Collective Sensemaking and Military Coalitions

Paul R. Smart (University of Southampton)
Katia P. Sycara (Carnegie Mellon University)

Abstract
Sensemaking is a key capability for military coalitions, enabling both individuals and teams to make sense of conflicting, ambiguous and uncertain information. Many features of the military coalition environment are likely to exert an effect on sensemaking capabilities; however, at the present time, we have little understanding of the precise nature of these relationships. Computational modelling provides one means of improving our understanding in this area. By developing models that enable us to explore the effect of factors such as network topology, cognitive heterogeneity, miscommunication and inter-agent trust on the dynamics of both individual and collective sensemaking, we may be able to better understand how specific features of the coalition communication environment affect the dynamics of collective sensemaking. The current paper reviews work in the US/UK International technology Alliance that aims to develop computational models of collective sensemaking in military coalition contexts.

Introduction
It is part of the nature of military operations that information is often incomplete, uncertain, ambiguous, conflicting, and inaccurate – the ‘fog of war’ always works to confound attempts at a complete understanding of the battlefield. Sensemaking is the process that is undertaken to deal with the fog of war. It is the attempt by individuals and teams to develop an understanding against which decisions can be made and plans for action formulated.

The importance of sensemaking to contemporary military organizations is reflected in the fact that sensemaking sits at the heart of the vision of network-centric operations (NCO). According to the NCO Conceptual Framework (NCO-CF), for example, sensemaking at both the individual and collective levels has a direct impact on decision synchronization, force agility and mission effectiveness [1]. In particular, sensemaking is seen as an intervening variable in the NCO value chain: it enables military organizations to capitalize on the progress made with respect to networking technology and improved information sharing capabilities [1]. In light of this, it is perhaps not surprising that sensemaking is a major focal point for current research and development efforts. The IARPA-funded Integrated Cognitive-Neuroscience Architectures for Understanding Sensemaking (ICArUS) program, for example, seeks to shed light on the neurocognitive processes associated with sensemaking abilities, while the joint US/UK International Technology Alliance (ITA) program aims to investigate the impact of military coalition communication environments on the dynamics of collective sensemaking processes.

Sensemaking is, at heart, a cognitive activity: it is an activity that involves the processing of information in order to yield an outcome (i.e., understanding) that is recognizably cognitive in nature. This does not mean that sensemaking is an activity that only individuals engage in. There is a growing appreciation of the prevalence and importance of what might be called ‘collective sensemaking’; i.e., the activities that are performed by groups of individuals in order to develop understanding at both the individual and
collective level [2]. This extension of sensemaking into the social domain is something that is explicitly recognized by the NCO-CF. Within the NCO-CF, collective (or shared) sensemaking is seen as the collective counterpart of individual sensemaking, which is strongly influenced by social interaction and social networks [1]. The notion of collective sensemaking is particularly important in military coalition contexts because coalition environments present significant challenges to the development of shared understanding. Unless a coalition organization is able to deal effectively with these challenges, it will not be able to press maximal benefit from the technological and informational resources it has at its disposal.

In addition to being a cognitive activity that is relevant to military coalition operations, sensemaking is also a process in which knowledge plays a critical role. Sensemaking is a process that takes place against a backdrop of knowledge and experience in a particular domain, and differences in knowledge and experience are often a key factor in discriminating between the performance of expert and novice sensemakers [3]. In particular, expert sensemakers do not seem to rely on any radically different processes to make sense of information; what seems to count is better access to domain-relevant knowledge [3]. This highlights the importance of knowledge to sensemaking performance, and it suggests that a consideration of knowledge should be at the heart of our attempts to both understand and improve sensemaking processes.

The current paper describes an approach to exploring the impact of coalition environments on collective sensemaking performance. We first describe why it is important to undertake empirical research into sensemaking in coalition settings, and we then present a computational model of collective sensemaking that is being developed within the context of the ITA research program. The results obtained with the model indicate how features of the coalition communication environment might affect sensemaking processes.

