https://doi.org/10.1098/rspb.2010.1739

Brent LJ, Franks DW, Foster EA, Balcomb KC, Cant MA, Croft DP (2015) Ecological knowledge, leadership, and the evolution of menopause in killer whales. Current biology, 25, 746-750. https://doi.org/10.1016/j.cub.2015.01.037

Brown MB (2009) Science in democracy: Expertise, institutions, and representation. MIT Press.

Buffin A, Goldman S, Deneubourg JL (2012) Collective regulatory stock management and spatiotemporal dynamics of the food flow in ants. The FASEB journal, 26, 2725-2733. https://doi.org/10.1096/fj.11-193698

Burns ALJ, Herbert-Read JE, Morrell LJ, Ward AJW (2012) Consistency of Leadership in Shoals of Mosquitofish (Gambusia holbrooki) in Novel and in Familiar Environments. PLoS ONE, 7, e36567. https://doi.org/10.1371/journal.pone.0036567

Canteloup C, Hoppitt W, van de Waal E (2020) Wild primates copy higher-ranked individuals in a social transmission experiment. Nature communications, 11, 1-10. https://doi.org/10.1038/s41467-019-14209-8

Chamley C (2004) Rational herds. Cambridge University Press, Cambridge, 3, 20. https://doi.org/10.1017/CBO9780511616372

Chapais B (1995) Alliances as a means of competition in primates: Evolutionary, developmental, and cognitive aspects. American Journal of Physical Anthropology, 38, 115-136. https://doi.org/10.1002/ajpa.1330380607

Collins H, Evans R, Durant D, Weinel M (2020) Introduction: Pluralist Democracy, Populism and Expertise. In: Experts and the Will of the People , pp. 1-9. Springer. https://doi.org/10.1007/978-3-030-26983-8_1

Conradt L, List C (2009) Group decisions in humans and animals: a survey. Philosophical Transactions of the Royal Society B: Biological Sciences, 364, 719-742. https://doi.org/10.1098/rstb.2008.0276

Conradt L, Roper TJ (2003) Group decision-making in animals. Nature, 421, 155-158. https://doi.org/10.1038/nature01294

Conradt L, Roper TJ (2005) Consensus decision making in animals. Trends in ecology & evolution, 20, 449-456. https://doi.org/10.1016/j.tree.2005.05.008

Couzin ID, Krause J, Franks NR, Levin SA (2005) Effective leadership and decision-making in animal groups on the move. Nature, 433, 513-516. https://doi.org/10.1038/nature03236

Crivelli C, Fridlund AJ (2018) Facial displays are tools for social influence. Trends in Cognitive Sciences, 22, 388-399. https://doi.org/10.1016/j.tics.2018.02.006

Czaczkes TJ, Grüter C, Jones SM, Ratnieks FL (2011) Synergy between social and private information increases foraging efficiency in ants. Biology letters, 7, 521-524. https://doi.org/10.1098/rsbl.2011.0067

Davenport C, Landler M (2019) Trump administration hardens its attack on climate science. New York Times, 27.

De Waal F (2016) Are we smart enough to know how smart animals are? WW Norton & Company.

Ding R-X, Palomares I, Wang X, Yang G-R, Liu B, Dong Y, Herrera-Viedma E, Herrera F (2020) Large-scale decision-making: characterization, taxonomy, challenges and future directions from an artificial intelligence and applications perspective. Information fusion, 59, 84-102. https://doi.org/10.1016/j.inffus.2020.01.006

Dorigo M, Theraulaz G, Trianni V (2020) Reflections on the future of swarm robotics. Science Robotics, 5, eabe4385. https://doi.org/10.1126/scirobotics.abe4385

Dryzek JS, Bächtiger A, Chambers S, Cohen J, Druckman JN, Felicetti A, Fishkin JS, Farrell DM, Fung A, Gutmann A (2019) The crisis of democracy and the science of deliberation. Science, 363, 1144-1146. https://doi.org/10.1126/science.aaw2694

Dryzek JS, Stevenson H (2011) Global democracy and earth system governance. Ecological economics, 70, 1865-1874. https://doi.org/10.1016/j.ecolecon.2011.01.021

Duan Y, Edwards JS, Dwivedi YK (2019) Artificial intelligence for decision making in the era of Big Data - evolution, challenges and research agenda. International journal of information management, 48, 63-71. https://doi.org/10.1016/j.ijinfomgt.2019.01.021

Duboscq J, Romano V, MacIntosh A, Sueur C (2016) Social Information Transmission in Animals: Lessons from Studies of Diffusion. Frontiers in Psychology, 7.

