

# Round #1

---

by Frédéric Amblard, 2021-06-08 13:39

## Interesting first version that would need revision in order to strengthen the arguments

Thank you very much. We answered positively to all the comments of the reviewers and the editor.

The proposed article is very interesting in pointing the potential interest of nature-inspired design as a source of inspiration for collective decision-making. The drawbacks of the majoritarian voting system are well identified in the literature and several disciplines, artificial intelligence in particular, are searching for mechanisms that would enable to obtain collective decisions that better represent the actual individual opinion of the population. The participation of ethology to this issue and debate is more than welcome and the actual contribution would definitely deserve attention.

Thank you, we tried to make the link between decision-making, AI and ethology clearer

Despite the very positive global aim of the paper, several issues, underlined by the recommenders would enable, I think, to improve the quality of the contribution. A first important aspect concerns the readership. If, as i think, the intended audience is rather pluridisciplinary, the authors should take care to clarify concepts (efficiency of a collective decision-making, representativity, eventually coming from moral and political philosophy, as J.Rawls...) and provide more details about the examples given.

We added a new section on "Recent advances in political science" (l. 62-91) and we added definitions of the different terms in the glossary (at the very end of the paper).

The presentation of a kind of synthetic scheme concerning collective decision-making in animal societies could also help in this perspective.

We added a figure (figure 3) and explanations for the steps of animal collective decisions.

Another important set of remarks concerns the risk of a direct transition from animal decision-making to human ones, in this perspective it would be important to position clearly the potential contributions and limitations of existing decision-making mechanisms and the particularities of human-being to integrate before than envisaging such solutions.

We added a paragraph to set our point of view with recent important references:

l. 485-493: "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 <sup>40</sup>. 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 <sup>40</sup>. Moreover, AI can also help to predict and understand how people make decisions even at large scale <sup>156</sup>. Then a strong link in the future research, between human collective decisions, AI and animal behaviour has to be made.”

We also added this part towards the end of the manuscript:

I. 544-547: “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.”

To summarize in few words, the proposed article has a great potential but would need some efforts of presentation at some point.

## Reviews

*Reviewed by anonymous reviewer, 2021-05-17 19:08*

Overall, I enjoyed reading this pre-print and learned plenty of interesting information from it. My expertise is from the animal behaviour side and so I have no expertise in the political science literature also reviewed here (I have already discussed this with the recommender/editor). I do feel though at the moment that the article would benefit from identifying specific similarities/differences and/or more tangible lessons to be learned (or not learned) than is currently the case, and to consider more of the caveats and key considerations when comparing animal collective behaviour and human political systems. Currently, this is a major limitation as I'm not quite sure what I am meant to take away from the paper other than that there are some similarities and differences. To this end, I also think providing a clearer and much more clearly sign-posted structure to the article would be helpful in achieving this. I have included my line-by-line comments below that came up as reading through, some were answer to some extent later on, but this would be resolved by a reader knowing what to expect.

Thank you very much. We deeply modified the structure of the manuscript to highlight comparisons between animal collective behaviour and human political systems. We also followed all your remarks below.

From a writing style, I think it would be really helpful to detail more examples. Presumably, the intention here is to appeal to a broad audience from really different research backgrounds. Assuming this is the case, I feel providing the specifics of more examples could be beneficial in helping readers grasp concepts they are less familiar with and to be engaged in research from other fields – some of the sections I enjoyed reading most took more of this approach.

We added more examples. (l. 102-107, 115-118, 271-273, 306-318, 404-412)

I also think there is a need for a bit more self-reflection on behalf of the authors. I think the general idea clearly has something to it, but there are a few key considerations that are consistently underplayed or avoided (in part because they are tricky!). There is a need for clearer definitions of some of the terms used when describing political systems (e.g. an early example is in describing election results as sub-optimal without highlighting that this is not necessarily universally true, certainly by potential) or the lack of clarity on what “effective” governance is (is it enacting lots of policies or making the “right” decisions) and its meaning shifts through the article in different contexts.

We added details and definitions all along the manuscript to make it clearer.

Similarly, very little attention is paid to the fact that not all animal groups reach consensus, and in some species groups often divide and rejoin (either in an ordered fashion or much more randomly) – consensus is common only in a select few animal societies. There are also very different pressures acting on social decision-making for non-human animal groups – e.g. the costs of leaving a group if “unhappy” may well be predation/death – the situation is altogether different in human democracies. Somewhere in the article the authors talk of decision ecologies and I think it would be good to do a broader compare/contrast of the similarities/differences in this regard.