**Military Coalition Environments and Collective Sensemaking**

Given the centrality of sensemaking processes to military coalitions, it is important that we develop a thorough understanding of the effect that specific features of the coalition communication environment have on sensemaking processes. Coalitions exist as complex socio-technical organizations in which a variety of factors, subtending the information, cognitive, social and technological domains, may be expected to exert an influence on collective cognitive outcomes. At the present time, however, we have little understanding of how these factors affect collective cognitive processes. This lack of understanding makes it difficult to test the hypotheses and assumptions associated with the vision of network-centric warfare (or network-enabled capability). The NCO-CF, for example, suggests that better networking, interoperability and information sharing capabilities are likely to improve collective sensemaking abilities [1]. This claim certainly has an intuitive appeal, but it is not always clear that greater levels of networking and information sharing do always yield the better cognitive outcomes. In the social psychology literature, for example, we encounter the phenomenon of production blocking [4], which is the tendency for the contributions of one individual to block or inhibit contributions from other group members. It thus seems that, at least in some situations, the tendency to share information can undermine the collective creative potential of a group of agents; instead of stimulating a greater
number and diversity of ideas, precipitant forms of information sharing can sometimes impede rather than improve the creative process.

A poor understanding of how collective sensemaking is affected by the features of coalition communication environments also makes it hard to know how to engineer coalition environments in ways that benefit sensemaking abilities. This does not just apply to the technological aspects of a military coalition, it also applies to the social aspects as well. For example, military coalitions are constituted by individuals from a variety of nation states and military services, and this means that military coalitions are in a position to benefit from the diverse knowledge, training and expertise that individuals bring to shared tasks. However, when it comes to collective cognitive processes, it is not always clear that cognitive diversity is always a virtue. On the one hand, there is evidence to suggest that cognitive heterogeneity is useful in terms of mitigating against the cognitive biases (e.g., confirmation bias) that are sometimes associated with collective sensemaking [5]. On the other hand, a team comprised of individuals with different background knowledge and beliefs may present challenges in terms of miscommunication due to linguistic and cultural differences [6]. The question thus arises as to how collective sensemaking activities should be organized at the social level. Should sensemaking teams be formed based on a principle of maximizing or minimizing the cognitive diversity of the constituent team members?

Issues of homogeneity and diversity are also important when it comes to a consideration of technology development and use within military coalitions. Typically, the tendency of different nation states or military services to adopt different approaches to the representation and storage of information is seen as a barrier to inter-operability and collaboration. This means that the use of standardized representational formats as well as the use of common search, retrieval and storage solutions seems like an ideal means by which cognitively-empowering forms of collaboration and engagement can be established. The downside of this sort of standardization, however, is that we potentially lose any diversity in the way information is indexed, retrieved, and presented. This risks exposing all individuals to the same information in the same way, which might impact a team’s ability to generate novel ideas and interpretations.

In general, efforts to press maximal cognitive benefit from a coalition’s technological and informational assets need to be grounded in an understanding of how the various features of the coalition communication environment affect collective cognitive processes. These features are many and varied. They include, for example, trust relationships, communication network topologies, the timing and frequency of inter-agent communication, the extent of information sharing, differential access to specific bodies of information, the presence of cognitive diversity and the potential for miscommunication. Research is needed to assess how these factors affect the dynamics of sensemaking processes and the quality of sensemaking outcomes.

**A Constraint Satisfaction Model of Collective Sensemaking**

Typically, research into collective cognition has been undertaken using two very different approaches. Firstly, social psychological research has tended to focus on small groups of human individuals who are observed in a particular task context. The advantage of this approach is that it uses real human subjects
Recent work in our laboratories has sought to develop a psychologically-interesting computational model of collective sensemaking that is intended to further our understanding of the effect that specific features of coalition communication environments have on collective sensemaking [7, 8]. The model adopts a network-of-networks approach to cognitive simulation in which each agent is implemented as a constraint satisfaction network (CSNs), and multiple instances of these networks are connected together to form an inter-agent communication network. The decision to use CSNs as the basis for individual sensemaking abilities is based on a number of considerations. Firstly, we suggest that sensemaking can be usefully cast as a form of constraint satisfaction problem. In particular, we suggest that in making sense of information, agents are often required to use background domain knowledge in order to form beliefs that are highly consistent or compatible with one another. This is important because CSNs have been used to model psychological processes in which issues of coherence and consistency play a major role. As an example, CSNs have been used to study the phenomenon of cognitive dissonance in which the process of cognitive change (e.g., belief modification) is driven by a need for consistency or compatibility between cognitive states [9].

