



U.S. ARMY COMBAT CAPABILITIES DEVELOPMENT COMMAND – ARMY RESEARCH LABORATORY

Network Science CTA Overview

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Consortium Director

Raytheon BBN Technologies

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GENESIS OF NETWORK SCIENCE



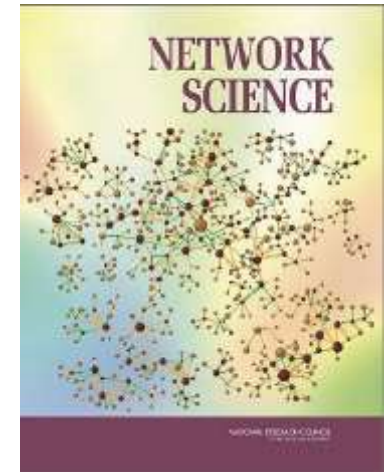
NRC Report on Network Science

Definition:

“The fundamental components of a network are its structure (nodes and links) & its dynamics, which together specify the network’s properties (functions & behaviors). Core research principles should enable predictions of network behaviors, given the structure & dynamics of the network as inputs.”

Overarching Conclusions

- Networks have a pervasive influence in all aspects of life
- Fundamental knowledge to predict properties of networks is primitive
- Research is fragmented with **disciplinary stovepipes**



NRC Report on Network Science
(2005)

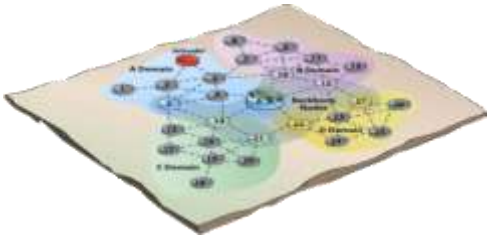


NETWORK SCIENCE CHALLENGES COMMERCIAL VS MILITARY NETWORKS



Commercial

Military



Communications

- Fixed infrastructure
- Resource-rich, stable
- Limited security constraints
- Interoperability by standards

- Hybrid networks: Convergence of mobile ad hoc, cellular, fixed
- Resource constrained, dynamic
- High & multiple levels of security
- Coalition interoperability



Information

- Google search, information apps rapidly evolving
- Networks are open, benign, observable
- Data mining & knowledge discovery tools

- Search noisy, volatile, incomplete, untrustworthy, hidden, adversarial
- Discovery of hidden attributes, semantic links, structures needed
- Analytics of heterogeneous, noisy, dynamic, & adversarial nets



Social-Cognitive

- Pervasive social networking and content creation
- Trusted social networking with friends & family
- Stable, non-threatening social environment

- Growing use of highly dynamic social networking
- Potential subversion of network, challenged trust
- Evolving, adversarial, social structures, influences, attitudes

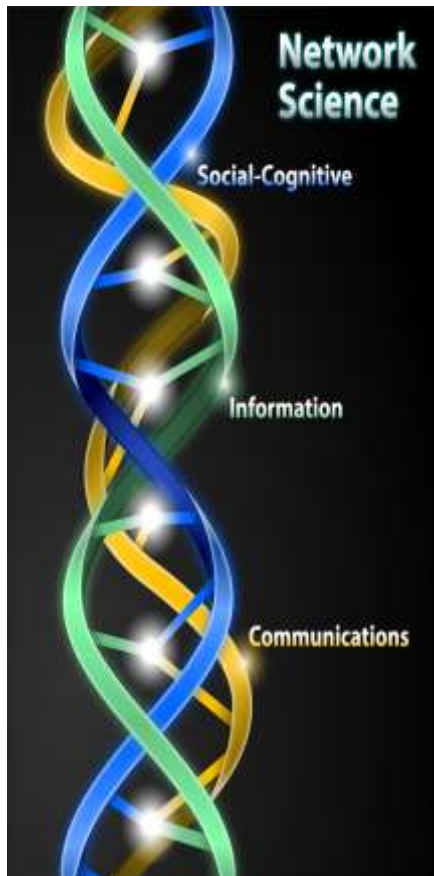
Increased complexity of design, discovery, prediction, & control
Increased interactions between comms, information, & social networks



THE NETWORK SCIENCE COLLABORATIVE TECHNOLOGY ALLIANCE



A Collaborative Venture between CCDC ARL, C5ISR Center, Academia, and Industry to create fundamental knowledge about complex multi-genre networks



