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1 **Improving human collective decision-making through animal and artificial intelligence**

2 Cédric Sueur^{1,2,§,*}, Christophe Bousquet^{3,4,§,*}, Romain Espinosa^{5,6}, Jean-Louis Deneubourg⁷

3 ¹ Université de Strasbourg, CNRS, IPHC UMR 7178, F-67000 Strasbourg, France

4 ² Institut Universitaire de France, Saint-Michel 103, F-75005 Paris, France

5 ³ Laboratoire Cogitamus, <https://www.cogitamus.fr/>

6 ⁴ Centre de Recherche en Neurosciences de Lyon, CRNL Inserm U1028 - CNRS UMR5292 -

7 UCBLyon1

8 ⁵ CNRS, CREM – Université Rennes 1, France

9 ⁶ Rennes School of Business, France

10 ⁷ Center for Nonlinear Phenomena and Complex Systems (Cenoli) - CP 231, Université Libre

11 de Bruxelles (ULB), Campus Plaine, Boulevard du Triomphe, Building NO - level 5, B-1050,

12 Bruxelles, Belgium.

13 § These authors contributed equally to this work

14 *Correspondence: cedric.sueur@iphc.cnrs.fr (C. Sueur); chr_bousquet@protonmail.com (C.

15 Bousquet)

16

17 **Abstract**

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

30

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

32

33 **Rethinking current voting systems**

34 Collective decision-making processes such as **voting systems** are pillars of our Western
35 societies ¹⁻⁶. However, democratic choices may sometimes lead to non-efficient or non-
36 representative decisions (see Glossary for definitions of **efficiency** and **representativeness**).

37 This was the case with the election of François Hollande in 2012 ⁷ and the election of Donald
38 Trump in 2016 ⁸. In the 2012 French presidential elections, François Hollande beat Nicolas
39 Sarkozy and was elected with 51.62% of votes. However, these two candidates would have
40 lost in a one-to-one vote to François Bayrou (a third candidate). In fact, Bayrou would have

41 won one-to-one against any other candidate in this election and would therefore have been
42 a Condorcet candidate (i.e., a candidate with a majority against any other candidate in a
43 one-to-one vote). Nevertheless, voters' preferences for Bayrou were not strong enough to
44 qualify him for the second round of elections in a two-round majority system ⁹. This example
45 shows how the choice offered to the voters and the institutions governing that vote are
46 perhaps as important as the way people vote. As illustrated by Donald Trump's victory over
47 Hillary Clinton in the 2016 election, another issue affecting the legitimacy of voting results is
48 the way in which citizens base their choice on media and news sources that were often
49 unreliable and played on people's fears ^{10,11}. In the long term, these biased choices lead to
50 non-efficient decisions that have to be revised frequently. Besides, society and political
51 parties have become more polarised on many issues, due to the massive use of social
52 networks and influencers ^{12,13}, while the political supply has not become more diverse. This
53 combination of high polarisation and low political diversity results in a decrease in citizens'
54 satisfaction with democracy ¹⁴. In addition, Western democracies suffer more and more
55 from low turnout rates ¹⁵, which further weakens the political systems. It is therefore
56 essential to find solutions that ensure citizens' support. The issues that may lead to
57 dissatisfaction with elections or referendums can be summarised into three categories: 1.
58 the voting systems and, more generally, the mechanisms used to aggregate preferences, 2.
59 the needs and/or desires of citizens, and 3. the knowledge on which voters decide. Each of
60 these categories could benefit from recent findings in animal and **artificial intelligence (AI)**.

61

62 **Recent advances in political science**

63 Political institutions are powerful organisations to articulate multi-level human societies and
64 to produce decisions that affect large numbers of people. However, to achieve these two

65 goals, most political institutions have excluded ordinary citizens from policy **agenda-setting**
66 and deliberation, two fundamental yet underestimated aspects of collective decision-making
67 ¹⁶. Even in representative democracies, ordinary citizens constitutionally have access only to
68 the final choice, through their vote. In political science, voting generally refers to the choice
69 of elected representatives by citizens. In most current cases, once the vote is over, the
70 elected representatives become independent and are in no way bound to deliver their
71 electoral promises: there is no recall option for the citizens. Over the years, two different
72 types of disadvantages of voting have been reported. First, it is possible to question the
73 capacity of the vote to represent society, based on the observation that, sociologically,
74 elected officials differ greatly from ordinary citizens ¹⁷. However, other forms of
75 representation are conceivable. For example, statistical research has developed random
76 sampling techniques that are representative of the general population. While these **sortition**
77 techniques are widely used for opinion polls, they are still not very popular for choosing
78 representatives of civil society, although recent experiments in Iceland and France (to name
79 but two) have taken place ¹⁶. Moreover, under certain conditions, it is possible to consider
80 the **self-selection** of certain individuals as representative of a desire of similar individuals to
81 take part in the public debate ¹⁶. Finally, liquid representation is a very recent concept in
82 political science ^{18,19} that implies ²⁰: (i) direct voting on any issue, (ii) flexible proxy voting, (iii)
83 meta proxy voting and (iv) possible instant recall by each original voter. The other major
84 form of disadvantage of voting is that it focuses attention on the final choice, while other
85 dimensions of power are also important to consider. For many political scientists,
86 representative democracy has come of age and should be either complemented or replaced
87 by **deliberative democracy** or open democracy ¹⁶. Voting as currently envisaged does not
88 allow citizens to access the political agenda-setting ²¹ or deliberation ²² to choose between

89 different options. Yet, these different forms of political participation are increasingly
90 recognised as crucial and, as we will see later, these two forms also exist in animal groups.

91

92 **Taking inspiration from animal collective decisions**

93 Humans are not the only species that uses group processes to make important choices.

94 These concepts also exist in other animal societies, in which voting systems are readily used,

95 for instance to decide where to go (Figure 1). In ethology, voting means that “an animal

96 communicates its individual preference with regard to the collective decision outcome”²³,

97 and the decision is a sign of an “ecological rationality” and intention, the effectiveness of

98 which is assessed over long evolutionary periods. These voting processes are mostly used to

99 decide about where and when to go for foraging or for resting. Of course, this does not

100 mean that these species have the same mental states as humans but their behaviours

101 suggest certain cognitive capabilities as degrees of theory of mind^{24,25}. Empirical studies

102 supported by modelling are able to differentiate simple copying process from true voting

103 decisions involving intentional communication and awareness of mental states of others²⁶.