We added different parts on this topic:

I. 112-126: “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 <sup>41</sup> 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 <sup>42-45</sup>, 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.”

I. 149-153: “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.”

I. 374-377: “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 <sup>114</sup>. Aggressive and coercive leaders are strongly disfavoured <sup>115</sup>.”

I. 485-493: “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 <sup>40</sup>. 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 <sup>40</sup>. Moreover, AI can also help to predict and understand how people make decisions even at large scale <sup>156</sup>. Then a strong link in the future research, between human collective decisions, AI and animal behaviour has to be made.”

Finally, AI is often painted as an ideal solution to some of the problems discussed without considering some of the ethical considerations or indeed human factors in designing/implementing the algorithms used – think it is worth considering this.

We added three parts to highlight this point:

I. 163-167: “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)<sup>55</sup> and (ii) the little attention paid to the privacy of their users by the major firms in the sector<sup>56</sup>.”

I. 169-175: “AI can influence decision-making of humans in different contexts (e.g., politics or dating)<sup>57</sup>. 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<sup>58</sup>. 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<sup>59</sup>. This example shows at the same time how much AI can be useful and very dangerous for democracies.”

I. 217-221: “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)<sup>72</sup>.”

I. 553-555: “However, AI can also be dangerous<sup>146,148</sup> and several scientists appeal to more and more develop the research field in AI ethics<sup>158-160</sup>.”

It also feels that some of the benefits of one form of democracy/political system/collective behaviour may also be costs in a different context or at different scale. I think it would be interesting to consider how this is influenced by the wider context (e.g. scale/group size) or any differences between species or social systems. Providing a clearer synthesis of different forms of collective decisions in animal societies and what democratic systems/voting systems they are related to would be really great – perhaps there is a way to do this with a figure?

Rules are not different according to the group size, neither according to the cognitive capacities of the species. We added some explanations:

I. 327-340: “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<sup>112</sup>. 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 member 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<sup>41</sup>. 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<sup>93,113</sup>, which is of great relevance for AI systems used in voting systems.”

This is my first time reviewing for PCI, and it is tricky to know how the system works for a review/opinion piece like this. I guess my overall feeling is that there is some interesting information and insight in this article but overall, it is a little overwhelming as I’m not sure what I’ve learned after reading it or how it has moved ideas forward. To that end, it could be

made much stronger through a clearer structure, more tangible links/lessons to learn and greater synthesis (in my opinion at least).

We followed all your comments and modified the structure of the paper to make it clearer, with the aims more understandable. Thank you very much for your help.

Line by line comments below:

L23 – how fair is this statement, versus individuals behaving selfishly?

We changed to “In these societies, animals balance between the needs of the group members and their own needs and rely on each individual’s (partial) knowledge.” (l. 22-24)

L30-32: I think real care needs to be taken with the wording here. While I completely agree with you in terms of the outcomes, it is not immediately clear as to what makes the results described non-representative or sub-optimal without very careful definition. For example, the result in the USA (which I have some more knowledge) is representative with respect to how the voting system is set up (first past the post type system in each state) with it not being clear if this is the best or fairest system (especially when it differs from the popular vote as it did in 2016). Similarly, while a large number of people and entities would see the election of Donald Trump as sub-optimal this is far from universal (indeed, plenty of people voted for him again in 2020 so must have been happy with what he achieved for some reason...).

We added details to explain the choices of these examples:

l. 34-50: “Collective decision-making processes such as voting systems are pillars of our Western societies <sup>1-6</sup>. 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 <sup>7</sup> and the election of Donald Trump in 2016 <sup>8</sup>. 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 <sup>9</sup>. 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 <sup>10,11</sup>. In the long term, these biased choices lead to non-efficient decisions that have to be revised frequently.”

L33-35: Is there not considerable evidence (again I am aware mainly from the US and UK) of polarisation also increasing substantially between political parties with much less bipartisanship? Again, something to be cautious with in terms of writing/explanation.

Yes, political parties are also becoming more polarised on many issues, even though the political supply is still not much more diverse (i.e., here is no significant increase in the number of political parties present in the elections).

We added specifically “political parties” on l. 50.