Durand C (2020) Technoféodalisme - Critique de l'économie numérique. Zones, Paris, France.

Edunov S, Diuk C, Filiz IO, Bhagat S, Burke M (2016) Three and a half degrees of separation. Research at Facebook, 694.

El Emam K, Mosquera L, Hoptroff R (2020) Practical synthetic data generation: balancing privacy and the broad availability of data. O'Reilly Media, Sebastopol, CA.

Enelow JM, Hinich MJ (1989) A general probabilistic spatial theory of elections. Public Choice, 61, 101-113. https://doi.org/10.1007/BF00115657

Fast E, Horvitz E (2016) Long-term trends in the public perception of artificial intelligence. arXiv preprint, arXiv:1609.04904.

Fatima S, Desouza KC, Denford JS, Dawson GS (2021) What explains governments interest in artificial intelligence? A signaling theory approach. Economic analysis and policy, 71, 238-254. https://doi.org/10.1016/j.eap.2021.05.001

Flack JC, Girvan M, De Waal FB, Krakauer DC (2006) Policing stabilizes construction of social niches in primates. Nature, 439, 426-429. https://doi.org/10.1038/nature04326

Fox RL, Lawless JL (2005) To run or not to run for office: explaining nascent political ambition. American journal of political science, 49, 642-659. https://doi.org/10.1111/j.1540-5907.2005.00147.x

Franks NR, Dornhaus A, Fitzsimmons JP, Stevens M (2003) Speed versus accuracy in collective decision making. Proceedings of the Royal Society of London. Series B: Biological Sciences, 270, 2457-2463. https://doi.org/10.1098/rspb.2003.2527

Gall GE, Strandburg-Peshkin A, Clutton-Brock T, Manser MB (2017) As dusk falls: collective decisions about the return to sleeping sites in meerkats. Animal behaviour, 132, 91-99. https://doi.org/10.1016/j.anbehav.2017.08.001

Giraldeau L, Valone TJ, Templeton JJ (2002) Potential disadvantages of using socially acquired information. Philosophical transactions of the Royal Society B: biological sciences, 357, 1559-1566. https://doi.org/10.1098/rstb.2002.1065

Golub B, Jackson MO (2010) Naive learning in social networks and the wisdom of crowds. American Economic Journal: Microeconomics, 2, 112-49. https://doi.org/10.1257/mic.2.1.112

Gunther R, Beck PA, Nisbet EC (2019) "Fake news" and the defection of 2012 Obama voters in the 2016 presidential election. Electoral studies, 61, 102030. https://doi.org/10.1016/j.electstud.2019.03.006

Hagendorff T (2020) The ethics of AI ethics: An evaluation of guidelines. Minds and Machines, 30, 99-120. https://doi.org/10.1007/s11023-020-09517-8

Harcourt JL, Sweetman G, Manica A, Johnstone RA (2010) Pairs of fish resolve conflicts over coordinated movement by taking turns. Current biology, 20, 156-160. https://doi.org/10.1016/j.cub.2009.11.045

Hassabis D, Kumaran D, Summerfield C, Botvinick M (2017) Neuroscience-Inspired Artificial Intelligence. Neuron, 95, 245-258. https://doi.org/10.1016/j.neuron.2017.06.011

Hemelrijk CK (1999) An individual-orientated model of the emergence of despotic and egalitarian societies. Proceedings of the Royal Society of London B, 266, 361-369. https://doi.org/10.1098/rspb.1999.0646

Henzi S, Lycett J, Piper S (1997) Fission and troop size in a mountain baboon population. Animal behaviour, 53, 525-535. https://doi.org/10.1006/anbe.1996.0302

Herbert-Read JE, Perna A, Mann RP, Schaerf TM, Sumpter DJ, Ward AJ (2011) Inferring the rules of interaction of shoaling fish. Proceedings of the National Academy of Sciences, 108, 18726-18731. https://doi.org/10.1073/pnas.1109355108

Hinich MJ, Munger MC (2008) The dynamics of issue introduction: A model based on the politics of ideology. Mathematical and computer modelling, 48, 1510-1518. https://doi.org/10.1016/j.mcm.2008.05.022