104 Group decision-making is common in the animal kingdom, and has been documented in

105 social insects (honeybees²⁷ or ants^{28–30}), fish^{31–34} and mammals (e.g., primates^{35,36},

106 meerkats³⁷, African wild dogs³⁸, bison³⁹ and deer²³). We do not mean here that cognitive

107 processes involved in animal collective decisions are similar to the ones in humans, they

108 differ in degrees. However, animal and human processes are comparable, and this

109 comparison may help to provide insight for the stewardship of human collective behaviour

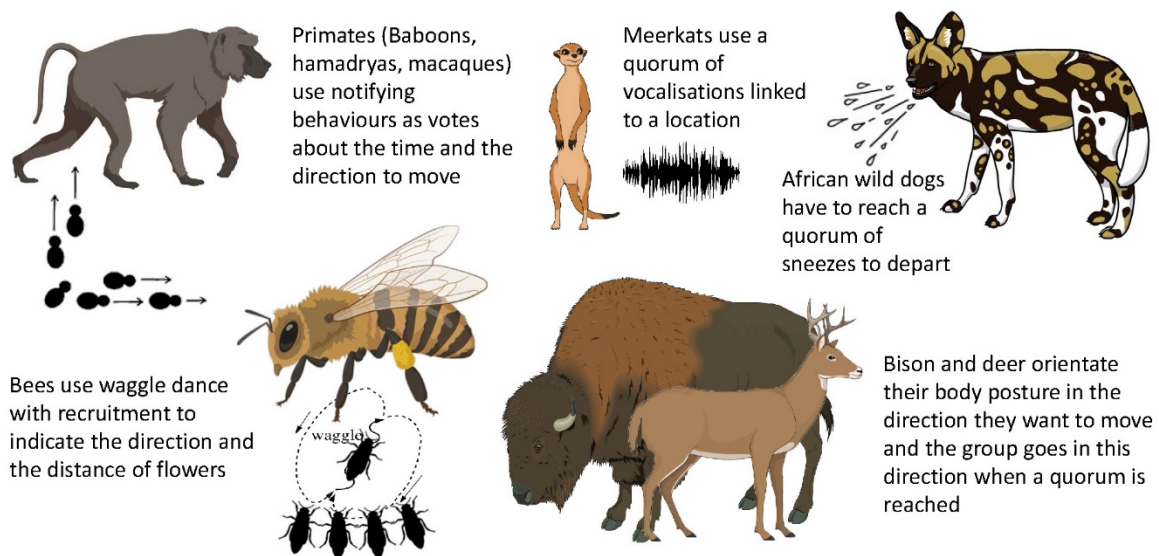
110⁴⁰. Living in groups brings many advantages but animals have to resolve conflicts of interest

111 to maintain their cohesion and these advantages, through collective decisions. Research

112 efforts largely have been directed in relatively stable and cohesive groups. Less well

113 understood is how fission-fusion dynamics mediate the processes and outcomes of collective
 114 decision making. However, collective decisions also happen in species with fission-fusion
 115 dynamics as shown in bison or hamadryas baboons and are based on similar concepts than
 116 the ones applied to cohesive groups (e.g., needs, information, social networks, see ⁴¹ for a
 117 review) but only partial consensus may apply. The difference between stable or cohesive
 118 groups and groups with fission-fusion dynamics also lies in the way individuals evaluate
 119 group membership: it is a common rule in animals that if the costs of being in the group
 120 outweighs the benefits, individuals will leave. It is this rule that partly sets an upper limit to
 121 the group sizes observed in animals: even in species living in stable groups, fissions are
 122 observed when a certain group size is reached ⁴²⁻⁴⁵, without necessarily always
 123 understanding the underlying mechanisms. This could shed new light on the low turnout
 124 rates observed in elections in Western societies: the benefits of the electoral process for
 125 some citizens are too low, leading them to desert the ballot box.

126



127

128 Figure 1: Species showing these different voting behaviours, specifically primates ^{35,36},

129 meerkats ³⁷, African wild dogs ³⁸, honeybees ²⁷, bison ³⁹ and deer ²³.

130

131 Animal decisions can be complex since they may involve many (up to thousands) individuals
132 having different needs and information about a complex environment with high conflicts
133 needing resolution and wrong decisions potentially leading to death. These conflicts of
134 interests might be due to differential needs of individuals as in primate groups or due to
135 private information about different sites as in swarming honeybees ⁴⁶. Acquiring information
136 is costly, which is why animals often rely on their groupmates to get informed ⁴⁷. By
137 signalling information and needs within the group, these social species engage in a sort of
138 deliberation that can take into account the magnitude of each signal as a proxy for individual
139 motivation (see the part “the needs of citizens for more details”). Over the course of
140 successive collective decisions, the identities of the individuals sending signals of information
141 or need vary, thus ensuring a rotation of the group members participating in the agenda-
142 setting and in the deliberation. Most likely, due to stochastic phenomena in physiological
143 processes or in information acquisition processes, the identities of the participants in each
144 collective decision vary randomly, thus basing the selection mechanism on sortition rather
145 than on election. Animal collective decisions are therefore based on mechanisms of
146 sortition, agenda-setting and deliberation. Furthermore, these mechanisms have been
147 selected over many generations to optimise the trade-off between speed and accuracy of
148 the collective decision and to favour the fitness of individuals belonging to these groups.
149 Although less studied from this perspective, animal groups with fission-fusion dynamics also
150 use the same collective decision mechanisms as stable groups, with the additional possibility
151 for each individual to choose the subgroup that best suits them. In some respects, this could
152 be similar to liquid representation, although more research is needed to confirm this link.

153 In a nutshell, animal processes and issues such as agenda-setting, deliberation, majority
154 rules, importance of minorities, uninformed individuals, source of information and
155 misinformation are very similar to human processes and issues^{31,40,48}. Therefore, because of
156 the strong natural selection increasing the efficiency of animal systems, authors call for
157 researches on animal systems to improve the decision-making process in human societies,
158 especially in link with AI⁴⁹⁻⁵³: bioinspiration for AI may conduct to better understand and
159 control AI behaviour⁵⁴.