L51-53: Completely agree with the sentiment of this statement but feel the parallels to human democracies are tricky and require clear caveats. For example, the descriptions of the problems in human democracies focus around voter dissatisfaction and turnout – it is very challenging to measure the satisfaction of individual animals with group movements (presumably those with individual optima further from the group optimum are more stressed, or to anthropomorphise, not best pleased!) and the costs of not maintaining a consensus are likely higher if there is a high risk of predation/death. I feel (and this may come later) that it is also very important to highlight this applies to particular animal groups and many other break up and reform in an ordered or even close to random way depending on the social system involved (i.e. various types of fission-fusion dynamics).

We added details here:

l. 137-156: “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 ”

L95-96: The second part of this sentence is crucial and more needs to be made of it.

We added some details:

I. 224-231: “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”).”

L98-100: This sentence needs to be expanded further so the logic is clearer.

We added some details:

I. 232-237: “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 <sup>73,74</sup>. This fighting advantage may be due to individual traits (strength, personality) but not only. Securing alliances is important to keep the power <sup>75,76</sup>, which gives prior access to resources as food <sup>77</sup>, reproduction <sup>78,79</sup>, safe places <sup>80</sup> but also to leadership <sup>81-83</sup>.”

L105: What is meant here by ineffective leadership? It strikes me that the majority system can enhance the ability of governments to effect policies (especially when they have an overall majority) but this governance may not be as likely to be universally beneficial/well-received/effective in improving society (c.f. for example, decision in a minority of coalition government).

We removed this term.

L107-109: I think that this argument is that with low turnout and a small majority you cannot be sure that a majority in the sample is representative of the population as a whole, but this takes some interpolation – it would be good to see this explained a little more clearly.

We removed this part.

L109-110: Need explaining in greater depth, feels like a bit of a throwaway sentence at the moment.

We removed this part.

L127-129: Important to be clear with what you mean by sub-optimal here. It would be good to have a walked through or illustrated example of how these two systems work side-by-side to help the reader distinguish between them.

We replaced suboptimal by non-efficient (I. 265-266), which is defined in the glossary.



L136: What do you mean by “decision ecology”? New jargon and not explained.

We added a definition in the glossary (l. 576-578).

L139-141: Again it would be good to explain/define sub- and supermajority quorums – could they be included in the glossary?

We added more details in the Glossary (l. 614-617).

L141-143: How does this differ from the types of voting systems that are widespread (and often heavily criticised) such as the first past the post system of voting for MPs in the UK. This seems to be an example of creating independent smaller groups of voters (each constituency) and then using a majority rule within each group. Or indeed larger systems such as the Welsh Senedd or European elections for MEPs with different rules? But then this makes me think I am misunderstanding the point being made here?

The first-past-the-pole (FPTP) rule is a kind of race model, as we mention it now (l. 263). The main difference between FPTP and mini-publics (or small groups of randomly selected voters) is that mini-publics are set up in order to foster deliberation among participants. It is only after deliberation that the vote of the group is taken into account. It is this combination of random selection and deliberation that makes mini-publics more effective (and less subject to partisanship) than traditional voting systems.

We rephrased:

l. 284-287: “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.”

L143-144: This seems important – would good to read more about the general patterns, current statement is very vague.

We added details:

l. 287-290: “If a large crowd (in which a meaningful deliberation cannot take place because of its size <sup>16</sup>) is structured into such mini-publics, deliberation and social influence within groups improve the crowd’s collective accuracy <sup>96</sup>: averaging consensus decisions is then significantly more accurate than aggregating the initial independent opinions.”

L150-152: Feels this could/should have citations to support it. Not my field but <https://doi.org/10.1016/j.cub.2015.01.037> seems relevant.

We added some instances here and the respective references:

l. 303-304: “as in elephants <sup>95</sup>, bonobos <sup>96</sup> or killer whales <sup>97</sup>”

L158-160: I think this concept needs expanding on a little – it also seems at some point to require a subjective decision to be made by someone.

We added more explanations:

I. 203-211: “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<sup>64</sup>. Once these individuals or clusters have been identified, their weight in the next round of deliberation could, for example, be penalised<sup>64</sup>. 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<sup>65</sup>. Without such a penalisation, small minorities could gain veto power blocking any progress.”