Hodge SJ, Manica A, Flower TP, Clutton-Brock TH (2008) Determinants of reproductive success in dominant female meerkats. Journal of Animal Ecology, 77, 92-102. https://doi.org/10.1111/j.1365-2656.2007.01318.x

Hodge SJ, Manica A, Flower TP, Clutton-Brock TH (2008) Determinants of reproductive success in dominant female meerkats. Journal of animal ecology, 77, 92-102. https://doi.org/10.1111/j.1365-2656.2007.01318.x

Hoerner JM, Hobolt SB (2019) Unity in diversity? Polarization, issue diversity and satisfaction with democracy. Journal of European public policy, 27(12), 1838-1857. https://doi.org/10.1080/13501763.2019.1699592

Hooper PL, Kaplan HS, Boone JL (2010) A theory of leadership in human cooperative groups. Journal of Theoretical Biology, 265, 633-646. https://doi.org/10.1016/j.jtbi.2010.05.034

Jackson MO (2019) The friendship paradox and systematic biases in perceptions and social norms. Journal of political economy, 127, 777-818. https://doi.org/10.1086/701031

Jensen P (2021) Your life in numbers: modeling society through data. Copernicus.

Jobin A, Ienca M, Vayena E (2019) The global landscape of AI ethics guidelines. Nature Machine Intelligence, 1, 389-399. https://doi.org/10.1038/s42256-019-0088-2

Jolles JW, King AJ, Killen SS (2020) The role of individual heterogeneity in collective animal behaviour. Trends in ecology & evolution, 35, 278-291. https://doi.org/10.1016/j.tree.2019.11.001

Jones JJ, Bond RM, Bakshy E, Eckles D, Fowler JH (2017) Social influence and political mobilization: Further evidence from a randomized experiment in the 2012 U.S. presidential election. PloS One, 12, e0173851. https://doi.org/10.1371/journal.pone.0173851

Jotzo F, Depledge J, Winkler H (2018) US and international climate policy under President Trump. Climate Policy, 18:7, 813-817. https://doi.org/10.1080/14693062.2018.1490051

Kao AB, Couzin ID (2014) Decision accuracy in complex environments is often maximized by small group sizes. Proceedings of the Royal Society of London B, 281, 20133305. https://doi.org/10.1098/rspb.2013.3305

Kaplan A (2020) Artificial intelligence, social media, and fake news: Is this the end of democracy? In Digital Transformation in Media & Society, Istanbul University Press, p149-161. https://doi.org/10.0.104.26/B/SS07.2020.013.09

Katsikopoulos KV, King AJ (2010) Swarm intelligence in animal groups: when can a collective out-perform an expert? PLoS ONE, 5, e15505. https://doi.org/10.1371/journal.pone.0015505

Katz Y, Tunstrøm K, Ioannou CC, Huepe C, Couzin ID (2011) Inferring the structure and dynamics of interactions in schooling fish. Proceedings of the National Academy of Sciences, 108, 18720-18725. https://doi.org/10.1073/pnas.1107583108

Kaur S, Kumar P, Kumaraguru P (2020) Deepfakes: temporal sequential analysis to detect face-swapped video clips using convolutional long short-term memory. Journal of electronic imaging, 29, 033013. https://doi.org/10.1117/1.JEI.29.3.033013

Kindleberger CP (1981) Dominance and Leadership in the International Economy: Exploitation, Public Goods, and Free Rides. International Studies Quarterly, 25, 242-254. https://doi.org/10.2307/2600355

King AJ (2010) Follow me! I'm a leader if you do; I'm a failed initiator if you don't? Behavioural processes, 84, 671-674. https://doi.org/10.1016/j.beproc.2010.03.006

King A, Douglas C, Huchard E, Isaac N, Cowlishaw G (2008) Dominance and Affiliation Mediate Despotism in a Social Primate. Current Biology, 18, 1833-1838. https://doi.org/10.1016/j.cub.2008.10.048

King AJ, Sueur C (2011) Where next? Group coordination and collective decision making by primates. International journal of primatology, 32, 1245-1267. https://doi.org/10.1007/s10764-011-9526-7

Kostelka F, Blais A (2021) The generational and institutional sources of the global decline in voter turnout. World politics. Kostelka_Blais_Manuscript.pdf (essex.ac.uk)

Krause J, Ruxton GD, Krause S (2010) Swarm intelligence in animals and humans. Trends in ecology & evolution, 25, 28-34. https://doi.org/10.1016/j.tree.2009.06.016

Kummer H (1968) Social Organization of Hamadryas Baboons. A Field Study. University of Chicago Press, Chicago, 189p.

