The Sequential Signatures of Success in Teams and Multiteam Systems

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Research Questions about MTS Communication

**FORM:** What are the GENERATIVE MECHANISMS of intra- and inter-team communication?

**PERFORM:** Which GENERATIVE MECHANISMS of intra- and inter-team communication predict TEAM and MTS PERFORMANCE?
Sequential Structural Signatures

• We study how the sequential unfolding of individual relational events leads to future behaviors (relational event approach)

• We hypothesize the generative mechanisms that account for the emergence of behavior; these generative mechanisms are sequential structural signatures (SSS)

• The prevalence of a SSS is determined by the accumulation of relational events over time (weighted to model the decay of team memory, “how long does a prior event influence subsequent events?”)
Two Views of Communication Structures

*Photographs vs. Movies*

Is this structure likely to emerge in the given network?

Is a tie between A and B likely to emerge based on accumulated past relational events?
Relational Events

*Relational Events* are any behavior that are directed from one individual to another. The most common relational event is a message (spoken or typed). We can think of an event as a data point containing a sender, receiver, and timestamp.
A relational event is a discrete event generated by a social actor and directed at one or more targets. An action \( e \) is a tuple:

\[
e = (i, j, k, t)
\]

- \( i \in S \) is the sender
- \( j \in R \) is the receiver
- \( k \in C \) is the event type
- \( t \in R \) is the event time

The relational event was a concept previously proposed, e.g. Heise (1997), but it had not been applied to computational social network analysis. This format of data can replace the static and memory-intensive sociomatrix that social network analysis has relied upon.
A Sample Event Sequence

\[ e_1 = (a, b, t_1) \quad e_2 = (b, c, t_2) \quad e_3 = (a, c, t_3) \]
The Relational Event Model

A data set can be viewed as $E=\{e_1,\ldots,e_m\}$, a sequence of relational events.

To analyze the likelihood of a particular sequence, we look at the probability of each event, as well as the probability that no other event happened in a time interval. This approach to modeling data is “event history analysis.”
Key Assumptions

• Actions occur via an inhomogeneous locally Poisson-like process, and the rates are independent conditional on the realized history of actions.
  • Assume that past history creates the context for present action, forming different relative probabilities for relational events to occur
  • Does not imply marginal or temporal independence
• Once an event occurs the network topology and individual rates are updated, and the process restarts.
The Hazard Rate

\[ h(t_e \mid i_e, j_e, k_e, G_e, E_{t_{e-1}}) \]

The hazard rate; equivalent to the conditional likelihood for event \( e \) at time \( t_e \), given the sender, receiver, type, network configuration, and sequence history
The Survival Functions

\[ \prod_{e' \in A(E_{t_{e-1}})} S(t_e - t_{e-1} | i'_e, j'_e, k'_e, G_{e}, E_{t_{e-1}}) \]

The probability of no other event occurring in the time between \( e_i \) and \( e_{i-1} \) is equivalent to the survival function for that length of time. This is the product over all alternatives in the set of possible actions.
The Likelihood Model

The likelihood model in terms of hazard and survival functions:

\[
Pr\{E\} = \prod_{e=1}^{M} h(t_e \mid i_e, j_e, k_e, G_e, E_{t_{e-1}}) \\
\times \prod_{e' \in A(E_{t_{e-1}})} S(t_e - t_{e-1} \mid i_{e'}, j_{e'}, k'_e, G_{e'}, E_{t_{e-1}}) \\
\times \prod_{e' \in A(E_{t_{e-1}})} S(t - t_e \mid i_{e'}, j_{e'}, k'_e, G_{e}, E_{t_e})
\]
Exponential Distribution of Waiting Times

• For ease of computation, it can be assumed that the hazard rate of a particular dyad is constant during the inter-event times. In other words, if nothing occurs in the network, the relative likelihoods of an event taking place do not change.