I. 323-326: “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<sup>110</sup>.”

L163-166: I get a bit lost here as to the role/use of AI. Is this voting systems for AI or using AI for human democracies as the implications seem rather different.

We focus mainly on how AI could be used to implement better voting systems and/or collective decision systems

L201-203: But who sets these algorithms and decides what is representative (presumably there is sampled information used to come to make these decisions).

You are right: the decision as to what is representative must be made before using the algorithm. Once this decision is made, the electoral maps produced by the algorithm following simple rules will be less contentious, especially if all stakeholders have been involved in developing the rules and evaluating the resulting maps.

We clarified our point:

I. 180-183: “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.”

L200-206: I am hoping these points will be expanded upon below? Would be good to have something at the end of the paragraph indicating this will happen perhaps?

We have now removed Box 3 and integrated it into a new section entitled “Taking inspiration from AI” (I. 162-221). There we give more details on the contributions of AI to collective decision making.

L215-218: How does group size play into this? I wonder whether scale is important here – it seems easy in practice for an animal group with a few tens or hundreds of individuals and I imagine small groups of humans use similar methods when making decisions often (e.g. a fairly direct analogy would be in deciding whether to stay in a bar or move to a new one on a night out), but how feasible (and efficient?) is this approach at the level of a country? Does it risk potentially generating some of the problems discussed previously (lower turnouts with regular votes) or controversial/disputed results based on low levels of knowledge? The latter is touched on here but only in passing.

We added the following part:

I. 354-360: “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<sup>85,114</sup>. How to take into account different needs and different knowledge of citizens is of matter and will be developed in the next sections.”

L226: I wonder whether there is an interesting example provided by the pandemic here?

Indeed, we added a sentence:

I. 368-370: “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.”

L255-257: Not immediately clear to me how this is directly analogous. Surely, it is more equivalent to a situation where someone is more enthusiastic they vote more times (probably most similar to phone voting in TV talent contests perhaps!). The link to Borda counts needs some more steps of explanation.

We removed this part.

L220-276: I thought this section was really interesting and well-written overall.

Thank you very much!

We still expanded this section a little bit (I. 362-430).

L289: Perhaps better (and more universal) to refer to this as misinformation?

Done (I. 443, 444 and 473)

L297: Similar to various previous comments it would be good to ensure clarity with what “vote well” means – as identified this is where heterogeneity is important between voters. In addition, people may end up voting on particular issues rather than the entirety of what a leader stands for which can compound things further in terms of voting “well”.

We added some details:

l. 452-454: “although it is good to vote, it is better when one has the knowledge to vote well<sup>139</sup>, meaning to be sure to have all the information for each alternative in order to make a choice representative of one’s needs.”

L314: This is easy in the case of clearly misleading or incorrect stories, but some of the problem arise from other information that can have different meanings depending on how it is presented – perhaps hard or unfair to remove algorithmically and (again) rather subjective.

We removed this part.

L323: Another important component is how easy it is to share these articles (e.g. Twitter now prompts a user to consider reading a link before sharing it, which is an interesting development in this regard).

Indeed, we added this information:

l. 479-481: “and can propose, as Twitter, to consider reading a link before sharing it or warn about specific content (violent, unsure).”

L324-332: Interesting paragraph but a lot of new ideas here that are covered really very briefly. Would be good to introduce concepts like social networks (first real focus on this), the majority illusion/friendship paradox and small world networks with greater explanation to help readers along.

We added a paragraph:

l. 483-489: “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<sup>151</sup> to three and half<sup>152</sup>. However, this booming of relationships may lead to different decision biases.”

L367-368: Typo in this sentence somewhere.

Corrected (l. 510).

L383-385: This distinction isn't especially fair, humans in small groups make decisions in similar ways everyday (whether it be friends on a walk, businesses, sports teams etc.). So perhaps it doesn't scale to our political systems but perhaps the general patterns aren't so distinct.

Indeed, we modified the paragraph to include small human groups.

I. 526-532: "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<sup>28,143</sup>."

Box 1:

General points: I found the key ideas in the box, and the distinction between them to be rather hard to follow – I found myself using Wikipedia alongside the text to help understand the concepts better. It's also not clear from the text that Arrow's "proposal" is also a paradox, which is what is suggested by the figure?

We removed Box 1.

L83: You switch from talking about cities to studies here

We removed Box 1.

