Improving human collective decision-making through animal and artificial intelligence

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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 criticized 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 individual's (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.

Keywords: collective decisions, vote, democracy, representativeness, machine learning

Rethinking current voting systems

Collective decision-making processes such as **voting systems** are pillars of our Western societies [1–6]. 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 [7] and the election of Donald Trump in 2016 [8]. 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, Bayrou did not have enough individual preferences to make it to the second round of the election [9]. This example shows how the choice offered to the vote 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 [10,11]. 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 [12,13], 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 [14]. In addition, Western democracies suffer more and more from low turnout rates [15], which further weakens the political systems. It is therefore essential to find solutions that ensure citizens' acceptance. The issues that may lead to dissatisfaction with elections or referendums can be summarised in 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 electors base their decisions. 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 [16]. 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 bond 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 [17]. 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 [16]. 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 [16]. Finally, liquid representation is a very recent concept in political science [18,19]. Its four key features are [20]: (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 [16]. Voting as currently envisaged does not allow citizens to access the political agenda-setting [21] or deliberation [22] 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 use 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 (Figure 1). In ethology, voting means that ‘‘an animal communicates its individual preference with regard to the decision outcome’’ [23] 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 [24,25]. 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 [26]. Group decision-making is common in the animal kingdom, and has been documented in social insects (honeybees [27] or ants [28–30]), fish [31–34] and mammals (e.g., primates [35,36], meerkats [37], African wild dogs [38], bison [39] and deer [23]). 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 [40]. 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 [41] 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 individuals do not find enough benefits in staying in a group, they 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 [42–45], 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.

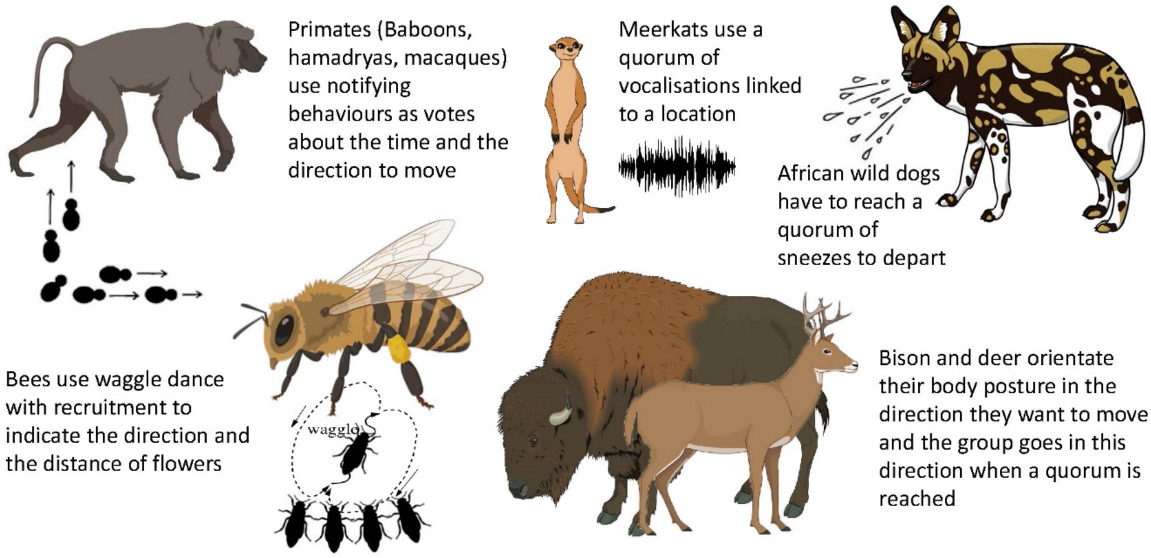

Figure 1: Species showing these different voting behaviours, specifically primates [35,36], meerkats [37], African wild dogs [38], honeybees [27], bison [39] and deer [23].

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 information about different sites as in swarming honeybees [46]. Acquiring information is costly, which is why animals often rely on their groupmates to get informed [47]. 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. To sum up this part, 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 [31,40,48]. Therefore, because of the strong natural selection increasing the efficiency of animal systems, authors call for researches on animal systems to improve the decision-making process in human societies, especially in link with AI [49–53]: bioinspiration for AI may conduct to better understand and control AI behaviour [54].

