From Team Intelligence to Social Intelligence

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A Festschrift for Richard Volz
Research Collaborators

- **Human Agent Teams**
  - TAMU: **R. Volz**, T. Ioerger, J. Wall, M. Miller, Y. Zhang, S. Cao
  - PSU: M. McNeese, X. Fang, S. Sun, R. Wang, S. Oh, H. Kim, D. Minotra,
  - SA Tech: M. Endsley, L. Strater, H. Cuevas,
  - ARL: L. Allender, T. Hanratty

- **Cyber SA**
  - PSU: P. Liu, M. McNeese, D. Hall, P. Chen, T. Mullen
  - CMU: C. Gonzalez

- **Network Growth**
  - PSU: L. Giles, H. Foley, K. Ivanova, B. Qiu, H. Wang

- **DARPA Network Challenge**
  - Penn State (D. Hall, N. Giacobe, H. Kiim et al), J. Unsworth, M. Reilly (UIUC), G. Marchionini (UNC), M. Weiss (Pitt), J. Stanton (Syracuse)

- **EMERSE:** P. Mitra, A. Tapia, J. Jansen, L. Giles, H. Kim, A. J.
Motivation: Team Training for NASA Space Shuttle Control Center

Problem: Training teams and subteams for effective teamwork are costly.

Goal: Improve the cost-effectiveness of training teams using intelligent coach and “virtual teammates”.

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Psychological Studies about Effective Human Teamwork

Indicated that

- Team members can anticipate needs of team mates
- Team members can offer information proactively.
- These teamwork behaviors are due to an overlapping shared mental model.
A Computational Shared Mental Model Can Capture the Context of Team Decision Making

Computational SMM Context

Team Decision Context

Information Fusion

Sensor Data

Human Reports

Images

Shared Mental Model

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CAST: Agents Anticipating Information Needs from A Team Process

- Capture the shared team process using a high-level language (MALLET).
- Infer needs of teammates from the team process.
- Agents generates proactive exchanges of information relevant to the needs.
CAST Software Architecture

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Formal Foundations of CAST

- Joint Intention Theory (Cohen & Levesque)
  - Ensures agents inform teammates about the success, failure, or abort of joint intentions.

- SharedPlan Theory (Kraus & Grosz)
  - Agents collaborate with a shared global plan.

- A Theoretical Framework of ProInform
  - Introduced a new communication performative (ProInform).
  - Proactive inform behavior is derived from assist axiom in SharedPlan Theory


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Using CAST for Teamwork Simulation

- University 21 (with Jim Wall, Dick Volz, Tom Ioerger)
  - Used CAST agents to develop “virtual teammates” for training Army’s Digital Brigade.
  - Army 101 (learned the jargon and symbols)
- MURI on Intelligent Team Training (PI: Dick Volz)
  - Developed a intelligent training framework for SA crews on AWACS.
  - PhD’s: Sen Cao, Yu Zhang, Mike Miller, and J. Yin.
Command and Control Team

S2: Intel Officer
S3: Maneuver Officer (Assign units to tasks)
S4: Logistic Officer

An Exemplar Scenario
S2: Access the actions, locations and intents of enemy entities.
S3: Defeat enemy and protect the supply route.
S4: Identify alternative supply route and sustain supplies.

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Can we have a reusable decision-making process?

- Implemented a decision-making process (RPD) in CAST
  - RPD models naturalistic decision making under time stress
  - Compare current situation with previous experiences to find a “satisfiable” solution/decision.

- Adopted RPD as the decision-making process of agents
  - Resulted in the second generation of agents: R-CAST

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R-CAST Anticipates Information Needs of Multiple Types

**Anticipate Information Requirements**
- Experiences
  - RPD Decision Model
  - Decisions
  - Recommender
  - Option
  - Process manager
  - Execute/Monitor
- Evaluation Criteria
  - How to evaluate options?
- Plan Knowledge
  - How to implement it?

