Self-Domestication and the Social Brain Hypothesis

a Recipe for Language Development

Graduation Thesis, August 2020

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Abstract. Dunbar's Social Brain Hypothesis claims that human intelligence evolved as a result of surviving and reproducing in large complex groups (1998). These groups imposed time and cognitive demands on our ancestors, likely causing the emergence of an alternative form of grooming (Dunbar, 1998). This expressed in gossiping, possibly being the start of natural language as we know it today. The Human Self-Domestication hypothesis claims that cooperative and communicative abilities evolved when natural selection favoured increased in-group pro-sociality over aggression in late human evolution (Hare, 2017). The current study investigates whether increased tolerance can facilitate the evolution of preference for gossip over grooming. To do so, we reconstruct the multi-agent model from Slingerland et al. (2009) and extend it by introducing in- and out-group interactions. The results reveal two mechanisms; firstly, group size can play a role in the general preference for gossiping over grooming, and secondly, tolerance seems to be subject to the group size. More specifically, agents from large groups seem to be masked from the need for pro-social behavior and develop a preference for in-group socialising, whereas agents from small groups tend to socialise out-group. Contrary to the Human Self-Domestication hypothesis, these results reveal an alternative view where tolerance results from selective pressures on information and social fitness rather than natural selection.

Keywords: Self-Domestication · Social Brain Hypothesis · Relaxed Selection · Agent-Based model

1 Introduction

Humans are highly social animals that can cooperate on large scales (Tomasello, 2014) and communicate using language. Through language we have the ability to share inventions and stories. This powerful tool seems to have helped us to become the successful species we are today. A multitude of theories speculate on the origins of language; however, it remains unknown. For the purpose of this research we focus on two well-known hypotheses, the Social Brain hypothesis and the Human Self-Domestication hypothesis (HSD). The first claims that human intelligence evolved as a result of surviving and reproducing in large complex societies (Dunbar and Gowlett, 2014). It describes the relationship between brain and group size. More specifically, a species' brain size correlates with the size of its typical group size. Typically, when the size of a group supersedes the species-specific limit, it starts to break up. One of the reasons for this is assumed to be the cognitive load and time consumption required to maintain coherent relationships with each other. Accordingly, Dunbar describes that social grooming in primate societies is physically restricted to being a one-on-one activity (2017). Although being effective for strengthening bonds, grooming costs considerable amounts of time. Inevitably, groups have started growing, imposing both time and cognitive constraints on social animals. To overcome the lack of time Dunbar (1998) argues that an alternative form of grooming must have evolved. The alternative to one-on-one grooming is one-to-many gossiping and even though it is still cognitively demanding, it is very time efficient in terms of bond maintenance. Hence, groups would not break up, and larger social groups could be effectively maintained.

The Human Self-Domestication theory argues for a different perspective. It proposes that cooperative and communicative abilities evolved when natural selection favoured increased in-group pro-sociality over aggression in late human evolution (Hare, 2017). Domestication as such results in behavioural, psychological, and morphological changes (e.g., reduced tooth and brain size). Sánchez-Villagra and Van Schaik (2019) argue that these changes possibly result in more social tolerance towards group encounters. Similarly, evidence from Apicella et al. (2012) suggests that early humans may have formed ties with kin and non-kin, based on their tendency to cooperate. In this way, social networks might have contributed to cooperation between groups.

In the case of domesticated species, there are usually minimal direct competition, reproduction or survival limitations, and the relaxation of such selective pressures can result in enhanced or new behaviours (Deacon, 2010). Some of which possibly favour social behaviours such as language. Likewise, it has been found that ecological factors seem to play a role for bonobos too as more friendly contact occurred in favourable environments (Lucchesi et al. (2020), Hare (2017)). Deacon (2010) suggests that the relaxation of selection at the organism level may have led to the complex synergistic features of the human language capacity. Relaxed selection is a phenomenon where selective pressures are lessened by for example external factors. As a result, the time and energy that was otherwise used to cope with these pressures could be spent elsewhere. Even though relaxed selection is not directly incorporated into the structure of the model, it is essential to understand its fundamentals for the purpose of this research.