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 self-evident when we see (i) the development of AI applications in non-democratic countries (China, Russia, among others) [55] and (ii) the little attention paid to the privacy of their users by the major firms in the sector [56]. AI can help shaping 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) [57]. 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 [58]. 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 [59]. This example shows at the same time how much AI can be useful and very dangerous for democracies. Indeed, 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 [60]. 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) [60]. 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 [61]. By combining human and AI, the Artificial Swarm Intelligence algorithm [61] 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 [62]. 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 [62]. 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 [63]. 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** [7]. 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 [64]. Once these individuals or clusters have been identified, their weight in the next round of deliberation could, for example, be penalised [64]. 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 [65]. Without such a penalisation, small minorities could gain veto power blocking any progress.

AI techniques, such as data mining [66] and synthetic data generation [67,68], will also be useful in producing consistent, unbiased and privacy-protecting data [69]. This last point underlines the importance of the acceptability of AI by the public. While AI is generally viewed positively by the media [70], significant concerns about data protection [69] and human employment have recently emerged. Thus, resistance to AI is stronger among those least inclined to innovation and most sensitive to data privacy [71]. 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) [72].

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 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 [73,74]. This fighting advantage may be due to individual traits (strength, personality) but not only. Securing alliances is important to keep the power [75,76], which gives prior access to resources as food [77], reproduction [78,79], safe places [80] but also to leadership [81–83]. 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 [76] 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 [23,27,84–86]. 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 [36,84,85,87]. 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) [88].