A second reason why CSNs are attractive as a model of sensemaking processes is that they provide opportunities to study the role of knowledge in guiding sensemaking performance. In particular, each node within the CSNs in our model corresponds to a particular belief that may be held by an agent. These nodes are referred to as cognitive units. The cognitive units are connected together using either excitatory or inhibitory connections, and each of these ‘inter-cognition’ linkages is associated with a weighting value. The pattern of connections between the cognitive units represents an agent’s background knowledge or experience in a particular domain. For instance, the CSN shown in Figure 1 consists of 6 cognitive units, each of which represents beliefs about two types of animals, namely cats and birds. The cognitive units in this network are connected together in such a way as to reflect the natural association of particular features with particular objects. Thus, the ‘has-feathers’, ‘tweets’ and ‘bird’ units are all connected to one another with excitatory connections. This organization is intended to reflect an agent’s (admittedly limited) knowledge about cat and bird objects. If one of the units is
artificially stimulated (a situation we consider as analogous to the presentation of specific kinds of evidence), then the activation of units that have positive connections to that unit will be increased across successive processing cycles. The end result is that agents settle on belief states that are most consistent with the evidence made available to them, as well as their background knowledge of the domain in question. If we artificially stimulate the ‘has-feathers’ unit, for example, then the activity of the ‘bird’ and ‘tweets’ units will increase, while that of the ‘cat’, ‘has-fur’ and ‘meows’ units will decrease. This reflects the agent’s belief that the unidentified object is a bird, which seems a perfectly sensible interpretation of the available evidence, given the agent’s background knowledge of the domain.

![Figure 1. Example constraint satisfaction network representing beliefs about two kinds of objects: cats and birds. Solid lines symbolize excitatory connections between the units, while broken lines symbolize inhibitory links. Circles represent cognitive units. Shaded circles represent beliefs about the features of objects (feature beliefs), while plain circles represent beliefs about object type (object beliefs).](image)

A third reason to countenance the use of CSNs centres on previous uses of such networks to explore the dynamics of collective sensemaking. In particular, Hutchins [10] has used CSNs to examine the psychological phenomenon of confirmation bias; i.e., the tendency to ignore or discount evidence that contradicts some initial interpretation of a situation. Using CSNs, Hutchins was able to show that the timing of inter-agent communication exerts a significant influence on the dynamics of collective sensemaking. In particular, if the individual agents were allowed to communicate with one another from the outset of a simulation, then extreme levels of confirmation bias arose. This occurred because each agent, under the influence of information provided by other agents in the social network, was under pressure to discover a shared interpretation of the input data. In other words, the community of agents strove to find a set of activation patterns that best satisfied the internal constraints established by inter-agent communication. The result was that agents often failed to give due weight to the evidence provided by external input data, and thus, more often than not, the community of agents tended to exhibit more extreme forms of confirmation bias than was the case with isolated individuals.
The Effect of Communication Network Structure on Sensemaking Performance

By using CSNs to model sensemaking processes, we have been able to explore the effect that different features of the military coalition communication environment might have on collective sensemaking performance. In one study, we sought to examine the role of different communication network structures in mediating minority influence under a variety of informational conditions; for example, a condition where a minority of agents receives strong evidence in favour of one interpretation, while a majority of agents receives weak evidence in favour of a conflicting interpretation. These simulations were performed using a particular form of CSN, namely one used to study the psychological phenomenon of cognitive dissonance [9]. The CSNs (each representing an individual sensemaking agent) were configured as is indicated in Figure 1, with 6 cognitive units representing beliefs about cats and birds. In each simulation, 20 agents were created, and these agents were then connected together to form various types of communication network (full details of the model architecture and activation update equations are presented in Smart and Shadbolt [7]). At the beginning of each simulation, 5 agents were selected at random and assigned to a ‘Minority’ group, while the remaining (15) agents were assigned to a ‘Majority’ group. The agents in each group were then initialized with activation vectors that established the initial activation levels of cognitive units within the agent. In the case of minority group members, the activation of the ‘has-fur’ unit was set at 0.5, while the activation of all other units was set at 0.0. In the case of the majority group members, the activation of the ‘has-feathers’ unit was set at 0.1, and all other units were again set of 0.0. Since the initial activation of cognitive units is deemed to represent an agent’s beliefs at the outset of the simulation (reflecting, perhaps, exposure to different kinds of evidence), we can see that agents in the two groups had different beliefs about the features of the object they were presented with. Over the course of successive processing cycles, we would expect these two initial belief states to give rise to different interpretations of the object type. Agents in the two groups also differed with respect to the levels of activation associated with cognitive units. In terms of the psychological significance of the activation levels, greater levels of activation are deemed to reflect an agent’s confidence or certainty in a particular belief. Thus, in our simulations, agents in the minority group were deemed to have greater certainty that a particular feature was present compared to agents in the majority group.

