

A Multi-Agent Systems Approach to Gossip and the Evolution of Language

Inge Slingerland (i.slingerland@student.rug.nl)¹

Maurice Mulder (mmulder@ai.rug.nl)¹

Elske van der Vaart (e.e.van.der.vaart@rug.nl)^{1,2}

Rineke Verbrugge (l.c.verbrugge@rug.nl)¹

¹Artificial Intelligence, University of Groningen, P.O. Box 407
9700 AK Groningen, the Netherlands

²Theoretical Biology, University of Groningen, P.O. Box 14
9750 AA Haren, the Netherlands

Abstract

In his book *Grooming, Gossip and the Evolution of Language*, biologist Robin Dunbar (1997) proposes a new way of looking at the evolution of language. According to this view, language evolved to provide a new social bonding mechanism: Gossiping. This allows humans to live in larger groups than other primates, which increasing predation risks forced our ancestors to do. We use a computational multi-agent model to test the internal workings of this hypothesis, with interesting results. Our work provides a fundamentally new kind of evidence for Dunbar's theory, by experimentally demonstrating that greater group sizes can stimulate the evolution of language as a tool for social cohesion.

Keywords: Evolution; language; multi-agent systems.

Introduction

As humans, we spend a great deal of time talking to each other. Most of this time is also spent talking *about* each other: Approximately 65% of our conversations focus on social topics (Dunbar, 2004). Given the amount of time we spend on all this gossip, it seems it must serve an important function. According to Robin Dunbar's (1997) theory of the evolution of language, it does: Gossip, he claims, is what allows humans to maintain social coherence in very large groups, and the selective pressure to do so is what drove us to evolve language in the first place. According to this theory, before humans learned to gossip, something else must have kept our groups together. The likeliest candidate is the mechanism still employed by other primates: Grooming. This keeps individuals clean, but it also serves an important social function. The exchange of grooming allows group hierarchies to be established and maintained, alliances to be formed, and apologies to be made (Seyfarth, 1977). For other primates, then, grooming is a very effective form of social glue. The only problem is that for groups comprising many individuals, grooming becomes a very time-intensive way of maintaining social bonds. As group size increases, so does the time primates invest in grooming (Dunbar, 2004). This is because larger group sizes create more ecological competition, as local food sources are more quickly exhausted. This creates fights, which makes effective alliances more important. But the effectiveness of an alliance directly depends on the time the members of that alliance devote to grooming each other (Dunbar, 2004).

Of course, primates cannot groom all the time - they also need to eat and look for food. This means that there is an upper limit to the time that can be devoted to grooming, which, according to Dunbar (2004), is about 20% of an individual's waking hours. Consequently, there is a maximum group size in which it is possible to maintain sufficiently strong alliances by means of grooming. According to Dunbar (2004), this maximum group size is approximately 80 individuals. However, somewhere over the course of human history, increasing predation risks forced our ancestors to live in groups larger than that. Modern humans seem to have a natural group size of about 150, which is the typical size of most religious communities and military units (Dunbar, 1993). This figure is known as Dunbar's number, and also follows from his analysis of neocortex size (Dunbar, 1992). By looking at living primate groups, he has found a fixed relationship between the a primate species' neocortex size and its group size. Dunbar concludes from this that neocortex size determines how many social contacts one can maintain. By extrapolating this measured relationship to humans, the same maximum group size of 150 individuals appears (Dunbar, 1993).

However, like other primates, we only spend about 20% of our time on social activities (Dunbar, 2004). Therefore, our social bonding mechanism must be more effective than grooming is. Gossip, or talking about social topics, fits the bill. Like grooming, it is a social activity that allows us to display selective interest in other individuals, strengthening relationships. But it also has a number of advantages over grooming: It can involve more than two participants at once, and it allows individuals to exchange social information, so they can learn about events they did not see themselves (Dunbar, 2004). In short, gossiping makes maintaining of social bonds much more efficient. But gossip also has disadvantages, the primary one being that it is less intimate. The physical aspects of grooming release endorphins, and when people want to share deep feelings and emotions with each other, they tend to do it by touching, rather than talking (Dunbar, 2004). According to Dunbar's hypothesis, then, at some point in our evolutionary history, we traded much of the intimacy of grooming for the efficiency of gossip, which was necessary to allow our ancestors to live in larger groups. In essence, humans evolved language and large neocortices to be able to talk about each other.