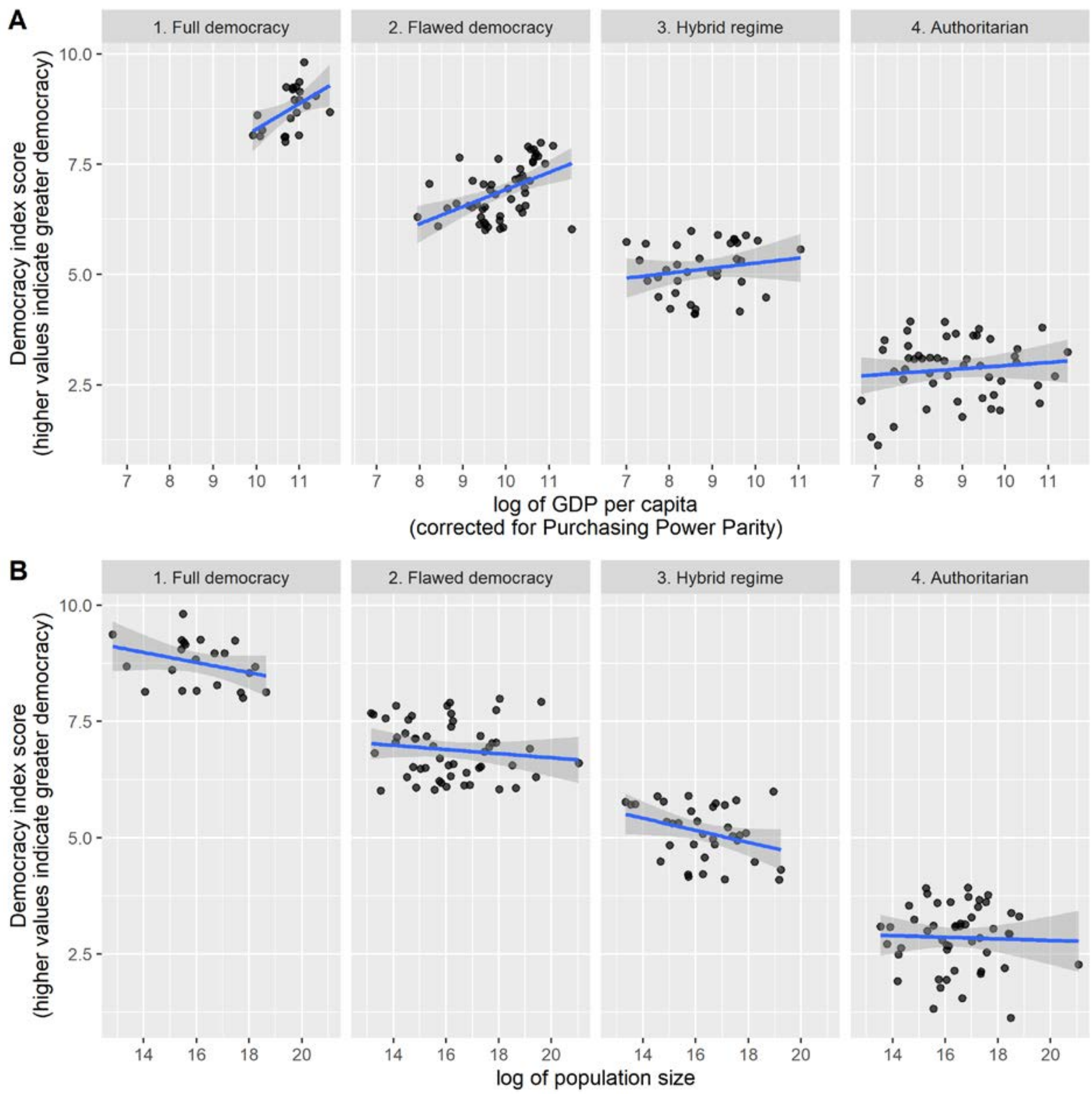

Figure 2. Relationship of the Democracy Index Score (DIS) (each point represents a country) with the logarithm of the country's Growth Domestic Product per capita, corrected for purchasing power parity (A) and the logarithm of the country's population size (B). Within each regime type, a higher democracy 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

Cases (for instance the first-past-the-post rule) where one alternative is chosen until it is more popular than another, however 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 [89–92]. 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 [93,94]. It is adaptive in urgent situations where decision speed is favoured over accuracy [92,94]. 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 [30,93]. This use of different quorums could help to generalise the **Condorcet's jury theorem** to a wider range of **decision ecologies** [95]. 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 [95]. 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**.

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 [16]) is structured into such mini-publics, deliberation and social influence within groups improve the crowd's collective accuracy [96]: 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 [96–98]. 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 [99]. These variables may have synergetic effects to determine which individuals will emerge as a leader [100]. Some species can be classified as despotic, particularly when there is a large difference in resource-holding potential within a group [101]. 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 [102], bonobos [103] or killer whales [104]. 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 [105], wild dogs [38], hamadryas baboons [106] or Tonkean macaques [107] are reported to use body orientation to vote and indicate their preferred direction to achieve a consensus on travel direction, while golden shiners [108,109] or goats [26] 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 [35,36,106]. Generally, a voting process to reach a quorum (i.e., a majority) in animals is divided in four steps (Figure 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 [64]. 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 [110]. Quorum decisions are used to manage competing needs and information in order to decrease decision errors [95,111]. 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 [112]. 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 [41]. 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 [93,113], which is of great relevance for AI systems used in voting systems.

