The Effect of Gossip on Social Networks

Allison Shaw
Ecology & Evolutionary Biology Department
Princeton University
Princeton, NJ, USA
akshaw@princeton.edu

Chang Yu
Harbin Institute of Technology
Harbin, Heilongjiang, China
chang@hit.edu.cn

Dave Brooks
MITRE Corporation
McLean, VA, USA
dgbrooks@mitre.org

Milena Tsvetkova
Department of Sociology
Utrecht University
Utrecht, Netherlands
milena@uu.nl

Roozbeh Daneshvar
Department of Electrical Engineering
Texas A&M University
College Station, TX, USA
roozbeh@tamu.edu

***Abstract*—In this project we look at the effects of gossip spread on social network structure. We define gossip as information passed between two individuals A and B about an individual C who is not present, which has the potential to affect the strengths of all three relationships A-B, B-C, and A-C. This work is novel in two respects: first, there is no theoretical work on how network structure changes when information passing through a network has the potential to affect edges not in the direct path, and second while past studies have looked at how network structure affects gossip spread, there is no work done on how gossip spread affects network structure.**

***Index Terms*—Gossip, Social Networks, Network Dynamics**

I. INTRODUCTION

Gossip is ubiquitous in human groups and has even been argued to be fundamental to human society [1]. Gossip usually has negative connotations: generally, no one wants to be thought of as a *gossip*, and gossiping has traditionally been viewed as an indirect form of aggressiveness. However, gossip also seems to have a variety of benefits, including helping individuals learn the cultural rules of their group [2]. [1] even proposed that gossip is analogous to grooming in primates: it is essentially a tool to create and maintain relationships between individuals, with little importance given to the accuracy or quality of the actual information being passed.

Unlike rumors, which pertain to issues and events of public concern, gossip targets the behavior and life of a private individual. Gossip can essentially be defined as information passed from one individual (originator) to another (gossiper) about an absent third individual (victim) [3]. Therefore, any analysis of gossip must occur at the level of the triad or higher [4].

Closely related to the vast body of literature studying the spread of cultural fads, technological innovations or contagious disease (e.g. [5]), previous work has explored how social structure influences the flow of gossip and which network types best promote gossip [3]. Gossiping, however, could damage some relationships and strengthen others [4]. This suggests a flip side to the problem of the spread of gossip that has remained unaddressed. Hence, in this paper, we investigate how gossip affects the structure of the social network it flows through.

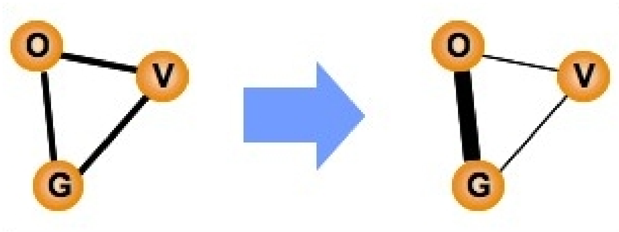

Fig. 1. Schematic for the effect of gossip on strengths of relationships of individuals in the triad. Individuals are represented as nodes and the strength of their relationship is represented by the thickness of the line between them. An originator (O) spreads gossip about a victim (V) to a mutual friend, the gossiper (G). The result is a stronger relationship between the originator and gossiper, and a weaker relationship between the victim and each the originator and the gossiper.

The process of an information flow molding a network has been previously studied in the context of Hebbian learning, where the simultaneous activation of neurons leads to an increase in the strength of their synaptic connection

To Roozbeh: Can you provide a ref here?

. A similar type of path reinforcement has also been observed in

sentence on ant trails by Allison?

. Both of the above models, however, concern modification of the network only along the flow's direct path. Our contribution is to reveal how information passed along one edge can affect the strengths of other edges in the network.

II. METHODS

We conducted simulations on a simple network model (built in NetLogo) to understand how the spread of gossip influences social network structure. Each simulation was run for 10,000 gossip events.

add a note about convergence

We ran simulations with 48 different parameter combinations (3 network types, 2 network sizes, 2 methods of victim choice, 2 methods of originator choice, 2 methods of changing connection strength) for 10 repetitions each, for a total of 480 simulation runs.

