REPORT DOCUMENTATION PAGE

Form Approved OMB NO. 0704-0188

1. REPORT DATE (DD-MM-YYYY)	2. REPORT TYPE	3. DATES COVERED (From - To)
06-01-2016	Final Report	25-Apr-2014 - 24-Apr-2015

4. TITLE AND SUBTITLE
Final Report: Cooperative Team Networks

5a. CONTRACT NUMBER
W911NF-14-1-0188

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER
611102

6. AUTHORS
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5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAMES AND ADDRESSES
Northwestern University Evanston Campus
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Evanston, IL 60201 -3149

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS (ES)
U.S. Army Research Office
P.O. Box 12211
Research Triangle Park, NC 27709-2211

10. SPONSOR/MONITOR'S ACRONYM(S)
ARO

11. SPONSOR/MONITOR'S REPORT NUMBER(S)
65674-NS-CF.2

12. DISTRIBUTION AVAILABILITY STATEMENT
Approved for Public Release; Distribution Unlimited

13. SUPPLEMENTARY NOTES
The views, opinions and/or findings contained in this report are those of the author(s) and should not contrued as an official Department of the Army position, policy or decision, unless so designated by other documentation.

14. ABSTRACT
Understanding social processes that lead to wise decision making and peak performance is critical for predicting, evaluating and building successful teams. Over the past 50+ years there have been many conceptual developments in understanding teams. A team is formally defined as “an intact social system, complete with boundaries, interdependence for some shared purpose, and differentiated member roles. Teams are organized, either by design or by natural evolution, into structured relationships that are governed by interactions that involve power, influence,

15. SUBJECT TERMS
Teams, Networks, Computational Social Science, Performance

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	15. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			Brian Uzzi
UU	UU	UU	UU		19b. TELEPHONE NUMBER 847-/49-1807

Standard Form 298 (Rev 8/98)
Prescribed by ANSI Std. Z39.18

Report Title

Final Report: Cooperative Team Networks

ABSTRACT

Understanding social processes that lead to wise decision making and peak performance is critical for predicting, evaluating and building successful teams. Over the past 50+ years there have been many conceptual developments in understanding teams. A team is formally defined as “an intact social system, complete with boundaries, interdependence for some shared purpose, and differentiated member roles. Teams are organized, either by design or by natural evolution, into structured relationships that are governed by interactions that involve power, influence, and varying degrees of cooperation, control, flexibility and adaptability. Team networks enable groups of people to build knowledge, reach consensus, achieve breakthroughs, and generally perform complex problem solving that would not be attainable through either individual efforts or a sequence of additive contributions. A critical question in army commands is how to improve the performance of teams and of multi-team systems (teams that work together to carry out missions).

Enter List of papers submitted or published that acknowledge ARO support from the start of the project to the date of this printing. List the papers, including journal references, in the following categories:

(a) Papers published in peer-reviewed journals (N/A for none)

Received Paper

TOTAL:

Number of Papers published in peer-reviewed journals:

(b) Papers published in non-peer-reviewed journals (N/A for none)

Received Paper

TOTAL:

Number of Papers published in non peer-reviewed journals:

(c) Presentations

Studying Human Teams using Virtual Environments - Noshir Contactor (Northwestern), Alice Leung (Raytheon BBN)

Cooperation and Subset Team Games - Elisha Peterson (Applied Physics Lab)

Analyzing Frontiers of Science - Daniel Romero (Michigan), Satyam Muhkerjee (Northwestern), Ben Jones (Northwestern), and Brian Uzzi (Northwestern)

Cooperative sensing, communication, information, and decision networks - Darryl Ahner (AFIT: Air Force Inst Tech)

Panel Session: Mathematical Models of Cooperation
Prithwish Basu (Raytheon BBN)
Chjan Lim (RPI)
Josh Lospinoso (US Army, Cyber)

Panel Session: Social Models of Cooperation
Brooke Foucault (Northeastern University)
Allison Abbe (Synergist, LLC)
Yulia Tyshchuk (RPI)

Plenary Talk: Leadership and Networks
Leslie DeChurch (Georgia Tech)

Number of Presentations: 11.00

Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

Received Paper

TOTAL:

Number of Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

Peer-Reviewed Conference Proceeding publications (other than abstracts):

Received Paper

TOTAL:

Number of Peer-Reviewed Conference Proceeding publications (other than abstracts):

(d) Manuscripts

Received | Paper

TOTAL:

Number of Manuscripts:

Books

Received | Book

TOTAL:

Received | Book Chapter

TOTAL:

Patents Submitted

Patents Awarded

Awards

Graduate Students

NAME	PERCENT_SUPPORTED
FTE Equivalent:	
Total Number:	

Names of Post Doctorates

NAME	PERCENT_SUPPORTED
Daniel Romero	1.00
Yulia Tyshchuk	1.00
FTE Equivalent:	**2.00**
Total Number:	**2**