160

161 **Taking inspiration from AI**

162 It is important and timely to ask how artificial intelligence and digital technologies can
163 contribute to strengthening democracy. This link is not straightforward when we see (i) the
164 development of AI applications in non-democratic countries (China, Russia, among others)⁵⁵
165 and (ii) the little attention paid to the privacy of their users by the major firms in the sector
166⁵⁶. AI can help shaping more democratic human collective-decision systems in several ways,
167 from the establishment of fair voting conditions to the integration of artificial voting agents.
168 AI can influence decision-making of humans in different contexts (e.g., politics or dating)⁵⁷.
169 A famous example is an experiment on voting behaviour during the 2010 congressional
170 election in the U.S., using a sample of 61 million Facebook users⁵⁸. The results showed that
171 Facebook messages influenced political self-expression and voting behaviour in millions of
172 people. These results were subsequently replicated during the 2012 U.S. Presidential
173 election⁵⁹. This example shows at the same time how much AI can be useful and very
174 dangerous for democracies.

175 Humans benefit from a number of recent advances in AI to improve voting systems. The first
176 example is an algorithm developed to counter electoral gerrymandering by creating electoral

177 districts that are representative of the global population ⁶⁰. By using an algorithm following a
178 divide-and-conquer approach, it is possible to produce electoral districts' maps that
179 maximise compactness (to ensure geographical continuity) and minimise population
180 deviation (to ensure representativeness) ⁶⁰. By following these two rules, the algorithm
181 avoids gerrymandering, thus providing fairer voting conditions, particularly if all stakeholders
182 participated in developing the rules and in evaluating the resulting maps. Another
183 perspective is the integration of principles derived from collective animal processes into AI
184 algorithms ⁶¹. By combining human and AI, the Artificial Swarm Intelligence algorithm ⁶¹
185 offers promising results: it performs better than humans-only and machine-only setups on a
186 variety of tasks. The resulting increase in accuracy and acceptance of the collective decision
187 is attributable to the direct involvement of humans in the decision process.

188 A third approach that requires a democratic debate makes it technically possible for citizens
189 to be represented by avatars reflecting the preferences of each voter rather than by
190 politicians ⁶². Technically, it will soon be possible to create intelligent e-democracy bots that
191 can infer the political preferences of their associated human voter. Such bots could then be
192 allowed to participate in voting processes on the voter's behalf ⁶². For example, these bots
193 could use Natural Language Processing (NLP) to copy the opinion expressed by the politician
194 deemed closest to the voter's position. This controversial topic could allow citizens to
195 express themselves on a wide range of issues. Yet this same technique could reinforce vote
196 manipulation or the abandonment of political life by voters by delegating the expression of
197 their opinions to a bot. When faced with electoral choices, voters sometimes find it difficult
198 to distinguish or rank the positions of different political offers on various issues. Analyses by
199 NLP make it easier to compare the contents of political programmes ⁶³. This tool provides a
200 more quantitative representation of political programmes, or an easier means to trace the

201 evolution of a party's positions on a specific topic over time. This leverage could be used to
202 improve the trade-offs among parties between rounds or in combination with **evaluative**
203 **voting**⁷. In addition, techniques based on distance analyses between the positions of
204 stakeholders in successive rounds of deliberation can identify individuals or clusters that
205 refuse to move towards a consensus⁶⁴. Once these individuals or clusters have been
206 identified, their weight in the next round of deliberation could, for example, be penalised⁶⁴.
207 Democratically, this could make sense because participants in a preference aggregation
208 process who refuse to change their position in response to other stakeholders indicate that
209 they are not prepared to seek consensus among reasonable perspectives⁶⁵. Without such a
210 penalisation, small minorities could gain veto power blocking any progress.

