Understanding and Shared Understanding in Military Coalitions

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Abstract—*Shared understanding is commonly seen as essential to the success of coalition operations, and current research efforts are attempting to develop techniques and technologies to improve shared understanding in coalition military contexts. In spite of this, our understanding of what the term 'shared understanding' actually means is surprisingly poor. In part, this problem is attributable to the difficulty in comprehending the true nature of understanding itself, although confusion also arises about the precise nature of the differences between shared understanding and ostensibly similar constructs, such as shared mental models and shared situation awareness. This paper discusses a number of issues associated with understanding and shared understanding. The paper begins with an attempt to identify what the notions of understanding and shared understanding might mean. It then attempts to distinguish understanding and shared understanding from ostensibly similar constructs, such as shared situation awareness, shared mental models and team sensemaking. Subsequent sections of the paper discuss the potential importance of shared understanding to military coalitions, approaches to measuring and representing shared understanding, and future research to further our understanding of the factors that influence shared understanding in military coalition contexts.*

1. INTRODUCTION

Shared understanding is a construct of apparent importance in military coalition operations. This is evidenced by anecdotal reports suggesting that shared understanding enables coalition forces to coordinate their efforts in respect of mission goals. Furthermore, major coalition-oriented research programmes, such as the International Technology Alliance (ITA), have identified shared understanding as a hard problem for future coalition operations, and considerable research effort is now being invested into the development of techniques and technologies to support improvements in shared understanding. In spite of all this, the notion of shared understanding is something that is surprisingly hard to understand. The notion is clearly related to individual forms of understanding, but there is no real consensus about what the true nature of individual forms of understanding might be. Clearly, if we are to undertake research exploring the notion of shared understanding, then it is important that we attempt to arrive at a clear definition of what the term 'shared understanding' actually means. Furthermore, we need to be clear about the precise inter-relationships between shared understanding and ostensibly similar notions such as shared situation awareness (SSA) and shared mental models (SMMs). In the absence of this kind of clarification, there is a danger that research efforts may be duplicated, or the relevance of particular research outcomes may be overlooked.

This paper discusses a number of issues associated with understanding and shared understanding. The paper begins with an attempt to identify what the notions of understanding and shared understanding might mean. It then attempts to distinguish understanding and shared understanding from ostensibly similar constructs, such as shared situation awareness, shared mental models and team sensemaking. Subsequent sections of the paper discuss the potential importance of shared understanding to military coalitions, approaches to measuring and representing shared understanding, and future research to further our understanding of the factors that influence shared understanding in military coalition contexts.

2. UNDERSTANDING UNDERSTANDING

In order to explore the notion of shared understanding it is first important that we understand what is meant by the term 'understanding'. Unfortunately, as is evidenced by previous philosophical discussions on the topic, the task of understanding understanding is not one to be undertaken lightly (Rosenberg, 1981). Indeed, in the first chapter of his book, entitled *Understanding Understanding*, Paul Ziff (1972) arrives at the rather dismal conclusion "that to understand understanding is a task to be attempted and not to be achieved today, or even tomorrow" (pg. 20). How, then, might we best make steps towards understanding understanding? In this section we pursue three approaches. The first approach is to review existing attempts to understand understanding. In this case, perhaps the most notable contribution to the philosophical debate surrounding the notion of 'understanding' derives from the work of Ludwig Wittgenstein, particularly his work in the *Philosophical Investigations* (Wittgenstein, 1967)[1]. Another approach that we pursue in this section is to look at the various contexts in which the notion of understanding is commonly used. Understanding thus emerges in discussions of how we make sense of various things, such as sensory stimuli, intentional actions, words and sentences, and situations. By examining the use of the term 'understanding'

[1] Clearly, there have been many attempts to understand understanding other than those of Wittgenstein. Føllesdal (1981), for example, sees understanding as a kind of knowledge. For reasons of space we refrain from a more complete survey of the relevant philosophical, psychological and linguistic literatures.

in these various contexts, we may perhaps arrive at a better understanding of what understanding actually means. Finally, we attempt to consider what it is that makes understanding so difficult to understand. We recognize that some things are more difficult to understand than others. As such, if we consider what it is that makes certain things hard to understand, then perhaps we will arrive at a better understanding of the thing that is perhaps the most difficult to understand: understanding itself.

2.1. Wittgenstein and Understanding

Perhaps the best starting point in our effort to understand understanding is to consider previous attempts to make sense of the notion. In this respect, the work of Ludwig Wittgenstein, particularly his work in the *Philosophical Investigations*, is a major focus of attention. Understanding is one of the central themes of the *Philosophical Investigations*, and throughout sections 143-242 Wittgenstein attempts to analyse the relationships between understanding and categories such as states, processes, events and abilities. The culmination of this analysis is the claim that understanding is something akin to an ability. To understand, claims Wittgenstein, is to be able to do certain things. Thus, to understand a sentence is to be able to do things that involve the sentence, e.g., to apply it correctly, to paraphrase it and to respond to it in appropriate ways. Similarly, to understand a word is, *inter alia*, to be able to use it correctly.

By casting understanding as a kind of ability, Wittgenstein hopes to avoid a number of confusions and pitfalls regarding a philosophical grasp of understanding. In particular, he is keen to resolve a number of categorization errors that may result from a reflection on the nature of understanding. One such category error is the notion that understanding is a kind of experience: the kind of experience we have when we feel we understanding something, or when we suddenly gain insight into some previously ill-understood phenomenon. Although tempting, this view of understanding is misconceived. It is misconceived for a number of reasons, not least because we may feel we understand something even though we do not. In addition, a description of the various experiences that accompany understanding does not seem to capture the true essence of understanding. A person may have many experiences when they understand something, and none of these seems sufficient (or indeed necessary) for our ascription of understanding – we do not say that someone understands something in virtue of the kind of experiences that they are subject to.

In addition to discounting the idea that understanding is an experience, Wittgenstein also rejects the idea that understanding is a mental state or a mental process[2] (see Baker & Hacker, 1980 for further discussion). Understanding is not a mental state, Wittgenstein argues, because it does not have the properties of a mental state. A mental state has what is called 'genuine duration'. Thus, one can be in a state of anxiety for 5 minutes or more, but it does not make sense to talk of being in a state of understanding for a specific period of time. If one lost consciousness, then one would no longer be in a state of anxiety; however, one's understanding of something, say English, would not be similarly curtailed.

Wittgenstein also rejects the idea that understanding is a mental process. A mental process can be interrupted; however, understanding does not seem to be similarly interruptible. An interruption of understanding is a failure of understanding, or a breakdown in understanding; it is not some sort of hiatus in understanding. Also, we do not go looking for mental processes when we attempt to ascertain whether someone understands something. A person's understanding of this paper is not based on the mental processes he or she has. It is rather based on the possession of certain abilities: an ability to ask questions about it, to recount it, to conclude that it is thoughtful and insightful, or to come to some other conclusion(!).

2.2. Varieties of Understanding

One of the things that may complicate an understanding of understanding is that the term 'understanding' is used in many different contexts. In addition to this, the objects of understanding – the things that are actually understood – are highly disparate and diverse. Although there have been some attempts to identify the common characteristics of things that are the legitimate targets of understanding (Ziff, 1972), it is by no means clear that the various things we can understand do, in fact, constitute a unified category. In addition, as mentioned in Smart et al (2009b), it is unclear whether the notion of understanding that is used in the context of language understanding is the same as that used in the context of understanding intentional action or in understanding particular situations. By looking at the various ways in which the notion of understanding is used in different contexts, we may be able to ascertain whether understanding can be treated as a unitary concept and, moreover, determine what are its essential properties.

Sensory Sense-Making

One context in which the notion of understanding has been used is in philosophical and psychological discussions of perception. Perception, it has been argued, depends on more than just an ability to detect stimuli; it also depends on an ability to make sense of them – to understand them. Support for such a view derives from the various cases of cataract surgery that have been undertaken with congenitally blind individuals. Although such surgical interventions were intended to restore the sight of patients, their success was limited to the restoration of something more limited: an ability to merely *sense* visual stimuli but not *perceive* them (Valvo, 1971). Sensation is not the same as seeing, it is argued, because seeing requires an ability to make sense of visual stimuli, to appreciate their significance and implications for future action. "To see", writes Noë (2004),

[2] As we will see in Section 4.2, this conclusion perhaps enables us to resolve a particular point of contention in discussions about situation awareness: the apparent duality of situation awareness as both a state and a process (see Rousseau et al., 2004).

"one must have visual impressions that one *understands*" (pg. 6) [original emphasis].

If perception is predicated on some form of understanding, in what might that understanding consist? According to one increasingly popular theory, the content and character of our perceptual experience derives from our (implicit) knowledge of what are called 'sensorimotor dependencies' (i.e. our knowledge of the relations between movement or change and the resulting patterns of sensory stimulation) (Noë, 2004; O'Regan & Noë, 2001). To perceive, on this view, is to be in possession of a body of (largely non-conscious) knowledge concerning the way in which patterns of sensory stimuli will change as a function of behaviour. In order to have the kind of phenomenal experiences we do (the sights, sounds, feelings, or whatever), we need to learn about the predictive relationships concerning the way in which our own behaviour affects sensory inputs. To understand, on this view, is to be in command of a kind of predictive ability, an ability to appreciate the sensory consequences of motor action and to coordinate behavioural output accordingly. Such a view has much to commend it in terms of what we know about the functional operation of certain brain circuits[3]. It also aligns itself pretty closely with Wittgenstein's notion of understanding as something akin to an ability – the ability in this case is to predict or anticipate the sensory consequences of movement or change.

Understanding Intentional Actions

Another context in which the notion of understanding is used is in the understanding of intentional action. In order to make sense of one another's actions, we seem to rely on a folk-theoretic framework that emphasizes the causal relevance of certain mental states and processes. Thus, in order to make sense of a person's actions, we say that they must have certain beliefs and desires, and that those beliefs and desires are causally-relevant to the actions that we observe. Understanding, on this view, seems to take the form of an ability to account for, or explain, a person's actions with respect to a particular theoretical framework. We might also be inclined to say that a person understands someone's actions if they are additionally able to predict what someone will do in light of the possession of certain mental states.