An example physiological change that is likely due to relaxed selection is the loss of vitamin C synthesis and introduction of colour vision in some vertebrate lineages. Deacon describes that at some point, apes probably changed diets from insects to eating reliable quantities of fruit. Hereby the function of vitamin C synthesis degraded without negative effects on reproduction. However, the loss of this function led to an addiction to fruit, because of the vital need for vitamin C. This vital nutrient was only available extrinsically, so selection shifted towards sensory, behavioural, and digestive-metabolic mechanisms that increased the chance of obtaining it. Colour vision, increasing the likelihood of finding coloured fruits, is one of the possible results of this selection shift Deacon (2010).

Another masking example that is more closely related to the evolution of language comes from holistic vocalizations. Fitch (2013) argues that holistic vocalizations presumably complexified into a language. More evidence suggesting that self-domestication might have played a role in complexifying human vocalizations comes from studies on birds. Accordingly, Kagawa et al. show that male White-Rumped Munias sing syntactically simpler songs than their domestic counterparts, Bengalese finches, as a result of a relaxed environment (2012). Song simplicity might play a role in species recognition for White-Rumped Munias. As such, the existence of related species in living environments might constrain song complexity through identifiability. Kagawa et al. find that song complexity is subject to the number of flocks in their environment. A lower number of flocks, hence, a lessening of selection pressure on identifiability, led to more complex identification calls. Arguably the main contributor to this effect is the process of domestication: threats cease to exist which leads to an environment of lessened selection pressures. Similarly, Ritchie and Kirby (2005) computationally show that domestication can result in an increase of song complexity and increased influence from early learning.

Both theories, HSD and the Social Brain Hypothesis speculate about the evolution of human intelligence and are thoroughly investigated individually, however, not much work is done on a combination of hypotheses-specific mechanisms of both. Hence, we attempt to investigate the possible synergies of tolerance alongside the preference for gossip over grooming. To do so we extent a multi-agent model by Slingerland et al. that supports the Social Brain Hypothesis by computationally showing that greater group sizes can stimulate the evolution of language as a tool for social cohesion Slingerland et al. (2009). Here we investigate whether increased tolerance can facilitate the evolution of preference for gossip over grooming.

We introduce groups to the model of Slingerland et al. (2009) that divide the population and creates the possibility for in- and out-group interaction based on social tolerance. The agents' social preferences, being tolerance and groom- or gossip probability, alter each generation due to mutation. The social interactions that take place in a generation cause groups to change in size. Here we look at the effects of this on the social preferences of agents, and make predictions about why other primates did not evolve into large cooperative societies whereas humans did. Finally, we use the outcomes to reflect on real-life observations and hypothesise regarding possible courses of the evolution of language.

2 Model

Our model builds further upon the earlier mentioned model by Slingerland et al. (2009). They focused on the pressure that living in larger groups has on the trade-off between grooming and gossiping. Here we extend it by incorporating social preferences for in- and out-group tolerance. Since Slingerland et al. did not make their code publicly available we rebuilt it as closely as possible and found similar results. Hereafter it is extended for the purpose of this research. In the following sections we first describe the base model from Slingerland et al. after which we provide a detailed overview of the extended model.

2.1 Slingerland model

To support the Social Brain Hypothesis, Slingerland et al., henceforth referred to as SMVV, built an agent-based model that showed that living in larger group sizes imposes a pressure that results in agents who are more prone to gossiping. In this model, a simulation consists of a population of social agents who can socialize for a number of rounds via two simplified actions; one-to-one grooming or one-to-many gossiping. The choice of social action is regulated by an agents' main variable *gossip probability*. Agents maintain a memory with social interactions that can be acquired by participating in, observing, or gossiping about an event. Each generation ends with selection over the entire population for agent fitness, being a combination of social and information fitness. Where social fitness reflects the number of others you have closely interacted with, information fitness resembles the memories an agent has. Where gossiping results in higher information gain, grooming results in a higher social gain. Agents only inherit the gossip probability from their predecessor. For each reproduction there is a 1% mutation chance, deviating the new gossip probability with 0.05 from the parents' probability. In the experiments, SMVV artificially set the population size and show that a higher *gossip probability* results from living in a larger population.

2.2 Extended model

The current research incorporates tolerance into the existing model, we refer to tolerance as the acceptance to out-group encounters. Accordingly it deviates from the definition of (Hare, 2017) as it does not include explicit natural selection for non-aggressive behavior but sociality in a more general sense. The model is not spatially explicit but individual-oriented. It consists of a population of social agents living in an initially distinct number of groups determined by the parameter *nGroups*. In each generation, agents can socialize during an arbitrary number of *nRounds* after which the population is shuffled to prevent any ordering effects. The type of social action is determined based on the core variables of an agent: *tolerance* and *gossip probability*. Moreover, the actions taken during the rounds influence the fitness of each agent in the population. When a generation of agents has gone through its social rounds, selection determines who can reproduce after which the new population socializes. This process is repeated for *nGenerations*. In a simulation, the number of social rounds is fixed and proportional to the number of agents and the number of groups.