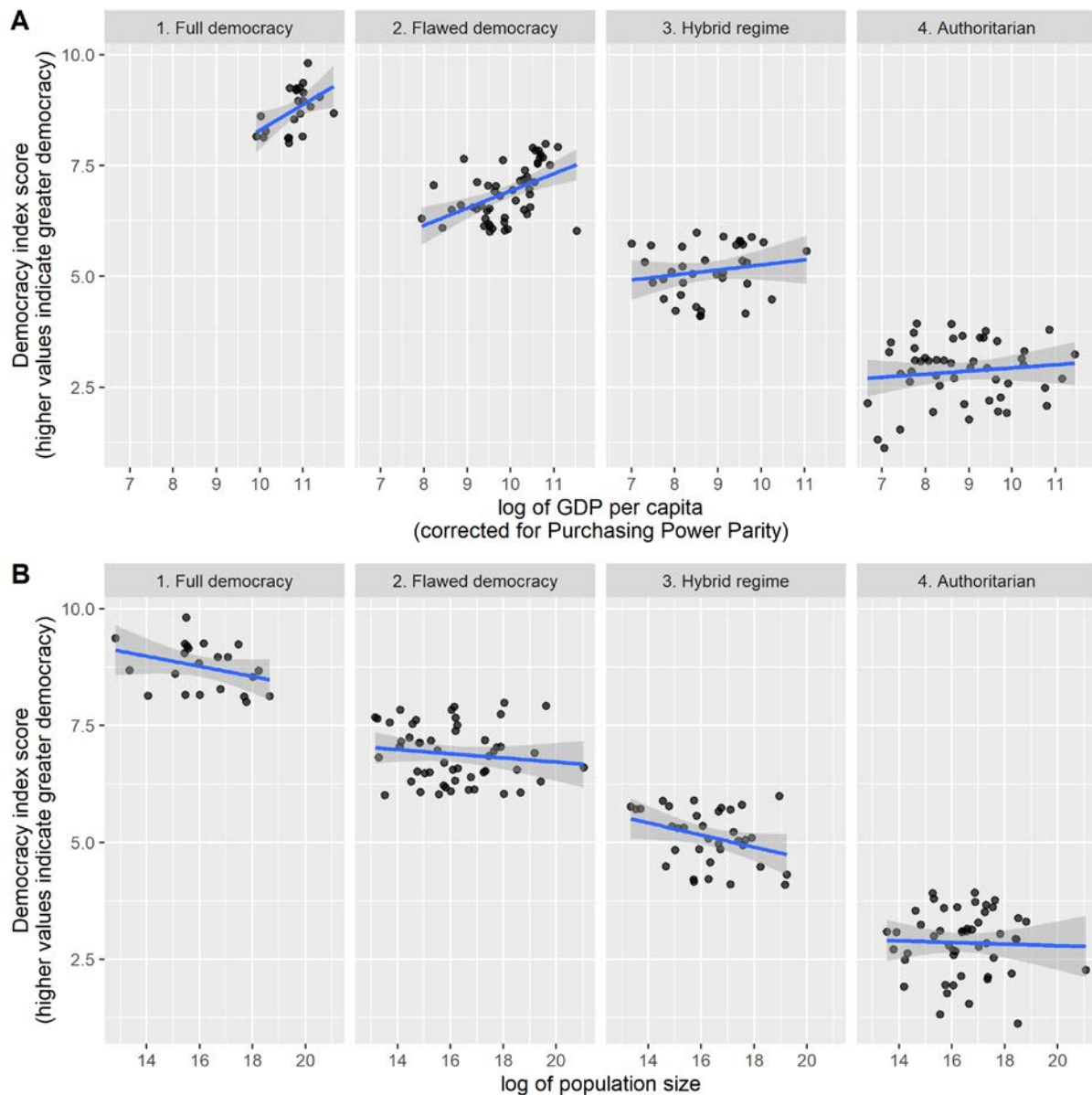
211 AI techniques, such as data mining⁶⁶ and synthetic data generation^{67,68}, will also be useful in
212 producing consistent, unbiased and privacy-protecting data⁶⁹. This last point underlines the
213 importance of the acceptability of AI by the public. While AI is generally viewed positively by
214 the media⁷⁰, significant concerns about data protection⁶⁹ and human employment have
215 recently emerged. Thus, resistance to AI is stronger among those least inclined to innovation
216 and most sensitive to data privacy⁷¹. Finally, AI is very good at identifying patterns in data,
217 but far less good at predicting complex social outcomes, perhaps because such outcomes are
218 inherently unpredictable (due to the inevitable reduction of real complexity in algorithms
219 and to the ability of living beings to react very differently to subtle changes in their
220 environment)⁷².

221

222 **The different systems used to aggregate individual preferences**

223 Different systems can be used to aggregate individual preferences, ranging from how
224 proportional they are (i.e., how the final choice represents the votes) and bearing in mind

225 that heterogeneous preferences and beliefs hinder conflict resolution. A parliament
226 selecting the proportion of deputies based exactly on the votes for each party is statistically
227 representative of the political preferences in the population, but one selecting the deputies
228 based only on the majority voting is not. Moreover, the voting systems may change the final
229 result according to how preferences of voters are taken into account (see the section “the
230 needs of citizens”). Human political systems range from authoritarian regimes to full
231 democracies, depending on the distribution of weights for each individual in society (Fig. 2).
232 Authoritarian regimes are more likely to emerge and sustain themselves if the despots
233 manage to secure a relative advantage in fighting ability both in humans and in animals ^{73,74}.
234 This fighting advantage may be due to individual traits (strength, personality) but not only.
235 Securing alliances is important to keep the power ^{75,76}, which gives prior access to resources
236 as food ⁷⁷, reproduction ^{78,79}, safe places ⁸⁰ but also to leadership ^{81–83}. In democracies, the
237 most commonly used representation system is the voting system with **majority voting**, for
238 instance the first-past-the-post rule. Whilst animals do not elect presidents (but see ⁷⁶ to
239 choose the dominant male in an animal society), they use democratic (equally shared
240 consensus) or semi-democratic (partially shared consensus with some individuals having
241 higher decision weights) systems in their everyday life ^{23,27,84–86}. Non-human animals do not
242 have the sophisticated language capacity of humans but this does not mean that they cannot
243 deliberate and negotiate over different alternatives and vote for them ^{36,84,85,87}. Recent
244 empirical studies have shown that the decision-making of social species happens through
245 the adoption of symbolic systems for consensus construction (vocalisations, movements of
246 intentions, notifying behaviours, and dances) ⁸⁸.
247



248

249 Figure 2. Relationship of the Democracy Index Score (DIS) (each point represents a country)

250 with the logarithm of the country's Growth Domestic Product per capita, corrected for

251 purchasing power parity (A) and the logarithm of the country's population size (B). Within

252 each regime type, a higher democracy index is more likely when GDP per capita is high

253 (LMM: 0.19 ± 0.06 , $t = 2.990$, $p < 0.01$) (Fig. 1A). There is also a tendency for countries with

254 smaller populations to be more democratic (LMM: -0.08 ± 0.05 , $t = -1.692$, $p = 0.09$) (Fig. 1B).

255 The analysis takes into account the overall regime type of the country by adding this variable

256 as a random effect in the model. Data come from the following websites: Democracy Index

257 (<https://www.eiu.com/topic/democracy-index>), GDP
258 (<https://data.worldbank.org/indicator/NY.GDP.PCAP.PP.CD>) and population size
259 (https://en.wikipedia.org/wiki/List_of_countries_and_dependencies_by_population).
260 Data and analyses script are available at Zenodo. <http://doi.org/10.5281/zenodo.4703733>
261
262 Cases (for instance the first-past-the-post rule) where one alternative is chosen until it is
263 more popular than another, however small the difference of evidence for the two
264 alternatives may be are said to derive from the **Race Model** and were proved to be non-
265 efficient compared to the **Drift-Diffusion Model** (DDM), described at the individual (i.e.,
266 brain) level or the collective level both in humans and animals⁸⁹⁻⁹². The DDM stipulates that
267 the differences between two alternatives have to reach a threshold and this model,
268 operating in brain and collective decision processes, is far more efficient than the race model
269^{93,94}. It is adaptive in urgent situations where decision speed is favoured over accuracy^{92,94}.
270 In ants, in emergency situations, individuals decrease their **quorum** threshold and the quality
271 of a future nest in profit of the decision time, whilst they take time and choose the best nest
272 in normal conditions by increasing the quorum threshold, which indicates a DDM^{30,93}. This
273 use of different quorums could help to generalise the **Condorcet's jury theorem** to a wider
274 range of **decision ecologies**⁹⁵. In decision ecology, individuals are prone to two different
275 types of errors: false positives and false negatives. Yet, in its simplest form, the Condorcet
276 theorem assumes that both errors are identical. When this assumption is relaxed (when the
277 probability of a false positive differs from the probability of a false negative), it can be shown
278 that majority voting becomes non representative and should be replaced by sub- or
279 supermajority quorums depending on the conditions⁹⁵. Sometimes, in humans, instead of
280 choosing one of the two alternatives with a small majority, a compromise can be found