**Seek Relevant Information**
- Knowledge base
- New/missing information
- Information manager
- Information Requirements
- Communication manager
- Conversations
- Inference Rules
  - Relate high-level info needs to lower-level information
  - How to seek/share information?
- Organization Strategies
  - How to communicate?

**RPD-based Decision Making**
- Situation analysis
  - Investigation
    - Feature matching
    - Expectancy monitor
    - Evaluate COA
    - Implement COA
    - Learning
  - familiar
  - workable
  - unworkable
  - anomalies detected
- Expectancy monitoring
- Evaluate COA
- Implement COA
- Learning

**Process**
- start
- end

**RPD-­‐based Decision Making**
- RPD Decision Model
- Decisions
- Recommender
- Option
- Process manager
- Execute/Monitor

**Knowledge Base**
- Situation Recognition
- Communication
- Expectancy Monitoring
- Teamwork Manager
- Taskwork Manager

**Experience Base**
- Experience Adaptation
- Decision & Adaptation
Agent as Teammates to Agents as Decision Aids

- Design a synthetic C2 team task involving multiple dimensions: The Three-Block Challenge
  - Combat
  - Peace keeping (crowd control)
  - Logistic support (IED on MSR)

- Study factors that affect human-agent team collaboration and trust through a series of experiments.
The Three Block Challenge Simulation Environment

MIDB

Other Intelligence

SPOT Reports

Performance Evaluator

Scenario Generator

Tasking Simulator

Simulation Engine

R-CAST

S2 Suite

Operation Effects

R-CAST

S3 Suite

Situational Information

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Decisions of S2-S3 Team

S2: Access the threat level of targets (key insurgents, crowds, and IED)
- Needs information about friendly/foe status of key persons in crowds.

S3: Allocate 9 platoons (including an EOD unit for IED) to remove threats based on
- Levels and types of threats of targets
- Distance of units to targets
- How long has the target appeared (Target disappears after a time, determined stochastically)
- Combat readiness of units
Four Human-Agents Experiments

- **Experiment 1:** Supporting Multiple-Context Decision Making
- **Experiment 2:** Trust on Cognitive Aids
- **Experiment 3:** Agent Error Patterns and Human Trust Calibration
- **Experiment 4:** Visualization of Agents Decision Space (VADS) of RPD Agents
Experiment 1: Supporting Multi-Context Decision Making

- Context switching frequency was varied in the experiments.
- C2 Performance in decision making was improved with R-CAST Agents.
- Performance improved by 40% under high context switching frequency.
- S2 agents and S3 agents both are needed.
Experiment 2: Human Trust on Agents

- A systematic-error was introduced into the agents recommendation.

- Experiment Group: knew the source of error,
- Control Group: did not know the source of error. (Both knew about the agents reliability.)

- Experiment Group had
  + Better Automation Usage Decisions (AUDs)
  + Better Trust
Experiment 2 Results

With knowledge about the factors that affect agent reliability, subjects showed:

• More suitable automation usage decisions.
• More suitable level of trust on the agents.
Experiment 3: Does Agent Error Patterns Affect Human Trust?

Research Question: Does the pattern of error affect the human trust on agents?

This study consisted of two conditions:
- agents with random-errors and
- agents with systematic-errors.

Result: Participants in the systematic-error condition made better automation usage decisions.
Experiment 3 Results

The number of correct recommendations accepted

The number of correct Recommendations changed correctly

Systematic errors vs. Random errors
A Cognitive Model about Human-Agent Trust (Experiment 2 and 3)

- For understandable error patterns, knowledge manipulation on the cause of automation error does improve automation usage decisions.
- Human trusts the agent less when it is hard to recognize the pattern of errors.
Experiment 4: Visualization of Agent Decision Space (VADS)

- Can it enhance war fighter’s global situation awareness (i.e., tracking change of threats of multiple targets)?

- Can it assist war fighters to project change of threats?
R-CAST Visualization of Agent Decision Space (VADS)
Experiment 4 Design

- 32 (16x2) participants recruited for this experiment.
- The display condition was a between subjects factor.
- One group used the VADS, and the other used an Agent-Decision Table (ADT).
Data Analysis

- Differences in scores in scenarios involving high-workload (3 and 4) is more significant than the ones involving low-workload (1 and 2).