Agents An agent holds three heritable main variables: *group label*, *tolerance* and *gossip probability*. The first, indicates to which group an agent belongs, the second regulates whether an agent socializes with members who are in- or outside of its group(s). Tolerance reflects reduced aggression towards out-group animals in real-life. The third variable regulates the type of social action taken, one-to-one grooming or one-to-many gossiping. During a generation, each agent builds a memory of social events. New social events are added when the agent either participated in it, heard of it through gossip, or observed it.

Groups The main contribution of this research comes with the addition of different groups. While SMVV artificially set group sizes, here they evolve naturally. In doing so it more closely resembles real-world situations, and additionally, it allows to carefully investigate the complex interaction between tolerance, group size and social interaction patterns. Each simulation is initialized with a population size and an arbitrary number of distinct groups. By splitting the population, we created an in- and out-group dilemma that is different for each generation. To create groups of variable sizes agents must be able to enter and leave groups, the next sections describe the implementation.

Entering groups There are two ways for an agent to become part of a group. Firstly, a new agent inherits the group label of its parent which is set for its entire life. Secondly, agents can become part of a group by frequently interacting with members of that specific group. More specifically, an agent is accepted into a group when the number of interactions with agents who are part of that group is larger than half the group size (equation 1, X represents a single group). Doing so entails that the acceptance into a group is relative to its size. Though no empirical findings support this abstraction, multiple runs with different fractions produce the same results and do not influence the main findings. The distinction between inherited and acquired group labels ties in with kinship and friendship. The latter being subject to fading or abrupt stopping whereas kinship lasts for life.

$$Group_x acceptance = \frac{Group_x Members}{2} \tag{1}$$

Leaving groups A single agent can be part of multiple groups. However, it can also be rejected from the non-native groups it is part of. When an agent has not been able to be accepted into a group during a social round it might randomly be rejected by a single non-native group to which it belongs. We assume this to draw parallels to in-group fights and group separation in nature. We simulate such *group rejection* as the probability of being rejected and it does not change throughout a simulation. Again, different initialisations of this threshold do not influence the results of the model.

Assigning actions Agents can engage in social events for *nRounds* during its life. The type of such events is regulated by its main variables. The tolerance variable describes the chance of an agent to initiate a social event with an out-group agent. Consequently, it also regulates the chance of initiating an in-group social event. Lucchesi et al. (2020) have empirically demonstrated that ecological factors influence the course of intergroup encounters for bonobos. They show that highly concentrated food patches result in a higher probability of terminating an encounter, likely due to an increase of contest. Not quite the same, but similarly, here agents can reject social invitations from agents out of non-native groups. Likewise, an invited agent can reject an in-group invitation based on its tolerance variable. Such rejection results in a lost opportunity for all involved participants, being the initiator and the invited agents.

The agents' gossip probability is borrowed from SMVV, and similar to the tolerance variable, it regulates the type of social event, being grooming or gossiping. A grooming event involves only two, the initiator and invited, agents and results in both to add the current event to their memory. Gossiping happens with up to three others, in this case not only the current event is added to the memory. A single participant is randomly selected to gossip and will share 10 random events from its memory. If unknown, the listening agents add these memories to their memory. As explained by SMVV, the total of four gossiping agents is based on findings that show that four is the maximum number of individuals to spontaneously interact in a conversation (Dunbar et al., 1995). The implementation leaves a social agent with two binary choices; hence, a social event can be one of the following four scenarios:

- In-group Grooming (one-to-one)
- In-group Gossiping (one-to-many)
- Out-group Grooming (one-to-one)
- Our-group Gossiping (one-to-many)

The initialization of a social interaction comes with risks as an invited agent can turn them down if they do not fit its current preferences. We assume that this draws parallels to aggressive responses in nature. More self-control would inhibit aggressive responses and thus stimulate pro-social behaviour (MacLean, 2016).

For each social event, four other agents are selected that are not part of that social event. These will observe the current event and add it to their memory. An agent can be part of only one social event, but can observe any number of other events.

