# A Computational Model of Collective Sensemaking: Differential Effects of Communication Network Structure on Collective Sensemaking Abilities

**Paul R. Smart (ps02v@ecs.soton.ac.uk)**
School of Electronics and Computer Science, University of Southampton,
Southampton, SO17 1BJ, UK

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## Introduction

Collective sensemaking is a form of socially-distributed cognition (see Hutchins, 1995) in which multiple agents attempt to interpret (make sense of) specific bodies of environmental information. In order to optimize performance at the collective level, agents often need to share information about the results of their own processing activity, and this raises questions about how the structure of communication networks affects collective sensemaking abilities. In the current study, we used a computational model of collective sensemaking in which individual agents were implemented as constraint satisfaction networks (CSNs) (see Smart & Shadbolt, 2012). We then investigated how the cognitive responses of agents were affected by different kinds of communication network structure.

## Method

In order to explore the effect of communication network structure on the dynamics of collective sensemaking, we used a multi-agent computational model in which individual agents were implemented as CSNs. The computational architecture of the CSNs is the same as that described in Smart and Shadbolt (2012). Each agent consisted of 6 cognitive units, which reflected the various kinds of beliefs that agents could have about two types of object, namely cats and birds. The net activation of each cognitive unit represented the extent to which an agent held a specific belief about an object. Thus, if the net activation of the 'Cat' unit was high then the agent could be said to hold the belief represented by the 'Cat' cognitive unit. The cognitive units were connected together in such a way as to yield two kinds of interpretive response to environmental information. On the one hand, agents could interpret environmental information as indicating the presence of a cat, and, on the other hand, they could interpret environmental information as indicating the presence of a bird. Across the course of each simulation, one of these cognitive responses tended to predominate due to the pattern of excitatory and inhibitory links between cognitive units. The way in which the activation of each cognitive unit was updated at each processing cycle is described in Smart and Shadbolt (2012).

Each of the agents within the computational model can be connected to other agents in order to create a communication network. Agents can share information about their beliefs at each cycle of a simulation in order to influence the kinds of beliefs that their network neighbors have at the next processing cycle. The way in which the information is shared and processed by agents is described in Smart and Shadbolt (2012).

The current study examined the effect of four types of communication network structure on collective sensemaking. In the 'Disconnected Network' condition, all agents operated autonomously and no communication was allowed between the agents at any stage of the simulation. In the 'Random Network' condition, agents were connected together using a random network topology. The random networks, in this case, were generated following the procedure described in Mason, Jones, and Goldstone (2005). Bidirectional links between agents were added at random until a specific number of links (i.e. 1.3 times the number of agents) had been created (given that all our simulations involved 10 agents, the number of links added to random network configurations was (1.3 * 10 =) 13 links). In the 'Small-World Network' condition, agents were connected together using a small-world network topology. As with random networks, small-world networks were generated using the procedure described in Mason et al. (2005). Agents were initially connected into a ring structure. Three agents were then selected at random and each of these randomly selected agents was connected to another randomly selected agent subject to the constraint that connected agents were at least 3 agents apart in the ring topology. Finally, in the case of the 'Fully-Connected Network' condition, all agents were connected to all other agents using a fully-connected network topology.

Each simulation started with the creation and configuration of CSNs corresponding to individual agents. Ten agents were created for every simulation, and all agents were identical to one another in terms of their constituent architecture. Agents were then organized into one of four types of network structure as described above. It should be noted that a new network structure was created for each simulation, thus the structure of some networks (namely, the random and small-world networks) was not invariant across the experimental conditions.

Table 1: Activation vectors used in the experiment.

| | Fur | Meows | Cat | Feathers | Tweets | Bird |
|---|---|---|---|---|---|---|
| Ambiguous | 0.1 | 0.1 | 0.0 | 0.2 | 0.2 | 0.0 |
| Unambiguous | 0.5 | 0.5 | 0.0 | 0.0 | 0.0 | 0.0 |

Once the network structure had been created, the activation levels of cognitive units within each agent were initialized using one of two types of activation vector (see Table 1).