Kurvers RH, Hertz U, Karpus J, Balode MP, Jayles B, Binmore K, Bahrami B (2020) Strategic dishonesty trumps truth-telling in competition for social influence. PsyArXiv preprints. https://doi.org/10.31234/osf.io/vpzg5

Kurvers RH, Herzog SM, Hertwig R, Krause J, Carney PA, Bogart A, Argenziano G, Zalaudek I, Wolf M (2016) Boosting medical diagnostics by pooling independent judgments. Proceedings of the National Academy of Sciences of the United States of America, 113, 8777-8782. https://doi.org/10.1073/pnas.1601827113

Kurvers RH, Herzog SM, Hertwig R, Krause J, Wolf M (2021) Pooling decisions decreases variation in response bias and accuracy. iScience, 24, 102740. https://doi.org/10.1016/j.isci.2021.102740

Landemore H (2020) Open democracy: reinventing popular rule for the twenty-first century. Princeton University Press.

Landemore H, Page SE (2015) Deliberation and disagreement: problem solving, prediction, and positive dissensus. Politics, philosophy & economics, 14, 229-254. https://doi.org/10.1177/1470594X14544284

Lane J (2020) Democratizing our data: a manifesto. MIT Press. https://doi.org/10.7551/mitpress/11990.001.0001

Lazer DM, Baum MA, Benkler Y, Berinsky AJ, Greenhill KM, Menczer F, Metzger MJ, Nyhan B, Pennycook G, Rothschild D (2018) The science of fake news. Science, 359, 1094-1096. https://doi.org/10.1126/science.aao2998

Lerman K, Yan X, Wu X-Z (2016) The "majority illusion" in social networks. PLoS ONE, 11, e0147617. https://doi.org/10.1371/journal.pone.0147617

Levin HA, Friedler SA (2019) Automated congressional redistricting. Journal of experimental algorithmics, 24, 1-24. https://doi.org/10.1145/3316513

Lisetti CL, Schiano DJ (2000) Automatic facial expression interpretation: Where human-computer interaction, artificial intelligence and cognitive science intersect. Pragmatics & cognition, 8, 185-235. https://doi.org/10.1075/pc.8.1.09lis

List C (2004) Democracy in animal groups: a political science perspective. Trends in Ecology & Evolution (Personal Edition), 19, 168-169. https://doi.org/10.1016/j.tree.2004.02.004

List C, Luskin RC, Fishkin JS, McLean I (2013) Deliberation, single-peakedness, and the possibility of meaningful democracy: evidence from deliberative polls. The journal of politics, 75, 80-95. https://doi.org/10.1017/S0022381612000886

Lobera J, Fernández Rodríguez CJ, Torres-Albero C (2020) Privacy, values and machines: predicting opposition to artificial intelligence. Communication studies, 71, 448-465. https://doi.org/10.1080/10510974.2020.1736114

Manno TG, Dobson FS, Hoogland JL, Foltz DW (2007) Social group fission and gene dynamics among black-tailed prairie dogs (Cynomys ludovicianus). Journal of mammalogy, 88, 448-456. https://doi.org/10.1644/06-MAMM-A-099R1.1

Marshall JA (2011) Optimal voting in groups with convergent interests. In 2011 AAAI Spring Symposium Series, 12-16, Technical Report SS-11-08, Stanford, California, USA

Marshall JA, Bogacz R, Dornhaus A, Planqué R, Kovacs T, Franks NR (2009) On optimal decision-making in brains and social insect colonies. Journal of the Royal Society Interface, 6, 1065-1074. https://doi.org/10.1098/rsif.2008.0511

Marshall JA, Kurvers RH, Krause J, Wolf M (2019) Quorums enable optimal pooling of independent judgements in biological systems. eLife, 8, e40368. https://doi.org/10.7554/eLife.40368

McComb K, Shannon G, Durant SM, Sayialel K, Slotow R, Poole J, Moss C (2011) Leadership in Elephants: The Adaptive Value of Age. Proceedings of the Royal Society B: Biological Sciences, 278, 3270-3276. https://doi.org/10.1098/rspb.2011.0168

Meijer E (2019) When Animals Speak: Toward an Interspecies Democracy. NYU Press. https://doi.org/10.18574/nyu/9781479859351.001.0001