Names of Faculty Supported

NAME	PERCENT_SUPPORTED	National Academy Member
Noshir Contractor	1.00	
Alice Leung	1.00	
Elisa Peterson	1.00	
Darrly Ahner	1.00	
New Entry	1.00	
Chjan Lim	1.00	
Joah Lospinoso	1.00	
Brooke Foucault	1.00	
Allison Abbe	1.00	
Leslie DeChurch	1.00	
FTE Equivalent:	**10.00**	
Total Number:	**10**	

Names of Under Graduate students supported

NAME	PERCENT_SUPPORTED
FTE Equivalent:	
Total Number:	

Student Metrics

This section only applies to graduating undergraduates supported by this agreement in this reporting period

The number of undergraduates funded by this agreement who graduated during this period: 0.00

The number of undergraduates funded by this agreement who graduated during this period with a degree in science, mathematics, engineering, or technology fields:...... 0.00

The number of undergraduates funded by your agreement who graduated during this period and will continue to pursue a graduate or Ph.D. degree in science, mathematics, engineering, or technology fields:...... 0.00

Number of graduating undergraduates who achieved a 3.5 GPA to 4.0 (4.0 max scale):...... 0.00

Number of graduating undergraduates funded by a DoD funded Center of Excellence grant for Education, Research and Engineering:...... 0.00

The number of undergraduates funded by your agreement who graduated during this period and intend to work for the Department of Defense 0.00

The number of undergraduates funded by your agreement who graduated during this period and will receive scholarships or fellowships for further studies in science, mathematics, engineering or technology fields:...... 0.00

Names of Personnel receiving masters degrees

NAME

Total Number:

Names of personnel receiving PHDs

NAME

Total Number:

Names of other research staff

NAME	PERCENT_SUPPORTED

FTE Equivalent:
Total Number:

Sub Contractors (DD882)

Inventions (DD882)

Scientific Progress

Final Report for:

Cooperative Team Networks Workshop

Held on Jun 2, 2014

Location: Berkeley California, at the Claremont Hotel and the Clark Kerr Campus of the University of California

Studying Human Teams using Virtual Environments - Noshir Contactor (Northwestern), Alice Leung (Raytheon BBN) Research was presented that uses games to conduct social experiments in team dynamics. Virtual environments, especially game-like frameworks, offer numerous benefits for the study of human teams. In this talk, they gave a few examples of how computer game-like activities, with their well defined goals, clear interaction rules, and potential for near-complete action data logging, have been used. In particularly they focused on two different approaches to research team behaviors. The most popular approach has been to develop multiplayer tasks/games designed deliberately for experiments, and then pay or entice participants to play. The other approach has been to conduct post-hoc analysis of data from large-scale entertainment games. They discuss some team and network phenomena that have been examined with these two methodologies, and some challenges in applying these different approaches. They presented the relational event framework for analyzing rich team interaction data.

Cooperation and Subset Team Games - Elisha Peterson (Applied Physics Lab)

The framework of Subset Team Games, introduced in 2008, allows one to quantify the altruistic and selfish components of cooperation. In this work, a framework and motivation for this mathematical formalization for cooperative principles. The insight was the quantification of an individual's contribution to the group effort by developing algorithms that aim to evaluate team outcomes when single contributions were eliminated. Using several examples of how the framework has been applied in the last eight years, he discussed the role it can play in providing insight into principles of cooperation.

Analyzing Frontiers of Science - Daniel Romero (University of Michigan)
We have witnessed an upsurge in the production of scientific papers. In 1950 there were approximately 26,000 papers indexed in Web of Science. In 2010 the number rose to 1.4 million. This suggests that the amount of scientific knowledge available to researchers is increasing at very fast rate. Since every scientist has a limited capacity to discover and process existing knowledge that is relevant to her research area, every scientific paper builds upon a relatively small subset of previous knowledge. This work presents the relationship between a paper's impact and its reach and breadth. The fundamental question presented was: what does citation data show about when in time we reference papers?
Hit papers are defined as the top 5 percentile papers for a given year, as measured by the cumulative number of citations 8 years after publication. Their findings suggest a universal pattern: the highest scientific impact is achieved when recent work is combined with a large variety of work from the past. In particular, the research focused on 'Reach', how far back in time a paper references, and 'Breadth', the standard deviation of years in the reference. Major finding is that low reach, high breadth seems to have the most impact on a paper's success. Finally, they present results for the robustness of their findings by testing whether it holds in other domains. Their findings show that low reach and high breadth also leads to high impact work in the context of patents and US.