Evolution When a generation has gone through its social rounds, a new generation must be formed. For this, each agent is evaluated in terms of social and information fitness. Identical to SMVV, we use an elitism selection mechanism (De Jong, 1975) where the fittest 5% will have two children, the weakest 5% will have none, and the remaining agents will have one child. This entails that selection is done over the entire population.

The three main variables of an agent; group label, gossip probability, and tolerance are passed on to its offspring during reproduction. For each reproduction, there is a mutation chance of 5% that regulates whether the last two variables are independently altered. In the case of mutation, the gossip probability and tolerance of the new tolerance and gossip probability deviate by 0.05 from the parents' values in the positive or negative direction.

Fitness The fitness functions shown in equation 2 and 3 are borrowed from SMVV. The general fitness of an agent is an equal combination of social and information fitness. The latter is measured by taking the square of the number of social events an agent has acquired, either through gossip, grooming, or observing, in its lifetime (equation 2). Here M represents the memory of an agent.

$$f_{information} = M^2 \tag{2}$$

Social fitness is based on the number of social partners an agent has interacted with (equation 3). Here, X is a single event of all grooming or gossiping events that an agent has been part of, described as $\mathrm{E_{groom}}$ or $\mathrm{E_{gossip}}$. One-to-one grooming is more intimate then gossiping with multiple others and therefore contributes more to the social fitness of agents. However, gossiping has the advantage of sharing information and hence, increases information fitness more. Moreover, the intimacy of a social event decreases with the number of participants, as such it contributes less to strengthened bonds and for example; the likelihood of cooperation in fights.

$$f_{social} = 5 \times \left(\sum_{x \in E_{groom}} \frac{1}{p_x - 1} \right) + 4 \times \left(\sum_{x \in E_{gossip}} \frac{1}{p_x - 1} \right) \tag{3}$$

Tolerance is not directly incorporated into the fitness of agents. Instead of directly selecting for it, we want to investigate how it interacts with groom- or gossip preferences.

3 Experiments

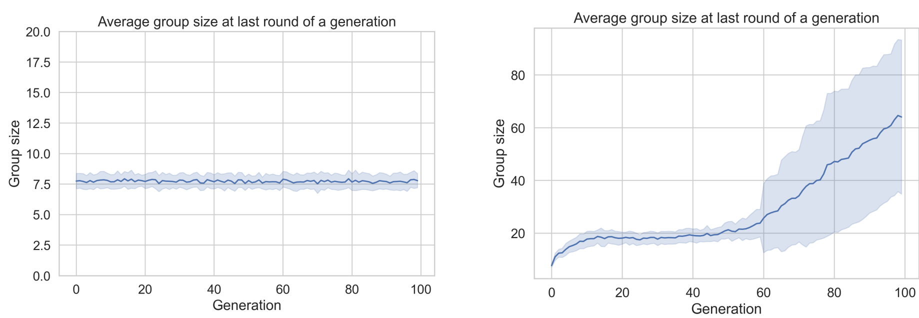
The model described previously is built to investigate the resulting effects of combining tolerance with the preference for gossip over grooming. Agents can benefit from interacting with others in two different ways; gossiping and grooming. If it were to be a real-life situation, high social fitness reflects strong alliances, whereas a high information fitness reflects the knowledge of present alliances within a society. Primates with more social alliances, or those who know more about them could have higher reproduction chances.

To test the model we conducted two experiments, each with a population of 100 agents where *nRounds* is 75, *nGroups* is 20, *GroupRejection* is 0.4, and the mutation rate is 0.05. In both simulations the agents start with a *gossip probability* and *tolerance* of 0.5. These parameters can be set to any arbitrary number, however, the current settings provide clear results. The first experiment investigates the incorporation of variable groups and the second looks at the effects of them on the preferences of agents.

3.1 Experiment 1 - Variable groups

SMVV have been able to provide computational evidence for the preference of gossiping in large groups. Here we investigate the incorporation of variable groups and tolerance on their model. The runs performed in this experiment are nearly identical and only differ by one parameter, selection for social and information fitness can be True or False.