One way in which we may be able to understand the actions of other agents is by a process of mental simulation; i.e., mentally simulating the observed actions in order to infer what we ourselves would need to think and feel in order to express the same action in the same context. This simulation-based view has much in common with the views of the German sociologist, Max Weber. Weber advocated an approach to understanding human action that is grounded in the notion of *verstehen* (German for 'understanding'). This approach emphasizes the importance of putting oneself in the mind of others, of trying to understand human action by knowing what in oneself would need to be the case in order for the action to be expressed. Recently, of course, a rich theoretical and empirical literature has emerged regarding the role of so-called 'mirror neurons' in our ability to understand (to make sense of) the actions of others (Gallese & Goldman, 1998; Rizzolatti & Craighero, 2004). Such mechanisms may be relevant to understanding in a variety of contexts, most notably our understanding of linguistic utterances. One, admittedly speculative, proposal is that mental simulation processes could be used to support an understanding of the *pragmatics* of spoken language. The general idea is that in order to understand why a particular speech act was performed, one might mentally simulate what was said in a given context in order to determine the kind of mental states (e.g. intentions) that would lead to the overt expression of that act. In support of this claim, there is some evidence that our perception of speech sounds involves the activation of those motor programs that would be used to produce the same sounds if we ourselves were to make those sounds (Porter & Lubker, 1980).

Language Understanding

The topic of language understanding is a vast and complex topic, and it is impossible to do justice to the various theoretical and empirical contributions in the current paper. Wittgenstein's views have been very influential in guiding the philosophical debate over language understanding, and, as mentioned in Section 2.1, Wittgenstein sees language understanding, and perhaps all forms of understanding, as akin to the possession of an ability, power or capacity. For Wittgenstein, understanding a language is a matter of being able to do things (many different things), and these performances underwrite the ascription of understanding – they are criteria against which we judge whether someone understands (or does not understand) a particular linguistic expression.

Going beyond the philosophical debates, most of the empirical work that has been undertaken in this area has focused on an elucidation of the cognitive processes that are involved in both language comprehension and language production. Influential work in this area includes Kintsch's (1988, 1998) construction-integration model for discourse comprehension. The model involves the construction of an initial set of propositional representations (representing the meaning of one or more sentences), followed by a process of propositional elaboration and then refinement and integration. The end result of these elaboration and integration processes is a situation representation, or a mental model, describing the situation referred to by the original sentences.

An alternative view of language comprehension is provided by perceptual-simulation theory (Zwaan & Kaschak, 2009; Zwaan & Taylor, 2006). This theory claims that language understanding involves the perceptual simulation of the situation(s) referred to by linguistic utterances or written

[3] Many neural circuits in the brain seem to be involved in the computation (and minimization) of prediction error signals; i.e. signals that represent the error between a predicted pattern of activity and the actual activity generated as a result of internal or external events (Schultz et al., 1997; Schultz & Dickinson, 2000).

texts.

Situational Understanding

The notion of situational understanding is something that seems very similar to the notion of situation awareness (SA). Situational understanding involves an ability to explain how the current situation, or elements thereof, came to be as they are, and it often involves an additional ability to predict how the current situation may develop or evolve in the future. Situational understanding therefore seems to be based on the possession of certain predictive and explanatory abilities, abilities that seem to be based on knowledge about the kind of causal relationships that exist between various situation elements. Crucially, situation understanding seems to be based on an ability to infer the existence of unseen, or unobserved, elements of the current situation. Thus, explanation and prediction rely on retrodictive and predictive inferences about states-of-affairs that are not currently accessible to an observer. This ability to 'see more than meets the eye' may be a common characteristic of many forms of understanding. In the case of sensory sense-making, for example, we spoke of an ability to predict the sensory consequences of movement; in the case of understanding intentional actions we spoke of an ability to infer the existence of causally-relevant mental states; and in the case of language comprehension we spoke of a collection of abilities that could be construed as dependent on a capacity to 'see beyond the symbol' (i.e. to infer the semantic referents of particular linguistic expressions).

2.3. Why is Understanding Understanding Difficult?

As mentioned in the introduction to this section, understanding is commonly seen as something that is difficult to understand. Why might this be so, and can we learn anything about the nature of understanding by considering why understanding is so difficult to understand? According to Ziff (1972), understanding is essentially an analytical process whose difficulty is related to the structural complexity of the object to be understood. Rosenberg (1981) extends this analysis by including two additional factors that may make something difficult to understand. One is the need to put an object of understanding in its proper context, of establishing a network of relationships between the thing to be understood and other elements of the surrounding context. Rosenberg (1981) argues that this is not a process of analysis, as Ziff (1972) seems to suggest; it is more a case of synthesis, of "bringing things into relation, of building up a network of connections, interdependencies and affinities" (Rosenberg, 1981; pg. 33). An ambiguous sentence or word is thus disambiguated by establishing relationships between the sentence or the word and a number of surrounding contextual elements.

The second additional factor that Rosenberg (1981) claims is a contributing factor to the difficulty in understanding something, is the vagueness or indefiniteness of the thing to be understood. What makes something difficult to understand, on this view, is the difficulty we have in identifying legitimate instances of the thing we seek to understand.

We therefore confront three sorts of reasons as to why something is difficult to understand. Something may be difficult to understand because 1) it is structurally complex, 2) because it is incoherent and ambiguous (i.e. it fails to cohere with the elements of a larger nexus of contextual elements), or 3) because it is vague and indistinct. In general, things that are difficult to understand all seem to involve a knowledge or awareness of the relationships between various things. Thus, in the case of things that are structurally complex, we need to know or be aware of the relationships between constituent parts of the object of understanding; in the case of things that are incoherent or ambiguous, we need to know or be aware of the relationships between the object of understanding and the wider relationships it has to external or surrounding objects; and in the case of things that are vague, we need to know or be aware of the relationships (properties) that dictate the conditions of category membership.

So understanding may be difficult to understand for a variety of reasons, all of which seem to involve, to a greater or lesser extent, our ability to know, identify, learn, discover, or use the relationships or connections between things. In the case of understanding, it may be that the relationships in question concern those with concepts such as meaning, knowledge, ability, and explanation, each of which is, in turn, somewhat difficult to understand. Alternatively, the relationships may concern those associated with the identification of particular instances of understanding. The large variety of things that can be understood, as well as the large number of disparate performances that seem to manifest understanding, may lie at the root of this particular difficulty. Whatever the reasons for the difficulty in understanding understanding, the main point of this discussion is that it perhaps reveals something of the nature of understanding (i.e. what it means to understand). Our analysis suggests that understanding seems to involve (and is perhaps constituted by) a particular form of knowledge, namely knowledge about the inter-relationships between various things. In order to understand something it seems to be important that relational knowledge is suitably poised to influence, guide and constrain thought and action in various ways.

2.4. What is Understanding?

We have now scouted some of the intellectual terrain associated with the notion of understanding. Does this enable us to better understand understanding in any way? And can we, by virtue of this understanding, propose an adequate definition for both 'understanding' and 'shared understanding'? In a previous paper, we defined understanding as "an ability to exploit bodies of causal knowledge (i.e. knowledge about the antecedents and consequents of particular phenomena) for the purpose of accomplishing cognitive and behavioural goals" (Smart et

al., 2009b). Understanding was thus cast as particular form of ability, and the ability in question related to the exploitation of causal knowledge. In part, this definition was motivated by an attempt to account for the predictive and explanatory performances that seem central to many cases of understanding (see Section 2.2). Seen in the light of the current discussion, however, the definition proposed in Smart et al (2009b) does not seem quite right. While it does seem appropriate to regard understanding as a kind of ability, it does not seem entirely appropriate to *equate* the notion of understanding and ability (see discussion in Baker & Hacker, 1980 for more on this). In addition, the attempt to equate understanding with a particular kind of (albeit highly generic) ability now seems somewhat overstretched. It risks restricting the notion of understanding to a particular set of performances which may not cover the full range of cases in which ascriptions of understanding are made (the definition does not, for example, seem to apply to cases of language understanding). What might be a better approach is to say that a knowledge of causal (and perhaps other) relationships is a means by which the exercise of certain abilities is made possible. For example, the thoughts and actions that merit the ascription of situational understanding to an agent are made possible by access to certain kinds of knowledge (e.g. knowledge about the causal contingencies between events). The understanding, in this case, is not the knowledge of causal contingencies *per se*; it is more the ability to make predictions and establish explanations about the situation in question. It is clear that one's background knowledge supports the exercise of such abilities, but it does not seem appropriate to equate understanding with such knowledge.

What about the third part of Smart et al's (2009b) definition – the part about the purpose of an ability being to accomplish cognitive and behavioural goals. The original motivation for referring to goals in this definition was based on the perceived importance of the flexible and adaptive use of knowledge in establishing genuine cases of understanding. Thus, in order to understand something, we claimed, one should be able to adaptively engage in thoughts and actions that realize some particular goal. Although we are aware of the considerable opposition to referring to goals in any definition of understanding, we still think that goals may be important in terms of understanding the nature of understanding. At first blush, it is somewhat difficult to see whether the notion of goals and understanding can really be disentangled; for inasmuch as understanding is akin to an ability, then the specific performances that manifest understanding may always be expressed in respect of some goal. For example, if we cast understanding as an ability to provide descriptions, explanations and predictions about (e.g.) a particular situation, then the goals of performances corresponding to the exercise of this ability are the ones to describe, explain and predict situation-relevant states-of-affairs. It is in striving to reach goals that the understanding of an agent is manifest.

In summary, then, it seems that the notion of understanding is similar to the notion of an ability. To understand is to be able to do things. Typically, understanding is evidenced by our descriptive, explanatory and predictive successes regarding the object of understanding, but there does not seem to be any firm basis for saying that understanding is a particular form of ability; e.g., an ability to predict or explain something. It may be that, in many cases, the performances that manifest understanding require a knowledge of particular relationships (e.g. causal linkages), and it may even be the case that our ability to infer those (unseen) relationships is one of the criteria for (some forms of) understanding. Nevertheless, it seems unlikely that the generic notion of understanding can be equated with any particular set of abilities.