Cooperative sensing, communication, information, and decision networks - Darryl Ahner (AFIT: Air Force Inst Tech)

Various levels of decision-making teams have orders of magnitude more data and sensing assets at their disposal than in the past. However, decision science, statistics, and cognitive theory are rarely considered in how data is gathered, communicated, processed into information, and eventually used to inform these decision-makers. He presented an approach in the form of mathematical feedback models using a cognitive model framework that addresses trust and uncertainty of information within sensing, communication, information, and decision networks. Specifically, the research focused on an organization based communication process based on Shattuck & Miller's situated cognition model.

Prithwish Basu (Raytheon BBN) focused on using simplicial complexes for collaboration (including ongoing work on generative models). He introduced two mathematical models that can effectively represent these two aspects of collaboration networks, respectively. The first is a higher-order generalization of a graph, namely, Simplicial Complex, which is a hypergraph closed under subset operation. This combinatorial object can capture the essence of a collaboration relationship by generalizing "edges" to higher dimensional "facets", and is amenable to deep analysis using tools from algebraic topology for characterizing certain fundamental aspects of these collaborations such as "holes" and "missed collaborations". The second model, called Composite Graph, jointly represents a collaboration network and the network of artifacts produced by it by means of an associative mapping between the two. While it is still difficult to work with large simplicial complexes, this approach leads to the following useful metrics: Number of facets; Facet degree, size; Betti numbers (holes and voids); Minimal non-faces (MNF); Extensions of centrality, diameter, etc. to higher dimensions. He argued that these metrics defined on this composite graph model can help characterize effectiveness of task assignments, likelihood of success etc. The panel discussed whether the existing structures could be used to predict success or improve task assignments.
Chjan Lim (RPI) discussed the role of quantitative and qualitative models to model opinion dynamics. He discussed how quantitative and rigorous correlates of changes at the local agent level in terms of measurable bulk statistical variables are recently appearing in simulations and analytical work on network science. One of these is the well known recent result that the canonical pure diffusion models known as the Voter models are fundamentally distinct from models with drift such as the Naming games, in that the latter class support a critical tipping fraction of committed minority. This was shown by this investigator et al in a PRE 2011 paper which proved the presence of such a critical threshold. He discussed the voter models

and naming games as examples of the effectiveness of using agent-based models of collaboration in which the content of the communication doesn't actually matter.
Josh Lospinoso (US Army) described approaches to statistical modeling of networks, in particular, the actor-oriented set. There are two very prominent statistical models in the social networks literature that we should be aware of: the stochastic actor oriented model (SAOM) and the exponential random graph model (ERGM). The main practical consideration on when to use either is whether one or multiple observations of the network under study is available. In the single observation case, ERGMs are used. In the multiple observations case, SAOMs are used. He gave example based introduction on both models. The key point was that these statistical models allow you to do is to formulate and test hypotheses.

Brooke Foucault (Northeastern University) discussed the data collection and experimental platform, Volunteer Science (volunteerscience.com). This is an online behavioral science laboratory for studying teams. Volunteer Science offers a number of advantages over traditional brick-and-mortar laboratories, including scalability, cost effectiveness, and the ability to experimentally manipulate endogenous team processes. She reviewed the results of a set of experiments in the Hidden Profile paradigm of team research that examine how endogenous communication processes influence emergent network structure and team performance.

Allison Abbe (Synergist, LLC) highlighted theoretical gaps in multiple levels of analysis in organizations, and gaps in our understanding of the bottom-up processes by which higher-level team structures emerge. Identifying such emergent phenomena is important step to moving from individual contributions to team-level dynamics and outcomes. Distributed teams with diverse or dynamic membership face particular challenges in developing trust and cohesion, problems that multilevel analysis may help address. Using unobtrusive measures of team communication, we presented her work to test the contribution of individual team member behaviors to the development of team trust and cohesion, as moderated by the emergence of team rapport. Team rapport may provide an early indicator of positive team processes that support optimal performance.

Yulia Tyshchuk (RPI) discussed how people organize themselves in groups for many reasons including shared knowledge, improved performance, and social connections. These groups form a frame of reference for its members by establishing the norms for the acceptable behavior. Throughout process of establishing these norms there emerges a leader who initiates and maintains these norms and, therefore, drives group's collective and individual behavior. Emerging technologies, such as social media, allow people to organize themselves into virtual groups without geographical constraints. These virtual groups can be long termed, organized around a particular issue or interest, or short termed, organized in a response to a particular event. Both types of groups share similar characteristics with physical groups as there emerge leaders who are capable of promoting individual and/or collective behavior. Through the study of emergence of leadership along with group dynamics she argues, we can better understand how the norms for acceptable behavior form and how these norms drive individual and collective action. This knowledge will enable us to build predicative models of human individual and collective behaviors.