NS CTA Objectives

- **Create knowledge & a fundamental understanding:**
 - Of interdependency, relations, & common underlying science
 - Among social-cognitive, information, & comms networks
- **Determine how processes in one network affect & are affected by those in other networks**
- **Develop approaches to prediction & control or influencing of the behaviors of these complex interacting networks**

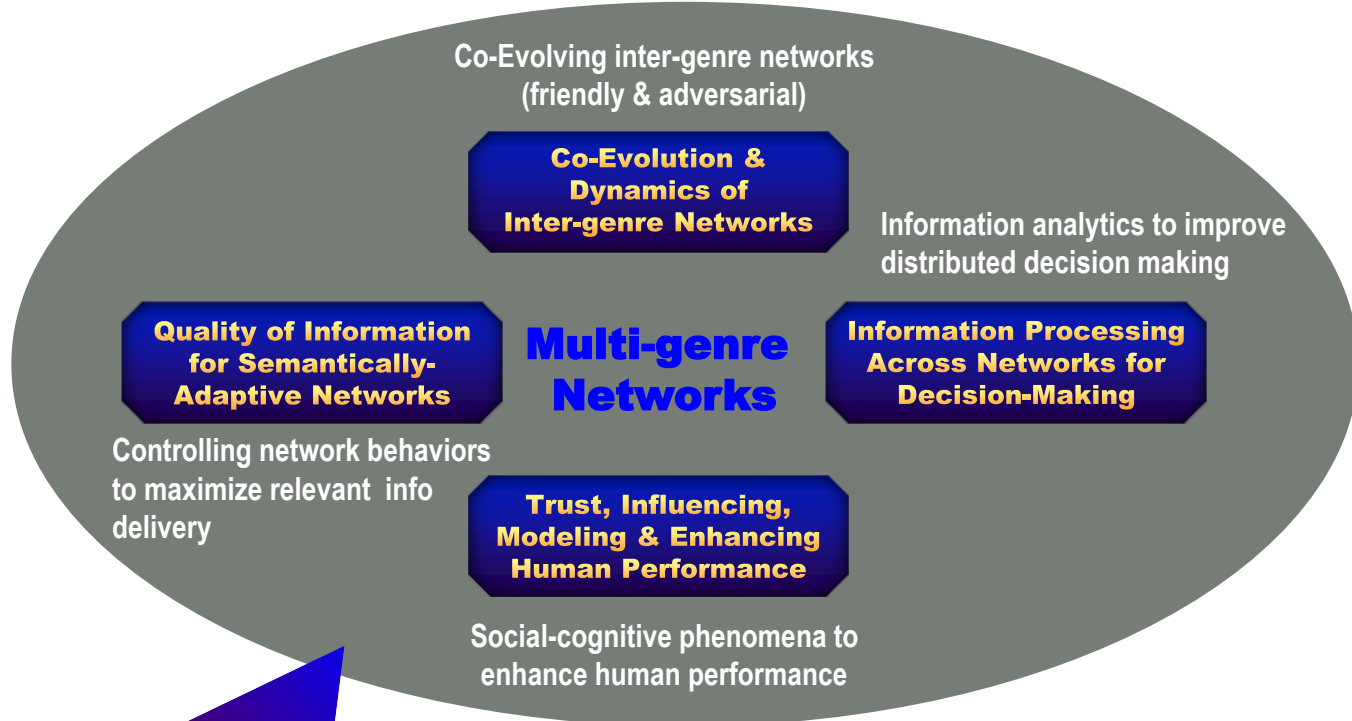


CTA PROGRAM EVOLUTION



Network Science CTA Awarded (2009)

- Created by combining four separately-awarded consortia: Interdisciplinary Research Center & three Academic Research Centers
- EDIN** Cross-Cutting Research Issue (CCRI) created during initial planning process
- Trust** CCRI created from proposed efforts in four Centers



- Integrated Program since 2014:**
 - Single Consortium
 - Focus on multi-genre networks, multi-disciplinary research thrusts



CTA TEAM



Raytheon
BBN Technologies



UC DAVIS
UNIVERSITY OF CALIFORNIA

CU NY The City University of New York



Rensselaer

PENNSTATE



ILLINOIS
UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN



ADVANCING NETWORK SCIENCE



Co-EDIN

- Co-evolution & dynamics
- Discovery, inference, & prediction
- Controlling networks

