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## Human Behavior Modeling in Network Science

### Panel Chair

*Sibel Adali*

110 8<sup>th</sup> Street, Troy, NY  
Rensselaer Polytechnic Institute  
518-276-8047  
sibel@cs.rpi.edu

### Panel Chair

*Jeffrey T. Hansberger*

115 Lake View Parkway, Suffolk, VA  
Army Research Laboratory  
757-203-3431  
jeff.hansberger@us.army.mil

The U.S. Army Research Laboratory (ARL) has begun a 5-10 year research program with the Network Science Collaborative Technology Alliance (NS CTA) in Network Science bringing three distinct research areas together, communication networks, information networks, and social/cognitive networks. The NS CTA is an alliance across a wide range of academic and industry researchers working collaboratively with ARL and the Department of Defense researchers.

A critical part of the social/cognitive network effort is the modeling of human behavior. The modeling efforts range from organizational behavior to social cognitive trust to explore and refine the theoretical and applied network relationships between and among the human, information, and artifacts used.

The participants are:

**William Wallace** – Rensselaer Poly. Inst.  
**Wayne Gray** – Rensselaer Poly. Inst.  
**Ching-Yung Lim** – IBM  
**David Hachen** – Notre Dame University

The participants will describe ongoing research in how information is transmitted along trusted paths both in case of emergency warnings and in an organizational setting, patterns of reciprocity in social communications and cognitive components of human behavior in social interactions.

### **Emergency Warnings: A Case of Diffusion of Information on Dynamic Networks, W.A. Wallace**

This presentation will discuss ongoing research concerned with warning messages in evacuation situations. We propose a model for studying the diffusion of evacuation warning messages through a population where the network dynamics are a function of the information flow. In evacuation situations, individuals in the network leave the network when they decide to evacuate, causing disruptions to the flow of information as warnings are still being diffused through the network. Propagation of the messages is based upon the interaction of agents in the network and includes consideration of the trust between them. When individual nodes receive a warning message, they often do not immediately take the prescribed action. Instead,

they will seek information, converge with others, and try to make a decision. Individual nodes can fall in to one of several states, depending on their perception of the information they have received. Depending on their state, the individual nodes will perform certain actions, such as spread information or evacuate and leave the network. We use the model to examine how social group structure, distribution of trust, and existence of weak ties affect the spread of evacuation warnings. Preliminary results from simulation experiments show that effectiveness of the diffusion process depends upon trust and social groups, and the structure of the network.

### **Markovian Information Propagation Behavior Modeling in Dynamic and Probabilistic Social Networks, Ching-Yung Lim**

While most existing social network research focus on finding and modeling the structure of social network graph topologies, we consider the dynamic topology of a network obtained from observation, instead of being modeled as a random graph. Because of the well-known small world phenomenon, small changes in edges can significantly alter the network topology, information propagation speed, etc. We consider the exact modeling of the behavior of each actor nodes as well as the relationships. We propose a novel Behavioral Information Flow (BIF) model which can be used to predict how information is propagated through a complex social network. We consider both the dynamic and probabilistic characteristics of human behavior in receiving and redirecting information. A significant difference between this model to the traditional random walk-based propagation model is that information is considered duplicable at nodes and thus the way information propagation does not really follow the entity-based 'walks' behavior. We first modeled Dynamic Probabilistic Social Network as a combination of the state probabilities of user nodes and connection edges and two transition functions that are dependent on the network topology and user properties. Then, we propose to model user transitions as Susceptible-Active-Informed (SAI) states and edge transitions as a Markov Model with Susceptible-Dormant-Active-Removed (SDAR) stages. Based on these modeling methods, we can then predict information flows in a social network. We have

deployed a real system in a big organization to collect 20 million of emails and instant messages from 10,000 users to examine this network-based behavior predictability issue.

### **The Evolution of Dyadic Reciprocity in Social Networks, David Hachen**

Dyadic reciprocity is an important dimension of social networks that is in all likelihood related to trust. Reciprocity is conceptualized as the degree to which the directional flows of social interaction (including information flows) between two nodes are more or less balanced. We expect that most new social ties begin in a more non-reciprocal (unbalanced) state, with one agent initiating interaction more often than the other agent. We also expect that if the tie is to persist, then the dyadic relationship will have to become more balanced. The central research question then concerns what factors predict which new non-reciprocal ties are more likely to become reciprocal over time and, therefore, persist. We test two different hypothesis about the evolution of reciprocity. According to the Social Distance Hypothesis, the more similar the nodes in a dyad are, the more balanced the dyad will become over time. Nodal similarity/difference can be measured in numerous ways: sex, age, social status, physical distance, nodal degree. The Embeddedness Hypothesis expects that the more neighbors two nodes have in common, the more balanced the dyad will become. Using cell phone network data on the calling patterns of over 9 million subscribers of a cellular telephone company we identify who communicates with who within a given time period and among those dyads calculate how often each node initiates communication. Then we measure whether the tie persists in subsequent time periods and if so the extent to which both the level of interaction and reciprocity between the nodes changes. Hazard rate and machine learning models are used to predict tie persistence,

while growth models are used to test hypothesis about the factors associated with increases in reciprocity.

### **Reductionism, Constructivism, Networks, and Cognitive Science, Wayne Gray**

In his 1971 *Science* article, *More is Different*, the Nobel Laureate physicist, Phillip W. Anderson maintained that the generally accepted reductionist hypothesis does not imply a constructionist one. That is, “the ability to reduce everything to simple fundamental laws does not imply the ability to start from those laws and reconstruct the universe”. For example, the elementary entities of cognitive science obey the laws of neuroscience but cognitive science has its own laws that cannot be “constructed” out of neuroscience. Likewise, the elementary entities of social psychology obey the laws of cognitive science but social science has its own laws that cannot be constructed out of the laws of cognitive science. Behavior at each level is an emergent function of the structure of the network and the behavior of its component parts. To make all of this more difficult, the network’s structure is dynamic in that it changes as a function of the behavior of its elements and the elements in the network are dynamic in that their behaviors also change as a function of the network’s structure. The good news is that the new science of networks promises to provide formal mechanisms by which to study this complex process. It also suggests a new paradigm for behavioral and social science in that research focused on one level must be informed by knowledge of the lower and higher levels. For example, basic research on the laws of cognitive science requires an understanding of the range in performance exhibited by individual cognitive components as parts of a network that produces social interactions, but also requires an understanding of the behavior of the neurocognitive elements underlying each cognitive component.