Plenary Talk: Leadership and Networks
Leslie DeChurch (Georgia Tech)
Researchers are increasingly harnessing social network theories and methods to understand two basic questions about organizational leadership: who leads? (i.e., leader emergence), and who leads effectively? (i.e., leader effectiveness). The network perspective is particularly well suited to the study of leadership, which has long been recognized as an inherently relational phenomenon between leaders and followers. However, network approaches to leadership have generally grown up apart from other areas of leadership research that focus on the characteristics of leaders, their behavior, organizational levels, and situational contingencies. This talk introduces an integrative framework for understanding the unique contribution of network approaches within the broader conceptualization of leadership. This framework - the five facets of leadership - recasts extant leadership theories and research based on their emphasis on features, functions, foci, forecast, and forms. The form facet captures network approaches.
Five facets/perspectives of leadership:
- Features, Personal characteristics (who are these people?)
- Functions, Behavioral approaches (what do they do?)
- Forecasts, Situational theories (when do they need to do what?)
- Foci, Multilevel leadership (who do they influence?)
- Forms, Networks (who influences whom? what is the pattern of influence?)

She then explores how leaders and networks relate, eg., do leaders arising from position in a social network?; do leaders leverage social networks?; is leadership a property of the network (e.g. network metrics). Research has shown that factors like charisma are more a product of a leader's position in the network, rather than the network position is a product of charisma. She discussed some of the structural elements that contribute to the emergence of leadership and effectiveness within multi-team systems. Experimental findings were mentioned to provide context for what is know about whether there are natural tendencies through which leadership networks emerge? And what tendencies are optimal for multiteam effectiveness? The answer is, naturally, it depends.
Next, two illustrative studies that leverage network theories and methods within the larger five facets framework were presented. The first study used traditional social science methods to study the emergence of leadership and the effectiveness of multiteam systems (MTS). The second used computational methods to address the same questions, but does so integrating the

network perspective with prior work on leadership that emphasizes features, functions, foci, and forecast in addition to form. The research questions were the following: (1) how does geographic dispersion affect resulting leadership networks?, and (2) how does organizational embeddedness affect resulting leadership networks? Agent-based model for emergence of leadership (based on empirical data) was explored in the following stages:

- Step 1: Who will attempt to influence the MTS (leader feature)?
- Step 2: What type of leadership will they provide (function)?
- Step 3: Who will they attempt to influence (focus)?
- Step 4: Who will accept this attempt (follower feature)?

Results showed that distributed teams may lead to a number of negative affects: Less dense leadership networks; more “divergent” leadership patterns; and less “convergent” leadership patterns

5. Summary. The purpose of this meeting was to bring together experts to discuss progress, challenges, and the way ahead for team network science and cooperative systems. The meeting was successful in facilitating cross pollenization of ideas and disciplines that will continue to inform models, metrics, and theory. Noshir Contractor and Alice Leung presented new metrics and ways to formulate team processes, such as identifying motifs of dynamic communication exchanges which goes well beyond simple dyadic and triadic configurations; as well as a promising framework, relational event modeling, for modeling rich time stamped data. As highlighted by the plenary talk, Leslie DeChurch, models are needed that integrate ideas of multilevel analyses that integrate individual traits of leadership as well as structural positions. These appear to be more interdependent than previously thought to be in the tranditional leadership research.

Recent developments in statistical models for networks were outlined by Dr Lospinoso, who presented two network statistical frameworks that enable multi-level casual inference modeling. Additionally, metrics of cooperation processes and collaborative performance outcomes need to be more rigorously refined and better integrated into dynamical models -- constructs like interdisciplinary, cooperation, and adaptability require operationalization in a team network context; while processes like group intelligence, shared mental models, and group think should be built as iterative algorithms. Elisha Peterson presented work on mathematical models of cooperation, formalizing and quantifying cooperative behaviors. Dr Ahner’s work offered a theoretical approach to integrating cognitive processes into communication models and workflow protocals.

One of the main insights from the panel sessions is that group-level cognition and social theories need to be formalized so they can better inform mathematical and computational models. The interest is clearly there. This conference was meant to seed future conversations and collaborations, which it seems to have successfully achieved. Based on findings discussed in the recent Nature issue on interdisciplinary science, publications that include citations from numerous disciplines is initially less influential, but can surpass it’s uni-disciplinary counterparts about thirteen years after publication. In other words, it is hard to make an impact in truly interdisciplinary fields. Multidisciplinary research and communities like this one are critical for building a common language and complementary approaches to understand how to model and predict the capabilities of teams, as well as other complex social processes.

Technology Transfer

Cooperative Team Networks Satellite Session

1. Background and overview

Understanding social processes that lead to wise decision making and peak performance is critical for predicting, evaluating and building successful teams. Over the past 50+ years there have been many conceptual developments in understanding teams. A team is formally defined as "an intact social system, complete with boundaries, interdependence for some shared purpose, and differentiated member roles. Teams are organized, either by design or by natural evolution, into structured relationships that are governed by interactions that involve power, influence, and varying degrees of cooperation, control, flexibility and adaptability. Team networks enable groups of people to build knowledge, reach consensus, achieve breakthroughs, and generally perform complex problem solving that would not be attainable through either individual efforts or a sequence of additive contributions. A critical question in army commands is how to improve the performance of teams and of multi-team systems (teams that work together to carry out missions).