- Difference in scores for scenario-3 is notably significant ($p = .024$). However, differences in scores were not as significant for scenario-4.

- The hypotheses about the possible effectiveness on scenario-3 can be tested in future experiments.
Real-world problems often require people and agents (robots or software) to form large-scale complex networks.

- Communication networks
- Transportation networks
- Information networks
- Energy networks
- Social networks

These networks have shown common properties:
- Long-tail degree distributions
- Scale-free networks
Research Agenda

- How to establish meaningful metrics about macro-level properties of networks?
  - Resilient of networks

- How to extract and/or identify patterns hidden in the networks?
  - Community Discovery
  - Cyber Security

- How to model the dynamic behaviors of networks?
  - Network evolution
  - Spreading of influence
Modeling Network Growth

Nano-technologist Co-authorship Network

- Rapid growth in short period
- The field started in recent years
- Can be used to predict trends of nanotechnology to analyze spread of ideas in the network

Table 1. Number of scientists and number of papers in different nanoscience communities as of year 2006

<table>
<thead>
<tr>
<th>Dataset</th>
<th>Scientists</th>
<th>Papers</th>
</tr>
</thead>
<tbody>
<tr>
<td>NanoSCI</td>
<td>292393</td>
<td>368511</td>
</tr>
<tr>
<td>NanoTube</td>
<td>31688</td>
<td>25285</td>
</tr>
<tr>
<td>NanoWire</td>
<td>86234</td>
<td>80645</td>
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<tr>
<td>NanoParticle</td>
<td>81734</td>
<td>69530</td>
</tr>
<tr>
<td>Fullerene</td>
<td>97641</td>
<td>96331</td>
</tr>
</tbody>
</table>

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Characterize network growth

Figure 1. Growth rate of the NanoParticle network for the period from 1980 to 2006 expressed as the number of papers versus the number of scientists that wrote the papers.

\[ |E(t)| = 3.0459 \times |V(t)|^{1.1141} \]

\[ \Delta \chi(t) = \frac{\Delta E}{\Delta V}. \]
A Hybrid Growth Model

A growth model that combines

- Preferential Attachment
- Locality-based Growth

Model: At each time step

- A new node is added
- Several new edges are added (based on edge/node ratio)
- The start node of a new edge is selected randomly and the end node is selected with probability
  - proportional to the degree of the node and
  - inversely proportional to the distance between the two nodes

\[ p_t(v_p) = \frac{d'_t(v_p)}{\sum_p d'_t(v_p) / r_t(v_p,v_s)} \]
Compare the Model with the Data

Properties of network structure that may affect the function of the networked system

- Degree distribution \( P(k) \)

\[ P(k) \sim k^{-\gamma} \]

Figure 4. Degree distributions of the NanoSCI network (diamonds) and of the DDG model data (circles). Each set of symbols is fitted with a power law with exponent \( \gamma_{\text{NanoSCI}} = 2.90 \pm 0.05 \) for NanoSCI and \( \gamma_{\text{DDG}} = 2.70 \pm 0.04 \) for DDG model data.
Assortative mixing

- Assortative mixing on networks
  - Assortativity coefficient $r$ – describes the correlation between the degrees of adjacent nodes
  - $r > 0$ implies assortative network
  - **Assortative network** is a network with dense hubs sparsely connected between each other.
  - $r < 0$ implies dissassortative network

$$ r = \frac{N^{-1} \sum_i j_i k_i - [N^{-1} \sum_i (j_i + k_i)/2]^2}{N^{-1} \sum_i (j_i^2 + k_i^2) - [N^{-1} \sum_i (j_i + k_i)/2]^2} $$

where $j_i, k_i$ are the degrees of the nodes at the ends of the $i$th edge, with $i = 1, 2, \ldots, N$. 