A. *Model*

To simulate a single gossip event on a network we first choose a victim of gossip as a random node in the network. We choose one of the victims neighbors as the originator of the gossip (Fig.2a). In the first wave of a gossip event, the gossip is spread to all the mutual neighbors, now gossipers, of the victim and originator (Fig.2b). Each of these new gossipers then spreads the gossip to their mutual friends with the victim, in subsequent waves (Fig.2c). This process continues until no new individuals become gossipers.

We assume that spreading gossip results in a stronger relationship between all gossipers, and a weakened relationship between the victim and all gossipers. Allowing link weights to take values between 0 and 1, we used two functions describing this effect:

- **normalized**: For increasing, $w_{n+1} \leftarrow w_n + \alpha(1 - w_n)$ and for decreasing, $w_{n+1} \leftarrow \beta w_n$ in which $\alpha < 1$ and $\beta < 1$. This method has hysteresis, i.e. an increase followed by a decrease does not necessarily lead to the initial value of strength.
- **quadratic**: For increasing, $w_{n+1} \leftarrow \sqrt{w_n}$ and for decreasing, $w_{n+1} \leftarrow w_n^2$. Other powers can be used for extensions.

All edges were initially set to have a strength of 0.5. Furthermore, those links whose weight dropped below 0.005 were severed.

Algorithm 1 Basic Model

```
for each gossip event do
    set all individuals as non-gossipers
    choose victim: pick a random individual
    choose originator: pick a random neighbor of victim
    set originator as a gossiper
    while $\exists$ mutual neighbors of the victim and a gossiper $\ni$ are non-gossipers do
        set all mutual neighbors of the victim and each gossiper as gossipers
    end while
    decrease the links between the victim and each gossiper
    increase the links between all pairs of gossipers
end for
```

To test if any results we saw were due to just strengthening and weakening connections between triads of nodes, we also ran simulations on a null-gossip network, where a single gossip event only occurred within a single triad of individuals. In other words, gossip was only allowed to spread from the originator to one other individual.

Algorithm 2 Null Model

```
for each gossip event do
    set all individuals as non-gossipers
    choose victim: pick a random individual
    choose originator: pick a random neighbor of victim
    set originator as a gossiper
    choose one random mutual neighbor of the victim and gossiper, and set as gossiper
    decrease the links between the victim and each gossiper
    increase the links between the pair of gossipers
end for
```

B. *Networks*

We conducted simulations on several network types to see if the effect of gossip varied with network structure. We used random, small-world, and spatially-clustered networks. We did not consider scale-free networks since these inherently have a branching form with no triads (ref), making them incompatible with our model of gossip.

why? Refs?

rewiring prob for small world?

For comparison we generated small (N=50) and large (N=200) networks that were sparsely (L=6) and densely (L=12), connected.

is L the right letter?

C. *Heterogeneity*

Also tried non-random victim choice – picked node with the most connections (since gossip hypothesized to level social playing field [6].

Algorithm 3 Victim-Choice = Degree-Random

```
for each gossip event do
    set all individuals as non-gossipers
    choose victim: pick a random individual, chosen based on degree – individuals with higher degree more likely to be picked
    choose originator: pick a random neighbor of victim, chosen completely randomly
    set originator as a gossiper
    while $\exists$ mutual neighbors of the victim and a gossiper $\ni$ are non-gossipers do
        set all mutual neighbors of the victim and each gossiper as gossipers
    end while
    decrease the links between the victim and each gossiper
    increase the links between all pairs of gossipers
end for
```

Tried non-random choice of originator weakest connection with victim, since expect that wouldnt pass gossip about close friends, benefit most by weakening already weak connection

ref

In the heterogeneity model, we add conformity behavior to nodes. Conformity behavior happens to everyone when a person pursues the fundamental sense of belongingness or social approval from groups. A person tends to follow the majority behavior in a group because he is eager to be admitted and accepted. Even it means to go against his original