1a) <u>Teams</u>. While there has been research on organizational processes that lead to successful outcomes, team research focuses on groups that are required to interact directly (face to face) in a cooperative (non-competitive) manner, to complete a task that involves shared mental schemas about the groups' role and the purpose of the mission. Thus, there are at least three features of team networks that make them distinct from other groups or organizational units: (a) unlike organizations who respond to competitive incentives, successful teams must coordinate and integrate diverse abilities to generate high quality products; (b) team members typically require most or all members to directly interact, activating social, cognitive and psychological processes (e.g., shared mental models, group think, social norms, influence), (c) interacting individuals with shared goals generate emergent capabilities not predictable by individual skills (e.g., collective intelligence).

Workshop goals are to discover different approaches to tackling team network science problems and to build interdisciplinary collaboration. Challenges ahead are to create theoretically-driven quantitative analysis framework for decision-making and productivity of collaborative teams.

- Constructs and mechanisms.
- Models that consider teams as complex systems.
- Verification and validation.

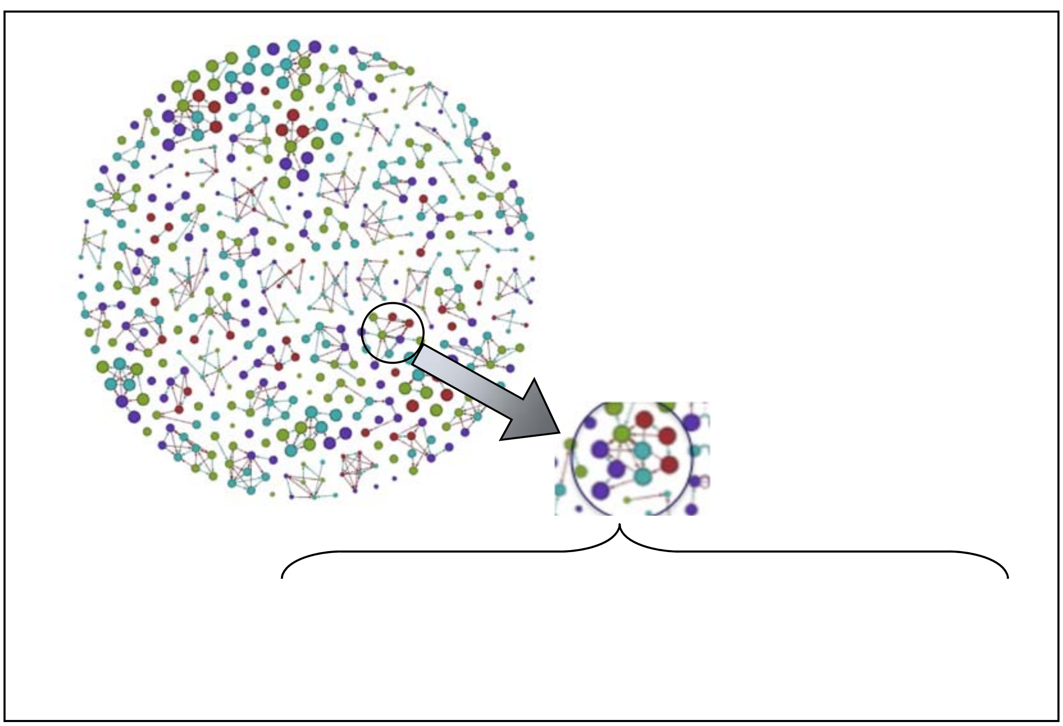
1b) <u>Network Science of Teams</u>: The building blocks of teams are dyadic or pair-wise relationships (e.g., trust, confidence, commitment) between people, whereas it is the collective or group-level properties (e.g., cohesion, collective efficacy, and transactive memory) that are more predictive of team and multi-team system readiness and resilience. That is, in order to accurately understand how individual characteristics come to affect team processes and outcomes, it is essential to consider the *relationships and interactions* of its members – requiring relational levels of analysis (i.e., not just individual capabilities but interactions among specific sets of individuals). Introducing a relational perspective to research linking team composition with team's effectiveness is one of the important contributions of this body of research.