QoI-SAN

- Unified semantics
- Pragmatics & constrained natural language
- Semantic information delivery & capacity

IPAN

- Context-aware analytics
- Uncertainty management
- Distributed processing for situational understanding

TIME

- Trust in groups
- Influencing multi-genre networks
- Modeling social-cognitive dynamics

Fundamental theory of composite networks to predict & influence their co-evolution

Intelligent information delivery derived from context & intent of information requests that adapts to cognitive needs of decision makers

Embed cognitive & social context in information networks to enable comprehensive mission understanding

Revolutionary approaches for experimentation across network genres



FY19 PROGRAM PLAN



Co-Evolving Dynamic Inter-Genre Networks

- **Learning and Optimizing Network Processes in Multilayer Time-evolving Networks**
- **Large Scale Deep Learning For Dynamic Multi-Genre Networks: Pattern Discovery, Classification and Prediction**
- **Co-evolution of multi-genre networks**
- **Stability Monitoring and Influencing in Social Terrain**

Multi-genre Network Experimentation

- **Capstone Integration, Experimentation, Visualization, and Exploitation**

Quality of Information for Semantically-Adaptive Networks

- **Semantic Information Theory**
- **Complex Activity Detection in Multi-Camera Tactical Settings**
- **Workflow-assisted Anticipatory QoI Optimization**

Information Processing Across Networks for Decision-Making

- **Multi-genre Knowledge-Network Construction for Intelligence Analysis and Foraging**
- **MissionCube: Multi-Dimensional Summarization and Analysis of Social Sensing Streams for Military Applications**
- **Collaborative Problem Solving and Information Routing in Dynamic Multi-Genre Networks**



LEADERS IN NETWORK SCIENCE



The Worldwide Forum for the Advancement of Network Science:

An interdisciplinary body bringing together researchers in network science: from physics to computer science, biology, social sciences, & economics

- Two annual conferences: **NetSci & NetSciX**
- Promotes Network Science symposia, workshops, training, PhD programs and other educational and research opportunities
- Annual awards, prizes and Fellowships
- **National Chapters:** Established in **Poland, Switzerland & China.**

NS CTA LEADERSHIP

- D'Souza (UC Davis) President
- Contractor (NWU) Board
- Szymanski (RPI) Board
- Uzzi (NWU) Board
- Swami (ARL) Board



LEADING THE FIELD OF NETWORK SCIENCE



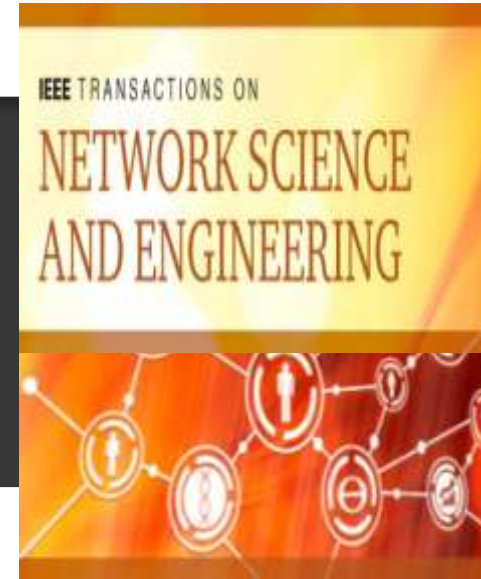
IEEE TRANSACTIONS ON NETWORK SCIENCE & ENGRG

Inaugural Issue Jan 2014

Associate Editor: D'Souza (UC Davis)

Steering Committee: Swami (ARL), Lin (IBM), Szymanski (RPI)

Focus: Theory & applications of network science & the interconnections among the elements in a system that form a network



IEEE JOURNAL ON SELECTED AREAS IN COMMUNICATIONS

A PUBLICATION OF THE IEEE COMMUNICATIONS SOCIETY



June 2013 VOLUME 31 NUMBER 6 ISSN 0733-8714

NETWORK SCIENCE

P. Basu, R. Gibben, Y. Lu, P. Li, C. Y. Lu, A. Sene, and E. Younis

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IEEE JSAC SPECIAL ISSUE ON NETWORK SCIENCE

June 2013 (Multi-Genre Emphasis)

Editors: Basu (BBN), Swami (ARL), La Porta (PSU), Lin (IBM)