3. SHARED UNDERSTANDING

3.1. What is Shared Understanding

If understanding is akin to an ability, what might shared understanding be? The most obvious answer to this question is that shared understanding is an ability (or something similar to an ability) that is common to multiple agents. But now we face a dilemma. If understanding is akin to an ability, then it cannot be that the behaviours that manifest shared understanding are the same for each agent. This is because the exercise of an ability is not the same as the ability itself, and the behaviours corresponding to the exercise of an ability may be many and varied. As such, how do we ascertain that two or more agents possess shared understanding of some target object in spite of the fact that the performances manifesting such understanding may be wildly multifarious?

The best we can do in this situation, it seems, is to determine whether the performances of the agents in question warrant the ascription of the same, or similar, kinds of understanding. In this respect, similar performances by multiple agents may be sufficient to merit conclusions about shared understanding, providing that the nature of the performance warrants the ascription of the same (or similar) kinds of understanding to each agent. Thus, two individuals who possess shared understanding will, at least in some cases, establish the same set of (e.g.) explanations and expectations given identical information about (e.g.) a situation (all other things being equal). In the case of medical diagnosis, for example, we might conclude that two individuals have the same understanding if they are able to account for symptoms in the same way, and are additionally able to anticipate the same set of pathophysiological outcomes as a result of disease progression. In a coalition military context, we might say that two commanders have the same (i.e. shared) understanding of a situation if they are able to anticipate the same effects of military actions and are also able to cite the same reasons as to why particular military actions should be undertaken (e.g., to ensure the efficient realization of particular mission objectives). Clearly, the shared understanding that individuals possess (as determined by their predictive and explanatory capabilities) will not be identical in most cases. In addition,

the shared understanding between individuals will rarely, if ever, be complete (see Section 3.2). More likely, individuals will possess limited forms of shared understanding that are specific to some particular situation or task context.

Although similarity of performances may be sufficient for conclusions about shared understanding, it should not be deemed as necessary. This is because different performances can still imply shared understanding. In discussions about military coalition operations, for example, the notion of shared understanding is typically seen as an enabling factor for what is called 'unity of effort'. This is the notion that coalition force elements, perhaps from different command structures, are able to cooperate and coordinate their efforts in order to realize common mission objectives. The specific actions that constitute unity of effort are unlikely, it should be clear, to be the same across all force elements. Rather, what seems to matter is that the actions are, in some sense, complementary or compatible with each other (when evaluated with respect to mission objectives). Presumably, what supports the expression of these complementary or compatible actions is a shared understanding about a particular set of things, including (perhaps) an understanding of how agent roles, responsibilities, capabilities, and goals relate to shared mission objectives and the vagaries of the current situation.

3.2. Shared Understanding: Identity, Similarity or Complementarity?

In addition to attempting to provide a definition of understanding and shared understanding, Smart et al (2009b) also discuss a number of ways in which shared understanding might be viewed. As Cannon-Bowers and Salas (2001) point out in the context of shared cognition, the notion of 'sharedness' can be viewed in multiple ways. One interpretation of 'shared' is that it denotes the common or joint possession of some resource (e.g., the sharing of a belief or item of equipment). An alternative view sees 'sharing' as implying the division of a resource between multiple recipients (e.g., the sharing of a workload or the sharing of a dessert). This latter notion of sharing is particularly relevant to team situations because teams typically feature a degree of specialization in which each team member undertakes a particular task, or element of some larger joint task. When it comes to matters of understanding in team situations, it seems that identity or similarity of understanding may not always be the thing that is most desired. Instead, what may be required is a distribution of the *responsibility* for understanding something. In this case, individual team members might be expected to have a *distinct* understanding of different parts of the shared object of understanding (e.g., a situation or system). Smart et al (2009b) identify this form of understanding as 'complementary understanding' and contrast it with two other forms of understanding: 'identical understanding (which is apparent when the understanding possessed by two or more agents with respect to some target object is identical) and 'similar understanding' (which is apparent when the understanding possessed by two or more agents with respect to some target object is similar or overlapping).

3.3. A Distributed Cognition Approach to Understanding

In addition to seeing shared understanding as something that is a function of the overlap in understanding between two or more agents, it is also possible to view understanding as something that may (at least occasionally) be distributed across multiple agents. On this perspective, individual agents need not necessarily possess any overlap in their understanding of some target state-of-affairs; instead, the understanding may be manifest in the systemic behaviour of the socio-technical organization in which such agents are situated. Clearly, this distributed approach to understanding requires a shift from an individual-level perspective to a more systems-level perspective. In particular, it requires us to see understanding as a property of a larger system in which the dynamics of inter-agent communication are responsible for yielding the kind of explanatory and predictive successes that warrant the ascription of understanding to the larger system.

To make this idea somewhat more concrete, imagine two teams of human subjects each engaged in a task that requires the explanation and prediction of system states. For the sake of argument, let us say that the target system (the one whose behaviour is being explained and predicted by the teams) is the behaviour of a specific tribal group in a military conflict zone. We assume that predictive and explanatory success in this domain depends on the availability of large and heterogeneous bodies of specialist knowledge (perhaps subtending disciplines as diverse as cultural anthropology, psychology, history, sociology and so on), and it is therefore necessary for the two teams to be composed of experts from multiple disciplines. The objective of each team is to use the expertise of team members in order to support the generation of reliable predictions and explanations regarding tribal behaviour. To the extent that the teams generate similar explanations and predictions, we may conclude that they (i.e., the teams) possess shared understanding of the target domain[4]. But note that within each team, the mechanisms that contribute to understanding are essentially distributed: the mechanisms undergirding explanatorily- and predictively-potent (team-level) outcomes are realized by processing loops that extend across all team members. It is in precisely this way that understanding (or at least the mechanisms that contribute to understanding) can be distributed. Specific individuals within a team need not understand a complex system in order for team-level understanding to emerge, and it may even be the case that shared understanding between team

[4] Similarity of response output is sufficient for conclusions about shared understanding in this case because we assume no interdependence between the teams with respect to the accomplishment of particular goals. Although similarity of response output may be sufficient for conclusions about shared understanding in cases such as these, we maintain that similarity of response output is not necessary for two or more agents to possess shared understanding (see Section 3, for more on this).

members is somewhat limited – each member may possess unique bodies of expertise and knowledge that is not shared with other members of the same team. What is important to note here is that the mechanisms that contribute to understanding need not be localized to the heads of individual human agents. Instead, they may extend across a variety of biological and (sometimes) non-biological resources. In addition, the system that does the understanding may not necessarily be an individual human agent. Instead, it may sometimes be a collection of (often) heterogeneous elements comprising multiple human agents, intelligent software systems, networked information resources and other technological artefacts.

Analogues to this distributed approach to understanding are apparent in the literature on SMMs. A core claim in the SMMs literature is that greater inter-individual similarity of mental models leads to greater similarity in the expectations and explanations generated by individuals. This, in turn, is seen to result in improved coordination, communication and other team behaviours (Rouse et al., 1992). Differences in mental models are expected to result in differences in expectations and explanations. Thus, the best way to ensure optimal team performance is to ensure that individuals possess the same mental models. In contrast to this view, Banks and Millward (2000) suggest that individuals do not need to share mental models (at least in the sense that individuals possess similar models). Instead they propose that the cognitive process of running a mental model can be divided or distributed amongst team members. One benefit of this approach, they argue, is that it avoids the need for team members to possess redundant bodies of knowledge. By distributing the workload for running the mental model, team members effectively spread the load imposed on the group; they essentially avoid the effort and work required for individuals to assimilate, maintain and execute full mental models of the target system (see Lewis & Sycara, 2004; Sycara & Lewis, 1991).

Distributed approaches are also apparent in the literature on situation awareness. In this case, Professor Neville Stanton and his colleagues have developed a distributed model of situation awareness, which has been used in a variety of complex sociotechnical environments (Salmon et al., 2009; Salmon et al., 2010; Stanton et al., 2006). Salmon et al (2009) argue that the traditional focus of situation awareness models, which target the cognitive processes of individual operators, are inadequate when it comes to understanding the development and maintenance of situation awareness in collaborative, team-based contexts. Instead of seeing situation awareness as something that occurs as a result of 'in-the-head' processes, they suggest that we should instead embrace a distributed cognition approach to understanding situation awareness and develop models that emphasize the contribution of social and technological elements to the information processing capabilities of the larger system.

Once we take a distributed approach to understanding, it becomes possible to entertain a different view of understanding in military coalition contexts. Rather than see understanding as something that exists inside the heads of individual human agents and shared understanding as something that inheres in the relationship between the understanding of individual agents, it becomes possible to see understanding as something that is manifest in the collective behaviour of all the elements that comprise the coalition. The coalition becomes, in effect, a kind of socially and technologically-extended cognitive machine (see Smart, 2010); one in which understanding is an emergent property of the larger systemic organization (the entire coalition, or its constituent force elements), and the interactions between a variety of biological, social, technological and informational elements constitutes the thing that realizes system-level understanding[5].

4. UNDERSTANDING THE RELATIONSHIP BETWEEN SHARED UNDERSTANDING AND OTHER COGNITIVE CONSTRUCTS

The notions of understanding and shared understanding are typically encountered in discussions about a variety of other cognitive constructs in the human factors literature. These include discussions about mental models, situation awareness and sensemaking. This section aims to provide a better understanding of the nature and inter-relationships between these ostensibly similar constructs.

4.1. Mental Models

According to Rouse and Morris (1986) mental models are the "mechanisms whereby humans are able to generate descriptions of system purpose and form, explanations of system functioning and observed system states, and predictions of future system states" (pg. 351). Mental models therefore support the expression of particular abilities, such as those related to the description, explanation or prediction of certain things. When it comes to individual forms of understanding, therefore, we may see mental models as providing the mechanistic basis of specific performances that warrant the ascription of understanding to an agent (see Smart et al., 2009b).