C. Sen Theory, is this the same as the other two? It would appear to be people voting with more information rather than a system for deciding how the outcome is decided?

We removed Box 1.

Box 2:

This is nicely explained in general, but it is not representative of the full diversity of scenarios. As highlighted in a previous comment the full consensus being achieved occurs in not all species and not all contexts. Often only partial consensus can be achieved and groups split.

We removed Box 2 and integrated it into a new section entitled "Taking inspiration from animal collective decisions" (I. 93-160).

You are right about the diversity of scenarios; we added some sentences to address this point:

I. 112-121: "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 <sup>41</sup> 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.”

L172-174: A qualification is needed here as not all animal groups are democratic.

We replaced by:

l. 239-242: “Whilst animals do not elect presidents (but see <sup>76</sup> 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 <sup>23,27,84–86</sup>.”

L177: Perhaps best to say it has been documented in, as it seems highly likely to occur in other taxa too

Done (l. 105).

Box 3:

L340-342: This is very vague – not clear what would be achieved or how from what is written here

We have now removed Box 3 and integrated it into a new section entitled “Taking inspiration from AI” (l. 162-221). There we give more details on the contributions of AI to collective decision making.

*Reviewed by Camelia Florela Voinea, 2021-05-26 10:35*

From my point of view, the preprint is really interesting, however not necessarily as an interdisciplinary approach to voting systems, but to human collective decision-making which could find some insight in animal world and some support in AI research.

We enlarged the title, abstract and introduction to fit better with human collective decision-making. We also added a new section on "Recent advances in political science" (l. 62-91).

I have two main observations to provide with respect to the approach suggested in this preprint:

First, the text appears as a literature review with respect to two main issues, (1) collective decision-making in the animal world with support from studies of intelligent non-human agent behavior (bees, ants, animals), and (2) artificial intelligence and machine learning studies which could get insight in such behaviors in order to provide solutions to replicate these behaviors, (voting behavior, especially) in AI-based research approaches to human voting systems. As a literature review, the text mentions (sometimes, without explicitly explaining what exactly the refereed systems are actually performing in terms of voting tasks) various applicative and/or fundamental research in voting systems viewed as collective decision-making systems. With regard to this dimension, one should notice that collective decision-making in the living non-human animal world cannot escape the notion of 'dominance' regardless the contribution of each such individual agent to the collective decision (see: J.L. Gould on animal behavior, animal navigation, language; GJ. Hofstede on synthetic cultures inspired by animal world). It is therefore with precauciousness that we could approach collective decision-making in the living non-human animal world in order to get inspiration for improving human voting systems.

We added two paragraphs on this purpose:

l. 374-377: "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<sup>114</sup>. Aggressive and coercive leaders are strongly disfavoured<sup>115</sup>."

l. 390-397: "In this way, voters maintain the leadership purposefully, which implicitly downplays the social and environmental conditions underlying egalitarianism<sup>118,119</sup>. 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<sup>115</sup>."

In the animal world, collective decision-making cannot be assimilated or identified with voting behavior in humans as the voting is a reflexive process in humans, and it is usually employed in the dynamics, change or even in the self-organization of human organizations or social systems. There is no 'democracy' dimension in the animal world in spite of apparent individual contributions in collective decision making to group final decision connected to tasks like the searching for food resources (for example, in ants and bees social systems) or defending from enemies (for example, in wolves groups).

Even though voting is associated with reflexion in humans, it is not always the case: many humans vote simply based on their feelings and humans are prone to biases when voting. Moreover, voting is not the distinctive feature of democracy. In political science, the 5 most important principles of a modern democracy are (i) participation rights, (ii) deliberation, (iii) majoritarian principle, (iv) representation and (v) transparency (Landemore, 2020, Open democracy). Voting is just a form of representation, but other forms based on sortition, self-selection or liquid representation exist. We introduce them in the revised manuscript:

I. 74-83: “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 <sup>16</sup>. 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 <sup>16</sup>. Finally, liquid representation is a very recent concept in political science <sup>18,19</sup>. Its four key features are <sup>20</sup>: (i) direct voting on any issue, (ii) flexible proxy voting, (iii) meta proxy voting and (iv) possible instant recall by each original voter.”

We argue that the 5 democratic principles can also be found in non-human animals.

