Proc. IEEE Network Science Workshop, West Point, NY, April 29-May 1, pp. 122-125.

Challenges of Social Cognitive Network Science:

Network Science Collaborative Technology Alliance Perspective

Keryl Ann Cosenzo
Human Research and Engineering Directorate
US Army Research Laboratory
Aberdeen Proving Ground, MD USA
Keryl.a.Cosenz.civ@mail.mil

Boleslaw Karol Szymanski
Social Cognitive Networks Academic Research Center
Rensselaer Polytechnic Institute
Troy, NY, USA
szymab@rpi.edu

***Abstract*—This paper reviews challenges and summarize the progress accomplished by the Social Cognitive Networks Academic Research Center of the Network Science Collaborative Technology Alliance. The focus is on potential impact that this research may have on unique needs of military, foremost the US Army, to effectively and efficiently operate in the increasingly complex and interconnected networks of societies and their component communities. The review of the progress and current status of research of the center provide state-of-the-art view of the relevant areas of social cognitive network science.**

Keywords—social cognitive networks; communities; trust; team performance

I. INTRODUCTION

Three years ago, the Army Research Laboratory created the Social Cognitive Networks Academic Research Center as a part of the Network Science Collaborative Technology to investigate challenges and explore opportunities in the newly arising research area of social cognitive network science. In this paper we present a vision and an agenda for the research in social and cognitive network science that we believe can have the strong impact on how large organizations, both civilian and military, operate in newly arising complex societies in increasingly interconnected world. The focus of the presentation is on the US Army challenges and opportunities in this area.

A. The Army Challenge

The Army is increasingly changing into a large, interacting and layered network of military personnel communicating across echelons. There is a dependence of military personnel on the robust interaction of networks at the communication, information, cognitive, and social level. The challenge is to provide the right information to the right Soldiers at the right time in the right format. Increasingly, information sources are embedded in complicating network of networks and the Army missions operate with, around or against some of these networks. Network science can enable efficient analysis of the networks involved and understanding of impact of missions on those networks. We seek to improve Soldier performance in such complex network-enabled environments. Networking capabilities can allow for improved information extraction and, sharing, which in turn will enhance the quality of information and shared situational awareness. However, we do not have a firm grasp of the socio-cognitive variables that interplay in performance in complex network enabled environment or even in its simplest case of a distributed but well-defined team.

The current force Soldier is overburdened with data but lacks information. Soldiers are getting information from disparate nonintegrated sources such as radios, text messages, emails, sensors and ground and air unmanned assets. Current interfaces support the presentation of information to the Soldier but the tailoring capability is not yet fully adaptive. For example, the battalion has access to many networks assets (e.g., TiGR) and thus should have been able to provide better data to the units on the ground to facilitate their mission planning and execution. However, the data comes from various inputs (e.g., personal interviews with indigenous personnel conducted by Human Intelligence teams) and as such can greatly vary in the quality of reporting accurately what the situation on the ground is. Yet, knowing the situation on the ground is essential to understanding activities in the area of interest and to developing a mission plan. Techniques to process vast amounts of data, convert it into actionable information, and assimilate different media on displays are not fully mature. Research is needed to develop tools and techniques to integrate information across the network layers for better information management and planning. Network science can improve the quality of information flow and validation of the data to enable optimal performance.

B. Army Network Science Research Program

Many experts agree that network science can be defined as the study of the properties, models, and theories that apply to many varieties of networks that leads to the understanding of how different genres of networks dynamically interact and co-evolve, and to the use of this understanding in the analysis, prediction, design, and influence of many varieties and systems of networks. The Army has instantiated a basic collaborative

Research was sponsored by the Army Research Laboratory and was accomplished under Cooperative Agreement Number W911NF-09-2-0053. The views and conclusions contained in this document are those of the authors and should not be interpreted as representing the official policies, either expressed or implied, of the Army Research Laboratory or the U.S. Government. The U.S. Government is authorized to reproduce and distribute reprints for Government purposes notwithstanding any copyright notation here on.

research program in Network Science called the Network Science Collaborative Technology Alliance (NS CTA). The Alliance unites research across organizations, technical disciplines, and research areas to address the critical technical challenges posed by the complex web of interacting networks within which the Army mission must be performed.

The objective of this program is to extend a fundamental and cross-cutting understanding of interdependency, relations and common underlying network science principles among social-cognitive, information, and communications networks and also to determine how processes and parameters in one network affect and are affected by those in other networks.

Many of the payoffs envisioned by the Army's transformation to network-enabled operations — from improved situational understanding to greater mission effectiveness — are at the sociotechnical and cognitive levels.