The way in which these initial informational conditions affected the emergence of belief states across the community of agents was studied using 4 network structure conditions. Examples of the network structures used in the experiment are shown in Figure 2i (full details of the procedure used to generate the network structures are described in Smart [8]). The question to be addressed by the study concerned how the different network structures would affect the tendency to settle on one or other interpretations of the available evidence. Would agents come to adopt the minority view that a cat object was present, or would they adopt the competing interpretation that a bird was present? In order to examine this, we ran 50 simulations in each network structure condition and recorded the activation levels of the ‘cat’ and ‘bird’ cognitive units after 20 processing cycles. The results of the experiment are shown in Figure 2ii.
Figure 2. i. Examples of the network topologies used to study the effect of communication network structure on collective sensemaking. Nodes represent agents and lines indicate channels of communication. ii. Mean activation levels of ‘cat’ and ‘bird’ cognitive units in each of the four network structure conditions. Standard error of the mean (SEM) is not shown. In all cases, SEM was less than 0.03.

Analysis of the results using Analysis of Variance (ANOVA) procedures revealed a significant two-way interaction between Belief Type (i.e., activation of ‘cat’ and ‘bird’ cognitive units) and Network Structure (i.e., type of communication network structure) factors ($F_{(3,3996)} = 93.131, P < 0.001$). Separate one-way ANOVAS at each level of the Belief Type factor revealed significant differences between network structure conditions for both the ‘cat’ ($F_{(3,3996)} = 93.140, P < 0.001$) and ‘bird’ ($F_{(3,3996)} = 93.121, P < 0.001$) cognitive units. Post hoc analyses revealed significant differences between the activation levels of the ‘cat’ cognitive unit across all the network conditions with the exception of the small-world and random networks, which did not differ from each other. The same pattern of results was seen in the case of the ‘bird’ cognitive unit (i.e., significant differences were observed across the different network structures with the exception of the small-world and random networks). As is suggested by Figure 2ii, in the case of the ‘cat’ cognitive unit, activation was greatest in the fully-connected network and lowest in the disconnected network; activation in the random and small-world networks was at an intermediate level between these two extremes. In the case of the ‘bird’ cognitive unit, the reverse pattern of results was obtained: activation was lowest in the fully-connected network, highest in the disconnected network, and at intermediate levels in the random and small-world networks. This pattern of results suggests that communication networks with different structural topologies differentially affect sensemaking performance. In situations where a minority of agents are presented with strong evidence in favour of one interpretation and a majority of agents are presented with evidence in favour of an alternative, competing interpretation, communication network structure served to mediate the effect of minority influence on collective interpretative outcomes. In particular, fully-connected networks enable strong, but uncommon, evidence to quickly influence the beliefs of all agents before weaker, contradictory evidence has had time to contribute to opposing beliefs. In the case of small-world and random networks, weaker evidence has longer to contribute to beliefs that are progressively more resistant to change across successive processing cycles.
Model Extensions and Future Work

In addition to network structure, there are a range of other factors that could affect sensemaking performance in coalition settings. As mentioned above, these include things such as the level of trust between agents, the extent of information sharing and the potential for miscommunication based on cultural or linguistic differences. Table 1 highlights some of the ways in which the model of collective sensemaking described above could be used to study the impact of these factors on collective sensemaking. The basis for these experimental studies rests on the mapping that is established between features of the coalition communication environment and model parameters. For example, each of the links between cognitive units within a single agent represents a psychological implication or association between belief states, with the weight of the link reflecting the strength of this implication or association. This means that the set of inter-cognition linkages for each agent represents the background knowledge (including assumptions, stereotypes and prejudices) that an agent brings to bear in making sense of presented information. It follows that individual variability in the structure of the CSNs (in terms of the weights associated with inter-cognition linkages) will reflect differences in background knowledge. This provides one means by which we can investigate the relative benefits of cognitive homogeneity/heterogeneity in sensemaking teams under different informational conditions.