In this paper, we present a new approach to Dunbar's theory by examining its assumptions in a computational multi-agent system. This methodology has already provided many new insights into related questions in cognitive science, and seems very suitable for investigating this particular hypothesis. In a multi-agent system, individual agents and their actions are explicitly simulated, so that the collective outcome of their behaviors can be analyzed. This offers a unique perspective on social and evolutionary processes, which can otherwise be difficult to break down into their component parts. Previous models of both primate social structure and the evolution of language have proven quite successful. Charlotte Hemelrijk's *DomWorld* (2002) simulation, for instance, closely replicates the dominance hierarchies of macaque species, while modeling work by Luc Steels and Tony Belpaeme (2005) demonstrates how shared communication may emerge across generations.

As far as we know, however, our work is the first attempt to evaluate Dunbar's hypothesis using this technique. By simulating populations of agents and their social interactions, we aim to investigate the fundamental trade-off between grooming and gossip. In our model, every time step, an agent can choose a social act to engage in. Grooming provides a higher social reward, but gossip can be shared among multiple agents, and allows them to exchange information about other social events. A single variable determines which action an agent is likely to choose, and this variable can evolve over time. Agents with higher fitness are preferentially reproduced, and this fitness depends on the social reward agents have collected, but also on their knowledge of other social events. We repeat this procedure for different group sizes, and examine which are most likely to evolve 'gossip' as their primary means of social interaction. In this way, we should be able to provide the first experimental support for Dunbar's hypothesis that larger group sizes can promote the evolution of language by virtue of its role as a social bonding mechanism.

Model

In this section a description of the model is given. The model is individual-oriented but not spatially explicit. It is likely that the coevolution of systems like a neo-cortex large enough to allow for theory of mind and a vocal tract to allow for accurate speech played a large role in the evolution of language (Dunbar, 1997; Hauser, Chomsky, & Fitch, 2002; Malle, 2002; Ritchie & Kirby, 2006), but these factors are not considered in our model. In contrast, we focus solely on the pressure that living in larger groups has on the trade-off between grooming and gossip.

Structure of the Simulation

In the model, populations of agents live in different group sizes. Per group size, a population of agents first socializes for a number of rounds, *nRounds*. In each round, social actions are randomly assigned to agents according to their *gossip probability*, their main variable. These social actions define the fitness of each agent in the population.

Every generation of agents then reproduces, after which the new generation socializes. This is repeated until the population has evolved for *nGenerations*. Both *nGenerations* and *nRounds* need to be large enough for a population to converge to the gossip probability maximizing its fitness. The parameter *nRounds* is arbitrarily set at 30 rounds, while *nGenerations* is set at 210 generations, approximately the number of generations it takes for the slowest evolving groups to maximize their fitness. Larger groups of agents evolve faster than smaller groups, due to the larger search space. To speed up evolution in group sizes smaller than 100, a population several times larger than the desired group size is divided into smaller groups of the desired size. Social actions between agents are confined to the smaller groups, while selection takes place over the entire population.

Agents

An agent in our model is composed of just two characteristics: A *gossip probability* and a *memory*.

An agent's gossip probability is the probability of that agent initiating a gossip event given that it has the opportunity to initiate a social event. Consequently, the grooming probability for an agent is complementary to its gossip probability. An agent's gossip probability is the only genetic material passed on to offspring and is evolved in this simulation to find the value that maximizes an agent's fitness for a particular group size.

An agent's memory contains a list of social events, added when the agent either participated in the event, witnessed it as an observer, or heard of it through gossip. The number of social events in an agent's memory directly contributes to its fitness, which will be explained in a later section.

Assigning Actions

In each round performed by a generation, a fraction of that group's agents are randomly drawn and allowed to initialize a social event by either *gossiping* or *grooming*. A round is over when all agents have either initiated grooming or gossiping with a number of other agents, or become engaged into a social event initiated by another agent, or been excluded from social interaction for this round because there are no potential partners left. If a randomly drawn value exceeds an agent's *gossip probability*, it will choose to groom; if it does not, the agent will gossip. At what value gossip probability is initiated has little influence on our results; only the speed of the evolutionary process is affected by it.