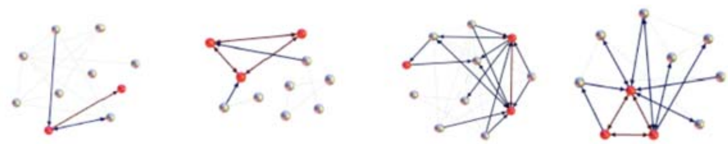
2. Scope of Problem. As examples of this type of research: *natural language processing* methods such as linguistic-style matching among dyads (pairs of individuals) have been implemented to evaluate team-oriented strategies and performance. In cognitive science studies, *collective intelligence* studies showing that group intelligence is an emergent group process that is not dependent on the sum or maximum ability of its members. *Science of Team Science* has made progress in the formalization of individual social factors that contribute to team-based scientific collaborations. *Science of Success* identifies network topologies that contribute to research breakthroughs from the perspective that these are determined by collective or group processes. Additionally, recent theoretical advances have focused on bridging complex systems with organization systems. For instance, *Complexity Leadership* and *Team Cognition* have focused on formalizing metrics of shared leadership, adaptability, flexibility, and resilience from a complex systems perspective.

3. Invited talks. The following summaries describe the work and discussion presented at this conference:

3a. Studying Human Teams using Virtual Environments - Noshir Contactor (Northwestern), Alice Leung (Raytheon BBN)

Research was presented that uses games to conduct social experiments in team dynamics. Virtual environments, especially game-like frameworks, offer numerous benefits for the study of human teams. In this talk, they gave a few examples of how computer game-like activities, with their well defined goals, clear interaction rules, and potential for near-complete action data logging, have been used. In particularly they focused on two different approaches to research team behaviors. The most popular approach has been to develop multiplayer tasks/games designed deliberately for experiments, and then pay or entice participants to play. The other approach has been to conduct post-hoc analysis of data from large-scale entertainment games. They discuss some team and network phenomena that have been examined with these two methodologies, and some challenges in applying these different approaches. They presented the relational event framework for analyzing rich team interaction data.





Motifs or patterns of activity can be identified and used as explanatory variables to model team processes (dynamics) and outcomes (e.g., performance)

Relational event models require four elements: source, receiver, type, time. The relational event model characterizes the probability of events as a function of past history. The novelty in this approach is the formalization of communication events – where the team identifies 'motifs' or patterns of activity that describe these probabilities. Given experimental data, the approach can be used to determine the statistical correlation of these motifs, and ultimately use them as explanatory measures.

3b. Cooperation and Subset Team Games - *Elisha Peterson (Applied Physics Lab)*

The framework of Subset Team Games, introduced in 2008, allows one to quantify the altruistic and selfish components of cooperation. In this work, a framework and motivation for this mathematical formalization for cooperative principles. The insight was the quantification of an individual's contribution to the group effort by developing algorithms that aim to evaluate team outcomes when single contributions were eliminated. Using several examples of how the framework has been applied in the last eight years, he discussed the role it can play in providing insight into principles of cooperation.

3c. Analyzing Frontiers of Science - *Daniel Romero (University of Michigan)*

We have witnessed an upsurge in the production of scientific papers. In 1950 there were approximately 26,000 papers indexed in Web of Science. In 2010 the number rose to 1.4 million. This suggests that the amount of scientific knowledge available to researchers is increasing at very fast rate. Since every scientist has a limited capacity to discover and process existing knowledge that is relevant to her research area, every scientific paper builds upon a relatively small subset of previous knowledge. This work presents the relationship between a paper's impact and its reach and breadth. The fundamental question presented was: what does citation data show about when in time we reference papers?

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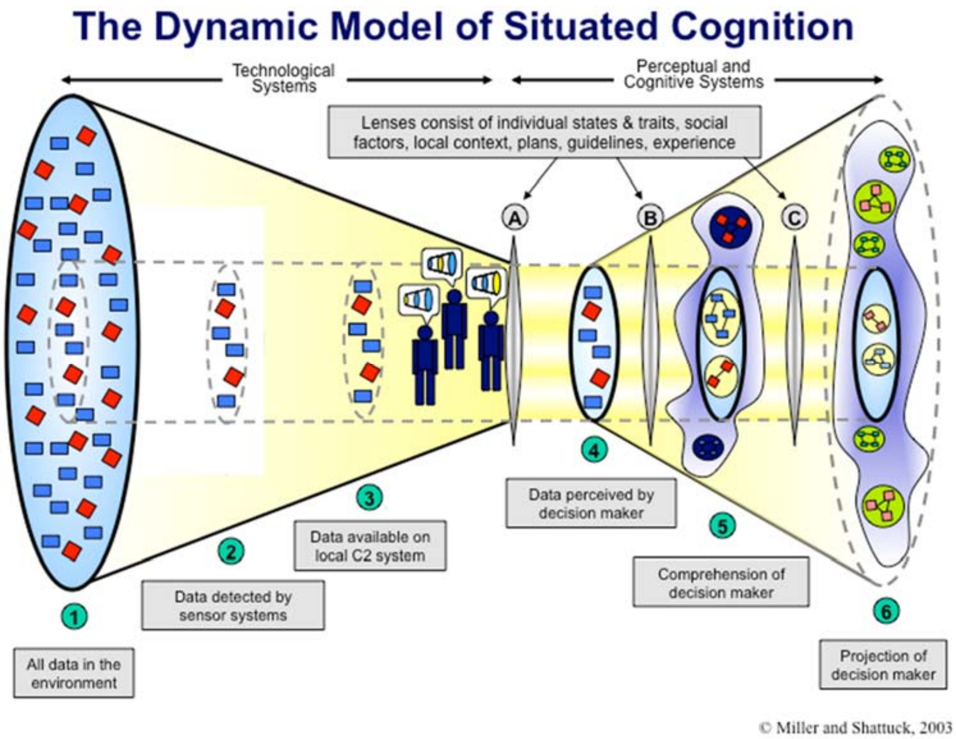