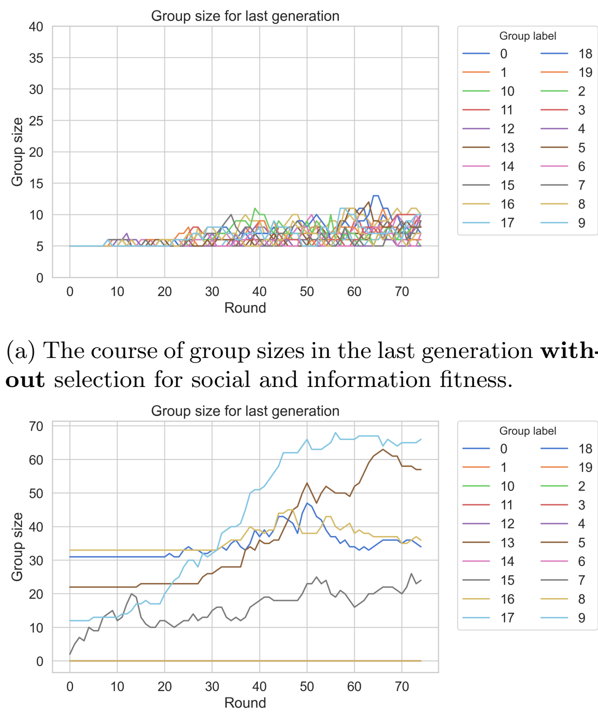
Results The plots from figure 1 show the average group size over the entire population for each generation. The results from figure 1a are those of simulations without selection, whereas those of figure 1b are a result of the selection mechanism being True. The latter clearly shows that the groups grow and are larger for later generations as a result of selection pressures. Besides the growth of groups, we observe that they die out during a simulation, usually, leaving a handful of groups to survive (figure 2).



(a) Average group size over the entire population on the last round of each generation. The simulations ran **without** selection for social and information fitness.

(b) Average group size over the entire population on the last round of each generation. The simulations ran **with** selection for social and information fitness.

Fig. 1: Average group sizes over the entire population. The results are from 40 simulations with identical initialisation settings except for selection for social and information fitness being True or False. The colored area reflects the standard deviation.



(a) The course of group sizes in the last generation **without** selection for social and information fitness.

(b) The course of group sizes in the last generation **with** selection for social and information fitness.

Fig. 2: Two different simulations that started with identical initialisation parameters except for selection for social and information fitness being True or False. Each line represents the group size of a single group in a generation.

Discussion The above figures indicate that our model creates a situation where larger groups evolve as a result of the selection pressures. Although different initialization parameters result in individual runs that are quantitatively slightly different, qualitatively similar effects arise. The chance of group rejection logically influences the size of the groups due to a higher rejection likelihood. However, the size of the groups still increases over the generations. Similar effects are observed for the number of social rounds as several interactions are required to enter a group.

The results can be accounted for by the reproduction mechanism. Agents that has optimal *tolerance* and *gossip* probabilities for that generation will be fitter and thus have a higher reproduction chance. Due to mutation this can result in their offspring being even more social in the next generation, thus creating a cumulative effect. We assume this to reflect nature because more tolerant primates would have fewer aggressive encounters and more information about possible alliances thus a higher chance of reproduction. The key explanation for groups to grow if selection takes place lies in the inheritance of group labels. An agent from the best 5% has two reproductions, which entails a group growth of at least one agent at the costs of another group. This in combination with the feedback into the new generation results in the observed effects.

3.2 Experiment 2 - Variable groups and the preference for gossiping

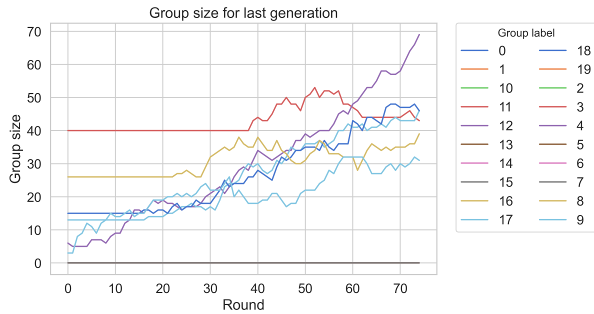
The previous experiment showed that groups grow over the generations. This experiment investigates the effect of these growing groups on the main probabilities of the agents per group for individual simulations. More specifically, it investigates whether an increased tolerance can facilitate a preference for gossip over grooming. The initialization parameters in this experiment are identical to those of experiment 1. However, selection for social and information fitness is True in all simulations.

Results - Individual Simulations The results shown in figure 3 are from a single run with selection for fitness. Due to the dependencies on randomness, a group may survive in one run but not in another. Hence, it is not possible to calculate means over multiple runs, however, experience shows that two scenarios occur for individual runs. The main contributor to this is the number of groups that survives. Figure 3 shows a run where multiple groups survive and figure 4 shows a run where one group is considerably larger.