Grooming

When an agent chooses to groom, a single available partner is randomly drawn from the group of agents that this agent can socialize with in its lifetime. The resulting grooming event rewards both participants with an increase of their social fitness as a result of the bond that is forged or strengthened between them. In addition, the grooming event itself is added to their memory.

Gossip

When instead an agent chooses to gossip, between one and three partners are drawn from the group of agents that this agent can socialize with in its lifetime. This upper limit of four agents per conversation is inspired by the fact that four is thought to be the upper limit of individuals who can spontaneously interact within a conversation (Dunbar, Nettle, & Duncan, 1995). An effective gossip event, just like a grooming event, rewards all of its participants with an increase of their social fitness. This increase is smaller than that for grooming events because gossiping is less intimate than grooming. We have chosen for gossiping to be 80% as intimate as grooming. However, gossip also has an advantage over grooming, which is that gossiping agents can exchange information. During a gossiping event, one of the conversation's participants is randomly selected, and 10 of its memories are selected as gossip topics. These can be memories of any social event the agent is aware of, so it could have obtained its knowledge of them through participation, observation, or earlier gossip. Every agent that does not yet know about these 10 social events will then have them added to its memory. In addition, of course, every agent will remember the gossip event itself.

Observation

Every social event can be observed by other agents. Such *observation* is achieved by randomly selecting a number of agents and adding the social event to their memory. The basic model takes four observers for each social event. Any agent may observe an event, except for those engaged in it. Thus, in any one round, an agent can be directly involved in only one bout of grooming or gossiping, but can be an observer for any number of other social events.

Evolution

When a generation has gone through its social rounds, a new generation must be produced. Every agent is evaluated and assigned a fitness value. Selection is then done according to the *elitism* selection mechanism (De Jong, 1975): The top scoring 5% will have two children, the lowest 5% will have none, and the remaining agents will have one child in the following generation. Reproduction is asexual: An agent's offspring inherits its predecessor's gossip probability save for a possible mutation. For every reproduction there is a 1% chance of mutation occurring, deviating the new agent's gossip probability with 5% at most.

Fitness Function

In this model, fitness represents an agent's social aptness. A high fitness makes for an agent that functions well in a group. We distinguish between two types of fitness: A *social* part and an *information* part. Social fitness depends on the number of social events the agent has engaged in, and is considered to reflect the strength of its social bonds, and thus the likelihood that it can count on effective alliances.

Information fitness depends on the number of social events that the agent has in its memory, and thus the knowledge that it has about its social group. In real life, this might help an agent for instance by making it possible for the agent to identify coalitions between other agents and a rival, therewith knowing who would help either the agent or its rival if they were to fight each other. Neither high nor low fitness imply that the agent is either dominant or subordinate. Information about its social group and alliances with other agents will help an agent and increase its chances to reproduce, regardless of an agent's social status.

The precise contribution of an agent's social fitness, f_{social} , and its information fitness, $f_{information}$, to its total fitness, f , is shown in Equation 1. Fitness was chosen to be the *product* of social fitness and information fitness, because these two factors are represented on different scales but need to influence the total fitness equally.

$$f = f_{social} * f_{information} \quad (1)$$

Social Fitness In Equation 2, the evaluation of the social part is shown, where E_{groom} is the set of grooming events that the agent has taken part in, E_{gossip} is the set of gossip events the agent has been in, and p_x is the number of agents that have participated in event x . For grooming events, p_x is always two; for gossip events it lies between two and four. The contribution of each event to social bonds has been divided by the number of partners. The intimacy of a social event decreases with the number of participating agents, so it contributes less to friendships. Grooming events are also inherently more useful to the creation of bonds because of the physical aspect of grooming and the endorphins released. This is why the fitness value of grooming events is multiplied by 5, and that of gossip events only by 4.

$$f_{social} = 5 * \left(\sum_{x \in E_{groom}} \frac{1}{p_x - 1} \right) + 4 * \left(\sum_{x \in E_{gossip}} \frac{1}{p_x - 1} \right) \quad (2)$$

Information Fitness The information part is the *squared* number of memories an agent has gathered in its lifetime. The motivation behind this choice is that information becomes increasingly more useful when more of it is available: On the bases of the combination of more pieces of information, more new information can be deduced and more false possibilities can be eliminated. See Equation 3, where M is the number of events in the agent's memory.