In team situations, the notion of SMMs (Cannon-Bowers et al., 1990; Cannon-Bowers et al., 1993) is typically encountered. SMMs are mental models that are possessed by multiple individuals, and they are assumed to benefit team performance by enabling individuals to anticipate one another's information requirements. Inasmuch as individual mental models provide a mechanistic realization for the performances that manifest individual forms of understanding, it seems likely that SMMs could support the expression of thoughts and actions warranting the ascription of shared understanding to a collection of agents. It is, however, important to be clear what is and what is not being claimed here. One of the claims made in a previous paper

[5] In other words, it is the network-mediated interactions between elements that constitutes the mechanistic basis for the expression of system-level behaviours warranting the ascription of understanding to the coalition organization (see Smart et al., 2010a, for more on this).

(see Smart et al., 2009b) was that SMMs "may provide one means by which shared forms of understanding may be realized". This is, in fact, subtly misleading because it implies that mental models provide a direct realization of understanding. Instead, it is probably more appropriate to say that mental models support the expression of behaviours (thoughts and actions) that manifest understanding in both its individual and shared forms. Another potential confusion, sometimes encountered in the human factors literature, is to equate the notions of understanding and mental models. This equation is misconceived because understanding is akin to an ability and abilities cannot be reduced to the things (vehicles) that explain the exercise of the ability. As Baker and Hacker (1980) comment: "Science explains powers by discovering underlying structures, but it is a mistake to think that it reduces powers to the structure of their vehicle" (pg. 337).

4.2. Situation Awareness

In addition to mental models, it is important to consider how notions of understanding relate to the concepts of SA and SSA. According to Endsley (1995), SA is "the perception of the elements in the environment within a volume of space and time, the comprehension of their meaning and the projection of their status in the near future" (pg. 36). Two elements of this definition seem immediately relevant to our notion of understanding: comprehension and projection. Comprehension implies that individuals who possess SA are capable of interpreting, combining and prioritizing information. Projection, on the other hand, implies that individuals are capable of formulating expectations about the occurrence of future events and system states. On the basis of Endsley's (1995) characterization it would therefore seem that SA is something that entails understanding, or at least a particular form of understanding. In fact, we suggest that SA is indeed best conceived of as a particular form of understanding – what we might refer to as *dynamic situational understanding*. The object of understanding in this case is, somewhat obviously, a situation, and the performances that manifest dynamic situational understanding are those typically encountered in many cases of situational understanding; i.e., an ability to describe elements of the situation, to provide explanations as to how the current situation emerged, and to predict how the situation is likely to evolve in the future. These descriptive, predictive and explanatory capabilities are, of course, precisely those that seem to be supported in the case of mental models. So perhaps an appropriate theoretical integration of the notions of understanding, SA and mental models is the following: mental models support the expression of behaviours that warrant the ascription of SA to an agent, and SA is a particular form or type of understanding, namely dynamic situational understanding.

By casting SA as a particular form of understanding, we may be able to deal with a number of issues that have proved contentious in the SA community. One of these is the apparent state/process duality of SA – the tendency for SA to sometimes be regarded as a state and at other times as a process (see Rousseau et al., 2004). While situation awareness has, in general, been regarded as a state, it has also been seen as a process, and even as both a state *and* a process (see discussion in Rousseau et al., 2004). Even Mica Endsley's classic definition of situation awareness seems to countenance a process-oriented view of situation awareness (perception, comprehension and projection all seem to refer to cognitive processes), and this is despite the fact that Endsley herself insists that situation awareness should be characterized as a state rather than a process, arguing that the processes giving rise to situation awareness should be characterized instead as situation assessment[6] rather than situation awareness.

By casting SA as a form of understanding, we can offer a potential resolution to the debate regarding the state/process duality of SA. In particular, if situation awareness is a form of understanding, then we can conclude that it is neither a state nor a process. This is the case because we saw in Section 2.1 that understanding should not be categorized as a state or a process. The problem with this conclusion, however, is that the reasons for stating that SA is a form of understanding now seem to conflict with the reasons that were given as to why understanding should not be regarded as a state. Recall from Section 2.1 that we rejected the idea of understanding as a state because understanding did not seem to have the essential properties of a state. In particular, states were seen as having genuine duration, whereas it did not seem appropriate to see understanding as having genuine duration. While it does seem appropriate, therefore, to say that someone could be in a state of anxiety for 5 minutes, it does not seem appropriate to say that someone could be in a state of understanding for 5 minutes. The implication is that anxiety is a kind of state, whereas understanding is not. If true, this seems to rule out the possibility that SA is a state because we have said that SA it is a type of understanding, and we have also stated that the notions of understanding and states are disjoint. However, the notion of dynamic situation understanding, which we have equated with the notion of situation awareness, *does* seem to involve a commitment to the idea of understanding as having genuine duration. Thus, it does seem appropriate to say that someone understood a situation for 5 minutes, and then their understanding broke down, perhaps because they received inaccurate information about how the situation was evolving. It is this notion of dynamic situational understanding as something that needs to be constantly maintained in the face of a dynamic, continuously evolving situation that makes it so appealing as a synonym for situation awareness. However, at the same time, it is precisely this feature that seems to undermine the idea that (situational) understanding should be seen as distinct from states. At this point, it seems, we have four options:

[6] Situation assessment is, in fact, another construct whose precise relationship to understanding deserves clarification. Situation assessment is most commonly seen as a process of gathering information about a situation, and it most closely resembles the notion of sensemaking (see Section 4.3). In all likelihood, situation assessment can be seen as a specific form of sensemaking; one in which sensemaking processes are geared to understanding a specific object, namely, a situation.

1) Conclude that understanding, or at least some forms of understanding, can have genuine duration and seek some other basis (one that does not appeal to notions of genuine duration) for claiming that understanding is not a state. This might enable us to preserve our original conjecture that SA is neither a state nor a process.

2) Conclude that understanding, or at least some forms of understanding, can have genuine duration and that the notions of state and understanding are not disjoint. This conclusion would inevitably mean rejecting Wittgenstein's claims about the nature of understanding, and it would also force us to reconsider our original conjecture that SA is neither a state nor a process (because such a conclusion would no longer be necessarily true).

3) Conclude that no forms of understanding can have genuine duration and that, as a result, they are not states. This might also lead to the conclusion that because SA does have genuine duration it is not a form of understanding. This conclusion leaves the relationship between understanding and SA uncomfortably vague, and this is especially galling given that understanding seems highly relevant to our commonsense intuitions about what SA actually is.

4) Conclude that no forms of understanding can have genuine duration, but still insist that dynamic situation understanding and SA are synonymous. This implies that SA does not have genuine duration; i.e., it is not appropriate to talk of an individual having SA for a particular period of time.

Choosing between these options will require additional work to explore what is meant by the notion of situation awareness and whether it really makes sense to see it as something that has the property of genuine duration.

4.3. Sensemaking

Another construct that may be confused with understanding is what has been referred to as sensemaking and (in a collective contexts) as team sensemaking. Sensemaking is a construct that is typically encountered in discussions of situation awareness, and there have been a number of attempts to distinguish between the two constructs. Thus, whereas situation awareness has typically been understood in terms of the knowledge an operator has of situation-relevant information (i.e. it has been seen as a mental state), sensemaking seems to be best characterized as a process, or set of processes, rather than a state of knowledge. Klein et al (2006) thus see sensemaking as "a motivated, continuous effort to understand connections (which can be among people, places, and events) in order to anticipate their trajectories and act effectively" (pg. 71). Based on these notions of situation awareness and sensemaking, one might be tempted to conclude that sensemaking is a process that contributes to a state of situation awareness, and team sensemaking is something that contributes to a state of shared situation awareness.

Notwithstanding the issues raised in the previous section regarding the state/process duality of situation awareness, it is important to recognize that the integrity of this simplistic view of the relationship between sensemaking and situation awareness is complicated by a number of factors. One problem is that even if it is true that sensemaking does give rise to situation awareness, it is not clear that it is *necessarily* true. Thus, while sensemaking may indeed be involved in the formation of situation awareness, in at least some cases, it is not clear that it is a necessary feature of situation awareness. Klein et al's (2006) definition casts sensemaking as a process of deliberate and effortful information acquisition and integration, but it seems that some kinds of situation awareness do not involve this kind of deliberate and effortful process. For example, drawing on Gary Klein's (Klein, 1993) previous work into naturalistic decision making, Kaempf et al (1996) discovered that 95% of tactical military commanders relied on a strategy of recognition-primed decision making to interpret situation-relevant information. In other words, in order to achieve situation awareness, the commanders in this study relied on a process of matching specific features to pre-existing situation schemas. As Endsley (2004) is at pains to point out here, the commanders in this study did not achieve situation awareness as a result of a deliberate and effortful process of information gathering, manipulation and synthesis. Instead, they accomplished situation awareness via an instantaneous and reflexive process of situation recognition. Endsley (2004) suggests that sensemaking closely resembles a subset of the process involved in situation awareness. In particular, she suggests that sensemaking is "the process of forming level 2 SA from level 1 data through effortful processes of gathering and synthesizing information" (pg. 324).

In terms of the relationship between sensemaking and understanding, it is probably the case that sensemaking can be seen as one of the means by which understanding comes about[7]. In other words, sensemaking should be seen as a set of deliberate processes employed to establish, maintain and validate understanding. At the level of individual understanding, sensemaking processes probably subsume all manner of interactions and engagements with social, technological and informational resources; however, in the case of shared understanding, the processes are probably more limited, perhaps being restricted to forms of social interaction and communication. In all likelihood, sensemaking processes are employed in situations where experience is limited or when information is ambiguous, unreliable, and conflicting. As Endsley (2004) suggests in relation to situation awareness, sensemaking processes are perhaps sufficient to yield understanding, but they need not

[7] In fact, the focus of the current paper in trying to understand understanding (and shared understanding) might be construed as a form of sensemaking. In this case, the aim is to understand understanding, and the processes that lead to that understanding are sensemaking processes. Certainly, the current undertaking bears all the apparent hallmarks of a sensemaking process: it is a deliberate, motivated and effortful process of gathering and synthesizing information in order to understand the connections between things (for example, the connections between notions of 'understanding' and 'sensemaking').

be necessary for understanding[8].