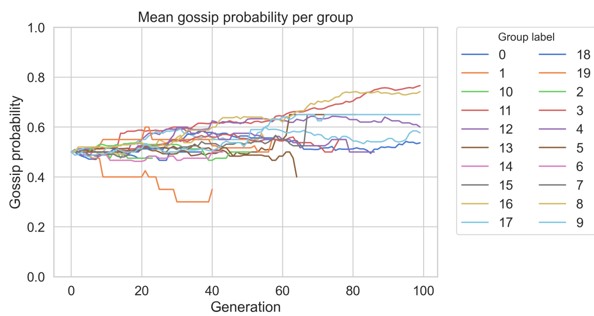
The plots in figure 3a show that the last generation consists of six relatively large groups. Moreover, figure 3b and 3c show that after 100 generations the groups seem to rely on both in- and out-group gossiping, gently preferring out-group contact. Group 11 started as the largest and accordingly, has a high gossip probability, interestingly, it has a lower tolerance for out-group members. In general, all groups follow similar trends. However, figure 3c shows that a group (1) whose agents do not adhere to the trend of the remaining population dies out.

The results shown in figure 4 are from another simulation that resulted in fewer surviving groups. Figure 4a clearly shows that group one is considerably larger than the three remaining small groups. On the population level, this causes the average gossip probability and tolerance to diverge. A closer look at the averages per group reveals that the large group has developed a reliance on gossip and is less interested in out-group contact. Additionally, the other remaining groups rely on both, high tolerance and gossip probability.

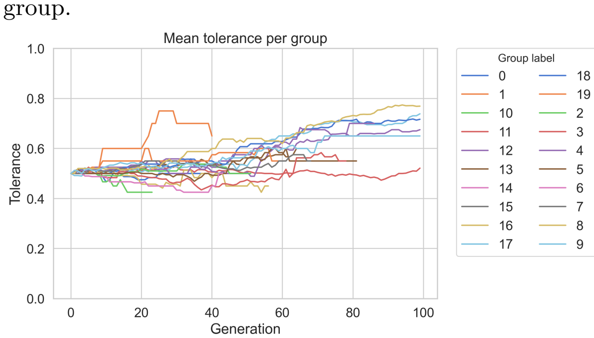
Results - Multiple Simulations Instead of an in-depth look at groups, here we look at the probabilities of the entire population for each generation. By doing so it is possible to average over multiple simulations and generalise conclusions.



(a) The course of the remaining group sizes in the last generation **with** selection for social and information fitness.

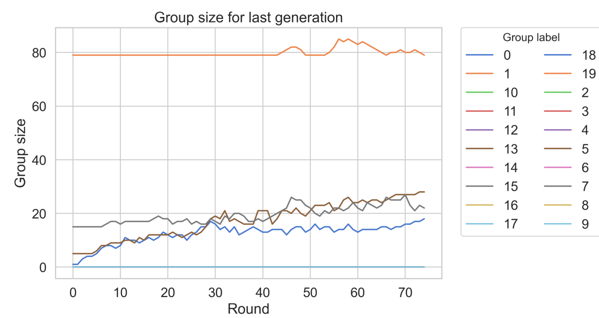


(b) The course of the average gossip probability per group.

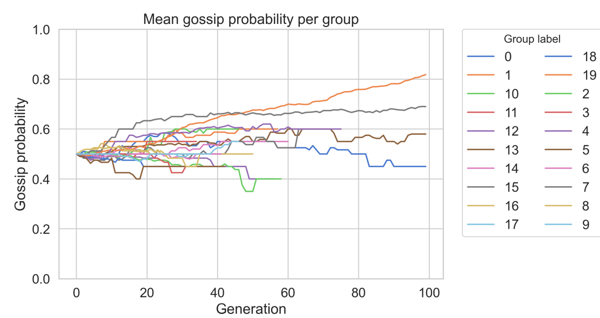


(c) The course of the average tolerance per group.