In reality, information may at some point become increasingly redundant, as it will only confirm what was already predicted. This would result in a sigmoid curve instead of the polynomial curve used in the model. However, implementing this would make the model more complex than desired. Squaring information fitness was deemed a satisfactory approximation.

$$f_{information} = M^2 \quad (3)$$

Experiments

In the model described in the previous section, we capture the fundamental trade-off between grooming and gossip from the perspective of an individual agent. Grooming strongly reinforces its social bonds, while gossip is slightly less intimate, but provides social information. If the agents were real primates competing for dominance, strong bonds would help them form effective alliances, while social information would allow them to predict the likelihood of other alliances forming. Thus, both grooming and gossip contribute to reproductive success, if in slightly different ways. This is reflected in our model's fitness function, which rewards agents both for the strength of their social bonds and for the amount of social information that they have. Whether agents prefer to groom or gossip depends on their *gossip probability*, which can evolve over time. Now, to test Dunbar's hypothesis, the question is whether or not this basic setup will cause agents in larger group sizes to evolve to higher gossip probabilities than agents in lower group sizes. To investigate this, we run three experiments where we allow agents to evolve for n Generations, set to 200, in group sizes that range from 1 to 200.

Experiment 1

In Experiment 1, we start agents with gossip probabilities of 0, and record the average gossip probabilities of the last generations of agents at different group sizes.

Results The results of this Experiment can be seen in Figure 1. For each group size, five different runs are plotted. It shows a strong correlation between group size and gossip probability. A gradual increase of gossip probability is apparent, until a limit of about 0.7 is reached once group sizes pass 150 individuals. In other words, our model's basic assumptions clearly predict that individuals in larger groups are more likely to benefit from the ability to gossip.

Discussion In our model, the fact that larger group sizes cause agents to evolve higher gossip probabilities can be accounted for as follows: For gossip probability to increase, it needs to provide agents with higher fitness. Because the social payoff of gossip is structurally lower than the social payoff of grooming, the information payoff of gossip needs to be high enough to outweigh its social costs. For this to occur, agents need to acquire enough new information while gossiping. In smaller group sizes, this will be difficult, as the number of potential gossiping partners and topics is limited. Because of this, agents will tend to discuss the same topics repeatedly, and gain no fitness increases by participating in conversation. To illustrate this with an example: Any given social event is always experienced by at least six agents, directly or indirectly: Two participants, and four observers. In a group of ten agents, this means at least 60% of agents is aware of it; in a group of 160 agents, this drops to 3.75%. This means that gossip is virtually useless to agents in small group sizes, while it can bring considerable benefits to agents in large group sizes.

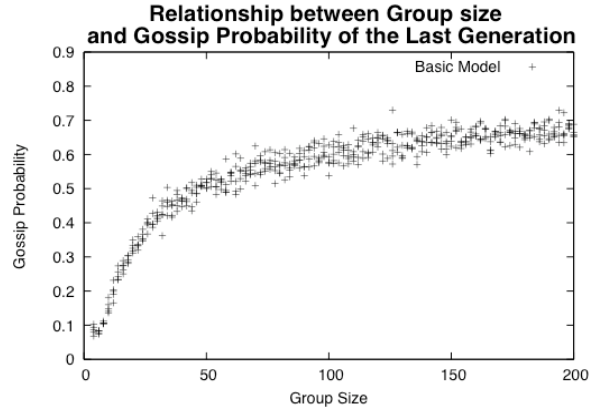


Figure 1: Gossip probability of the last generations of agents at different group sizes.

Experiment 2

In Experiment 2, we attempt to further investigate the relationship between gossip probability and group size by examining the evolutionary process across generations. To this end, we start agents in group sizes of 10, 50, 130, 150 and 190 with gossip probabilities of 0.5, and record their average gossip probabilities every generation.