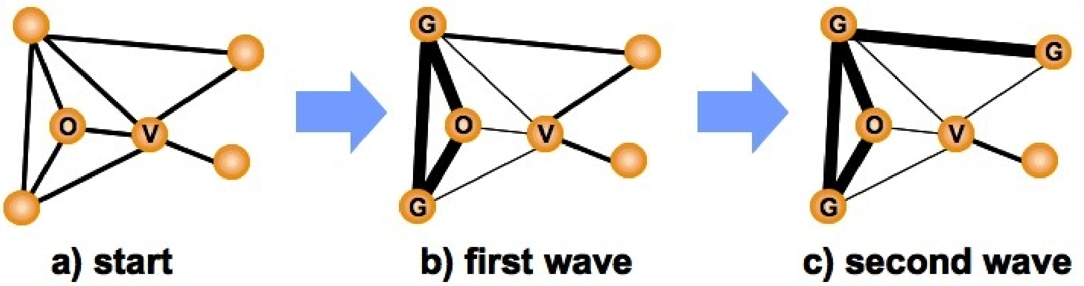

Fig. 2. Schematic for how gossip spreads in a social network. a) We randomly chose a node to be the victim (V) and one of its neighbors to be the originator of the gossip (O). b) the originator spreads the gossip to all mutual friends with the victim, strengthening connections between all gossipers and weakening all connections between the victim and gossipers. c) This process continues until no more individuals can become gossipers.

Algorithm 4 Originator-Choice = Weakest-Link

```
for each gossip event do
    set all individuals as non-gossipers
    choose victim: pick a random individual, chosen completely randomly
    choose originator: pick neighbor of victim with the weakest connection to victim
    set originator as a gossiper
    while ∃ mutual neighbors of the victim and a gossiper ∋ are non-gossipers do
        set all mutual neighbors of the victim and each gossiper as gossipers
    end while
    decrease the links between the victim and each gossiper
    increase the links between all pairs of gossipers
end for
```

perceptions. Study shows that individuals with a high need for social approval will distort their judgments of objectively determinable stimuli in response to perceived group pressure more frequently(Strickland, Bonnie R.; Crowne, Douglas P.1962). In this model, the probability of a node to become an originator depends on the Tendancy to Originate Gossip (which is a slider in the interface).

Also we consider how peer pressure from gossiping group pushes a node to be a gossiper. According to Solomon Asch, that social influences shape every person's practices, judgments and beliefs is a truism to which anyone will readily assent(Solomon Asch.1955). It means a node will join in the gossiping group to be a gossiper under the group pressure although he initially doesnt want to be.

D. Statistics

Looked at average node degree, average path length, clustering coefficient, degree distributions.

we didnt really use all these in the end – which stats were the most helpful?

III. ANALYSIS

A. Triads

For the simplest case, we assume that we have only three connected nodes. Without loss of generality, we assume that A gossips to B about C (see Fig.3).

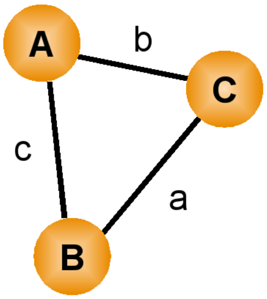

Fig. 3. A gossips to B about C

In this case, c is replaced with $c^{\frac{1}{2}}$, a is replaced with a^2 and b is replaced with b^2. After n steps of the same action, the new values are

$$a^{2n}, b^{2n}, c^{\frac{1}{2n}} \tag{1}$$

if the victim is chosen at random for each step, after n steps the new values are (assuming that n is large enough)

$$a^{2(\frac{2n}{3})\times\frac{1}{2}(\frac{n}{3})} = a^{\frac{2n^2}{9}}, b^{\frac{2n^2}{9}}, c^{\frac{2n^2}{9}} \tag{2}$$

which means that when the victims are chosen at random, with further steps, the strengths of the connections weaken (until all of them tend to zero).