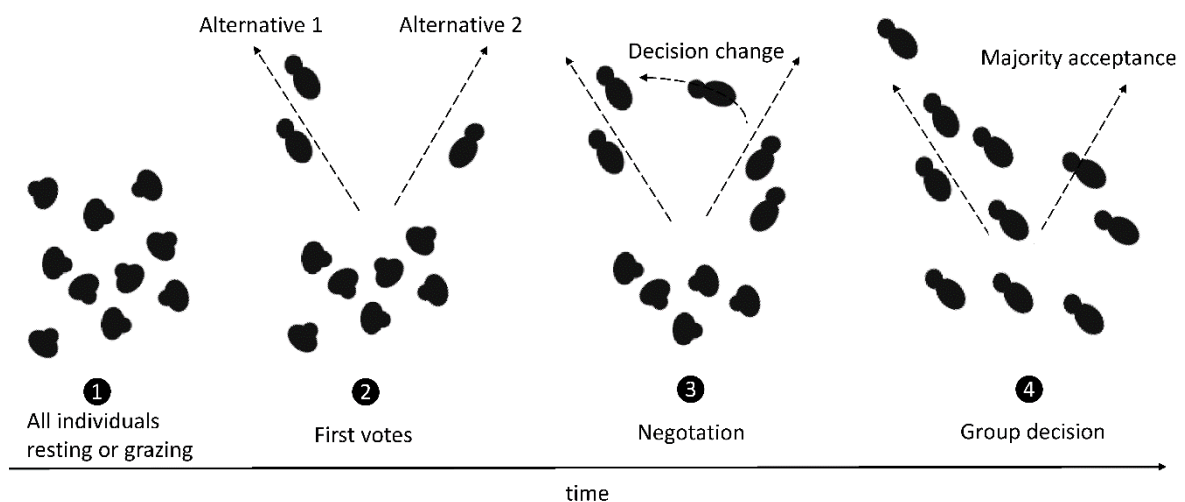
281 thanks to a new alternative satisfying a greater majority. This phenomenon has been coined
282 the **median voter theorem**.

283 Current voting systems could also be improved by creating small, independent groups of
284 randomly selected voters before deliberation and voting. In this context (called mini-
285 publics), the deliberation phase is crucial to reduce the partisanship bias observed in other
286 voting methods. If a large crowd (in which a meaningful deliberation cannot take place
287 because of its size ¹⁶) is structured into such mini-publics, deliberation and social influence
288 within groups improve the crowd's collective accuracy ⁹⁶: averaging consensus decisions is
289 then significantly more accurate than aggregating the initial independent opinions. Such
290 settings have proved to provide better and more robust collective decisions in a variety of
291 contexts ⁹⁶⁻⁹⁸. This may also be where fission-fusion groups could have an evolutionary
292 advantage over stable groups: for instance, for the same number of individuals over a
293 territory, fission-fusion subgroups may more effectively collect resources than one stable
294 group. However, this hypothesis still needs to be tested empirically.

295 In animals, the spectrum of weight distributions for individual preferences is also quite
296 broad. Animals have different needs according to their physiological status, different
297 knowledge about their environment, and different personality types ⁹⁹. These variables may
298 have synergetic effects to determine which individuals will emerge as a leader ¹⁰⁰. Some
299 species can be classified as despotic, particularly when there is a large difference in
300 resource-holding potential within a group ¹⁰¹. In other species, some group members have a
301 greater weight in group decisions, especially when these individuals possess a greater
302 knowledge of the environment that can benefit all group members as in elephants ¹⁰²,
303 bonobos ¹⁰³ or killer whales ¹⁰⁴. Still, mechanisms are at work to allow most if not all group
304 members to express their preferences. One such mechanism is to attain a specific number of

305 individuals (a quorum) notifying a preference. For example, African buffalo ¹⁰⁵, wild dogs ³⁸,
306 hamadryas baboons ¹⁰⁶ or Tonkean macaques ¹⁰⁷ are reported to use body orientation to
307 vote and indicate their preferred direction to achieve a consensus on travel direction, while
308 golden shiners ^{108,109} or goats ²⁶ achieve consensus of direction by responding to the
309 movement cues of their neighbours. In voting processes, long negotiation processes happen
310 during the collective decision to reach a quorum showing implication of theory of mind,
311 particularly described in primates ^{35,36,106}. Generally, a voting process to reach a quorum (i.e.,
312 a majority) in animals is divided in four steps (Figure 3): initially, all animals are resting or
313 grazing ❶; then, some individuals stand up and indicate with their body posture or
314 intentional movements their willingness to move in a specific direction ❷; then, group
315 members enter in a negotiation (or deliberation) process where some individuals try to
316 influence others ❸; eventually, all individuals move in the same direction according to the
317 majority choice ❹. Once this quorum is reached, the probability of deciding for the
318 proposed alternative sharply shifts, leading to a group consensus. However, supermajority
319 quorums could be used by a minority to maintain the status quo, without aiming at finding a
320 consensus. As already mentioned, such an attitude could be identified by detection
321 algorithms of non-cooperative behaviour, which could then reduce the weight of this
322 uncooperative minority in the calculation of the consensus degree ⁶⁴. A functionally similar
323 mechanism is present in bees searching for new nests: scouts that indicate a potential nest
324 decrease the intensity of their dance each time they return to the hive, causing scouts that
325 found a poorer quality nest to stop dancing faster ¹¹⁰. Quorum decisions are used to manage
326 competing needs and information in order to decrease decision errors ^{95,111}. This solution to
327 a collective problem can work without needing high cognitive capacities: much of these
328 collective decisions are the result of relatively simple interaction patterns among group

329 members but not only. Sometimes very high cognitive capacities are involved, but this does
 330 not change the implication of self-organised rules. Self-organisation principles also rule
 331 collective decisions in species with high cognitive abilities as primates ¹¹². In this context,
 332 group size does not influence behavioural or communication processes involved in the
 333 collective processes, the system just switches from global to local communication, which
 334 means that group members do not have a full perception of what happens in the group, but
 335 they do not need it to decide, as local perception is sufficient ⁴¹. Voting systems in bees,
 336 macaques or bison are not so different even if species differ in social organisation or
 337 cognitive capacities. In such 'self-organising systems', multiple individuals following simple
 338 rules can produce complex collective behaviours without requiring high abilities at the
 339 individual level ^{93,113}, which is of great relevance for AI systems used in voting systems.