Results The results of this Experiment are plotted in Figure 2, averaged over the outcomes of five different runs. It appears that converging to lower gossip probabilities is generally a faster process than converging to higher gossip probabilities; at group size 10, agents can lose 0.3 points of gossip probability in just 100 generations, while agents in group size 190 have only increased their gossip probability by half that amount. This suggests that, even without the additional challenge of evolving language in the first place, evolving gossip as a primary means of maintaining social cohesion is rather difficult, and may take many generations.

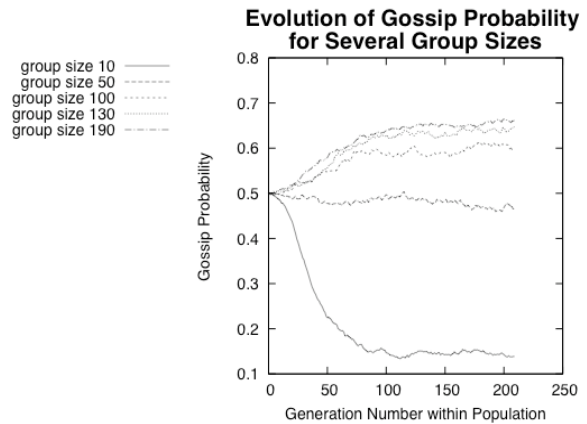


Figure 2: Evolution of gossip probability across generations, for five different group sizes.

Discussion The difference in evolutionary speed visible in Figure 2 can be explained by the uncertain benefits that gossip brings in our model, compared to the stable payoffs of grooming. When grooming, an agent's social gain is fixed, but when gossiping, an agent may learn little new information, either because its conversation partners have none, or because chance causes the gossip to concern information it already has. It is this unpredictability that slows the convergence to high optimal gossip probabilities.

Experiment 3

In Experiment 3, we look at the trade-off between grooming and gossip in more detail. Specifically, we are interested in whether or not gossiping agents have *relatively* more knowledge of the dynamics of their social group as compared to agents who cannot gossip. We do this by comparing our *basic model* against a *null model*, where agents can only groom, and gossip probabilities play no role. For the basic model, we start agents with gossip probabilities of 0.1, and for both models, we record the average percentage of social events that the last generations of agents at different group sizes know about.

Results In Figure 3, we plot a scaled information fitness value, which reflects the percentage of social events that agents are aware of. For both models, as group sizes get larger, scaled information fitness decreases. However, agents in the basic model clearly are relatively more informed about the social events occurring in their group than the agents in the null model are.

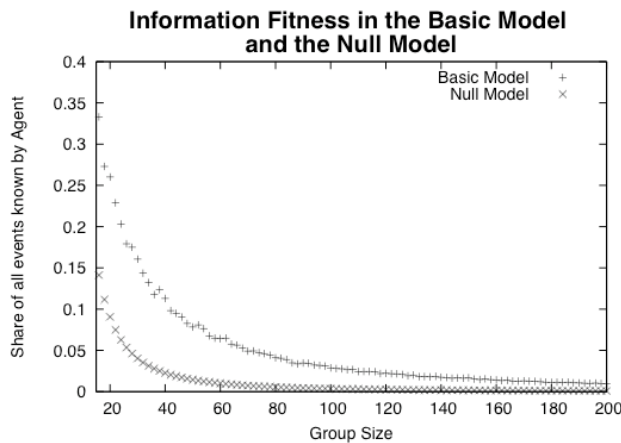


Figure 3: Average scaled information fitness at different group sizes, for the basic model and the null model.

Discussion In the null model, the fact that agents in larger group sizes are always relatively less informed, is perhaps not surprising: As group sizes get larger, the total number of social events increases, while the number of observers per event stays fixed. However, one might have expected gossiping agents to be able to compensate for this effect by exchanging information; this does not seem to be the case.

Robustness of Results

The results of Experiments 1, 2 and 3 are dependent on the model's parameters. Most of the model's parameters within their reasonable limits seem only to affect the speed of evolution, but one parameter does affect the results, namely the number of observers per event. An increase in the number of observers per event makes gossiping less necessary because agents can obtain a large part of the information needed to maximize fitness through observation. If the possible number of observers per event were as large as the group itself, there would be no need for gossiping at all: Every agent would be aware of each event, always. Because of this, agents in the null model have a greater fitness when there are more observers.