Ménard N, Vallet D (1993) Dynamics of fission in a wild Barbary macaque group (Macaca sylvanus). International journal of primatology, 14, 479-500. https://doi.org/10.1007/BF02192778

Mercier H, Morin O (2019) Majority rules: how good are we at aggregating convergent opinions? Evolutionary human sciences, 1, e6. https://doi.org/10.1017/ehs.2019.6

Merz N, Regel S, Lewandowski J (2016) The Manifesto Corpus: a new resource for research on political parties and quantitative text analysis. Research & politics, 3, 2053168016643346. https://doi.org/10.1177/2053168016643346

Metcalf L, Askay DA, Rosenberg LB (2019) Keeping humans in the loop: pooling knowledge through artificial swarm intelligence to improve business decision making. California management review, 61, 84-109. https://doi.org/10.1177/0008125619862256

Mezza-Garcia N (2013) Bio-inspired Political Systems: Opening a Field. In: Proceedings of the European Conference on Complex Systems 2012 Springer Proceedings in Complexity. (eds Gilbert T, Kirkilionis M, Nicolis G), pp. 785-812. Springer International Publishing, Cham. https://doi.org/10.1007/978-3-319-00395-5_97

Milgram S (1967) The small world problem. Psychology today, 1, 60-67. https://doi.org/10.1037/e400002009-005

Miller JC (1969) A program for direct and proxy voting in the legislative process. Public choice, 7, 107-113. https://doi.org/10.1007/BF01718736

Miorandi D, Maltese V, Rovatsos M, Nijholt A, Stewart J (2014) Social collective intelligence - Combining the powers of humans and machines to build a smarter society. Springer.

Nagy M, Horicsányi A, Kubinyi E, Couzin ID, Vásárhelyi G, Flack A, Vicsek T (2020) Synergistic Benefits of Group Search in Rats. Current Biology, 0. https://doi.org/10.1016/j.cub.2020.08.079

Navajas J, Niella T, Garbulsky G, Bahrami B, Sigman M (2018) Aggregated knowledge from a small number of debates outperforms the wisdom of large crowds. Nature human behaviour, 2, 126-132. https://doi.org/10.1038/s41562-017-0273-4

Okamoto K, Matsumura S (2001) Group fission in moor macaques (Macaca maurus). International journal of primatology, 22, 481-493. https://doi.org/10.1023/A:1010711813637

Olivola CY, Todorov A (2010) Elected in 100 milliseconds: Appearance-Based Trait Inferences and Voting. Journal of Nonverbal Behavior, 34, 83-110. https://doi.org/10.1007/s10919-009-0082-1

Ozbay FA, Alatas B (2020) Fake news detection within online social media using supervised artificial intelligence algorithms. Physica A: statistical mechanics and its applications, 540, 123174. https://doi.org/10.1016/j.physa.2019.123174

Pasquaretta C, Battesti M, Klenschi E, Bousquet CAH, Sueur C, Mery F (2016) How social network structure affects decision-making in Drosophila melanogaster. Proceedings of the Royal Society of London B, 283, 20152954. https://doi.org/10.1098/rspb.2015.2954

Pelé M, Sueur C (2013) Decision-making theories: linking the disparate research areas of individual and collective cognition. Animal cognition, 16, 543-556. https://doi.org/10.1007/s10071-013-0631-1

Pennisi A, Giallongo L (2018) Animal biopolitics: how animals vote. International journal for the semiotics of law - Revue internationale de sémiotique juridique, 31, 491-499. https://doi.org/10.1007/s11196-018-9560-2

Perez O (2020) Collaborative e-rulemaking, democratic bots, and the future of digital democracy. Digital government: research and practice, 1, 1-13. https://doi.org/10.1145/3352463

Peterson JC, Bourgin DD, Agrawal M, Reichman D, Griffiths TL (2021) Using large-scale experiments and machine learning to discover theories of human decision-making. Science, 372, 1209-1214. https://doi.org/10.1126/science.abe2629

Peterson R.O., Jacobs A.K., Drummer T.D., Mech L.D., Smith D.W. (2002) Leadership behavior in relation to dominance and reproductive status in gray wolves, Canis lupus. Canadian Journal of Zoology, 80, 1405-1412. https://doi.org/10.1139/z02-124

Pirrone A, Stafford T, Marshall JA (2014) When natural selection should optimize speed-accuracy trade-offs. Frontiers in neuroscience, 8, 73. https://doi.org/10.3389/fnins.2014.00073

Prins HHT (1996) Ecology and behaviour of the African buffalo: social inequality and decision making. Springer.