340

341 Figure 3. Steps of a voting process in animals

342

343 Overall, many studies confirmed that the DDM with a quorum threshold seems to be more
 344 efficient than simple majority voting. Another difference between collective decisions in
 345 humans and non-human animals is that the latter do not elect representatives like humans
 346 do, but decide together throughout the day, as a **participatory democracy**. Besides, non-

347 human animals typically take decisions for short-term aims (those that will occur within
348 minutes or hours after the decision). There are many multilevel animal societies in which
349 some individuals have more influence than others at different organisation levels.
350 Importantly, having a greater weight in the decision does not mean that they are the sole
351 decision makers. This looks like the participatory democracy (or shared consensus) that
352 many human citizens request today and seems to be more efficient than a monopolised
353 leadership (unshared consensus). For instance, in Switzerland, there are seven Councillors
354 who are indirectly representative of the population but the citizens are invited to vote on
355 various issues several times a year, which can be done by mail. So, this system can also work
356 for large sample size and AI can help to pool these votes and avoid errors. However, the
357 consensus type also depends on the population homogeneity in terms of needs and
358 knowledge^{85,114}. How to take into account different needs and different knowledge of
359 citizens is of matter and will be developed in the next sections.

360

361 **The needs of citizens**

362 Decision makers within a group vary in terms of needs, goals and preferences. Therefore,
363 choosing an alternative generally only satisfies individuals who vote for this alternative.
364 Arrow's impossibility theorem stipulates that there is no way to always aggregate all
365 individual choices within one voting system. However, when within-group choices become
366 more aligned, as in emergency or wars, more cohesive or coercive systems may become
367 more acceptable. The current COVID-19 sanitary situation leads us, for example, to accept
368 coercive decisions such as lockdowns and closures of establishments that are not accepted
369 in other situations. Previous theoretical studies worked on this homogeneity concept^{85,114}:
370 when animals or humans all have the same needs, there is no issue about preferences

371 pooling and a single leader system is more viable as all individuals are satisfied and the
372 decisions are taken more rapidly than those made using democratic systems, which require
373 participants to vote. This is an auto-emergent dictatorship ¹¹⁴. Collective decision-making in
374 the non-human animal world cannot escape the notion of dominance. However, true
375 despotic societies are rare in animal societies, as they are typically not evolutionarily stable
376 due to the diversity of group members ¹¹⁴. Aggressive and coercive leaders are strongly
377 disfavoured ¹¹⁵. It is clear that this system is not viable when group members differ in their
378 physiological and social needs and preferences. Moreover, models, confirmed by empirical
379 data ¹⁰¹, show that the system collapses if the despot disappears, and a wrong decision taken
380 by the despot may have strong negative consequences for all individuals ^{85,114,116}. Conradt
381 and Roper's model ⁸⁵ indicates that democratic decisions can evolve when groups have a
382 heterogeneous composition, but the higher the heterogeneity, the harsher the conflicts and
383 the more unlikely the conflict resolution. From an evolutionary perspective, animal societies
384 have managed to resolve these conflicts of interest by giving all members the opportunity to
385 participate in daily decisions (i.e., to have a say in agenda-setting) but to different extents.
386 Although dominant individuals can take the role of leader in African wild dogs ³⁸, meerkats ³⁷
387 and baboons ¹⁰¹, they do not have the exclusive right to decide, but simply a greater weight
388 in the decision ⁸⁸. The alternating of leadership roles among animals can ensure the
389 expression of individual needs ¹¹⁷. In this way, voters maintain the leadership purposefully,
390 which implicitly downplays the social and environmental conditions underlying
391 egalitarianism ^{118,119}. Indeed, true egalitarianism may lead to a very long decision time or
392 even to an absence of consensus. Even if the needs of group members are different,
393 leadership allows a better group coordination but does not permit other members to
394 express their intentions. Indeed, in larger human and non-human groups, group members

395 may willingly give leaders greater leeway to make decisions, in view of the functional
396 benefits of leader-follower relationships in such contexts ¹¹⁵. For a fully functioning
397 democracy, some researchers in political science favour a switch from participatory
398 democracy to deliberative democracy ^{16,120}. In deliberative human democracies, it is crucial
399 to allow every citizen to express themselves freely, with a seamless interface between this
400 public space and the empowered space ¹²¹ and to have an equal right to participate in the
401 public debate, even outside of the electoral process ¹⁶. For instance, the European
402 Commission regularly launches public consultations to which all stakeholders, including
403 unions or NGOs, can contribute.