C. Social-Cognitive Network Science

The research in Social Cognitive Network Science is aimed at the development of a fundamental understanding of social and cognitive networks and their impact on the U.S. Army networked operations, to develop underlying theory, and to create scientific foundations for modeling, simulation, measurements, analysis, prediction and control of social-cognitive network behavior. The research in Network Science contributes to the development of theory, measures, models, and understanding of social networks as well as Soldier cognition and work-processes involved in network-enabled operations. Advances in understanding the social and cultural landscape in theater of operations coupled with the ability to extract and process data and knowledge from the network can have a significant impact across all echelons of the Army. Advancements in network science can enable capabilities that will allow the platoon or squad to know more and communicate more broadly than it is possible today. With this fundamental knowledge, we can improve distributed collaboration and decision-making in complex, network-enabled operations and design networked environments to make the most effective and efficient interactions between human cognition/behavior and the network.

Social-Cognitive Networks Science examines the interconnections among diverse networks with an emphasis on the role that Behavior, Cognition, and Relationships play in governing network. Social-cognitive network science studies networks whose nodes are endowed with these three elements, as depicted in Fig. 1, which affect the dynamics of the network and ultimately have an impact on the decision maker. Key facets of social cognitive network science include relationships between people as the basis for forming networks in which connections are between people with cognitive constructs.

The Social-Cognitive Network Science component of NS CTA program focuses on a basic research approach directed at improving distributed collaboration and decision making in complex network-enabled operations using cognitive science, computer science, and social network innovations. This research includes behavioral aspects of networking, human behavior, and cognitive constructs impacted by networks, networks affecting the socio-cognitive factors, relationships affected by socio-technical networks, and cognitive constraints on interactions with networks. The last factor includes limits on amount of information that humans can process and their perceptions, biases, and heuristics affecting activities in the network.

Army has instantiated a basic collaborative research program

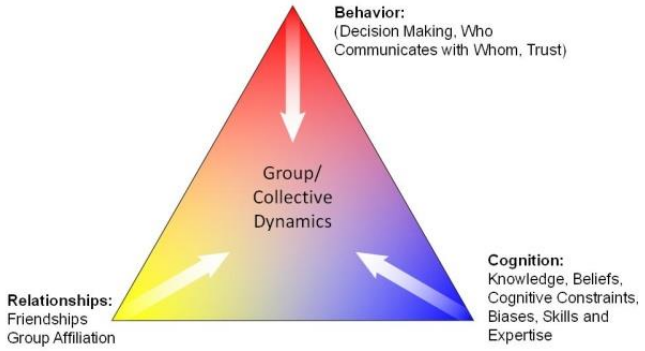

Fig. 1. Three elements of nodes of social cognitive networks.

Today, an important aspect of social cognitive networks is human perception of social interactions via socio-technical networks without personal contact and its context. It takes into account indirect, practical and theoretical relationship between trust, influence, proximity and mobility, not only of individuals but also of groups, and finding about how behavior is shaped by cognitive constraints, such as personality, cultural interaction, information processing, and decision making.

Within the Army research program, the Social-Cognitive Network Science Research Center (SCNARC) leads the research in this domain. SCNARC's objective is to gain a deeper understanding of how social cognitive networks form, operate, and evolve; how they affect the societies in which they operate; and how they affect the functioning of large complex networked organizations; to control, influence and predict behavior or outcomes. Its overall objective is consistent with the overall program objective of contributing to an understanding of the interplay between the communication, information and social networks and, specifically for SCNARC, their impact on cognition, behavior, and relationships in network contexts. SCNARC has three main technical areas, Socio-technical Systems, Influence and Control of Network Behavior, and Formal and Informal Networks.

1) Socio-technical systems

The research here aims at understanding the basic principles of socio-technical systems and networks. It includes formation of networks and answers the questions of how and why does this happen, what are the relational, behavioral, and cognitive drivers in the formation of networks, how do the individual elements in the network behave and what impact the individual capacities at the hub have, and vice versa, how does the network impact the individual and group behavior. Other questions include how the proximity and locations of human activities shape and are influenced by social relations and individual beliefs and attitudes, and how to create incentives in

a network to motivate behavior at the individual node or of an entire network, what are the dynamics of network interactions, and what characteristics of the individual are important for the individual's network interactions.

2) Influence and control of network behavior: The role of social and cognitive factors

Research in this area addresses how social incentives shape network behavior, what are key aspects of an individual that shape and influence behavior, and how to intervene in a network to get desired outcomes. The research aims also at optimization of knowledge dissemination, efficient strategies for discovery of social network behavior and outcomes, while taking into consideration the people in the network to maintain the performance of individuals, as well as the groups, and to avoid disruption of group behavior. Finally, this research seeks to discover which nodes control the network, the social cognitive abilities of such nodes, the fundamental time scales associated with transformational changes in social and techno-social networks, and the key individual-level, technological, endogenous, and exogenous factors and drivers influencing and controlling these macro-level time scales. It also seeks to find out how one can influence or control the underlying transformational changes and/or the associated time scales in social and techno-social networks.