We can also consider a case in which the probability of choosing a victim is related to the strengths of the links in triads. For instance, when originators have more tendency to strengthen their strong connections, they might gossip with a close friend about a common friend. For this case, we can write the probabilities $P(N)$ of gossips about node N as below

$$P(A) = \frac{a}{a+b+c}$$
$$P(B) = \frac{b}{a+b+c}$$
$$P(C) = \frac{c}{a+b+c}$$

We have basins of attraction in this state space. It means that when one link is stronger than the others, it has higher chance to become stronger during iterations. This has a positive feedback effect that leads to a very strong connection and two connections that are very weak. There is still a probability that a connection that is not the strongest, become strongest over time. This change is more probable when the strengths are close to each other. Without loss of generality, we assume that $a_0 > b_0 > c_0$ in a triad. In this case, the probability that connection between nodes A and C becomes stronger in one iteration is

$$\frac{b_0}{a_0 + b_0 + c_0}$$

This makes the new values of connections as follows

$$\begin{aligned} a_1 &= a_0^2 \\ b_1 &= b_0^{\frac{1}{2}} \\ c_1 &= c_0^2 \end{aligned}$$

Hence, for the next step, the probability of strengthening connection AC is

$$\frac{b_1}{a_1 + b_1 + c_1} = \frac{b_0^{\frac{1}{2}}}{a_0^2 + b_0^{\frac{1}{2}} + c_0^2} \tag{3}$$

and so the probability of choosing connection AC for n consecutive steps is

$$\prod_{i=0}^{n-1} \frac{b_i}{a_i + b_i + c_i} = \prod_{i=0}^{n-1} \frac{b_0^{\frac{1}{2i}}}{a_0^{2i} + b_0^{\frac{1}{2i}} + c_0^{2i}} \tag{4}$$

If $P_{0k} > P_{ik}$, then

$$\sum_{i=1}^{n} A_{0ik} > A_{0ik} + A_{i-1ik} + A_{ii+1k}$$

When this condition holds, node A_0 has a higher chance of being selected as the victim. For each time that node A_0 is selected, links L_{01k} to L_{0nk} weaken (with the mentioned configuration) and other connections strengthen. This means that

$$\begin{aligned} &\sum_{i=1}^{n}(A_{0ik+1}) - A_{0ik+1} - A_{i-1ik+1} - A_{ii+1k+1} \\ &\qquad < \sum_{i=1}^{n}(A_{0ik}) - A_{0ik} - A_{i-1ik} - A_{ii+1k} \end{aligned}$$

which shows that the difference has decreased and the total weights of A_0 is becoming closer to total link weights of A_i. It seems that for the mentioned configuration, gossip has a modifying effect (reducing the link strengths of the central node and increasing the strengths of links on the circle).

B. Star-Like Clusters

In a Star-Like formation, a node is in the middle and the surrounding nodes form a circle around it (Fig.4). We have assumed that the boundary nodes are also connected to their neighbors[1]. In this case, the total links is $n+n = 2n$ and hence the number of total ends is $4n$. When probability of choosing a node as the victim is proportional to the number of node friends, the probabilty of choosing node i as the victim (P_i) is

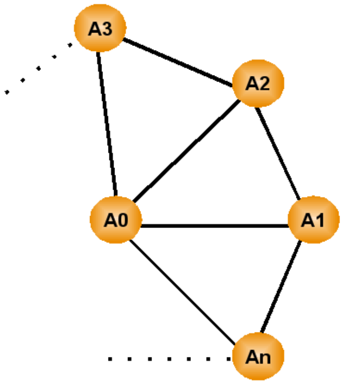

Fig. 4. A star-like cluster with a node in the middle and the rest of the nodes in a circular formation around the central node

$$P_i = \begin{cases} \frac{n}{4n} = \frac{1}{4}, & i = 0 \\ \\ \frac{3}{4n}, & i \neq 0 \end{cases} \tag{5}$$

for $n > 3$, the probability of choosing A_0 is higher than each of the other nodes (these are the non-trivial cases that we study).

When the gossip spreads in this case, if A_i is the originator and A_0 is the victim, A_{i+1} becomes another gossiper and hence there is a gossip wave to $A_{i+2}, A_{i+3}, ..., A_n, A_1, A_2, ..., A_{i-1}$. Hence, in this case, for each i (except 0) L_{0ik} decreases (L_{ijk} is the strength of the connection between nodes *i* and *j* at time *k*).