404 In animal groups, leadership can respect the needs of different individuals in a number of
405 ways. First, the generality dimension of leadership allows it to be split into various sub-
406 domains ¹¹⁵. For example, dominant meerkat individuals fight fiercely to secure a
407 disproportionate share of the reproductive output ¹²², but are much less assertive when the
408 group has to take decisions about changes in daily activities ^{37,117,123}. Second, the alternating
409 of leadership roles amongst group members can ensure the expression of individual needs
410 and leadership. Indeed, studies in sticklebacks ¹²⁴ and meerkats ¹¹⁷ show that individuals
411 with conflicting information take turns in leading the group to their respective favourite
412 location. Another issue with leadership is that it does not safeguard against profiteers
413 becoming leaders. Humans elect people who propose an electoral platform but who may
414 want to be leaders for their personal gain and not for the public good. Leaders can be
415 described as individuals who have a disproportionate level of influence and decision-making
416 power within their communities, and can distort social relationships to their advantage
417 ^{23,119,125}. Even in non-human animals, leaders shape social dynamics through policing ¹²⁶ or
418 by embodying culturally appropriate behaviour ¹²⁷. In return, leaders are often rewarded

419 with privileges^{101,126}. Hence, leadership itself is a frequently contested resource that
420 individuals compete to obtain and/or maintain. This issue may concern humans¹²⁸ and some
421 vertebrates with theory of mind (see a discussion about Machiavellian intelligence in
422 primates¹²⁹), but is absent in species such as ants. Machiavellian Intelligence also applies in
423 the context of strategic votes, which is quite difficult to measure in animals even if studies
424 on private versus social information may give some cues about decision-making processes²⁸.
425 Are human leaders alpha individuals in a dominance hierarchy¹¹⁵? When we look at
426 presidents or monarchs, this appears to be quite plausible. Work in psychology showed that
427 dominant appearance traits are chosen by voters in absence of more political information
428^{130,131}. Current knowledge in animal and artificial decision-making can help our societies
429 improve their public decision-making systems and can provide insight about institutional and
430 electoral design to select the most appropriate candidates for the offices.

431

432 **The knowledge on which citizens base their decisions**

433 Knowledge is important to decide which alternative to vote for. Whilst there is a huge work
434 on this domain in political science^{132,133}, only a few scholars grasped the potential
435 contribution of animal studies to this field^{48,134}. Humans and non-human animals have two
436 ways to access information: learning by themselves and/or learning from others^{28,47}. The
437 most obvious constraint on majority rules for questions having a correct answer is that the
438 majority of informants the group relies on need to be right^{95,135}. In eusocial insects, groups
439 seem to identify the best information: even though very few individuals actually possess
440 relevant information regarding the decision at hand, decisions are still efficient with a mix
441 between private and social information²⁸. In many cases, individuals check and compare
442 their private and social information before making a decision. Yet we currently observe in

443 human societies many fake news or misinformation voluntarily spread to influence votes for
444 representatives^{12,13}. Misinformation is a clear threat to private and social learning as they
445 drive the majority towards a non-efficient decision that is beneficial to the group of
446 manipulators. Many AI algorithms try to identify fake news, particularly during election
447 periods^{8,136,137}.

448 To comply with the Condorcet theorem, votes should be independent from each other.
449 However, the heavy reliance on social information in humans is at odds with this
450 assumption. Therefore, trusting others may have consequences at the individual level¹³⁸,
451 but also at the group level. At the individual level, this is what Amartya Sen called the
452 'capability to vote': although it is good to vote, it is better when one has the knowledge to
453 vote well¹³⁹, meaning to be sure to have all the information for each alternative in order to
454 make a choice representative of one's needs. At the group level, the sum of knowledge leads
455 to the emergence of the 'wisdom of crowds' for humans and 'swarm intelligence' for non-
456 human animals^{48,140}, both of which sometimes fail^{31,138,141}. As already mentioned, several
457 vote-pooling mechanisms can efficiently improve outcome accuracy, both when voters
458 cannot communicate^{97,98} and when communication is allowed⁹⁶. Theoretical and empirical
459 works suggest that collective decisions can be more accurate than individual decisions.
460 However, homogeneity of individual traits may lead to non-efficient collective decisions¹⁴²
461 as group members all search for or have the same information and needs reinforcing the
462 probability to take wrong decisions, whilst diversity of individual traits conducts to diversity
463 of information and diversity of alternatives. In fish, social insects, birds and humans, two or
464 more individuals independently collect information that is processed through social
465 interactions, providing a solution to a cognitive problem that is not available to single
466 individuals⁴⁸. Different studies have attempted to identify who should be trusted and which

467 decision is the best when faced with the choice between one expert and ten non-experts.
468 Collective decisions are almost always preferred to individual ones ^{143,144}. However, it is not
469 necessary to know who has the best information as the combination of individual behaviours
470 and social interactions lead to the emergence of effective systems ¹¹³.
471 Importantly, two phenomena may prevent individuals or algorithms from correctly assessing
472 a situation: misinformation (or lack of information) and biases. Currently, fake news and
473 misinformation appears to be on the rise and poses a threat to democracy, particularly when
474 elected politicians and activist groups interact to relay such news ¹⁴⁵. This type of
475 misinformation could be mitigated by providing citizens with a better understanding of how
476 to differentiate between fake and real news. However, sometimes, fake news can also
477 convince well-informed people through other cognitive mechanisms (confirmation bias,
478 desirability bias ¹⁴⁶). In such cases, algorithms relying on advanced AI can detect fake news
479 from real information in social media posts ¹⁴⁷ or in video speeches ¹⁴⁸ and can propose, as
480 Twitter, to consider reading a link before sharing it or warn about specific content (violent,
481 unsure). This better identification also comes from research on animal and human
482 communication, particularly facial expressions ^{149,150}.
483 Nowadays, humans are connected to many other people directly or indirectly through
484 Facebook and other social media, people who they know as friends or family members or
485 who they do not know but with whom they share similar interests. These connections form a
486 social network which can be embedded into the real and the virtual world. Since the
487 development of these social media, the number of relationships a human has increased,
488 thus reducing the six degrees of separation ¹⁵¹ to three and half ¹⁵². However, this booming
489 of relationships may lead to different decision biases. Specific connections in social networks
490 may lead information that is considered untrue by the majority to be excessively over-

491 trusted by voters who only have access to these connections. This social effect, called the
492 'majority illusion', is derived from the 'friendship paradox'. It leads individuals to
493 systematically overestimate the prevalence of a piece of information, manipulating
494 evidences in the DDM, which may accelerate the spread of fake news and the ultimate
495 choice of an unsuitable alternative ^{153,154}. Such so-called 'small world' networks ¹⁵¹ lead to
496 partial views of the world. To our knowledge, only one study has shown this effect in non-
497 human animals ¹⁵⁵. This is maybe the most difficult issue to control when trying to take
498 individual and collective decisions.