• Each dyad has a unique rate which dictates the pace of the events

• Now, we need to parameterize the rate so that it incorporates network characteristics, as well as the full history of events
The Rate Function

The rate function is an exponential function of a linear combinations of statistics and parameters:

\[ \lambda_{ab}(G_e, \theta) = \exp(\sum_h \theta_h \cdot s_h(a, b, G_e)) \]

The statistics are functions of communication volume, and represent the prevalence of a particular signature in the network.
Sufficient Statistics

- The only limits on the statistics are that they must be finite, dependent on past history (in terms of volume and timing), and are affinely independent.
- We use the term “sequential structural signature” (SSS) to describe the sequential unfolding of individual relational events in a particular pattern or configuration.
- To capture the effect of a SSS on the rate of events, we can calculate its prevalence in the event sequence over time.
Calculating Volume

The prevalence of a SSS is represented by the frequency it appears; this is dictated by the volume of communication.

The accumulated chat volume from $a$ to $b$ up to time $t$, weighted by some half life is calculated by:

$$\omega_t(a, b) = \sum_{e:a_e=a, b_e=b, t_e<t} x_e \cdot \frac{\ln(2)}{T_{1/2}} \cdot e^{-(t-t_e)\frac{\ln(2)}{T_{1/2}}}$$

The half-life is optional.
ERGMs vs. Relational Event Networks

Photographs vs. Movies

**Exponential Random Graph Models (ERGMs)** capture cumulative network structures within a predefined time interval (for example, see Robins & Pattison, 2001 or Wasserman & Robins, 2005)

Is this structure likely to emerge in the given network?

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**Relational Event Models (REM)** use sequential structural signatures to explain the rate at which a single event from actor A to actor B is likely to occur at any time, given any prior interaction (see Butts, 2008 and Brandes et al., 2009)

Is a tie between A and B likely to emerge based on accumulated past relational events?
Unitizing Communication

- Unit of analysis is the “relational event”
- A relational event is a directed communication tie from $i$ to $j$
- Skype logs were used to generate communication networks
- Each MTS mission runs 40 minutes & generates > 1000 skype chat messages
Time-Based Generative Mechanisms of Team Process

• Mechanism 1: Within-team communication
  • Team membership rules generate within-team communication (H1)
  • Representation and Gatekeeping rules generate within-team communication (H2a, H2b)

• Mechanism 2: Between-team communication
  • Gatekeeping, Representation, and Contagion rules generate between-team selection (H3a, H3b, H3c)
  • Personal and Generalized inertia rules generate between-team communication (H4a, H4b)
**H1:** Communication is more likely amongst team members than between teams

Signature = Team Membership
**H2a,b**: External communication drives within-team communication

Signature = Intra-team representation (attraction; H2a)

Signature = Intra-team gatekeeping (sending; H2b)
H3a,b,c: Between-team selection is governed by representation, gatekeeping, and contagion

Signature = Inter-team representation (H3a)

Signature = Inter-team gatekeeping (H3b)

Signature = Inter-team contagion (H3c)
Generators of **INTER-TEAM** communication

**H4a,b:** Inter-team communication behavior tends to continue and expand (*Personal Inertia; Generalized Inertia*)

- **Signature = Inter-team personal inertia (H4a)**
- **Signature = Inter-team generalized inertia (H4b)**
Method: Participants, Roles, Task

Sample:
660 individuals
33 MTSs w/4 teams each

Task:
Lead a humanitarian convoy through a hostile region

MTS Structure:
4 teams of 5 individuals
Method: Team & MTS Goals

Each team is responsible for threats in a single quadrant.

Convoy movements are controlled by the leaders of the 4 teams.
SONIC advancing the science of networks in communities

Fully Open Communication via Skype
RQ1: Analytic Approach

• We used REM to determine the significance of each network hypothesis in each of 33 MTSs, & then did a meta-analysis

• A significant result for a given SSS indicates the corresponding effect was a driver of future behavior
GENERATORS OF INTRA-TEAM COMMUNICATION
What are the signatures of team communication?