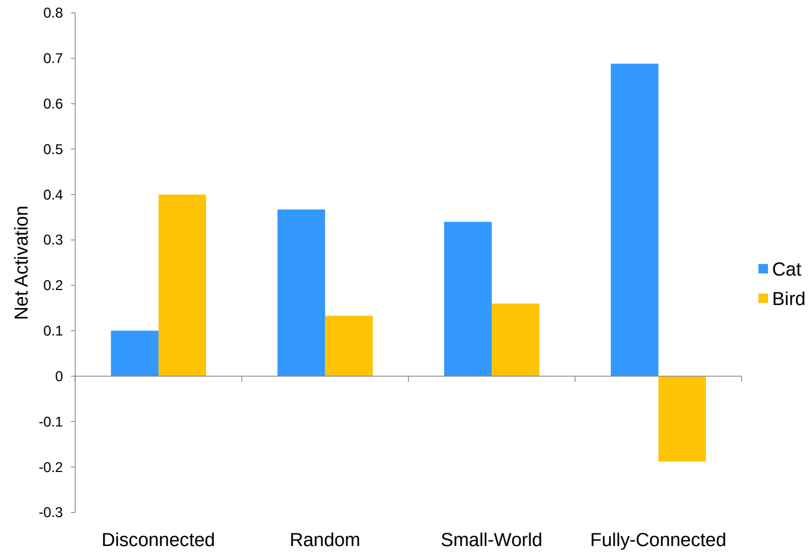


Figure 1: Mean responses of 'Cat' and 'Bird' cognitive units in each of the four network structure conditions.

At the start of each simulation, 4 agents were selected at random and were initialized with the 'Unambiguous' activation vector; the remainder of the agents were initialized with the 'Ambiguous' activation vector.

After the initial activation levels had been established, the simulation commenced and processing occurred in a series of processing cycles. Within each cycle, the activation of all cognitive units was updated as per the procedure described in Smart and Shadbolt (2012). The simulation continued for 20 processing cycles, and, at the end of each simulation (i.e. at the 20th processing cycle), the activation level of the 'Cat' and 'Bird' cognitive units was recorded for subsequent analysis. A total of 50 simulations were run in each of the four network structure conditions.

## Results

The results are shown in Figure 1. ANOVA revealed a significant main effect of Cognitive Unit (i.e. activation of the 'Cat' and 'Bird' cognitive units) ($F_{(1,1996)} = 60.723$, $P < 0.001$) and a significant two-way interaction between the Network Structure and Cognitive Unit factors ($F_{(3,1996)} = 57.780$, $P < 0.001$). There was no significant main effect of Network Structure (using a conservative alpha criterion of 0.01). Post hoc comparisons using Tukey's HSD test were performed at each level of the Cognitive Unit factor. These analyses revealed that cognitive responses in the random and small-world network conditions were not significantly different from each other for either of the 'Bird' or 'Cat' cognitive units. The activation level of the 'Cat' cognitive unit was higher in both the random and small-world network conditions as compared to the disconnected network condition, and the activation of the 'Bird' cognitive unit was lower in the random and small-world network conditions as compared to the disconnected network condition. Activation of the 'Cat' cognitive unit was higher in the fully-connected network as compared to all other networks, and activation of the 'Bird' unit was lower in the fully-connected network as compared to all other networks. Post hoc comparisons of the cognitive responses for each of the network structures revealed significant differences between the activation of 'Cat' and 'Bird' cognitive units for all network conditions. Activation of the 'Cat' cognitive unit was higher than 'Bird' cognitive units for all networks, with the exception of disconnected networks (see Figure 1).

## Conclusion

The results of this study suggest that collective sensemaking is influenced by network structure under certain informational conditions. In all of the conditions in which agents were allowed to communicate information, a particular kind of cognitive response emerged in which cat-related beliefs predominated. This differed from the situation in which agents were not allowed to communicate (i.e. the disconnected network condition). The cognitive responses of agents that were organized into random and small-world network topologies were very similar; however, they were less extreme than those of agents organized into fully-connected network topologies.

## References

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