4.4. Summary

We have seen that considerable confusion and ambiguity exists regarding the appropriate use of terms such as sensemaking, situation awareness, and understanding. Additional confusion is encountered when these (and other constructs) are applied in a collective, team-based setting. Thus, the relationships between notions such as team sensemaking (Klein et al., 2010), team situation awareness (Brannick et al., 1999), distributed situation awareness (Salmon et al., 2009), shared mental models (Cannon-Bowers et al., 1993), and shared understanding (Smart et al., 2009a) are all somewhat vague at the present time. In order to develop an understanding of understanding it is imperative that we understand how these notions relate to one another. Establishing what effectively amounts to a formal ontology of these constructs will enable us to identify and reuse appropriate elements of existing models in the research literature as well as identify relevant technology components that have been developed in other human factors contexts.

5. SHARED UNDERSTANDING AND MILITARY COALITIONS

5.1. Why is Shared Understanding Important in Military Coalitions?

As mentioned in the introduction, shared understanding is something that is seen as important to military coalition operations; however, the precise contribution of shared understanding to such operations is currently unclear. Perhaps the main reason why shared understanding is important relates to the need for coalition elements to coordinate their efforts in respect of some common or joint goal. In this case, shared understanding might fulfil the same function for military coalitions as mental models do in the case of team performance: it enables coalition elements to predict and anticipate one another's behaviours and information requirements. In the context of the SMM literature, the ability to anticipate information requirements and proactively provide information in advance of its actual use has been shown to improve team effectiveness in a number of empirical studies (Oser et al., 1990; Stout et al., 1999). Similar performance benefits might apply in the case of shared understanding and coalition operations.

Another reason for the apparent importance of shared understanding in coalition operations could relate to the efficient use of limited communication resources. Inasmuch as shared understanding contributes to the realization of efficient modes of inter-agent communication and coordination, it may have particular value in the context of coalition operations. This is because coalition environments are often resource-constrained environments in which power overheads and network traffic must be kept to a minimum. If shared understanding improves the efficiency of inter-agent communication (perhaps reducing the need for communication altogether), it may contribute to the optimized use of limited network assets.

In addition to supporting improved performance and optimizing the use of available resources, shared understanding may also be important for factors such as group cohesion, group solidarity and trust. Intuitively, it seems that an ability to anticipate the information needs of team-mates and behave in a way that accords with the expectations of others could be a key ingredient of what it means for someone to be regarded as a 'team player'. Inasmuch as this is the case, we may expect shared understanding to be an important contributor to a range of psychoaffective outcomes as well as group performance variables.

5.2. Issues for Shared Understanding Research in Military Coalition Contexts

There are a number of issues for future research concerning shared understanding in military coalition contexts. This section provides an overview of (at least some of) these issues.

Who (or what) shares the understanding?

Given the notion of understanding as something akin to an ability and shared understanding as the sharing of that ability, the possession of shared understanding makes no commitment about the nature of the realizing mechanism underlying shared understanding – two or more individuals could possess the same or similar understanding whilst using completely different realizing mechanisms. What implication does this have for our notions of who (or what) is deemed to possess shared understanding? Must it always be the case that notions of shared understanding are developed with regard to individual human agents, or can collections of human (and perhaps machine) agents also possess shared understanding?

Besides the question of whether shared understanding is something possessed by individuals, groups or machine entities, there is also the question of who *should* share understanding in particular task contexts. Military coalitions have complex group structures and group dynamics. Small *ad hoc* teams may be assembled in response to specific challenges, and large scale operations may necessitate complex patterns of inter-team coordination and collaboration. Such complexity raises questions about how we should identify which subset of individuals need to possess shared understanding, and what kind of shared understanding (e.g. scope and depth) they should possess.

What is the value of shared understanding?

A key question for future research in coalition contexts is

[8] Of course, if the conjecture mentioned in the previous section about situation awareness being a form of dynamic situational understanding is correct, then we are justified in seeing sensemaking as a set of processes that (potentially) give rise to situation awareness (dynamic situation understanding), and which typically need to be executed in a more or less continuous fashion in order to maintain situation awareness (dynamic situational understanding).

the relationship between shared understanding and group performance outcomes. Shared understanding may be important for the accuracy, quality, volume and timeliness of task outcomes, and future research should clearly aim to explore this possibility. Another effect of shared understanding may be to enhance team processes or team behaviours. For example, shared understanding may improve inter-agent communication, enabling both human and synthetic agents to anticipate the information requirements of team-mates and provide them with advance information. Shared understanding may also improve the efficiency of communication or reduce the need for communication altogether. This can be useful in terms of reducing the burden on communication systems that may be limited in terms of their available bandwidth and power. Finally, it is possible that greater levels of shared understanding may deliver a number of beneficial 'psychoaffective' outcomes. These could include things such as improved morale, trust and team satisfaction.

Is shared understanding always desirable?

Even if shared understanding can be found to exert a positive effect on performance in some situations, it is by no means clear that we should strive to enhance shared understanding in *every* situation. There are clearly some situations in which shared understanding will be difficult to establish (e.g. multi-disciplinary teams of experts that are brought together to collaboratively resolve a complex problem). Moreover, in some situations, shared understanding may stifle creativity or contribute to negative group behaviours such as groupthink (Janis, 1982).

What factors contribute to shared understanding?

Inasmuch as SMMs can be considered as one of the realizing mechanisms for shared understanding, then some of the interventions that have been proposed to foster the development of SMM may be important in the quest to enhance shared understanding (Smith-Jentsch et al., 2008; Stout et al., 1999). It should be remembered, however, that many of these interventions are based on small-team situations and they may not be suitable for the kind of environments in which coalition operations are typically undertaken. In addition, coalition operations feature a diversity of groups differing with respect to factors such as entitativity, permeability, size, culture and opportunities for interpersonal (face-to-face) interaction. This suggests that the factors contributing to shared understanding may be highly heterogeneous, and that interventions aimed at enhancing shared understanding will need to consider the nature of groups, as well as the dynamics of inter-group interaction.

What kind of understanding is required?

The kind of understanding that needs to be shared by two or more agents will vary depending on the nature of the tasks in which the agents participate, as well as the nature of the agents themselves (e.g., whether they are all humans, software agents or some mixture of the two) (Sycara & Lewis, 2004). For example, shared understanding may target aspects of a particular situation, the dynamics of team interaction or the strategies that need to be pursued in order to realize task goals. Future research thus needs to be sensitive to the kind of understanding that is required in particular situations[9].

6. MEASURING UNDERSTANDING AND SHARED UNDERSTANDING

The notion that shared understanding is akin to the sharing of an ability (or something like an ability) does not necessarily help us in pinpointing a specific set of techniques that can be used to measure shared understanding. The characterization does, however, at least suggest that shared understanding is the kind of thing that *can* be measured. By casting shared understanding as a kind of shared ability, the process of measuring shared understanding emerges as the measurement of shared abilities. And abilities (shared or otherwise) are clearly the kinds of things that can (in principle) be measured. What seems to be important when it comes to the measurement of shared understanding is to determine the kinds of responses that warrant the ascription of understanding to an individual and then to develop a way of measuring those responses. So, if we want to determine whether two individuals have the same understanding of a specific situation, we may need to decide that the kind of understanding we are interested in is evidenced by an ability to 1) identify what events led to the current situation, 2) predict how the situation will evolve in the future, and 3) determine the kinds of constraints and opportunities that the situation presents for ongoing military actions. Following this characterization, we can devise tests that tap into these abilities. Admittedly, the process of designing and validating these tests is likely to be a difficult undertaking. In all likelihood, the nature of the tests to measure shared understanding will vary according to the measurement context – the kind of thing that is to be understood, the people who do the understanding, and so on. As such, the development of a single all-purpose test for shared understanding is something that is unlikely to be achieved. There may, however, be some value in looking at general approaches to the assessment of understanding. White and Gunstone (1992), for example, describe a range of techniques, primarily for use in educational contexts, that can be used to probe understanding. These include the use of concept maps, relational diagrams and word association tests. By adapting these techniques for specific application contexts (e.g., understanding military coalition plans), we might obtain measurements of understanding that can then be compared across multiple individuals.

In addition to these techniques, we might be able to draw on the idea that mental models can be used to index an

[9] It should also be remembered that multiple forms of shared understanding may be conceptualized (see Section 3.2), and that not all these forms of shared understanding require agents to posses similar or overlapping abilities. In some task contexts, it may make more sense to adopt a more distributed perspective with respect to shared understanding (see Section 3.3).