The insight was to show a mathematical representation of when information is needed and how information sharing should be targeted; account also for how we can account for perception, comprehension, and projection of social entities within the communication process in this modeling paradigm.

4. Panel Sessions. The following is the summary of the two panel sessions: Mathematical models of cooperation and social models of cooperation

4a. Panel Session: Mathematical Models of Cooperation

Prithwish Basu (Raytheon BBN)
Chjan Lim (RPI)
Josh Lospinoso (US Army, Cyber)

Prithwish Basu (Raytheon BBN) focused on using simplicial complexes for collaboration (including ongoing work on generative models). He introduced two mathematical models that can effectively represent these two aspects of collaboration networks, respectively. The first is a higher-order generalization of a graph, namely, *Simplicial Complex*, which is a hypergraph closed under subset operation. This combinatorial object can capture the essence of a collaboration relationship by generalizing "edges" to higher dimensional "facets", and is amenable to deep analysis using tools from algebraic topology for characterizing certain fundamental aspects of these collaborations such as "holes" and "missed collaborations". The second model, called *Composite Graph*, jointly represents a collaboration network and the network of artifacts produced by it by means of an associative mapping between the two. While it is still difficult to work with large simplicial complexes, this approach leads to the following useful metrics: Number of facets; Facet degree, size; Betti numbers (holes and voids); Minimal non-faces (MNF); Extensions of centrality, diameter, etc. to higher dimensions. He argued that these metrics defined on this composite graph model can help characterize effectiveness of task assignments, likelihood of success etc. The panel discussed whether the existing structures could be used to predict success or improve task assignments.

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Josh Lospinoso (US Army) described **approaches to statistical modeling of networks, in particular, the actor-oriented set.** There are two very prominent statistical models in the social networks literature that we should be aware of: the stochastic actor oriented model (SAOM) and the exponential random graph model (ERGM). The main practical consideration on when to use either is whether one or multiple observations of the network under study is available. In the single observation case, ERGMs are used. In the multiple observations case, SAOMs are used. He gave example based introduction on both models. The key point was that these statistical models allow you to do is to formulate and test hypotheses.

4b. Panel Session: Social Models of Cooperation

Brooke Foucault (Northeastern University)
Allison Abbe (Synergist, LLC)
Yulia Tyshchuk (RPI)

Brooke Foucault (Northeastern University) discussed the data collection and experimental platform, Volunteer Science (volunteerscience.com). This is an online behavioral science laboratory for studying teams. Volunteer Science offers a number of advantages over traditional brick-and-mortar laboratories, including scalability, cost effectiveness, and the ability to experimentally manipulate endogenous team processes. She reviewed the results of a set of experiments in the Hidden Profile paradigm of team research that examine how endogenous communication processes influence emergent network structure and team performance.

Allison Abbe (Synergist, LLC) highlighted theoretical gaps in multiple levels of analysis in organizations, and gaps in our understanding of the bottom-up processes by which higher-level team structures emerge. Identifying such emergent phenomena is important step to moving from individual contributions to team-level dynamics and outcomes. Distributed teams with diverse or dynamic membership face particular challenges in developing trust and cohesion, problems that multilevel analysis may help address. Using unobtrusive measures of team communication, we presented her work to test the contribution of individual team member behaviors to the development of team trust and cohesion, as moderated by the emergence of team rapport. Team rapport may provide an early indicator of positive team processes that support optimal performance.

Yulia Tyshchuk (RPI) discussed how people organize themselves in groups for many reasons including shared knowledge, improved performance, and social connections. These groups form a frame of reference for its members by establishing the norms for the acceptable behavior. Throughout process of establishing these norms there emerges a leader who initiates and maintains these norms and, therefore, drives group's collective and individual behavior. Emerging technologies, such as social media, allow people to organize themselves into virtual groups without geographical constraints. These virtual groups can be long termed, organized around a particular issue or interest, or short termed, organized in a response to a particular event. Both types of groups share similar characteristics with physical groups as there emerge leaders who are capable of promoting individual and/or collective behavior. Through the study of emergence of leadership along with group dynamics she argues, we can better understand how the norms for acceptable behavior form and how these norms drive individual and collective action. This knowledge will enable us to build predicative models of human individual and collective behaviors.