Rahwan I, Cebrian M, Obradovich N, Bongard J, Bonnefon J-F, Breazeal C, Crandall JW, Christakis NA, Couzin ID, Jackson MO, Jennings NR, Kamar E, Kloumann IM, Larochelle H, Lazer D, McElreath R, Mislove A, Parkes DC, Pentland A 'Sandy,' Roberts ME, Shariff A, Tenenbaum JB, Wellman M (2019) Machine behaviour. Nature, 568, 477-486. https://doi.org/10.1038/s41586-019-1138-y

Ramos A, Petit O, Longour P, Pasquaretta C, Sueur C (2015) Collective decision making during group movements in European bison, Bison bonasus. Animal behaviour, 109, 149-160. https://doi.org/10.1016/j.anbehav.2015.08.016

Rankin D, Black M, Bond R, Wallace J, Mulvenna M, Epelde G (2020) Reliability of supervised machine learning using synthetic data in health care: model to preserve privacy for data sharing. JMIR medical informatics, 8, e18910. https://doi.org/10.2196/18910

Ratcliff R, Smith PL, Brown SD, McKoon G (2016) Diffusion decision model: current issues and history. Trends in cognitive sciences, 20, 260-281. https://doi.org/10.1016/j.tics.2016.01.007

Reebs SG (2000) Can a minority of informed leaders determine the foraging movements of a fish shoal? Animal Behaviour, 59, 403-409. https://doi.org/10.1006/anbe.1999.1314

Riker WH, Ordeshook PC (1968) A Theory of the Calculus of Voting. The American political science review, 62, 25-42. https://doi.org/10.1017/S000305540011562X

Riker WH (1986) The art of political manipulation. Yale University Press.

Saari DG (2008) Complexity and the geometry of voting. Mathematical and Computer Modelling, 48, 1335-1356. https://doi.org/10.1016/j.mcm.2008.05.033

Sankey DWE, O'Bryan LR, Garnier S, Cowlishaw G, Hopkins P, Holton M, Fürtbauer I, King AJ (2021) Consensus of travel direction is achieved by simple copying, not voting, in free-ranging goats. Royal Society Open Science, 8, 201128. https://doi.org/10.1098/rsos.201128

Schein MW, Fohrman MH (1955) Social dominance relationships in a herd of dairy cattle. The British Journal of Animal Behaviour, 3, 45-55. https://doi.org/10.1016/S0950-5601(55)80012-3

Seeley TD (2003) Consensus building during nest-site selection in honey bee swarms: the expiration of dissent. Behavioral ecology and sociobiology, 53, 417-424. https://doi.org/10.1007/s00265-003-0598-z

Seeley TD (2010) Honeybee democracy. Princeton University Press. https://doi.org/10.1515/9781400835959

Sen AK (2009) The idea of justice. Harvard University Press. https://doi.org/10.2307/j.ctvjnrv7n

Smith JE, Gavrilets S, Borgerhoff Mulder M, Hooper PL, El Mouden C, Nettle D, Hauert C, Hill K, Perry S, Pusey AE, van Vugt M, Smith EA (2016) Leadership in mammalian societies: emergence, distribution, power, and payoff. Trends in ecology & evolution, 31, 54-66. https://doi.org/10.1016/j.tree.2015.09.013

Strandburg-Peshkin A, Farine DR, Couzin ID, Crofoot MC (2015) Shared decision-making drives collective movement in wild baboons. Science, 348, 1358-1361. https://doi.org/10.1126/science.aaa5099

Sueur C (2012) Viability of decision-making systems in human and animal groups. Journal of theoretical biology, 306, 93-103. https://doi.org/10.1016/j.jtbi.2012.04.020

Sueur C, Deneubourg J-L (2011) Self-Organization in Primates: Understanding the Rules Underlying Collective Movements. International Journal of Primatology, 32, 1413-1432. https://doi.org/10.1007/s10764-011-9520-0

Sueur C, Deneubourg J-L, Petit O (2010) Sequence of quorums during collective decision making in macaques. Behavioral Ecology and Sociobiology, 64, 1875-1885. https://doi.org/10.1007/s00265-010-0999-8

Sueur C, Deneubourg J-L, Petit O (2011) From the first intention movement to the last joiner: macaques combine mimetic rules to optimize their collective decisions. Proceedings of the Royal Society of London B, 278, 1697-1704. https://doi.org/10.1098/rspb.2010.2084