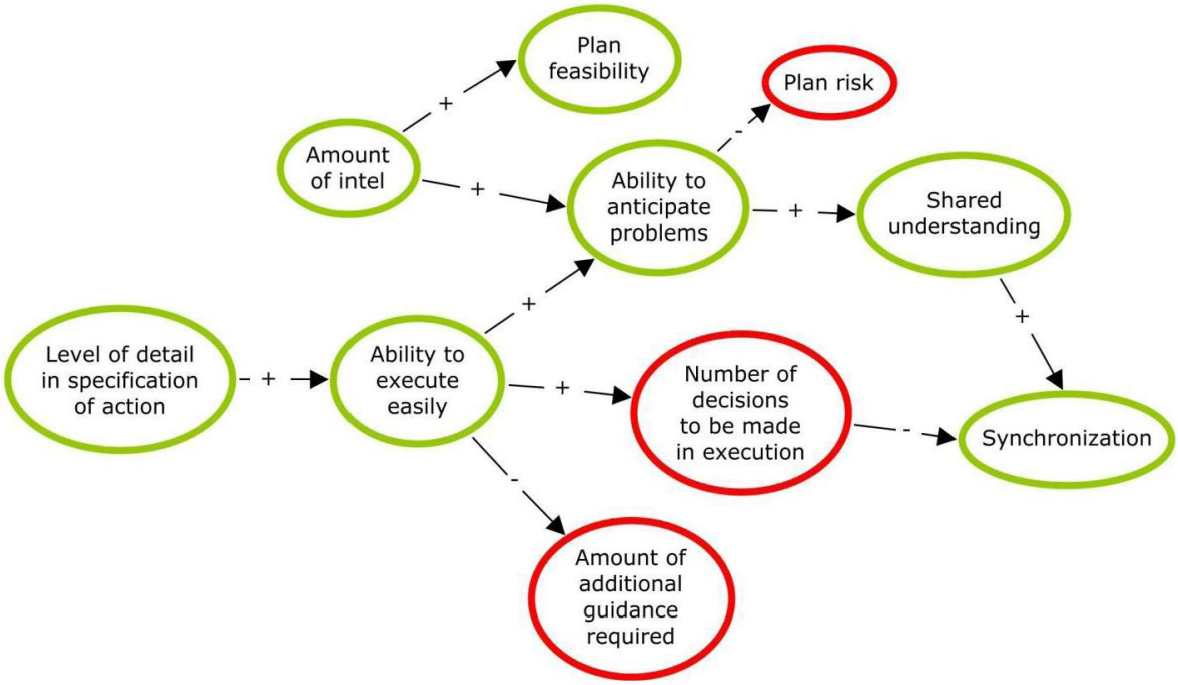

Fig. 1. Cultural model showing the dependencies between concepts in the domain of military coalition planning.

individual's understanding of some domain and that the similarity between mental models might therefore provide a measure of shared understanding. One type of mental model that may prove particularly useful here are cultural models (Sieck et al., 2010), which are typically used to support the analysis of cultural differences in target communities. Importantly, cultural models can be pitched at the level of specific individuals or groups, so their value in terms of measuring shared understanding is not just that they provide a means to assess inter-individual differences in shared understanding, they can also be used to assess differences in understanding between particular *groups*. This is important when it comes to a consideration of military coalitions. Because military coalitions feature multiple groups of individuals (e.g., from particular nations, military services or ethno-linguistic categories), we will often want to assess shared understanding at the group or collective level. That is, rather than focus on the extent of shared understanding between specific individuals (as we might do in the case of a small team), in a coalition context we often want to assess the extent of shared understanding between specific groups of individuals. This is a feature that is not easily provided by other approaches to measuring shared understanding (e.g., the approaches discussed by White and Gunstone (1992)), and, as such, the use of cultural models to measure shared understanding in coalition contexts may have much to commend it.

An example of a cultural model (in this case applied to the domain of military planning) is shown in Fig. 1. The nodes in this diagram represent concepts and properties associated with the domain of planning, and the linkages between the concepts reflect the community's beliefs regarding the relationships and dependencies between the concepts. The links associated with a plus sign reflect a positive association between the concepts (e.g., 'Level of detail in specification of action' has a positive effect on ease of execution (i.e. 'Ability to execute easily')), whereas the links associated with a minus sign reflect negative associations between the concepts (e.g., 'Ability to anticipate problems' has a negative effect on the perceived riskiness of a plan (i.e. 'Plan risk')).

One thing that makes cultural models interesting in terms of understanding is that their content is often based on an individual's or group's knowledge of causal contingencies in a particular domain of discourse. This establishes a natural linkage with previous attempts to provide a definition of understanding. Thus, Smart et al (2009b) proposed that understanding corresponds to an ability to exploit bodies of causal knowledge. Inasmuch as cultural models can be seen to represent the kind of knowledge that enables an individual to manifest behaviours (e.g., explanations and predictions of system states) that warrant the ascription of understanding to an agent, then they may provide a potential realizing mechanism for at least some forms of understanding. This is significant because it suggests that one way of measuring the similarity of understanding between agents (either individuals or groups) is to assess the structural isomorphism of the cultural models developed for the agents in question. If the models are identical, then the level of shared understanding between the agents concerned will be at its theoretical maximum; if the models bear no resemblance to one another, then shared

understanding will be at its minimum. In between these two extremes, we will encounter variable degrees of similarity between the models, and such similarity will (at least potentially) provide a measure of shared understanding.

What is required, then, is some way of computing the structural similarity of cultural models. This is where we encounter the first of three problems associated with the use of cultural models to assess shared understanding. The fact is that the technique used to develop cultural models (a technique known as cultural network analysis (Sieck et al., 2010) does not, at the present time, provide a means of assessing the structural isomorphism of cultural models. This problem might be addressed by turning to the literature on SMMs (Cannon-Bowers et al., 1990; Cannon-Bowers et al., 1993). SMMs are mental models that are possessed by multiple individuals, and they are typically operationalized as the correlation between link-weighted networks using Pathfinder analysis (Schvaneveldt et al., 1985). The adaptation of such techniques for the comparative analysis of cultural models may serve as the basis for deriving future quantitative measures of cultural model similarity.

Two additional problems are associated with the use of cultural models to index shared understanding. Firstly, the process of creating cultural models is somewhat labour-intensive. This means that it might not be suitable for all cases in which shared understanding needs to be assessed. Secondly, it is not always clear that structural differences in cultural models necessarily indicate differences in understanding. The reason for this is twofold: firstly, a cultural model does not equate to understanding, and, secondly, differences in cultural models need not result in different abilities. In terms of the former issue, there is a tendency, sometimes encountered in the human factors literature, to equate the notions of understanding and mental models. As was discussed in Section 4.1, this is misconceived.

The second reason why structural differences in cultural models do not necessarily indicate differences in understanding is because of what has, in the shared cognition literature, been referred to as equifinality (Mathieu et al., 2005). This is the idea that two or more individuals may be able to generate the same expectations and explanations despite expressing differences in their respective mental models. This is important because it is typically the expectations and explanations that are deemed to be the main focus of interest from the perspective of team performance. As Cannon-Bowers et al (1993) argue: "[the] function or benefit of shared mental models is that they lead to common expectations of the task and team, it is the expectations rather than the mental models themselves that must be shared." Something similar can be seen to be the case for cultural models. Thus, from the perspective of understanding, what counts are the performances that manifest understanding, not the mechanisms that make such performances possible. While similar cultural models may be highly suggestive of similar abilities, particularly when it comes to forming explanations and predictions in the target domain, it need not be the case that such differences will *always* translate to differences in inter-individual understanding.

Despite these caveats, the use of cultural models to index shared understanding may be of value in at least some contexts. Thus, while differences in cultural models need not always indicate a lack of shared understanding, some types of cultural model may be much more suitable than others in terms of revealing such differences. For example, if the content of the cultural model is focused on an individual's causal knowledge of some domain, then it seems likely that differences in the cultural models will reveal at least some differences in the explanatory and predictive abilities of the individuals concerned. Further research needs to be undertaken in order to explore this possibility.

7. REPRESENTING SHARED UNDERSTANDING: A NETWORK-BASED APPROACH

In undertaking scientific research on shared understanding, researchers need analytical and presentational techniques that support their understanding of the various factors that influence shared understanding. One recent suggestion is to use network-based representations to support the analysis of shared understanding (Smart et al., 2010e). This approach is based on the use of semantic networks, which have been used on the organizational communication literature, to explore the shared interpretations that people have of organizational message content. The current section outlines the use of semantic networks to represent, visualize and analyse shared understanding in military coalition contexts.

7.1. Semantic Networks

In order to explore the shared interpretations that people have of organizational message content (particularly those messages that highlight important elements of an organization's culture, such as corporate goals, slogans, myths and stories), Monge and Eisenberg (1987) developed a technique that relies on the network-based articulation of individual differences (and similarities) in the interpretation of message content. The basic approach adopted by Monge and Eisenberg (1987) was to measure peoples' interpretations of message content, and then create a network of weighted links, with each node in the network representing a specific individual and each link representing the extent of agreement between individuals. They referred to the resulting network as a 'semantic network'[10].

[10] It is important to understand that the notion of a semantic network in this context differs from that which is encountered in the artificial intelligence and cognitive science literatures. In the organizational communication literature, the notion of a semantic network refers to the similarity of individuals' interpretations of particular things (e.g., messages, events or artefacts), whereas in the artificial intelligence and cognitive science literatures the notion of a semantic network most commonly refers to a network representing the semantic relations between a number of concepts. The use of the term 'semantic network' in the

The process of constructing a semantic network is quite straightforward. Given a set of scores reflecting peoples' response to organizational messages (or anything else), we can construct a network of weighted linkages that reflects the extent of inter-individual similarity between those scores. Although it is possible to include the links between all individuals in these networks (i.e.. to produce fully-connected semantic networks), it is often more useful to restrict the number of links that appear in the network. An upper threshold can be imposed on the inter-individual similarity scores in order to determine what similarity scores will actually appear in the final network. The application of this filter results in a variety of complex network structures.

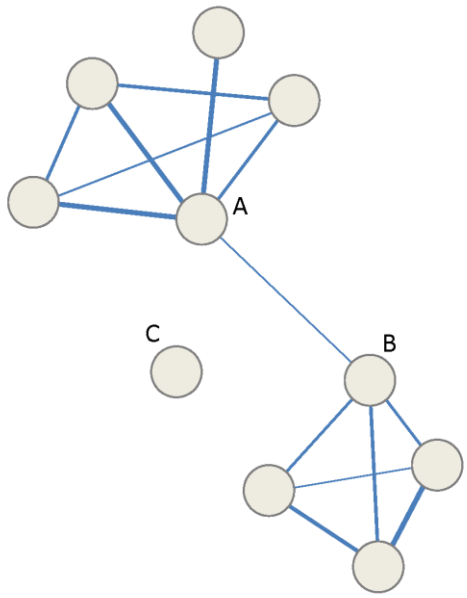

Fig. 2. Semantic network of inter-individual similarity scores following the application of a threshold criterion (any link with a weighting value below a specified value is eliminated from the network).