I. 96-110: “In ethology, voting means that “an animal communicates its individual preference with regard to the decision outcome” <sup>23</sup> 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 <sup>24,25</sup>. 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 <sup>26</sup>. Group decision-making is common in the animal kingdom, and has been documented in social insects (honeybees <sup>27</sup> or ants <sup>28-30</sup>), fish <sup>31-34</sup> and mammals (e.g., primates <sup>35,36</sup>, meerkats <sup>37</sup>, African wild dogs <sup>38</sup>, bison <sup>39</sup> and deer <sup>23</sup>). 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 <sup>40</sup>.”

I. 137-156: “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 ”

As a literature review however, the preprint is interesting because it makes references to several research approaches which could inspire the research on human collective decision-making in participative societies, which is essentially different from what actually 'voting system' means. Perhaps, it might be useful to remind the huge literature and research work developed at M.I.T. (to take but this one example) on how studying the non-human behavior could enhance developing artefacts and artificial intelligent systems which could assist or replace humans (I like the 'avatar' example in this preprint!) in collective decision making. I still remember Rodney Brooks and his pioneering research work and I find useful to combine in the interdisciplinary research the studies on animal world with studies on human social and political systems. However, this kind of research (which has meanwhile produced intelligent robots able to perform amazing tasks as humans do) is different from the political human-world of decision making, so I would recommend care in making parallels between human and non-human voting systems or what appears to be a voting system in the animal world, but in fact it is not such one.

Thank you, we added different instances and details all along the manuscript to make clear the parallel between human and non-human collective decisions. We added this sentence in the introduction:

I. 107-110: “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 <sup>40</sup>.”

Second, the preprint aims to improve on voting systems by employing characteristics of collective decision-making in the animal world, like for example knowledge. I would make a brief comparative analysis and evaluation (if I may) with a research project on the same issues which has been developed some years ago, but which has not got any follow up (at least, to my knowledge) due to issue complexity: Social Collective Intelligence (Miorandi et al., 2016) is an approach which combines Ai with several aspects of human behavior, human action,

human decision-making, and human political organization rules. In this project, many aspects of human society and polity are approached from an AI perspective combined with ALife, AA and ML. These two approaches have something in common: they aim to improve human systems by AI systems. While the approach in Miorandi et al., (2016) reports research concepts, architectures, systems and performances, the approach in this preprint reports a literature review in studies on animal behaviors which could be assimilated to human behaviors and translated into artificial intelligent systems able to assist humans. As far as this preprint keeps a literature review approach, the text should further include research which could explain how AI and ML could be employed in extracting and/or achieving aspects of behavior which could further benefit human societies and polities. As far as this preprint aims at improving human voting systems, than 'voting system' and 'collective decision-making' should be defined and compared, and the approach should explain how studies on (non-human) animal behavior could touch on democratic dimensions of human voting and not only on human collective decision-making. It should also take into consideration various models of voting systems (rational choice theory, welfare, psychology, geometry & complexity, etc.).

We now detail that voting systems in humans are a type of selection of representatives and that other types of selection for representatives exist (l. 74-83).

We did not know this work by Miorandi et al., in particular its focus on the necessity to develop ethical guidelines for how AI should be used by human societies. We mention this work in the revised version:

l. 553-555: "However, AI can also be dangerous <sup>146,148</sup> and several scientists appeal to more and more develop the research field in AI ethics <sup>158-160</sup>."

Some informal references:

J.L. Gould: The Honey Bee (1988), The Mystery of Animal Navigation (2012)

Miorandi et al., (2016) Social Collective Intelligence. Combining the Powers of Humans and Machines to Build a Smarter Society, by Daniele Miorandi, Vincenzo Maltese, Michael Rovatsos, Anton Nijholt, James Stewart, Springer.

Hofstede, G.J., Pedersen, P. (1999) Synthetic Cultures: Intercultural Learning Through Simulation Games, December 1999, Simulation & Gaming 30(4). DOI: 10.1177/104687819903000402

Types of Voting systems/Models of voting: welfare (Arrow, K., 1950), economic model of voting in a democracy (Downs, 1958), voting models based on politics of ideology (Hinich & Munger, 2008; Enelow & Hinich, 1990), psychology of participation in human voter (Cox, 1997), political manipulation (Riker, 1986), calculus of voting (Riker & Ordeshook, 1968), complexity & geometry of voting (Saari, 2008).

We added some of these references in the manuscript.