If choosing the victim is based on the strengths of the links, then

$$TotalWeights = \sum_{i=1}^{n} A_{0ik} + \sum_{i=1}^{n-1} A_{ii+1k} + A_{n1k} \tag{6}$$

so, the probability of choosing node i as the victim (P_i) is

$$P_i = \begin{cases} \dfrac{\sum\limits_{i=1}^{n} A_{0ik}}{\sum\limits_{i=1}^{n} A_{0ik} + \sum\limits_{i=1}^{n-1} A_{ii+1k} + A_{n1k}}, & i = 0 \\ \\ \dfrac{A_{0ik} + A_{i-1ik} + A_{ii+1k}}{\sum\limits_{i=1}^{n} A_{0ik} + \sum\limits_{i=1}^{n-1} A_{ii+1k} + A_{n1k}}, & i \neq 0 \end{cases} \tag{7}$$

C. Complete Clusters

In a complete cluster we have n nodes $A_1 - A_n$ and there is a link between each pair of the nodes. The total link weights of node A_i is $\sum_{j=1}^{n} L_{ijk}$ (assuming that $A_{iik} = 0$). If

---

[1] This is a simplified version, as except the central node, each node is connected to exactly three other nodes.

$$\sum_{j=1}^{n} L_{ijk} > \sum_{j=1}^{n} L_{ljk}$$

then node A_i has more probability than node A_l to become victim. So, considering the expected values regarding the probabilities, total link weights of A_i after change is[2]

$$\sum_{j=1}^{n} L_{ijk+1} = P_i \times NewValues + (1 - P_i) \times OldValues$$

Because of the dissipating effects of gossip on the victim, $NewValues < OldValues$. When P_i is small, $\sum_{j=1}^{n} L_{ijk+1}$ is close to $\sum_{j=1}^{n} L_{ijk}$ (as the second term, $(1 - P_i \times OldValues$, is dominant). But when P_i is a big enough number, $NewValues$ after being gossiped plays more role and decreases $\sum_{j=1}^{n} L_{ijk+1}$ compared to $\sum_{j=1}^{n} L_{ijk}$. This means that the proposed model of gossip moderates the network and brings the total weights of the nodes closer to each other.

IV. RESULTS

In our model, although gossip both weakens and strengthens links, weak links break but no new links are created. Hence, a priori, we expect that gossip will decrease the networks clustering and average node degree.

The negative effect of gossip on clustering is most extreme in the null model: when gossip does not spread but occurs randomly in triads, the simulations quickly converge to networks with zero clustering, regardless of the properties of the initial network, the link-change function or the rules for selecting a gossip victim and a gossip originator. Furthermore, triads are unstable also when gossip spreads in networks with small initial clustering. For example, the average clustering coefficient after convergence in all 160 runs with random networks is effectively zero (mean = 0.0048, std. dev. = 0.0076). These results confirm the analytical prediction that gossip breaks triads.

Nevertheless, in networks with sufficient initial clustering, the spread of gossip can have exactly the opposite effect it can make certain triads more stable. When gossip originates in and spreads throughout a dense cluster, it strengthens more ties than those that it weakens. For example, in a complete network of five agents, gossip weakens only four relations (between the victim and each of the gossipers), while it strengthens six (among all gossipers). Hence, although over the long run gossip destroys weakly triangulated links (i.e. *bridges*), it makes the links in dense clusters maximally strong. The result is a more fragmented and cliquish network (Figure 4).

When we account for initial clustering, the effect of gossip does not appear to differ among network types (Table 1). We only find that gossip tends to destroy links and weaken clustering to a lesser degree in large networks. Furthermore, when the gossip originator is the victims weakest link, average degree and clustering are lower compared to the case when the originator is randomly chosen from the victims links. This is so because, as elaborated in the analysis, under this rule weaker links become more likely to be severed.