Authors: Abdelzaher, Aggarwal, C. Faloutsos, M. Faloutsos, Prakash, Ribeiro, Towsley, Valler, Wang, Wie, Zhao, Kaplan (ARL), Swami (ARL)



LEADING THE FIELD OF NETWORK SCIENCE



NETWORK SCIENCE: CAMBRIDGE UNIVERSITY PRESS

Inaugural Issue April 2013

Founding Editors: Adamic (Mich), Contractor (NWU), Vespignani (NEU), Wasserman (IU)

Associate Editors: Aral (NYU), C. Faloutsos (CMU), Lazer (NEU), Srivastava (UMN), Toroczkai (ND)

Focus: A new journal for a new discipline - one using the network paradigm, focusing on actors and relational linkages, to inform research, methodology, & applications from many fields across the natural, social, engineering & informational sciences.



Journal of
Complex Networks

JOURNAL OF COMPLEX NETWORKS: OXFORD UNIVERSITY PRESS

Inaugural Issue June 2013

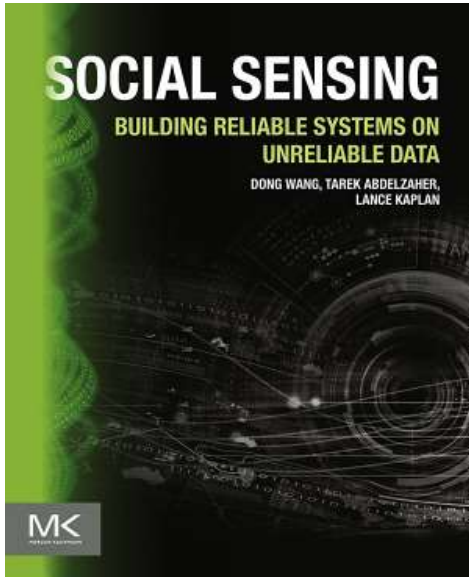
Associate Editor: D'Souza (UC Davis)

Focus: Analysis & understanding of complex networks & its applications in diverse fields. Covers everything from the basic mathematical, physical & computational principles needed for studying complex networks to their applications leading to predictive models in molecular, biological, ecological, informational, engineering, social, technological & other systems.

OXFORD
UNIVERSITY PRESS



NETWORK SCIENCE CTA BOOKS



Increasingly, human beings are sensors engaging directly with the mobile Internet. Individuals can now share real-time experiences at an unprecedented scale.

Social Sensing: Building Reliable Systems on Unreliable Data looks at recent advances in the emerging field of social sensing, emphasizing the key problem faced by application designers: how to extract reliable information from data collected from largely unknown and possibly unreliable sources.

Social Sensing: Building Reliable Systems on Unreliable Data (April 2015)

Authors: Dong Wang (Notre Dame), Tarek Abdelzaher (UIUC), **Lance Kaplan (ARL)**

“Social Physics is filled with rich findings about what makes people tick. Using millions of data points measured over a long period of time in real settings, which Pentland calls ‘living laboratories,’ the author has monitored human behavior on an unprecedented scale ...

***Social Physics is a fascinating look at a new field by one of its principal geeks.”**
— *The Economist**

Social Physics: How Good Ideas Spread – The Lessons From a New Science (January 2014)

Author: Alex (Sandy) Pentland (MIT)



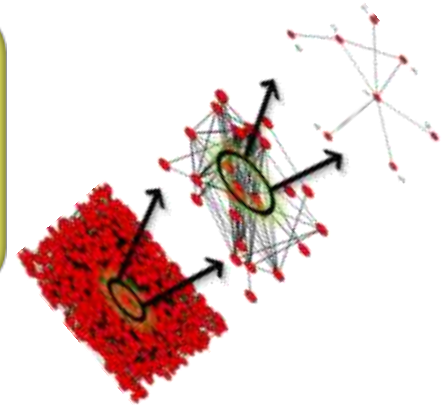


RESEARCH RESULTS



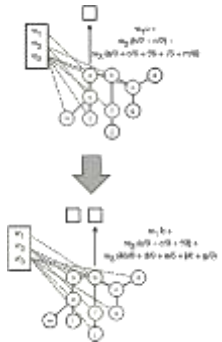
Network classification using Deep Network Signatures:

Novel permutation-invariant image embedding combined with greedy Deep Learning enables extraction of network signatures for classifying networks of special interest (e.g. adversarial) in early stages of growth



