Propagation of Innovations in Networked Groups

Winter A. Mason
Indiana University
1101 E. 10th St.
Bloomington, IN 47401
+1 (812) 856-1350
wimason@indiana.edu

Andy Jones
University of North Carolina
250 E Franklin St.
Chapel Hill, NC 27514
andjones@unc.edu

Robert L. Goldstone
Indiana University
1101 E. 10th St.
Bloomington, IN 47401
+1 (812) 855-4853
rgoldsto@indiana.edu

ABSTRACT
We examined how different network structures affect the propagation of information in laboratory-created groups. Participants made numerical guesses and received scores that were also made available to their neighbors in the network. The networks were compared on speed of discovery and convergence on the optimal solution. The results indicate that the optimal network structure depends on the amount of exploration required.

Categories and Subject Descriptors
H.1.1 [**Systems and Information Theory**]: Value of Information – *abstract data types, polymorphism, control structures.*

General Terms
Experimentation

Keywords
Social Networks, Information Dissemination, Group Problem Solving.

1. INTRODUCTION
Leavitt [1] was one of the first to study group performance in networks, noting that the communication structure of a group could aid or inhibit the ability of the group to find a solution to a problem. In the tasks they studied the group was working cooperatively on a problem. With innovations, however, each individual is trying to find their own best solution to a problem, and then subsequent individuals imitate good solutions.

The studies reported in this paper explore the diffusion of innovative ideas among a group of networked participants, each of whom is trying to individually find the best solution to a search problem. This provides a unique and novel method for studying the effect of network structure on group performance with respect to innovation diffusion in different formally defined problem spaces using actual human behavior.

2. OUR PARADIGM
Each problem consisted of 15 rounds in which participants guessed a number between 0 – 100 and received points based on a continuous function with added random noise. The participants also obtained information on their neighbors' guesses and outcomes. In this manner, participants could choose to imitate high-scoring guesses from their peers. The network structure for each problem was either full, lattice, small-world, or random.

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The random network had a number of edges equal to 1.3 times the number of nodes that connected randomly selected nodes under the constraint that a path exists between every node (i.e., that the graph is connected). The lattice network connected the participants in a ring with an additional 30% of the nodes connected to a neighbor two steps away. The small-world network connected the participants in a ring with an additional 30% of the nodes connected to a neighbor at least 3 nodes apart following the lattice path. The fully-connected network had all of the nodes connected to all other nodes. Therefore each participant had access to more information in the fully connected network than the other three networks.

3. PROBLEM SPACES
3.1 Unimodal

3.1.1 Method
Fifty-six groups of Indiana University undergraduate students ranging in size from 5 – 18 people with a median of 12 people per group participated for partial course credit, for a total of 679 participants. Five groups had to be dropped due to data logging error, but this did not affect the distribution of group sizes.

The unimodal function has a single best solution that could be found with a hill-climbing method. To compare performance of groups, we looked at the average time it took for a group member to guess within ½ standard deviation from the maximum, and percent of participants guessing within that range of the maximum over all 15 rounds.

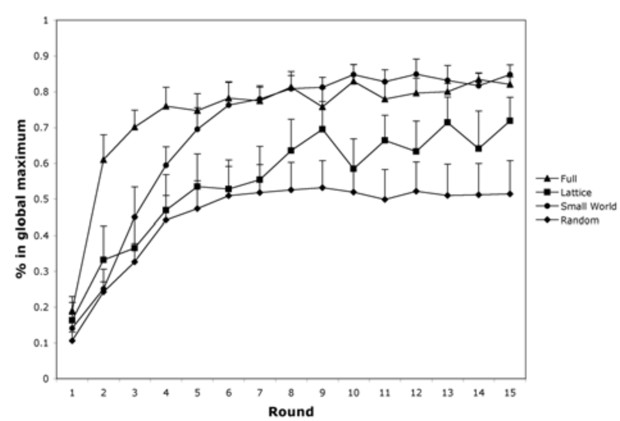

Figure 1. Percent guessing best solution to unimodal function over 15 rounds by graph type

3.1.2 Results
There was a significant difference between the network types in the speed of converegence, $F(3, 37) = 3.405$, $p < 0.05$. In the

fully-connected network participants on average took 2.95 rounds (SD = 0.93) to reach the maximum. The second fastest was the small-world network (M = 4.0, SD = 1.46), followed by the lattice network (M = 4.92, SD = 2.19) and the random network (M = 5.21, SD = 2.07). An analysis of the percent of participants in each group guessing within the global maximum over all 15 rounds showed a significant main effect for network type, $F(3,779) = 38.284$, $p < 0.001$. Averaged over all groups and rounds, the fully-connected networks had 73.31 percent of participants guessing in the maximum (SD = 20.94), compared to 68.78 (SD = 26.7) for the small-world network, 54.89 (SD = 29.53) for the lattice network, and 45.04 (SD = 35.29) for the random network (see Figure 1).