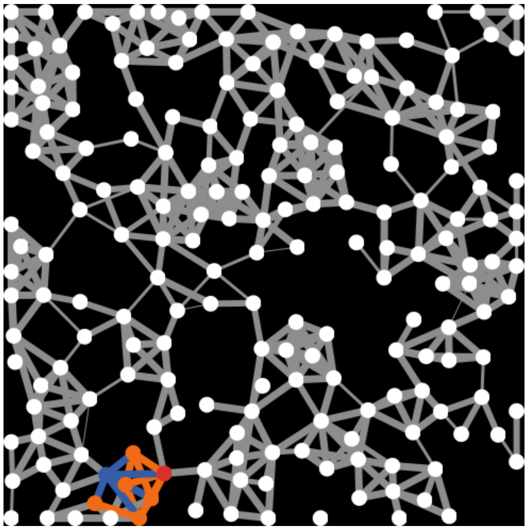

Fig. 5. View of the network after some iterations. Thicker links show stronger connections.

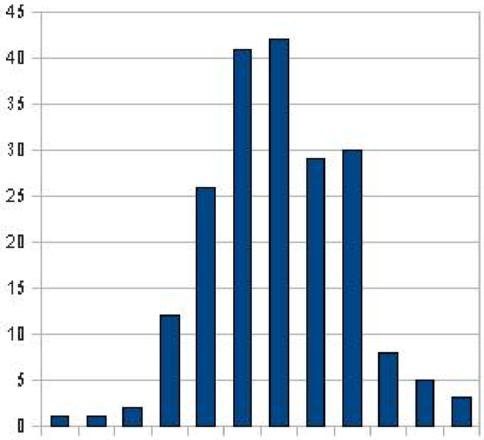

Fig. 6. Initial degree distribution of the nodes in the network.

V. DISCUSSION AND FUTURE DIRECTIONS

Simple:

- drop connections if they fall below a certain threshold
- in model2: have 'impact' of gossip change as you go down with each step away from original gossiper
- in model2: if A gossips to five secondary individuals (B1,B2,...) about C, does A-C increase 5x over?
- on-random node choice: pick nodes with respect to their overall connectedness (either picking strongly or weakly connected individuals more)
- on-random edge choice: stronger (or weaker) edges are more likely to have gossip passed along them

Alternative gossip rules are as follows:

- try positive (instead of negative) gossip: pick V-shaped connection (see figure), add B-C connection
- possibly strengthen A-B since gossip increases trust. Alternatively assume that if B shares with A positive

---

[2] This is disregarding the increase in value when A_i is selected by another originator to gossip.

TABLE I
LINEAR RREGRESSIONS OF FINAL NETWORK PROPERTIES ON SIMULATION PARAMETERS WITH STANDARD ERRORS ADAPTED FOR CLUSTERING WITHIN INITIAL CONDITION

	Clustering		**Average Node Degree**	
Variable	Coef.	Std. Err.	Coef.	Std. Err.
Large network	.0631**	.0167	.5085**	.0928
Quadratic effect	-.0699**	.0147	-.4006**	.0838
Spatially-clustered network	.0628	.0812	.6746	.4522
Small-world network	-.0698	.0499	-.3833	.2908
Victim: degree-central	.0081	.0147	.1131	.0841
Originator: weakest-link	-.0763**	.0147	-.4286**	.0843
Initial clustering	.8340**	.1539	-2.0728*	.8660
Constant	-.0221	.0242	5.5103**	.1241
R-squared	.9183		.7456	

* $p < 0.05$, ** $p < 0.001$
Number of observations = 480, Number of clusters = 48

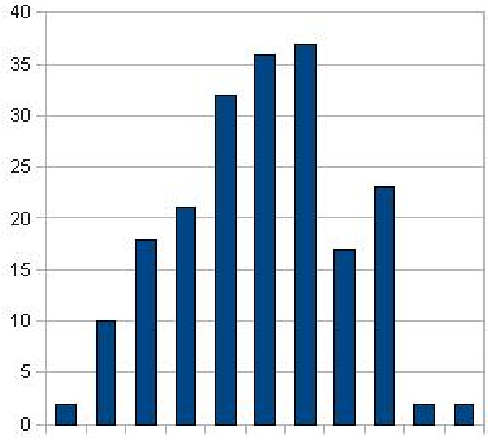

Fig. 7. Final degree distribution of the nodes in the network.