3) Formal and informal networks: Social and cognitive network dynamics and discovery

Research in this area seeks to understand fundamentals of networks that make the individuals and organizations work well, including internal networks, collective cognition, formal networks and society as a whole, and informal networks, including adversarial networks. The issues being investigated include how we can (i) obtain informal and formal relationships from the network and robustly extract data about those relationships, (ii) gain insights about social elements of these relationships, and (iii) understand formal and informal networks and the interplay between the two.

II. Review of Current Research

Research in the Social Cognitive Networks Academic Research Center (SCNARC) can be classified into two classes: (i) core SCNARC research with tasks conducted by SCNARC researchers only, and (ii) inter-center research involving researchers from several centers and organized into four broad collaborative Thrusts.

Fig. 2 depicts classification of social networks according to network transparency and node hierarchy structure. The entire spectrum of social networks can accordingly be divided into four quadrants. Quadrant I includes externally visible networks with clear hierarchy structures. Examples of networks of this type include employees of a company, members and workers of the democratic governments and soldiers in regular military. The relevant research conducted in SCNARC in this area focuses on team formation and performance.

Quadrant II includes networks that are externally visible but have a hierarchical structures of their nodes ranging from flexible (e.g. a family) to nearly flat (e.g. a LinkedIt peer group). Critical issues in this area include community formation, link stability, spread of opinion, and understanding factors that impact social group choices and actions.

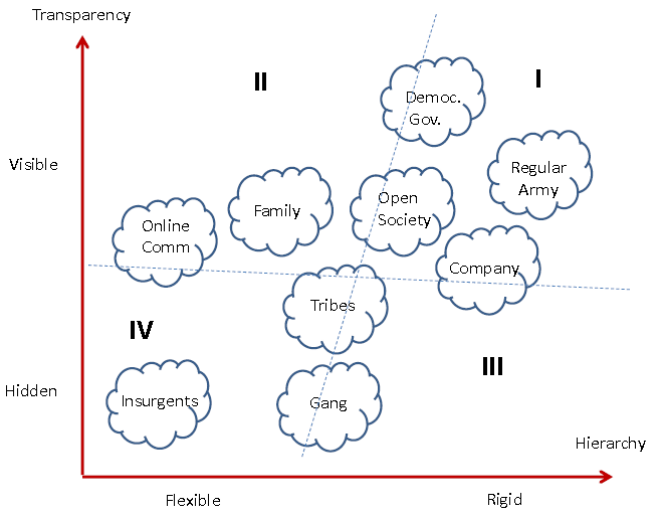

Fig. 2. Classification of social networks according to network transparency and node hierarchy structure.

Quadrant IV contains networks that are not easily visible and often actively attempt to remain hidden. The need for hiding limits the information about the network even among members, often making the entire hierarchy of its node partially unknown, leading to a flexible and distributed leadership. Examples include networks of insurgents, gangs, and even, to some extent, tribes, especially if they are in competition or fighting with other tribes or with central authority of the country. Initially limited to the geographical area in which they operated, today some of such hidden communities achieved global reach by the use of global media to spread their ideology, provide instructions and guidance, recruit new members and operate in flexible, often fully distributed manner with minimal or none personal contact between their dispersed units. The SCNARC research in this important area focuses on discovery, evolution and dynamics of such hidden groups and on understanding how they spread their ideology and opinions across societies.

Finally, quadrant III includes networks which are rigidly hierarchical and yet opaque to the outside world, so it is nearly empty, with social networks such as gangs, or tribes, lingering on the boundaries of this quadrant.

A. Core SCNARC Research

The core-SCNARC research focuses on three objectives. The first one is the development of models capturing the sensitivity of network behavior to network incentives, as studied in [1]. The basic questions addressed include how do we create incentives in a network to motivate behavior at the individual node or of an entire network? How do networks [2] and their links [3] form and evolve? What are the relational drivers in the formation of networks? Note that they may include drivers that are sociological (homophily based on broadly shared interests) economical (employment), political

interests (party membership), shared goals, etc. How does the environmental context (i.e., social dynamics) impact network behavior?

Another objective is to identify hidden networks using statistical and algorithmic methods based on social behavioral properties of hidden networks such as internal structure, stability and organization, as well as on their observed interactions, e.g. [4]. The third objective is to investigate the role of individual-level social drivers and mechanisms in understanding macro level behavior of the system including opinion spreading and influencing in social networks (see examples in [5]); the impact of indirect, practical and theoretical relationship between trust, influence, proximity and mobility, e.g. [6]; and understanding and utilizing the impact of composite (or multi-relational) networks in organizations on individual collective behavior, such as team performance. We address here questions such as what is the optimal strategy for discovering social network behavior and its outcomes? How can group behavior be disrupted? What are the fundamental time scales associated with transformational changes in social and cognitive networks? What are the key exogenous factors and drivers for influencing and controlling the networks and through which nodes the network can be controlled (see [7])?