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<td>-0.21</td>
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<td>Between-Team</td>
<td>-0.17</td>
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<td>H3c: Intra-team contagion</td>
<td>Between-Team</td>
<td>1.62</td>
<td>-0.46</td>
<td>3.70</td>
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<td>H4a: Inter-team personal inertia</td>
<td>Between-Team</td>
<td>10.09***</td>
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<td>12.48</td>
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Emergent Behavioral Patterns

Most MTSs form internal communication based on:
• Team membership
• Avoiding Intra-team representation

And between-team communication based on:
• Inter-team personalized inertia
• Inter-team generalized inertia
RQ2: Predicting Performance

• Given observed variation in the intensities of each SSS from MTS to MTS
• The variation in communication behavior can be used to explain the variation in the performance outcomes of each MTS
• Performance measured at both the local (team) level and global (MTS) level
• Poisson regression used to test SSS – performance relationships
Performance Measures

- Team Performance - Safety of the Team’s Assigned Region
  - # threats accurately identified + # threats effectively neutralized

- MTS Performance - Safe Delivery of Humanitarian Aid Throughout the Region
  - # of grid spaces each unit of aid was moved (distance corrected for damage)
Generative Measures of Team Performance

- **Mechanism 1: Within-team communication**
  - **H1**: When external communication drives within-team communication, the team improves
  - **H2**: When external communication drives within-team communication, the MTS suffers

- **Mechanism 2: Between-team communication**
  - **H3**: When coordination between teams increases, the team suffers
  - **H4**: When coordination between teams increases, the MTS improves
Analytic Method

**Poisson Regression** is a regression technique that relates independent variables to count data. In our case, the independent variables were the intensities of each behavioral effect; the dependent variables were performance metrics collected from the MTS experiment.

REM Communication ➔ Certain structures are more influential in determining behavior ➔ Poisson Regression ➔ Performance
PREDICTORS OF TEAM PERFORMANCE
**DV = Team Performance**

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**Intra-team representation**

- Within-Team: 4.40***
- Between-Team: 1.41

**Intra-team gatekeeping**

- Within-Team: 1.68*
- Between-Team: 0.05

**Inter-team representation**

- Between-Team: 1.41

**Inter-team gatekeeping**

- Between-Team: 0.05

**Inter-team contagion**

- Between-Team: 2.10**

**Inter-team personal inertia**

- Between-Team: 2.27**

**Inter-team general inertia**

- Between-Team: 1.03

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Which Communication Structures Benefit Teams?

Within-team Communication Generators
- Team Membership
- Representation (boundary spanners attract communication)
- Gate-keeping (boundary spanners send communication)

Between-team Communication Generators
- Contagion
  - Benefits team information access
- Inter-team personal inertia
  - Benefits team information access
  - Harms team use of that information
PREDICTORS OF MTS PERFORMANCE
**DV = MTS Performance**

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Within-team Communication Generators

• Team Membership

• Representation harms MTSs (boundary spanners attract internal communication)

• Gate-keeping benefits MTSs (boundary spanners send internal communication)

Between-team Communication Generators

• Personal inertia harms MTSs

• Generalized inertia harms MTSs
Takeaways: Form vs. Perform Paradox
Generative Mechanisms that Occur Naturally Have Mixed Effects

Most MTSs form internal communication based on:
• Team membership (helps teams, MTSs)
• Avoiding intra-team representation (benefits team, harms the MTS)

And between-team communication based on:
• Inter-team personalized inertia (benefits team info. access, harms team info. use & harms MTS)
• Inter-team generalized inertia (harms MTS)
Takeaways: Form vs. Perform Paradox
Two Generative Mechanisms that DO NOT Occur Naturally Have Beneficial Effects

- Intra-team gatekeeping (helps teams & MTSs)
- Inter-team contagion (helps teams)