<table>
<thead>
<tr>
<th>Dataset</th>
<th>Assortativity coefficient $r$</th>
</tr>
</thead>
<tbody>
<tr>
<td>NanoSCI (all)</td>
<td>0.04</td>
</tr>
<tr>
<td>NanoTube</td>
<td>0.12</td>
</tr>
<tr>
<td>NanoWire</td>
<td>0.06</td>
</tr>
<tr>
<td>NanoParticle</td>
<td>0.04</td>
</tr>
<tr>
<td>Fullerene</td>
<td>0.09</td>
</tr>
<tr>
<td>NanoFabrication</td>
<td>0.66</td>
</tr>
<tr>
<td>DDG model</td>
<td><strong>0.30</strong></td>
</tr>
</tbody>
</table>

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Degree-dependent clustering coefficient

- Network transitivity or Clustering (hierarchical structure)
  - Degree-dependent clustering coefficient $C(k)$ – a quantitative measure of intrinsic hierarchy

\[ C(k) \sim k^{-\alpha} \]

\( \alpha = 1 \) Implies intrinsic hierarchical structure of the network

Deterministic scale-free network [Dorogovtsev et al., 2001]
Average degree of the nearest neighbors

Average degree of the nearest neighbors $<k_{nn}(k)>$ characterizes the assortativity of the network.

$<k_{nn}(k)> \sim k^\beta$

For assortative networks: $<k_{nn}(k)>$ is a monotonically increasing function of $k$. 

$\beta > 0$ Assortative network

For disassortative networks: $<k_{nn}(k)>$ is a monotonically decreasing function of $k$. 

Figure 3. Average degree of the nearest neighbors of the NanoSCI network (diamonds) and of the DDG model data (circles).
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Research Questions

- How to establish meaningful metrics about macro-level properties of networks?
  - Resilient of networks

- How to extract and/or identify patterns hidden in the networks?
  - Community Discovery
  - Cyber Security

- How to model the dynamic behaviors of networks?
  - Network evolution
  - Spreading of influence

- Ultimately, design networks, optimize networks, adapt networks in real-time.
MURI: Cyber Situation Awareness

R-CAST
and Relational Networks
Goal: Social Intelligence

- Design, optimize, and adapt networks in real-time to achieve social intelligence (i.e., intelligence that can not be achieved by people or machines alone)
  - Cyber Situation Awareness
  - Detecting and Responding to Extreme Events
  - Smart Space for Aging in Place
Networks for Extreme Events (Emergency Informatics)

- How people use social media during Extreme Events?
- How to develop social computing technology to support the coordination of first responders and NGO’s for disaster relief?
iSchool Team for DARPA Network Challenge (3rd among academic teams)
Geotag of Tweets are Important

“Red balloon siting in Marina Del Rey, CA #DARPA”

( 33.9741,-118.4317 )
➡ Pacific Coast Hwy
Los Angeles, CA 90094

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Map from maps.google.com
Validate Information Source

Hey there! [REDACTED] is using Twitter.

Twitter is a free service that lets you keep in touch with people through the exchange of quick, frequent answers to one simple question: What’s happening? Join today to start receiving jmason110’s tweets.

There’s a strange red balloon with a number near the Philadelphia Art Museum. Wondering what it is for...

10:56 AM Dec 8th, 2009 from web
Tweets can be useful for Crowd Sourcing

Help MIT Team at balloon.media.mit.edu

- Balloons Launched
- Winner Announced
- Balloons began to be put down
EMERSE:
Enhanced Messaging for Emergency Response SErvices

- NSF RAPID project to support the relief of Haiti (Chile, and others)
- Automate
  - Topic Classification of Tweets
  - Geotagging of Tweets
  - Translation of Tweets
- Subscription by topic and regions
- Collaboration with NetHOPE, a coordination body of NGO’s.
Summary

- Certain aspects of team intelligence can be first class behavior of “agents”
- A suitable “trust” relationship between human and agents can improve the performance of human-agent teams.
- The studies of properties, patterns, and behaviors of large-scale networks formed by human and agents (physical robots or software agents) are keys for enhancing social intelligence.