These investigations form the basis for developing algorithms and predictive models to discover, influence, and control behavior for hidden, informal, and organizational networks.

B. SCNARC Research Contributions to Trust

Network Science Collaborative Technology Alliance (NS CTA) supports four interdisciplinary research Thrusts. The one most closely associated with SCNARC is Trust. It currently has three main research areas: (i) role of endogenous (cognition, e.g. [8]) and exogenous (social, context, see [9]) factors in the development of trust; (ii) impact of trust on Distributed Decision Making (DDM) and measurement, prediction and evaluation of trust for DDM, and (iii) network properties and trust: extraction and management. Accordingly, the research in Trust focuses on understanding the role trust plays in composite networks that consist of large systems with complex interactions between communication, information, and social and cognitive networks. Adding to the complexity, trust itself can be highly dynamic with uni- and bi-directional relationships forming, adapting, and dissolving at multiple timescales.

To address these dynamics, the NS CTA research in Trust ranges from the propagation and staging of data in the network to support for establishment of trust and to the revocation of network privileges or use in situations of distrust. Trust is contextual, and the degree of trust placed in a relationship can directly relate to factors that exist in each network type. Counterinsurgency (COIN) and Irregular Warfare (IW) place significant demands on trust tactical decision-making, as any number of social and cultural factors can influence relationships with the local population and governmental officials. Our work in developing models of trust in composite networks aims at identifying these factors and developing trust metrics than expose utility versus risk in specific courses of action. Trust plays also a significant role in how soldiers perceive and act upon information provided through tactical information systems.

The ultimate goal of these studies is to develop predictive models of trust and effective algorithms to measure trust in interactions within multi-genre networks to help to achieve optimal or near-optimal information transfer and decision-making in networked environments.

III. CONCUSIONS

The SCNARC research aims to develop fundamental scientific knowledge and theories underlying social cognitive networks to enable development of the predictive models and algorithmic tools for efficient incentive mechanisms for network activities, for predicting and influencing evolution of opinions in societies, for discovery and monitoring of hidden network, and for forming and maintaining high performance teams in organizational networks.

To achieve these objectives, SCNARC researchers continue developing models that capture the sensitivity of network behavior to network incentives; that identify hidden networks using statistical and algorithmic methods, that uncover the role of individual-level social drivers and mechanisms in understanding macro-level behavior of the system including opinion spreading and influencing in social networks; and that deepens our understanding and utilizes the impact of composite (or multi-relational) networks in organization on individual collective behavior, such as team performance. These investigations will form the basis for developing algorithms and predictive models to discover, influence, and control behavior for hidden, informal, and organizational networks.

IV. REFERENCES

[1] G. Pickard, W. Pan, I. Rahwan, M. Cebrian, R. Crane, A. Madan, & A. Pentland, "Time-critical social mobilization," *Science*, **334**(6055}, 2011, pp. 509—512.

[2] J. Xie, S. Kelly & B.K. Szymanski, "Overlapping Community Detection in Networks: the State of the Art and Comparative Study," *ACM Computing Surveys* **45**(4), 2013.

[3] R.N. Lichtenwalter, J.T. Lussier, & N. Chawla, "New perspectives and methods in link prediction, " *ACM SIGKDD Knowledge Discovery and Data Mining*, pp. 243—252, 2010.

[4] M. Goldberg, M. Magdon-Ismail, S. Nambirajan, & J. Thompson, "Tracking and predicting evolution of social communities," *Privacy, Security, Risk and Trust*, Conf. Social Computing, pp. 780—783, 2011.

[5] J. Xie, J. Emenheiser, M. Kirby, M. S. Sreenivasan, B.K. Szymanski, & G. Korniss, "Evolution of opinions on social networks in the presence of competing committed groups," *PLoS One*, 7(3), 33215, 2012.

[6] C. Song, Z. Qu, N. Blumm, N. and A.L. Barabasi, "Limits of predictability in human mobility," *Science*, **327**(5968), pp. 1018—1021, 2010.

[7] Y.Y. Liu, J.J. Slotine, & A.L. Barabasi, "Controllability of complex networks," Nature, **473**(7346), pp. 167—173, 2011.

[8] S. Saavedra, K. Hagerty, & B. Uzzi, "Synchronicity, instant messaging, and performance among financial traders," *Proc. Nat. Acad. Sc.*, **108**(13), pp. 5296—5301, 2011.

[9] S. Adali, R. Escriva, M. Goldberg, M Hayvanovych, M. Magdon-Ismail, B. Szymanski, W. Wallace, & G. Williams, "Measuring behavioral trust in social networks," *Intelligence and Security Informatics (ISI)*, pp. 150—152, 2010.