3.2 Multimodal

3.2.1 Method

The same groups that searched the unimodal problem spaces also searched the multimodal problem spaces. The multi-modal functions had three peaks, one of which was somewhat higher than the other two.

3.2.2 Results

In the multimodal landscape the average number of steps for the first person to reach the global maximum was less in the small-world network (M = 5.07, SD = 1.43) than even the fully-connected network (M = 6.12, SD = 2.09), and the main effect of network type was significant ($F(3,38) = 4.787$, $p < 0.01$). The small-world network also had the greatest convergence on the global maximum across all rounds (M = 0.519, SD = 0.27), again closely followed by the fully-connected network (M = 0.481, SD = 0.3), with the lattice (M = 0.341, SD = 0.3) and the random networks (M = 0.29, SD = 0.26) showing very little convergence on the global maximum. The differences between the networks were significant, $F(3, 794) = 28.239$, $p < 0.001$ (see Figure 2).

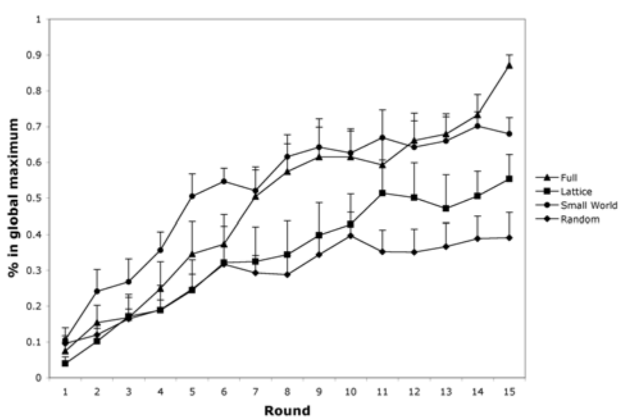

Figure 2. Percent guessing best solution to multimodal function over 15 rounds by graph type

3.3 Needle

3.3.1 Method

Forty-eight groups of Indiana University undergraduate students ranging in size from 7 – 19 people with a median of 12.5 people per group participated for partial course credit, for a total of 628 participants. In some cases the best solution is harder to find than other solutions. To examine this situation, we created a bimodal payout function with one wide local maximum and one thin, hard-to-find global maximum.

3.3.2 Results

There were no significant differences in the average number of steps it took for a participant to guess near the global maximum. Nonetheless, the average fraction of participants in the global maximum over all rounds was significantly higher with the lattice network (M = 0.241, SD = 0.346) than the other three network structures (Full = 0.155 (0.267); Small-world = 0.118 (0.203); Random = 0.114 (0.243), $F(3,704) = 8.027$, $p < 0.005$.

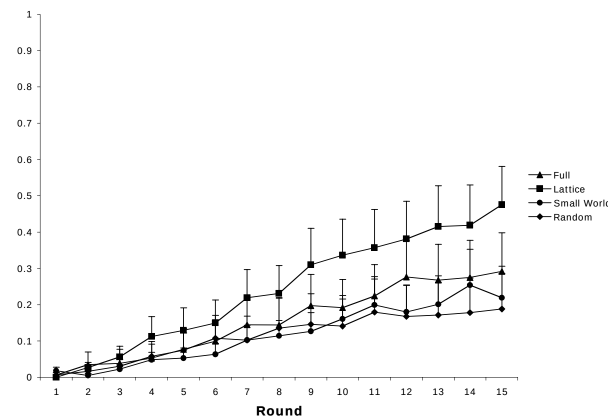

Figure 3. Percent guessing best solution to needle function over 15 rounds by graph type

4. DISCUSSION

Past research on the benefits of network structure on the flow of information has often focused on the positive properties of small-world networks [2, 3]. The results of our research cast this view in the wider perspective of fit between network structure and problem space, highlighting the importance of exploration vs. imitation. For the network structures we studied, the lattice promotes the most exploration, followed by the small-world, and the random networks, with the fully connected network producing the least exploration. The needle payout function requires the most exploration to find the global maximum, followed by the multimodal, and then the unimodal. Since there is a tradeoff between the exploration of a problem space and the exploitation of good solutions [4, 5] this tradeoff seems to be highly relevant to the ability of a group to succeed at our task.

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6. REFERENCES

[1] Leavitt, H. J. Some effects of certain communication patterns on group performance. Journal of Abnormal Psychology, 46, (1951), 38-50.

[2] Kleinberg, J. Navigation in a small world. Nature, 406, (2000), 845.

[3] Watts, D. J., & Strogatz, S. H. Collective dynamics of “small-world” networks. Nature, 393, (1998), 440-442.

[4] March, J. G. Exploration and exploitation in organizational learning. Organization Science, 2, (1991), 71-87.

[5] Holland, J. H. Adaptation in Natural and Artificial Systems. Ann Arbor: University of Michigan, 1975.