Fig. 2 illustrates a semantic network constructed from a matrix of inter-individual similarity scores following the application of a threshold criterion. The number of nodes in this network corresponds to the number of people in the target population. The network-based representation reveals a number of important facts about the distribution of interpretations in the target population. For a start, we can see from Fig. 2 that there are two distinct clusters of individuals. These clusters (or cliques) represent two sub-groups that are differentiated with respect to their interpretations. Within each sub-group, individuals share similar interpretations, but these interpretations are different from those of individuals belonging to the other subgroup. We can also see that one individual (node C) is an isolate. This individual has an interpretation that differs from all other members of the focal population. Another feature of the network representation is its ability to highlight nodes of particular interest. Thus, we can see that nodes A and B are 'bridging' or 'liaison' nodes. They provide weak links between one sub-group and the other sub-group. Such nodes may have particular significance when it comes to understanding the contribution of particular individuals to coordinating interpretations between different sub-groups. Other features of the network representation include the following:

- the overall connectivity of the network highlights the degree or extent of commonality in the interpretations of the entire population,
- the number of links associated with a specific individual indicates that that individual has interpretations in common with lots of other individuals
- a disconnected component (disconnected subset of nodes) indicates a group of members who lack any commonality with the wider population, and
- an individual who has high degree centrality in the semantic network is one who shares interpretations in common with many other individuals.

The question that emerges at this point is to what extent semantic networks can be usefully applied to support the analysis of shared understanding. In fact, the application is quite straightforward since the distinction between the notions of shared interpretations and shared understanding is not one that is necessarily clear-cut. Monge and Contractor (2003), for example, suggest that a semantic network "provides a picture of the groups of people who share common *understandings*" (pg. 187) [emphasis added]. In the next section, we move away from a discussion of shared interpretations and talk explicitly about the use of semantic networks to support the visualization and representation of shared understanding.

7.2. Using Semantic Networks to Represent Shared Understanding

One thing that should be clear from the discussion in Section 7.1 is that providing we can obtain a reliable measure of individual understanding, we can easily create a network-based representation of shared understanding. Nothing restricts the application of semantic networks to interpretations of message content, and, providing we can measure understanding, the process of developing a semantic network representation of shared understanding is relatively straightforward. When used to represent shared understanding, semantic networks yield a number of important benefits and opportunities. For example, the network-based representation supports the easy visual identification of particular features, such as those listed in Section 7.1. Thus, semantic networks can reveal individuals (known as 'stars') whose understanding is similar to those of many others, individuals that serve to link two or more otherwise disconnected groups (known as 'liaisons'), and individuals whose interpretations are at odds with everyone else's (known as 'isolates'). The structural profile of a

current paper is intended to reflect the former usage of the term; i.e., a semantic network refers to a network representation of inter-individual similarities (or differences).

semantic network across time can also reveal important insights as to how shared understanding emerges within a particular community. A sudden transition in network density, for example, indicates discontinuous jumps in the level of shared understanding, while a slow, progressive increase in network connectivity indicates a more gradual form of emergence. Importantly, this ability to monitor dynamic changes in network structure across time has profound implications for the scientific study of shared understanding. Any manipulation that enhances shared understanding within the target population will be reflected in an increase in the overall connectivity of the network, as well as an increase in the strength of connections between particular nodes. A decrease in shared understanding will be reflected in a progressive weakening of the connection strengths and, eventually, a fragmentation of the network into distinct components. As such, the structural analysis (across time) of semantic networks can serve a number of useful purposes. In particular, it can highlight important changes or fluctuations in shared understanding (as when a previously highly connected network component, reflecting high levels of shared understanding, begins to fragment into smaller constituents). It can also (potentially) shed light on the ways in which shared understanding develops within a community across time. For example, if we note that a semantic network (representing inter-individual commonalities in understanding) begins to grow according to a particular law (say the law of preferential attachment), then we can hypothesize that the understanding achieved by certain individuals (those to which others preferentially attach) may represent a form of understanding through which all individuals must go *en route* to the realization of shared understanding. Semantic networks may also help us understand some of the factors that contribute to changes in shared understanding. For example, we can monitor dynamic changes in the values of particular network-level variables (e.g., average path length, inclusivity, density, centralization, etc.), or the variables associated with particular nodes (e.g., degree, centrality, closeness, etc.), in response to certain manipulations or events. Of particular interest, is the fact that we can use semantic networks to assess the effect of other types of networks on dynamic changes in a community's shared understanding. Thus, suppose we are interested in how the topology of a communication network impacts the emergence of shared understanding within a community. We can begin to assess this by investigating how the features of one network (the communication network) affect the features of another network (the semantic network). This was, in fact, one of the early motivations for introducing semantic networks into the organizational communication literature:

> "An early motivation for the study of semantic networks was to disambiguate the relationship between communication and shared understanding. A semantic network perspective challenges the received view that communication does, or even should, lead to shared interpretations and understanding. The focus therefore is on understanding how other relations among individuals may influence a semantic relation, which is a relation of shared interpretations among people" (Monge & Contractor, 2003, pg.187)

One might assume that increments in the density of communication networks would lead to greater convergence in understanding and increases in the density in semantic networks, but this may not necessarily be the case, especially once one begins to factor in the psychological processes that regulate understanding at the individual level. To date, very few studies have examined how changes in one type of network influence the dynamic structural profile of semantic networks. In one study, however, Contractor and Grant (1996) examined the effect of social contagion in communication and semantic networks using a computer simulation approach. They found that the latency for semantic convergence (i.e., the time required to develop a common interpretation or shared understanding) was positively related to the initial density of the communication and semantic networks, inversely related to the heterogeneity of the communication network, and inversely related to the individual's resistance to social influence. Studies such as this provide an interesting starting point for further simulations that aim to examine the effect of multiple networks (e.g., communication networks) on the dynamic profile of shared understanding within a particular population (e.g., military coalitions). Ideally, such simulations should aim to include at least some of the factors that affect an individual's resistance to particular kinds of knowledge and information, for example, the pre-existing level of consistency in an individual's belief network (see Smart et al., 2010d). Above all, what should now be clear is that semantic networks do not merely provide a representational format that supports the easy visual identification of particular features associated with a community's understanding, they also pave the way for applications and analyses that benefit from the tools, techniques and concepts made available by the emerging science of networks (see Watts, 2003). By developing a network-based articulation of shared understanding, we make it amenable to various forms of network scientific investigation.

7.3. Applying Semantic Networks to Military Coalitions

We have already discussed a number of ways in which semantic networks might support the analysis and monitoring of shared understanding, and these benefits are clearly applicable to military coalitions. Thus, the identification of groups of individuals, distinguished on the basis of shared understanding, might yield important insights into how factors like nationality, training, language, attitudes and values contribute to shared understanding (or misunderstanding). Such groups also raise a number of interesting questions regarding the way in which coalition teams should be formed (for example, should the teams be formed based on the identified groups?) and the way in which communication policies are established (should special measures be taken to monitor the communications

taking place between the members of different groups, perhaps as a means of dealing with the risk of miscommunication?). Other benefits to military coalitions include the ability to monitor the effectiveness of interventions designed to enhance shared understanding (an effective intervention is thus one that increases the overall connectedness of the network and increases the strength of network linkages); an ability to associate coalition performance outcomes with particular semantic network configurations (for example, do certain types of semantic network topology predict better performance outcomes?); and an ability to undertake network science simulations that reveal the potential effect of changes in social networks and physical infrastructure networks (e.g., MANETS) on the topological organization of semantic networks (see Contractor & Grant, 1996, for some initial simulation results in this area).

8. FUTURE RESEARCH ON SHARED UNDERSTANDING IN MILITARY COALITIONS

Future research into shared understanding in military coalition contexts could assume a variety of forms. As discussed in Section 5.2, there are a wide variety of issues and challenges for those engaged in shared understanding research, and these could all serve as the focus of future research efforts. One of the issues that is of perhaps the greatest interest at the present time concerns our understanding of the factors that influence shared understanding in military coalitions. In particular, we need to understand what features of the military coalition communication environment support the emergence of shared understanding and what factors undermine shared understanding once it is established. This is, in fact, the focus of one of the research components of the ITA research program. The following discussion describes, in broad outline, the nature of the work to be undertaken in the 2011-2013 timeframe.

One way in which we might develop a better understanding of the factors affecting shared understanding in military coalition environments is to develop a computational model of military coalitions and then systematically manipulate model parameters in order to understand how these parameters affect variables related to shared understanding. This simulation-based approach has a number of advantages compared to real-world empirical studies. For example, it avoids the cost (or risk) of running large-scale coalition-based experiments, and it also enables the research community to explore 'what-if' scenarios involving the systematic manipulation of variables that would simply be too impractical (or dangerous) to manipulate in real-world contexts[11]. Despite the advantages, however, there are a number of issues and concerns associated with the use of simulation studies. Notwithstanding the difficulty of modelling and measuring shared understanding *in silico*, we also have to confront the complexity of the modern military communication environment. To make the results of simulation studies relevant to military coalition operations, we have to ensure that we adequately identify and represent those features of the military communication environment that might affect shared understanding.

The proposed approach to addressing these challenges is twofold. Firstly, as regards the modelling of coalition communication environments, we can readily identify a set of features that could serve as the initial targets of simulation-based research. These features include the following:

1) Variable, time-variant inter-agent trust relationships (particularly trust relationships that change as a result of previous interaction or experience).
2) Variable certainty in information received from external sources (e.g., variable certainty assigned to information from particular sensors).
3) Variable confidence or certainty in one's own beliefs and that of other agents[12].
4) Group-specific differences in communication network structure.
5) Partial and restricted views of relevant environmental information (e.g., different agents have different levels of access to particular sensor feeds or information sources).
6) Information sharing policies (some information may be shared among the coalition, while other information may have limited distribution due to security constraints[13]).
7) Ambiguous, conflicting and uncertain information.
8) Differences in background knowledge and beliefs (e.g., cultural differences).
9) Linguistic differences (these may, on occasion, result in the misinterpretation of communicated information (see Poteet et al., 2008)).