499

500 **Future perspectives about using animal and artificial intelligence**

501 Human social adaptations evolved in the context of small hunter-gatherer groups solving
502 local problems through vocalizations and gestures. Now humans face complex challenges
503 from pandemics to climate change and communicate on dispersed networks connected by
504 digital technologies and social media ⁴⁰. We are not ready for this, cognitively speaking,
505 facing numerous biases, but decentralised systems exist in animal societies and we can use
506 their decision-making processes via AI to increase the efficiency of our collective decisions ⁴⁰.
507 Moreover, AI can also help to predict and understand how people make decisions even at
508 large scale ¹⁵⁶. Then a strong link in the future research, between human collective decisions,
509 AI and animal behaviour has to be made.

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

513 1. Animal studies have shown that collective rules evolve to achieve efficient
514 decisions. Many of these results inspired AI to help reach better democratic decisions.

515 Continuing to think about a diffusion model with an appropriate difference threshold
516 between alternatives and with an appropriate quorum ^{89,93} would increase effectiveness of
517 human systems. We have to create systems in which minorities can attempt different
518 strategies that search through the solution space. We need to “rethink democracy” not as an
519 all-or-nothing system ¹⁵⁷, with always opposite alternatives where one wins and one loses
520 but to build integrative solutions leading to unified societies as defined in deliberative or
521 open democracies ¹⁶. As Seeley says in *Honeybee Democracy* ²⁷, “It often pays a group to
522 *argue* things carefully through to find the best solution to a tough problem” (p. 2). This is
523 where applying the DDM might be useful to balance between accuracy and speed of the
524 collective decision.

525 2. A second aim would be to increase participatory and deliberative democracy and
526 AI helping it. The frequencies and the weights of decisions of each member in non-human
527 animal groups or in small human groups are much higher than those observed in large
528 human societies, as these groups decide on a daily basis: non-human animals or hunter-
529 gatherers appear to hold referendums every day. A more participatory democracy in large
530 human societies resembling those we observe in animal societies could result in greater
531 satisfaction of citizens but also more efficient decisions due to a greater accumulation of
532 knowledge ^{28,143}. Indeed, from our animal roots, the current decrease in voter turnout is not
533 surprising, because current voting systems prevent ordinary citizens from participating in
534 agenda-setting and deliberation phases, two important facets of animal collective decision
535 making. Agenda-setting should therefore be given back to citizens, for instance via sortition-
536 based assemblies or mini-publics ¹⁶.

537 3. Third, we need to better understand how our connections affect the quality of
538 information we get and as a consequence the efficiency of our decisions. The digital age and

539 the rise of social media have accelerated changes to our social systems, with poorly
540 understood functional consequences. We can gain a better picture of how our individual or
541 collective decisions are constructed through the study of the real or imaginative links we
542 make between the information provided by TV, social networks, social media and influential
543 people ³¹. As humans we tend to think that we have control over our decisions and
544 knowledge, but recent events in elections have shown this to be untrue. Collective
545 behaviour reveals how large-scale higher-order properties of the group feedback to
546 influence individual behaviour, which in turn can influence the behaviour of the group, and
547 so on. Many voting processes are self-organized in the animal kingdom and we should admit
548 that this is also the case in humans ^{31,111}.

549

550 **Concluding remarks**

551 Identifying these animal collective solutions shaped by selection over millions of years and
552 implementing them into AI algorithms devoted to democracy is likely to increase the stability
553 of our political systems in achieving larger consensus and reducing polarization. However, AI
554 can also be dangerous ^{146,148} and several scientists appeal to more and more develop the
555 research field in AI ethics ¹⁵⁸⁻¹⁶⁰. More research on efficient collective decisions in algorithms
556 and animals has to be done focusing on the outcomes and their effectiveness. Indeed,
557 humans are limited by their cognitive capacities, some biases and their mental dimensions,
558 leading to higher polarization of societies and mental block to think about new voting
559 systems. As animals do not think as we do, behavioural experiments on multiple species and
560 modelling can help to get out of these human dimensions, and to find new ones ^{161,162}. This
561 could improve humanity and yield novel bioinspired technologies.

562

563 **Glossary**

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

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

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

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

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

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

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

587 **Efficiency:** In the context of voting, efficiency relies on a decision that maximizes the
588 difference between the benefits and the costs. These benefits and costs can be measured in
589 two ways: first, the time to take a decision, which can increase costs if it is too long; second
590 the representativeness of the decision. Usually, there is a trade-off between the decision
591 time and the representativeness. This trade-off reflects the decision efficiency^{94,163}. Time to
592 take a decision often reflects the quantity of information or evidence one can get to take a
593 decision. A short decision time indicates low quantity and quality of information conducting
594 to higher probability of wrong decision. With efficient decisions, the divide between
595 competing participants is likely to decrease and such decisions are therefore more likely to
596 be implemented for longer periods of time^{22,120}. As a corollary, efficient decisions are
597 generally more representative of the diversity of the group¹²⁰.

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

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

602 **Median voter theorem:** Proposition relating to direct ranked preference voting put forward
603 by Duncan Black¹⁶⁴. It states that if opinions are distributed along a one-dimensional
604 spectrum, then any voting method which satisfies the **Condorcet winner criterion** will
605 produce a winner close to the median voter.

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

608 **Quorum:** Minimum number of group members necessary to observe a drastic change in
609 group behaviour or to validate a group decision. Majority voting is a special case of quorum.
610 50% for a quorum makes sense when only two alternatives are proposed, which is rare in

611 animal societies as researchers count all animals even those which do not have opinions.
612 50% majority is present in humans but removing individuals with no opinion. If we consider
613 individuals who do not vote or do white vote, the majority does not reach 50%. For instance,
614 if only 60% of the population vote, then the real quorum is 30% (60%*50%). Sub-majority
615 quorums refer to cases where the collective decision is taken as soon as a threshold of less
616 than 50% is reached. Symmetrically, super-majority quorums refer to cases where the
617 collective decision is taken as soon as a threshold of more than 50% is reached.

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

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

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

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

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

630

631 **Twitter accounts:** @cedrisueur, @EspinosaRomain, @KrisAnathema

632

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636

637 **Conflicts of interest**

638 The authors declare no competing interests

639

640 **Authors contribution**

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

643

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