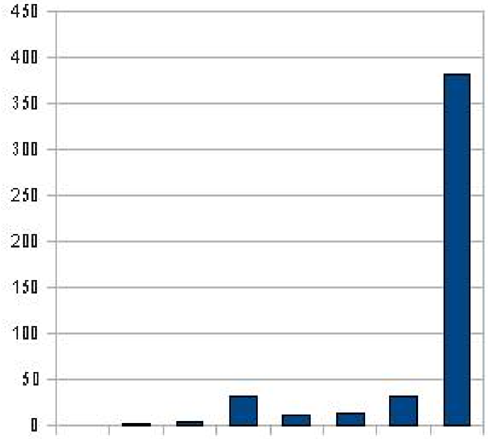

Fig. 8. Final link strength distribution in the network.

gossip about C, A diverts time from her relationship with B and starts hanging out with C, so weaken A-B instead.

- start from a sparse random network and see if we get a complete network?
- NOTE: is this a reasonable model for positive gossip? if nodes are only increased in strength, network will never converge...
- how do networks resulting from positive vs negative gossip differ?

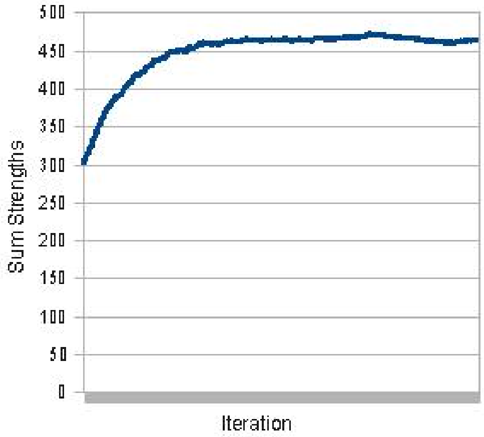

Fig. 9. Sum of strengths of connections in the network with iteration of the algorithm.

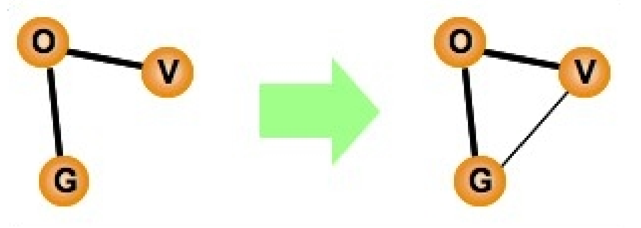

Fig. 10. Schematic for positive gossip (as opposed to negative gossip as depicted in Fig.1).

- (a priori expect that positive gossip will result in the network becoming more connected)
- combined gossip types: pass both positive and negative gossip through network, vary
- if A gossips to B about C: B weakens A-B and strengths B-C
- let all links (friendships) grow over time according to some function. gossip events change link location on curve (negative moves down, positive moves up).

Adding heterogeneity:

- individual variation: tendency to gossip, gossip target, impact of gossip
- individual behavior: individuals can choose to pass on the gossip, ignore it, or reject the gossiper and sever the

connection

- How do individual properties (e.g. range of social circle, poverty, wealth, the information itself, or geographic location) speed up or slow down the spread of gossip?
- Can individuals influence their location in a network (e.g. increase centrality) by changing their gossiping frequency?

VI. ACKNOWLEDGMENTS

We would like to appreciate Santa Fe Institute for giving the opportunity to work on this project. We would also like to appreciate Dr. Tom Carter for all his helpful comments.

REFERENCES

[1] Dunbar, “Gossip in evolutionary perspective,” *Review of General Psychology*, p. 100110, 2004.
[2] L. Z. Baumeister, RF and K. Vohs, “Gossip as cultural learning,” *Review of General Psychology*, pp. 111–121, 2004.
[3] L. R. d. S. J. S. A. J. Lind, Pedro G. and H. J. Herrmann, “Spreading gossip in social networks,” *Physical Review*, pp. 1–10, 2007.
[4] R. Wittek and R. Wielers, “Gossip in organizations,” *Computational & Mathematical Organization Theory*, p. 189204, 1998.
[5] P. S. Dodds and D. J. Watts, “Universal behavior in a generalized model of contagion,” *Physical Review Letters*, 2004.
[6] C. Boehm, “Hierarchy in the forest: The evolution of egalitarian behavior,” 1999.