In terms of the second challenge – modelling and measuring shared understanding – we propose to use a multi-agent simulation technique in which the extent of shared understanding will be indicated by commonality of belief states across multiple (synthetic) agents. The beliefs of each agent, in this case, will reflect their interpretation of some

[11] This is not to say that real-world studies should not be undertaken. The role of multi-agent simulation work should be twofold: firstly, to verify the results of real-world studies and to determine the precise conditions under which the results hold; secondly, to inform, guide and inspire the direction of future empirical research. In particular, multi-agent simulations play an important role in the development of theoretical predictions and testable hypothesis that can then be evaluated in the context of real-world empirical studies.

[12] Previous research has identified confidence in one's own beliefs to be a key factor in some cases of collective cognitive processing (Kuhn & Sniezek, 1996; Van Swol & Sniezek, 2002).

[13] This profile of information sharing may be the result of the kind of errors and biases seen in group-based research (e.g. the common knowledge effect; Stasser & Titus, 1985).

external source of information, and they will be permitted to communicate their interpretations to other agents based on the constraints imposed by the (simulated) communication network. In developing this simulation capability, we aim to draw on previous work in the multi-agent simulation community; however, not all previous work in this area is necessarily relevant to our research goals. In particular, a review of multi-agent simulation work reveals a number of shortcomings relative to the demands of the current project. These include (but are necessarily not limited to) the following:

- **Psychological Realism.** As described by Smart et al (2010c), any simulation study should include a judicious mix of psychological realism and real-world simplification, but the problem with many multi-agent simulations is that the agents are too rigid and simplistic to be even approximate simulacra of their real-world human counterparts. In many cases, the agents are simply represented by single, time-variant numerical values, and they lack any kind of internal cognitive processing capability. This is a crucial limitation, and one that needs to be addressed in the context of future work on collective cognition (see Sun, 2001).
- **Variable Network Structure.** Another shortcoming of multi-agent models (and even social psychological studies) concerns the fact that the communication structure is often fixed throughout the course of cognitive processing. This is a very unrealistic representation of the social world, and it is also fails to adequately reflect the nature of military coalition environments (in particular, their use of mobile *ad hoc* communication networks). Furthermore, our own work in the ITA program has shown that dynamic networks sometimes have cognitive processing advantages that may be absent in their more statically-configured counterparts (Huynh et al., 2010; Smart et al., 2010b; Smart et al., 2010d). What this suggests is that further research on dynamic networks, specifically in relation to the variable nature of coalition communication networks, should be an important focus of future research efforts.
- **Group-Level Abstractions.** A further concern that is inspired by a consideration of the military coalition environment relates to the absence of inter-group relationships in many simulation studies. The interaction between agents from different groups is a vital consideration for coalition-oriented research because military coalitions consist of multiple *groups* of individuals that can be differentiated in terms of language, culture, training, expertise, and so on. Despite the fact that inter-group factors have been shown to be important for collective cognitive processing[14], this aspect of collective cognition has largely been ignored by previous simulation efforts.

Addressing these shortcomings requires the development of a simulation capability in which 1) the agents possess cognitive properties that are approximate simulacra of those seen in human agents, 2) the communication network structure is highly dynamic and configurable, and 3) the behaviour of agents is subject to group-level influences. Meeting these requirements is a significant challenge; however, there are a number of existing models which might serve as a useful point of departure. The extant models all feature the use of what might be called a 'network-of-networks' approach to collective cognitive simulation. In all cases, the agents are represented by networks of representational and computational elements, which are themselves connected together by inter-agent channels of communication. One such model was proposed by the cognitive anthropologist Edwin Hutchins (1991). Hutchins (1991) used a network of constraint satisfaction networks to model the way in which a collection of agents responded to ambiguous environmental information. He showed that when agents are allowed to share information from the outset of the simulation they rapidly converge on a particular (sometimes inaccurate) interpretation of environmental information, and they subsequently discount competing interpretations. Hutchins (1991) thus developed a compelling model of group-level confirmation bias and showed that under certain circumstances it can be even more extreme than individual forms of confirmation bias. A second model is the 'Talking Nets' model of Van Overwalle and Heylighen (2006). The interesting feature of this model is that it explicitly includes a representation of inter-agent trust (referred to as 'cognitive trust'), and it shows how a dynamic profile of inter-agent trust relationships contributes to the emergence of a number of notable collective cognitive phenomena. Finally, our own research in the ITA has led to a multi-level model for socially-mediated cognitive change (Smart et al., 2010c; Smart et al., 2010d). The specific value of this model is that it incorporates group-level abstractions, which (in the current version of the model) roughly correspond to distinct cultures. The model therefore provides a means by which collective cognitive processes can be examined in complex multi-group (multi-cultural) situations, similar to those encountered in military coalition contexts.

Once a simulation capability is available, it will be used to study the effect of a number of variables on collective cognition. The specific questions we intend to address as part of this research include the following:

1) How does the topological structure of the communication network affect the ability of a group of agents to form an accurate interpretation of ambiguous/conflicting sensor information? How do inter-group differences in communication network topology (e.g., high intra-group connectivity and low inter-group connectivity) influence cognitive convergence?

[14] For example, Mackie and Cooper (1984) found that people's attitudes were strongly influenced by a member of the same group, but were much less affected by an individual who was seen as an outsider.

2) What effect does inter-agent trust have on the ability of a coalition to converge on an accurate interpretation of ambiguous information? If we assume that intra-group trust relationships (e.g., between individuals of the same nationality) are stronger (at least initially) than inter-group ones, what impact does this have on the potential for accurate convergence?

3) How do cultural differences in agents' pre-existing belief structures affect the dynamics of cognitive convergence and divergence (this issue is discussed at length in Smart et al (2010d) and Smart et al (2010c)).

4) What effect does partial information sharing have on cognitive convergence? If some information is shared and the rest is not, what impact does this have on collective interpretation capabilities? Previous research suggests that the shared information will bias decision outcomes at the expense of non-shared information (Stasser & Titus, 1985), but can this bias be attenuated if information sharing is restricted to specific sub-groups?

5) What effect does differential exposure to ambiguous sensor information have on cognitive convergence? Is it better for ambiguous sensor information to be diffusely spread across a community of agents, or does it help if sensor information is restricted to particular sub-groups of agents?

The result of running simulations to answer these questions will be an improved understanding of how (some) features of the military coalition environment (for example, group differences in communication network structure) affect the formation of a common coalition-wide interpretation (or shared understanding) of ambiguous, uncertain or conflicting situations[15]. Inasmuch, as we are able to equate the notions of dynamic situational understanding and situation awareness (see Section 4.2), it may be that these results also shed light on the factors that affect the emergence of SSA in military coalition contexts.

9. CONCLUSION

The primary aim of this paper has been to improve our understanding of both individual and shared forms of understanding. Such an improvement is important given the perceived significance of shared understanding to coalition operations and the current focus of ongoing research efforts into coalition capabilities (shared understanding has, for example, been recognized as a major research challenge in the context of the ITA research program). Unfortunately, the notion of understanding is something that has proved notoriously difficult to understand, and this is the source of considerable confusion in both the philosophical and scientific literatures.

In spite of the definitional difficulties, we have seen that the expression of behaviours that manifest at least some kinds of understanding (e.g. situational understanding and the understanding of intentional actions) *do* seem to have some common features. These include an ability to make inferences about the unseen and perhaps forever unobservable. In essence, what we encounter in many cases of understanding is an ability to 'see more than meets the eye'. Often these inferences give a predictive and explanatory grasp on the thing that is to be understood, and they often enable us to express thoughts and actions that are suited to the realization of diverse goals. Although we do not agree with Føllesdal (1981) that understanding is a particular form of knowledge, it is true that, in many cases, understanding is evidenced by the expression of a flexible performance ability, and this ability seems to rest on the exploitation of particular bodies of knowledge. Perhaps if we were to attempt to capture the essence of understanding it would be this ability to use our knowledge in highly flexible, adaptive and context-sensitive ways that would most occupy our attention. Understanding often seems to be ascribed when people are able to use their knowledge to solve particular problems – the performances that manifest understanding are often cases of, what we might refer to as, 'knowledge in use'.

The characterization of understanding as akin to an ability sheds light on what it means to have shared understanding. Shared understanding, we have suggested, implies similarity of understanding with respect to particular things, for example, goals, tasks, and situations. In the case of coalition operations, the abilities that are likely to emerge as important are those related to the formation of expectations and predictions regarding future actions, events and information requirements. Shared understanding is therefore likely to be important in coalition contexts for a variety of reasons. For example, it may enable coalition members to anticipate one another's information requirements and thereby optimize the distribution of information within a network environment (i.e., it may enable information to be sent to the right place at the right time). Inasmuch as shared understanding contributes to the deployment of efficient modes of inter-agent communication and coordination, it may have particular value in the context of coalition operations. This is because coalition environments are often resource constrained environments in which power overheads and network traffic must be kept to a minimum. If shared understanding improves the efficiency of inter-agent communication (perhaps reducing the need for communication altogether), it may optimize the use of limited network assets.

We have seen that there are a number of important areas for future research on shared understanding. One of these areas is a theoretical undertaking: an attempt to identify the precise relationships between shared understanding and other human factors constructs, such as shared situation awareness, shared mental models and team sensemaking. Another focus of research attention concerns techniques and

[15] The representational and visualization techniques discussed in Section 7 and Smart et al (2010e) provide a potential means by which the dynamics of cognitive convergence in the synthetic agent community might be analyzed and understood.

methods to measure shared understanding. Finally, we need to develop a better understanding of the factors that affect shared understanding in military coalition environments. In particular, we need to understand how specific features of the military coalition communication environment affect the emergence, maintenance and disruption of shared understanding between culturally- and linguistically-disparate groups. Research in the next phase of the ITA program will attempt to shed light on precisely this issue. The work will attempt to identify and model particular features of the coalition communication environment that affect shared understanding. It will then use multi-agent simulation techniques to explore the effect of those features on the emergence of shared understanding in synthetic agent communities. The outcome of this research will be a better understanding of how at least some features of the coalition communication environment affect understanding. It will also begin to shed light on how future technologies might be used to regulate shared understanding in ways that enable military coalition organizations to adaptively coordinate (or synchronize) their collective behaviours in support of common mission objectives.

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