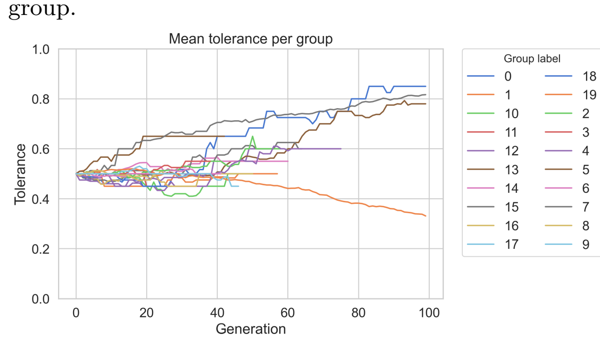
Fig. 3: Simulation results of a single simulation **with** selection for social and information fitness where multiple groups survive. Each colored line represents a group in the population, the group numbers and colors in the legend are colour matched.



(a) The course of the remaining groups in the last generation **with** selection for social and information fitness.

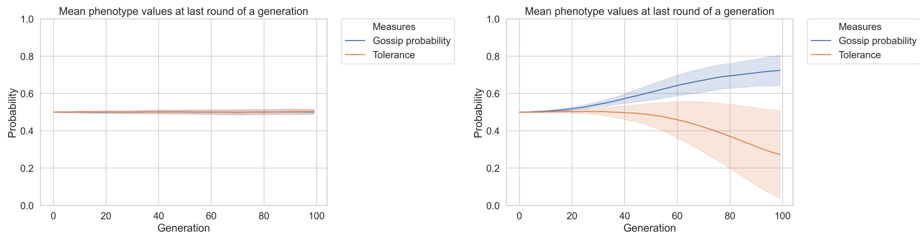


(b) The course of the average gossip probability per group.



(c) The course of the average tolerance per group.

Fig. 4: Simulation results of a single simulation **with** selection where few groups survive. Each colored line represents a group in the population, the group numbers and colors in the legend are colour matched.



(a) The average gossip probability and tolerance **Without** selection for social and information fitness.

(b) The average gossip probability and tolerance **With** selection for social and information fitness.

Fig. 5: The average probabilities for each generation over the entire population. The results are from 40 simulations with nearly identical initialisation settings with only selection for social and information fitness being True or False. The colored areas reflect the standard deviation.

In figure 5 the average probabilities of the last round for each generation over 40 simulations are plotted. It clearly shows that tolerance becomes less beneficial when the chance for gossip rises. Moreover, the deviation is larger for tolerance. This is due to the different scenarios that can occur, being multiple relatively large groups, or one considerably larger group. In the former scenario, agents tend to depend more on out-group socializing. Conversely, simulations that end with one considerably large group result in a high preference for in-group gossip while a lower group size average shows that a combination is more useful (figure 6).

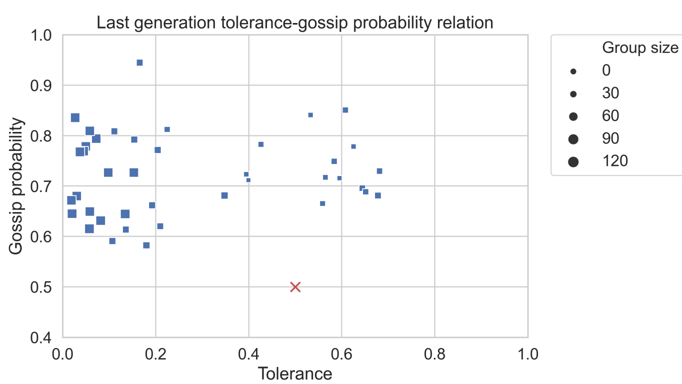


Fig. 6: The average gossip probability and tolerance over the entire population at the last generation are plotted. Each point represents an individual run where the size reflects the average group size over the entire population. The red marker represents the starting probabilities of each agent.

Discussion The results show that different scenarios can occur as a result of the number of surviving groups. Some resulting in one group that is considerably larger than the others. Rather surprisingly, figure 5b suggests that tolerance is only beneficial in the early generations. This is not predicted by our hypothesis as we expected that a combination of both, thus being able to gossip in- and out-group, would be advantageous to other agents. However, this does not seem to be the case. Figure 4b and 4c show the average probabilities per group and provide a more elaborate look into the dynamics. They show a distinction between large and small groups. Where small groups rely mainly on a combination of pro-social and gossiping behaviour, large groups gain fitness through gossiping within their own community (figure 6). In real-life, this seems plausible as large groups provide safety and ample possibilities for reproduction. It seems as if the tolerance of agents from a larger group is masked in this way by its group size.