<table>
<thead>
<tr>
<th>Factor</th>
<th>Simulation Approach</th>
</tr>
</thead>
<tbody>
<tr>
<td>Communication Frequency</td>
<td>Irrespective of the communication network structure that exists in any given simulation, communication need not be enabled on every processing cycle. Instead, we can limit communication to particular cycles or stages of a simulation. We can thus look at collective sensemaking performance under conditions of both high and low frequency communication.</td>
</tr>
<tr>
<td>Trust</td>
<td>Trust is represented by the weighting associated with specific inter-agent connections, and different values can be specified for each channel of communication between two agents (i.e., agents may have different levels of trust in respect of particular kinds of beliefs). This means we can vary the weighting between agents in order to examine the effect of trust on sensemaking performance.</td>
</tr>
<tr>
<td>Cultural Differences</td>
<td>Cultural differences can be represented by creating groups of agents with different kinds of connectivity between cognitive units. For example, a strong positive connection between two cognitive units in agents of one cultural group may exist as a weak negative connection between agents in a different cultural group. This will lead agents to process information in different ways and come to different conclusions given the same body of external information.</td>
</tr>
<tr>
<td>Information Distribution</td>
<td>The effects of information distribution can be studied by presenting different agents with different kinds of information (i.e., external activation) at the beginning and throughout a simulation. This distribution could be organized with respect to group membership</td>
</tr>
</tbody>
</table>
Table 1. Exploring the dynamics of collective sensemaking in military coalition environments.

<table>
<thead>
<tr>
<th>Factor</th>
<th>Simulation Approach</th>
</tr>
</thead>
<tbody>
<tr>
<td>Miscommunication</td>
<td>Miscommunication can be represented in the model by connecting different types of cognitive units in different agents together either on a permanent or intermittent basis. Under normal circumstances, connections should exist between cognitive units that represent the same cognition. If a connection exists between cognitive units that represent different cognitions, then communication will cause the listening agent to have a cognitive state that is different from that intended by the talking agent.</td>
</tr>
</tbody>
</table>

**Conclusion**
Sensemaking has been described as a macrocognitive function that enables individuals and groups to make sense of information and develop the understanding required for effective decision-making [12]. Sensemaking is a particularly important topic for research in military coalition contexts because it constitutes a central part of the value chain that leads from higher quality networking technologies through to greater levels of command agility and mission effectiveness [1]. In light of the importance of sensemaking to coalition operations, especially with regard to its putative role in enabling military coalitions to capitalize on the benefits of more advanced networking and information sharing solutions, it is imperative that we develop a better understanding of the factors that influence collective sensemaking performance. Computer simulation studies are one way in which such an understanding may be achieved. By systematically exploring the effect of factors such as network topology, cognitive heterogeneity, miscommunication and inter-agent trust on the dynamics of both individual and collective sensemaking, we may be able to better understand how specific features of the coalition communication environment affect the dynamics of collective sensemaking performance.

The computational model presented here is intended to improve our understanding of how specific features of the coalition communication environment might affect collective sensemaking processes. Obviously, computer simulation experiments are not a substitute for real-world observational or experimental studies; however, the results from studies using the aforementioned model may be used to generate specific hypotheses that can be evaluated using other approaches. By combining the results from both real-world experiments and computer simulation studies we can hope to derive some insight into how collective cognition is affected by the features of coalition communication environments. This, in turn, will help to guide scientific research and technology development in ways that enable military coalitions to press maximal cognitive benefit from informational, technological and human resources they have at their disposal.

**Acknowledgment**
This research was sponsored by the US Army Research Laboratory and the UK Ministry of Defence and was accomplished under Agreement Number W911NF-06-3-0001. The views and conclusions contained in this document are those of the authors and should not be interpreted as representing the official policies, either expressed or implied, of the US Army Research Laboratory, the US Government, the UK
Ministry of Defence or the UK Government. The US and UK Governments are authorized to reproduce and distribute reprints for Government purposes notwithstanding any copyright notation hereon.

References

Author Biographies
Paul Smart is a senior research fellow in the School of Electronics and Computer Science at the University of Southampton. His research interests include cognitive modelling, knowledge engineering, and the Semantic Web. He received his PhD in experimental psychology from the University of Sussex. Contact him at ps02v@ecs.soton.ac.uk.

Katia Sycara is a research professor in the School of Computer Science at Carnegie Mellon University. He is a Fellow of the IEEE and Fellow of AAAI. Her research interests include autonomous agents, planning,
Web Services, human agent interaction, negotiation and game theory. She received her PhD in CS from Georgia Institute of Technology. Contact her at katia@cs.cmu.edu.