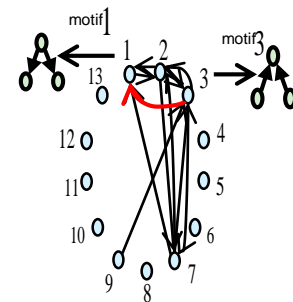
Diffusion-Convolutional Neural Networks (DCNNs) for classification:

A new model for graph-structured data that provides a convolution-like operation that extends from grid-structured to graph-structured data while preserving isomorphism → Polynomial-time prediction & learning for nodes & graphs



Learning causal information structures in multi-layer networks:

Novel information-theoretic measures of causal influence using directed information measures to identify causal relations between network structures such as motifs & subgraphs in multi-layer networks



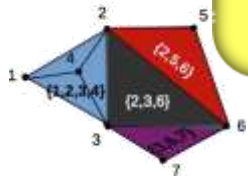
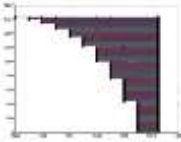


RESEARCH RESULTS



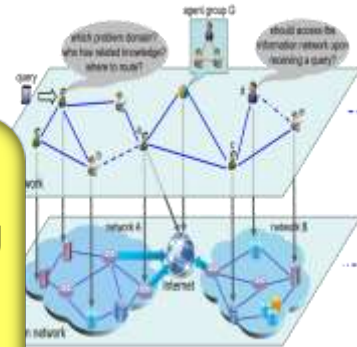
Topological Data Analysis theory to characterize evolving networks:

Applied TDA theory to characterize & compare temporally-evolving complex networks by exploited tools from persistent homology to derive novel metrics to analyze relative topological growth → First work to apply TDA to temporally evolving complex networks



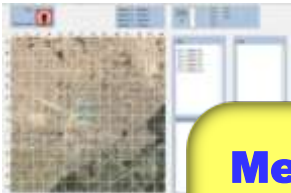
Group Complex used to capture inter-agent connections:

Provides fundamental insights on correlation between efficient query answering & network structural properties in collaborative expert networks → Investigated & experimentally validated interactive human-machine problem solving



Methods to measure & enhance human trust in decision-making:

3-level SA model (context, trust & information availability) experimentally investigated the impact of confidence & competence based cues in information credibility decisions → Experimental dataset (B-Knorms) for credibility research has been open-sourced



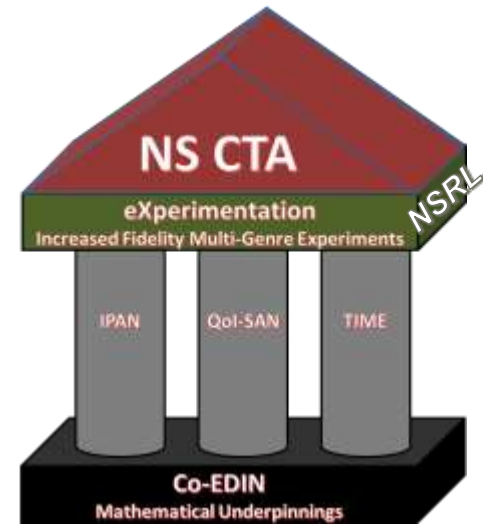


NS CTA MULTI-GENRE EXPERIMENTATION



Goals

- Advance insights and challenge hypotheses with ***integrated, cross-network experiments***, bringing together results from multiple tasks and thrusts
- Meet challenges in the ***science & practice*** of experimentation with new experiment and analysis methodologies, scenarios, & datasets
- Increase the ease, size, timescale, realism, & military relevance of experiments



Approach

- New experimentation paradigms, methodologies, & designs that will increase the range of composite network science phenomena that can be experimentally studied
 - Experimentation methodologies to study multi-time scale cross-network interactions
 - Increasing experimental validity by understanding mapping outcomes across different contexts
- Explore & develop new concepts & re-usable capabilities for integrated, multi-genre networks science experimentation
 - Collaborative applied experiments in multi-genre networks to study, validate, & demonstrate basic research results in military relevant scenarios



SUMMARY



- We are advancing the state-of-the-art in Network Science
 - Multi-disciplinary research
 - Multi-genre (social/cognitive, information, and communications) networks
 - Experimentation

- Achievements enhanced by synergies gained from academia, industry, & government collaborations