5. The following is the summary of the plenary talk titled "Leadership and Networks"

Plenary Talk: Leadership and Networks
Leslie DeChurch (Georgia Tech)

Researchers are increasingly harnessing social network theories and methods to understand two basic questions about organizational leadership: who leads? (i.e., leader emergence), and who leads effectively? (i.e., leader effectiveness). The network perspective is particularly well suited to the study of leadership, which has long been recognized as an inherently relational phenomenon between leaders and followers. However, network approaches to leadership have generally grown up apart from other areas of leadership research that focus on the characteristics of leaders, their behavior, organizational levels, and situational contingencies. This talk introduces an integrative framework for understanding the unique contribution of network approaches within the broader conceptualization of leadership. This framework - the *five facets of leadership* - recasts extant leadership theories and research based on their emphasis on *features*, *functions*, *foci*, *forecast*, and *forms*. The *form* facet captures network approaches.

Five facets/perspectives of leadership:

- Features, Personal characteristics (who are these people?)
- Functions, Behavioral approaches (what do they do?)
- Forecasts, Situational theories (when do they need to do what?)
- Foci, Multilevel leadership (who do they influence?)
- Forms, Networks (who influences whom? what is the pattern of influence?)

She then explores how leaders and networks relate, eg., do leaders arising from position in a social network?; do leaders leverage social networks?; is leadership a property of the network (e.g. network metrics). Research has shown that factors like charisma are more a product of a leader's position in the network, rather than the network position is a product of charisma. She discussed some of the structural elements that contribute to the emergence of leadership and effectiveness within multi-team systems. Experimental findings were mentioned to provide context for what is know about whether there are natural tendencies through which leadership networks emerge? And what tendencies are optimal for multiteam effectiveness? The answer is, naturally, it depends.

Next, two illustrative studies that leverage network theories and methods within the larger five facets framework were presented. The first study used traditional social science methods to study the emergence of leadership and the effectiveness of multiteam systems (MTS). The second used computational methods to address the same questions, but does so integrating the network perspective with prior work on leadership that emphasizes features, functions, foci, and forecast in addition to form. The **research questions** were the following: (1) how does geographic dispersion affect resulting leadership networks?, and (2) how does organizational embeddedness affect resulting leadership networks? Agent-based model for emergence of leadership (based on empirical data) was explored in the following stages:

- *Step 1*: Who will attempt to influence the MTS (leader feature)?
- *Step 2*: What type of leadership will they provide (function)?
- *Step 3*: Who will they attempt to influence (focus)?
- *Step 4*: Who will accept this attempt (follower feature)?

Results showed that distributed teams may lead to a number of negative affects: Less dense leadership networks; more "divergent" leadership patterns; and less "convergent" leadership patterns

5. <u>Summary</u>. The purpose of this meeting was to bring together experts to discuss progress, challenges, and the way ahead for team network science and cooperative systems. The meeting was successful in facilitating cross pollenization of ideas and disciplines that will continue to inform models, metrics, and theory. Noshir Contractor and Alice Leung presented new metrics and ways to formulate team processes, such as identifying motifs of dynamic communication exchanges which goes well beyond simple dyadic and triadic configurations; as well as a promising framework, relational event modeling, for modeling rich time stamped data. As highlighted by the plenary talk, Leslie DeChurch, models are needed that integrate ideas of multilevel analyses that integrate individual traits of leadership as well as structural positions. These appear to be more interdependent than previously thought to be in the tranditional leadership research.

Recent developments in statistical models for networks were outlined by Dr Lospinoso, who presented two network statistical frameworks that enable multi-level casual inference modeling. Additionally, metrics of cooperation processes and collaborative performance outcomes need to be more rigorously refined and better integrated into dynamical models -- constructs like interdisciplinary, cooperation, and adaptability require operationalization in a team network context; while processes like group intelligence, shared mental models, and group think should be built as iterative algorithms. Elisha Peterson presented work on mathematical models of cooperation, formalizing and quantifying cooperative behaviors. Dr Ahner's work offered a theoretical approach to integrating cognitive processes into communication models and workflow protocals.

One of the main insights from the panel sessions is that group-level cognition and social theories need to be formalized so they can better inform mathematical and computational models. The interest is clearly there. This conference was meant to seed future conversations and collaborations, which it seems to have successfully achieved. Based on findings discussed in the recent Nature issue on interdisciplinary science, publications that include citations from numerous disciplines is initially less influential, but can surpass it's uni-disciplinary counterparts about thirteen years after publication. In other words, it is hard to make an impact in truly interdisciplinary fields. Multidisciplinary research and communities like this one are critical for building a common language and complementary approaches to understand how to model and predict the capabilities of teams, as well as other complex social processes.