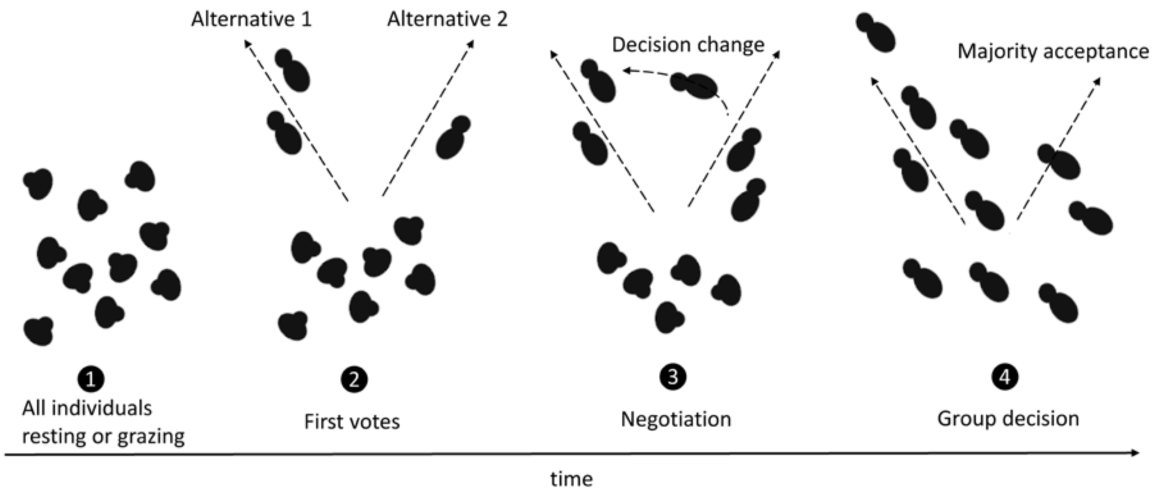

Figure 3. Steps of a voting process in animals

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 [85,114]. 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 [85,114]: when animals or humans all have the same needs, 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 [114]. 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 [114]. Aggressive and coercive leaders are strongly disfavoured [115]. 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 [101], 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 [85,114,116]. Conradt and Roper's model [85] 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 [38], meerkats [37] and baboons [101], they do not have the exclusive right to decide, but simply a greater weight in the decision [88]. The alternating of leadership roles among animals can ensure the expression of individual needs [117]. In this way, voters maintain the leadership purposefully, which implicitly downplays the social and environmental conditions underlying egalitarianism [118,119]. 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 [115]. For a fully functioning democracy, some researchers in political science favour a switch from participatory democracy to deliberative democracy [16,120]. 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 [121] and to have an equal right to participate in the public debate, even outside of the electoral process [16]. 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 [115]. For example, dominant meerkat individuals fight fiercely to secure a disproportionate share of the reproductive output [122], but are much less assertive when the group has to take decisions about changes in daily activities [37,117,123]. Second, the alternating of leadership roles amongst group members can ensure the expression of individual needs and leadership. Indeed, studies in sticklebacks [124] and meerkats [117] 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 [23,119,125]. Even in non-human animals, leaders shape social dynamics through policing [126] or by embodying culturally appropriate behaviour [127]. In return, leaders are often rewarded with privileges [101,126]. Hence, leadership itself is a frequently contested resource that individuals compete to obtain and/or maintain. This issue may concern humans[128] and some vertebrates with theory of mind (see a discussion about Machiavellian intelligence in primates [129]), 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 [28]. Are human leaders alpha individuals in a dominance hierarchy [115]? When we look at our 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 [130,131]. 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 [132,133], only a few scholars grasped the potential contribution of animal studies to this field [48,134]. Humans and non-human animals have two ways to access information: learning by themselves and/or learning from others [28,47]. 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 [95,135]. 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 [28]. 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 [12,13]. Misinformation is a clear threat to private and social learning as they drive the majority towards a non-efficient decision that is beneficial to the group of manipulators. Many AI algorithms try to identify fake news, particularly during election periods [8,136,137].

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 [138], 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 [139], 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 [48,140], both of which sometimes fail [31,138,141]. As already mentioned, several vote-pooling mechanisms can efficiently improve outcome accuracy, both when voters cannot communicate [97,98] and when communication is allowed [96]. 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 [142] 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 [48]. 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 [143,144]. 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 [113].

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 appears to be on the rise and poses a threat to democracy, particularly when elected politicians and activist groups interact to relay such news [145]. 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 [146]). In such cases, algorithms relying on advanced AI can detect fake news from real information in social media posts [147] or in video speeches [148] 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 [149,150].

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 [151] to three and half [152]. 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 [153,154]. Such so-called 'small world' networks [151] lead to partial views of the world. To our knowledge, only one study has shown this effect in non-human animals [155]. 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 vocalizations and gestures. Now humans face complex challenges from pandemics to climate change and communicate on dispersed networks connected by digital technologies and social media [40]. 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 [40]. Moreover, AI can also help to predict and understand how people make decisions even at large scale [156]. 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 [89,93] 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 [157], 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 [16]. As Seeley says in Honeybee Democracy [27], “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 [28,143]. 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 [16].

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 [31]. 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 [31,111].

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 polarization. However, AI can also be dangerous [146,148] and several scientists appeal to more and more develop the research field in AI ethics [158–160]. 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 polarization 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 [161,162]. 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 optimizes the speed of decision-making for a required accuracy.

Efficiency: In the context of voting, efficiency relies on a decision that maximizes 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 [94,163]. 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 high probability to take the wrong decision. With efficient decisions, the divide between competing participants is decreased and such decisions are therefore more likely to be implemented for longer periods of time [22,120]. As a corollary, efficient decisions are generally more representative of the diversity of the group [120].

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 [164]. 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. 50% 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. 50% 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.

Twitter accounts: @cedrisueur, @EspinosaRomain, @KrisAnathema

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Conflicts of interest

The authors declare no competing interests

Authors contribution

CS and CB wrote a first version of the paper. RE and JLD reviewed, commented and enhanced the different versions. All authors read and agreed with the final version.

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