Different effects are observed when multiple groups grow larger, indicating that the adaptations of the main variables is subject to the number of groups that survive. This can be accounted for by the fact that in-group socializing can only account for a limited gain of information fitness. Hence, out-group socializing is especially favourable when the number of groups is large, but the number of group members is small. Figures 3a and 3b show such a situation where the development of both tolerance and a preference for gossiping is beneficial due to the selection pressures.

Finally, some groups die out even though they seem to have the right genetics to be thriving. being a high tolerance and gossip probability. Such a case can be visible in figure 3b and 3c where group one has a relatively high tolerance and low gossip probability. Even though evolution is not a goal, rather a result of selection pressures this seems to suggest that they have evolved 'too early' with regard to the rest of the population. For the development to be truly advantageous you need to be accepted by others too. This would imply that primates would have been required to develop in unconscious sync with their conspecifics.

4 Conclusion

We built a multi-agent model to investigate whether an increased tolerance can facilitate a preference for gossiping over grooming. Here agents engage in social events that are either in- or out-group and use one-to-one grooming or one-to-many gossiping. These two mechanisms are simplifications and prone to many abstractions. Similarly, the model is prone to many abstractions, however, a model like the one presented here can reveal mechanisms that can otherwise be missed or are not considered before. The current model revealed two such mechanisms; firstly, group size can play a role in the general preference for gossiping over grooming, and secondly, tolerance seems to be subject to the group size.

The first mechanism is similar to the finding to Slingerland et al. who found that agents from larger groups develop a high preference for gossiping over grooming. This finding is in line with Dunbar who suggests that gossiping has evolved to overcome the time problem of maintaining social bonds in larger societies (Dunbar, 1998).

For a group to survive it appears that the agents of that group need to be highly tolerant at the right moment in comparison to the remaining population. Nevertheless, adaptations can also be disadvantageous if they are asynchronous to the rest of a population. For example, a relatively high tolerance leads to taking risks in out-group socializing, that is likely to fail and is ultimately reflected in fitness. Subsequently, late adaptations lead to the discrepancy where, contrary to small groups, large groups are not interested in out-group socializing anymore. Hence, the smaller groups will suffer in terms of fitness and need to survive with their original preferences. Interestingly, when groups are large enough, some form of selective masking seems to occur as preferences start to change. Figure 5b and 6 show that out-group tolerance decreases in later generations, indicating that agents can deal with the selection pressures through socializing within their group. This reveals a new perspective on how tolerance might have evolved in humans, possibly being prone to the size of the societies they lived in. Contrary to the Human Self-Domestication hypothesis it shows that we do not need to assume that explicit sexual selection happened to get an effect that looks like selection for pro-sociality. It could also have been selection for individual social fitness that has nothing to do with some individuals choosing a pro-social feature in others.

The initialization of tolerance plays an important role in the course of the phenotypes. When initialized far below 0.5 it almost always decreases over the generations. This can be accounted for by the risks taken if one decides to socialize out-group. The chance of being rejected and losing your fitness gain is large. These findings suggest that for tolerance to have impact, the overall generation needs to be ready for it too. Further research is required, but this could implicate that a species as a whole need to have developed a minimal pro-social trait before it to be truly beneficial.

5 Future work

In future research several adaptations can be considered. First and foremost, the definition of a group should be built so that it reflects history between agents. Possibly also including maintenance of contacts. In this way groups are more variable and resemble real-life more closely. Additionally, instead of equal phenotype initialization for each group, it would be interesting to investigate different starting phenotypes for different groups. In doing so, it is possible to look at the response of agents to the selection pressures relative to the population.

Secondly, gossiping and observing should be relative to groups of the participating agents. The current implementation allows a gossiping event to be with agents from multiple groups. The same is true for observations, these can be done by any agent from any group in the population. Both do not reflect real-life and should become relative to the social event and context.

The model can also be extended by incorporating communicative, semantic and complex signals for interactions. Doing so leads to more complex interactions where they are not necessarily successful anymore. Agents would need to develop an abstract language, for example through cumulative learning, to overcome this problem. Subsequently, it is possible to investigate how the current phenotypes influence the development of language. Moreover, it could reveal effects such as relaxed selection on the development of language.

Lastly, primates tend to live in hierarchical groups where primates that have a high status receive more attention (Seyfarth, 1977). Such hierarchical dynamics could be added to the current implementation. It would be interesting to trace the course of phenotypes of dominant agents as maintaining social dominance could also become a pressure.

6 Code

The code that is created for this project can be found here and is publicly available and re-usable.

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