There is no consensus on the average number of primates that observes an event. This number depends on a multitude of environmental and social factors that are hard to estimate or observe and different for each population and species. To name a few of those factors: The density in which they live together, the likeliness of group members being obscured by foliage, possible protection of privacy by hiding when grooming or gossiping, and possibility of individuals to actively look for each other. The chosen number of observers in the basic model is four, which is our own estimation and is not based on empirical research.

To illustrate the influence of the number of observers, the model was run with different values for the number of observers. The results were as predicted: The more observers, the lower the final gossip probability. In this way the model indicates that the number of observers must be limited for gossiping to become favored over grooming at all. It should be noted that the number we are looking for is not the average number of agents to merely *see* a social event happening. Our model directly adds the social event to the memory of the observers. This means that an observer needs to be *interested* in a social event in which the agent itself is not involved. It needs to *recognize* what actually happens and which agents are involved, without misinterpreting. The number of such *effective observers* may well be significantly smaller than the average number of agents to merely *see* the social event. Thus, four observers may not be an implausibly low estimate after all.

To sum up, the model is quite robust, provided that the values of the parameters are kept within reasonable limits.

Further Work

In further research several additions could be made to the model to make it more realistic. Primates have a social hierarchy where special privileges are reserved for the most dominant. Dominant primates are groomed more often than they groom others (Seyfarth, 1977). Secondly, they are more closely watched by group members than nondominant primates are. One could imagine that also in gossip, dominant and subordinate agents are treated differently. Not only could dominance be relevant to partner choice for grooming and gossip sessions, it could also influence the choice of topics. In our model, partners and topics are

chosen at random. By implementing a social hierarchy one could model these social interactions with more detail and control. Results could provide insight in how well a social hierarchy can be maintained through grooming and gossip.

Another simplification made is that the basic model only takes the gossip probability of the initiator of the event into account, and not the preferences for grooming or gossiping of the randomly chosen partners. This is not biologically plausible: If a primate starts grooming another primate who would rather do something else, the action is likely to be terminated. The model can be extended by letting each initiator choose his partners. This way, agents can deduce preferences of other agents by looking in their own memory about the other agent's usual actions. In this extended model, the information fitness is even more important because agents need information, gained mainly by gossiping, in order to choose good partners.

Thirdly, the organization of social events could be modeled more realistically. At present, agents all get a number of rounds in which they either gossip or groom once. The fact that gossiping takes a smaller amount of time than grooming is represented in how many topics are discussed in a single conversation. This simplification assumes that gossiping agents keep gossiping within the same group for the same amount of time as a grooming event. However, by gossiping about fewer topics and in several different groups, agents may be more successful in increasing their information fitness, especially if they avoid talking about previously discussed topics. Implementing this change could prove troublesome. Agents might become socially isolated: Agents that were previously involved in a shorter lasting gossip event will in the next round only find potential partners that gossiped as well. This way smaller and smaller groups of agents that only socialize with each other will form with time. This can be avoided by instead treating time like a limited resource. Each agent is given a number of time points. Every time an event occurs, time points are subtracted from the participating agents so that all agents can participate equally. This way, events can still be organized as they are in our model without any asynchrony.

Conclusions

In this paper, we have described a multi-agent system, where social agents can choose to groom or gossip. From just two fundamental assumptions - namely, that grooming is the most effective way of strengthening social bonds, while gossip has the additional advantage of providing social information - we show that the ability to gossip becomes relatively more beneficial as group sizes become larger. Thus, we provide new support for Robin Dunbar's (1997) theory of the evolution of language. His hypothesis is that language evolved when increasing predation pressure forced humans to live in larger groups, requiring the invention of gossip to maintain social cohesion; our model provides the first experimental demonstration that greater group sizes can indeed favor gossip over grooming. In addition, we show that evolving towards gossip is slower

than evolving towards grooming, and that gossiping agents are always fundamentally more informed than grooming agents are, even in small group sizes. These results seem to be robust and are not drastically altered by most variables when they remain within a plausible range of values, with the exception of the number of observers per social event. This number will be physically limited in reality however, and although it is difficult to estimate, it will probably not drastically alter the model's outcomes.

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