Sueur C, King AJ, Conradt L, Kerth G, Lusseau D, Mettke-Hofmann C, Schaffner CM, Williams L, Zinner D, Aureli F (2011) Collective decision-making and fission-fusion dynamics: a conceptual framework. Oikos, 120, 1608-1617. https://doi.org/10.1111/j.1600-0706.2011.19685.x

Sueur C, King AJ, Pelé M, Petit O (2013) Fast and accurate decisions as a result of scale-free network properties in two primate species. In: Proceedings of the European conference on complex systems 2012 (eds Gilbert T, Kirkilionis M, Nicolis G), pp. 579-584. https://doi.org/10.1007/978-3-319-00395-5_71

Sueur C, MacIntosh AJJ, Jacobs AT, Watanabe K, Petit O (2013) Predicting leadership using nutrient requirements and dominance rank of group members. Behavioral Ecology and Sociobiology, 67, 457-470. https://doi.org/10.1007/s00265-012-1466-5

Sueur C, Petit O (2008) Shared or unshared consensus decision in macaques? Behavioral Processes, 78, 84-92. https://doi.org/10.1016/j.beproc.2008.01.004

Summers K (2005) The evolutionary ecology of despotism. Evolution and human behavior, 26, 106-135. https://doi.org/10.1016/j.evolhumbehav.2004.09.001

Sumpter DJT, Pratt SC (2009) Quorum responses and consensus decision making. Philosophical transactions of the Royal Society B: biological sciences, 364, 743-753. https://doi.org/10.1098/rstb.2008.0204

Tavares G, Perona P, Rangel A (2017) The Attentional Drift Diffusion Model of Simple Perceptual Decision-Making. Frontiers in Neuroscience, 11. https://doi.org/10.3389/fnins.2017.00468

Tokuyama N, Furuichi T (2017) Leadership of old females in collective departures in wild bonobos (Pan paniscus) at Wamba. Behavioral Ecology and Sociobiology, 71, 55. https://doi.org/10.1007/s00265-017-2277-5

Tollefson J (2021) Tracking QAnon: how Trump turned conspiracy-theory research upside down. Nature, 590, 192-193. https://doi.org/10.1038/d41586-021-00257-y

Tullock G (1967) Toward a mathematics of politics. Ann Arbor: University of Michigan Press.

Van der Straeten K, Laslier J-F, Blais A (2013) Vote au pluriel: how people vote when offered to vote under different rules. PS: political science & politics, 46, 324-328. https://doi.org/10.1017/S1049096513000036

Van Vugt M, Hogan R, Kaiser RB (2008) Leadership, followership, and evolution: some lessons from the past. American psychologist, 63, 182-196. https://doi.org/10.1037/0003-066X.63.3.182

Waal F de (2007) Chimpanzee Politics: Power and Sex Among Apes. JHU Press.

Walker RH, King AJ, McNutt JW, Jordan NR (2017) Sneeze to leave: African wild dogs (Lycaon pictus) use variable quorum thresholds facilitated by sneezes in collective decisions. Proceedings of the Royal Society of London B, 284, 20170347. https://doi.org/10.1098/rspb.2017.0347

Ward AJW, Herbert-Read JE, Sumpter DJT, Krause J (2011) Fast and accurate decisions through collective vigilance in fish shoals. Proceedings of the National Academy of Sciences, 108, 2312-2315. https://doi.org/10.1073/pnas.1007102108

Whiten A, Byrne RW (1997) Machiavellian intelligence II - Extensions and evaluations. Cambridge University Press. https://doi.org/10.1017/CBO9780511525636

Wolf M, Weissing FJ (2012) Animal personalities: consequences for ecology and evolution. Trends in Ecology & Evolution, 27, 452-461. https://doi.org/10.1016/j.tree.2012.05.001

Wroblewski EE, Murray CM, Keele BF, Schumacher-Stankey JC, Hahn BH, Pusey AE (2009) Male dominance rank and reproductive success in chimpanzees, Pan troglodytes schweinfurthii. Animal Behaviour, 77, 873-885. https://doi.org/10.1016/j.anbehav.2008.12.014

Zador AM (2019) A critique of pure learning and what artificial neural networks can learn from animal brains. Nature Communications, 10, 3770. https://doi.org/10.1038/s41467-019-11786-6