STONE: Shaping Terrorist Organizational Network Efficiency

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Talk Outline

• STONE Approach
• The Vertex Successor Prediction Problem
• The Multi-Vertex Replacement Problem
• Predicting a Reshaped Network
• Experimental Results
• Conclusion and Future Work
Architecture of STONE

Predict Successor of a Removed Vertex
- Suppose we choose to remove a person from the network.
- Who will replace that node?

Predict how a network will re-structure itself when multiple vertices are removed
- Induce a probability distribution over a space of possible networks that result

Identify which nodes to remove so as to minimize the “expected lethality” of the resulting network
- Each possible new network has a lethality
- The value of removing a set of vertices is an expected value computation

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Organizational Networks

• An organizational network consists of
  – A bunch of vertices (or nodes)
  – A bunch of edges connecting those nodes
  – A rank labeling each node specifying how important the node is within the hierarchy
  – A list of properties for each node – with discrete and numeric values, e.g.
    • Role of the node in the organization
    • Clustering coefficient – how “tightly connected” is the node to its neighbors
    • Blowback level – level of blowback if the node is removed
    • Hostility Level including support for carrying out terror attacks
    • Competence in carrying out terrorist acts
    • Whether the individual is dead/otherwise removed from network/alive and active
Node Properties Considered
Replacing B with A yields the graph on the right. Logic:

- A retains all of its connections (C,D,F)
- A gets all of B’s connections as well (C,D,E)
- So A is connected to C,D,E,F
- A keeps its properties (but gets B’s rank)
Vertex Successor Prediction

• **Assumptions**
  – Replacement $v$ is not too far away from $u$
  – Probability that $u$ is replaced by $v$ depends on $v$’s rank in the network
  – Individuals with a *strictly* higher rank than $u$ will not seek $u$’s position – but individuals at the same (or lower) rank might
  – The network will reshape itself to be maximally lethal
  – The network does not split into factions
Weighted Removal PageRank

- Build on top of Google’s PageRank algorithm.
- Define Weighted Removal PageRank.
- $r$ is vertex being removed.
- $v$ is a vertex being considered for removal.

\[
WRP(v, r) = (1 - \delta) \frac{wt(v)}{\sum_{u \in V \setminus \{r\}} wt(u)} + \delta \sum_{u \in \text{nbr}(v) \setminus \{r\}} \frac{WRP(u)}{|\text{nbr}(u) \setminus \{r\}|}
\]

Look at neighbors of $v$ that are not removed. $v$’s neighbors WRP is evenly distributed to $v$. Relative weight of $v$
Replacement Value

- Replacement value of vertex \( v \) when removing vertex \( r \) is

\[
rv(v) = \alpha_0 \cdot WRP(v) + \sum_{p_i \in VP} \alpha_i \cdot \varphi(v, p_i)
\]

- where the \( \alpha \)'s add up to 1 and specify the relative importance of each vertex to the mission.

Look at neighbors of \( v \) that are not removed. \( v \)'s neighbors WRP is evenly distributed to \( v \).
Candidate Set

$v$ is a candidate to replace $r$ if:

• $\text{rank}(v) \leq \text{rank}(r)$ and

• Distance between $v$ and $r$ (in the network) is less than some threshold $k$ [set by expert]

• $v$ has a set of properties specified by an expert [e.g. $v$ is capable of playing the role played by $r$]
Replacement Probability

- Probability that $u$ is the replacement for $r$ is simply the relative replacement score of $u$ compared to all candidates.

\[ P_{\text{cand}(r,P,k)}(u) = \frac{\sigma(u)}{\sum_{u' \in \text{cand}(r,P,k)} \sigma(u')} \]
Removing Multiple Vertices (near) Simultaneously

• Definition of replacements and replacement probabilities can be extended to multiple vertices.

• Will skip details – but when R is a set of nodes being removed,
  – R is replaced by a set R1 of nodes
  – R1 must then by replaced by another set R2
  – And so on.
Substitution Tree

- Given an organizational network ON and a set R of vertices being removed, we define a data structure called a substitution diagram.
  - Root is set of nodes being removed
  - For a given node N, N’ is a child of N if it’s a possible replacement for the set of nodes specified in N.
  - Each edge is assigned a normalized probability.

C1 is a candidate set to replace R. D1 is a candidate set to replace C1. And so forth.
Possible World

• Result of the replacements along a path.

• Example:
  – Replace R by C2.
  – Replace C2 by D2.

• Probability of this possible world is the product of the two edge probabilities.
Pictorially.....
Network Lethality

• Each possible world is a network that has a lethality.

• Many possible measures of lethality – just discussing 3 today.

• A vertex is violence-prone if its hostility and its support for terror acts both exceed some threshold.

• Otherwise it is violence averse.
Network Lethality

- **L1**: Sum of the weights of the violence prone nodes – Sum of the weights of the violence averse nodes.
- **L2**:  
  - Each vertex has a normalized weight which is its degree times its weight.
  - Add up the normalized weights of violence prone vertices and then subtract the normalized weights of the violence averse vertices.
- **L3**: Same as above by uses WRP instead of degree.
- **L4**: The most important measure that correlates L1, L2, L3 above with actual network attacks.
Correlated Measure L4

- We have different networks as people are removed from the network.
- Initially, we have network N1 and during this time, A1 attacks occur. Network N1 has properties L1(1), L2(1), and L3(1).
- When person P1 was removed, we have a new network N2 and during the time N2 existed, there were A2 attacks. Network N2 has properties L1(2), L2(2), L3(3).
- We build a regression model to predict number of attacks from historical data about the L1(i)’s, L2(i)’s and L3(i)’s.

Predictive regression model is highly accurate.
- 0.83 Pearson Correlation Coefficient for LeT network.
- 0.652 for AQ network
Who to Remove

\[ L_{EV}(\mathcal{O}N, R) = \sum_{N \in \mathcal{N}(\mathcal{O}N, R)} p(N)L(N) \]

- Denotes the expected lethality of the network when R is the set of nodes to be removed.
- We want to find R so that expected lethality is minimal.

The algorithm for finding R is as follows:

1. Input: Organizational network \( \mathcal{O}N = (V, E, wt, \phi) \), maximum set size \( k \).
2. Output: Set \( R \) of nodes to remove.
3. function RESHAPE(\( \mathcal{O}N \), \( k \))
4. \( R = \emptyset \)
5. \( \ell = L(\mathcal{O}N) \)
6. continue = true
7. do
8. \( r = \arg \min_{v \in V \setminus r} L_{EV}(\mathcal{O}N, R \cup \{v\}) \)
9. \( \ell_r = L_{EV}(\mathcal{O}N, R \cup \{r\}) \)
10. If(\( \ell_r \leq \ell \))
11. \( R = R \cup \{r\} \)
12. \( \ell = \ell_r \)
13. Else continue = false
14. EndIf
15. while(continue \&\& |R| \leq k)
16. return R
17. end function

- First find person who minimizes lethality when removed. Remove him from the network.
- Recompute network and scores.
- Find the next person who minimizes lethality and remove him from the network. Recompute.
- Keep doing this until you have removed the required number of people.
Experiment: Predicting Vertex Replacement


<table>
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<tr>
<th>Setting</th>
<th>$\alpha_{WPR}$</th>
<th>$\alpha_{POCC}$</th>
<th>$\alpha_{rank}$</th>
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</table>

- Results need to trade off between
  - How likely we are to predict a correct replacement and
  - How big the answer is.
- Note that HUMAN INPUT IS REQUIRED. We predict a set of people and the predicted replacements for a vertex are presented to the expert.
- Importance of WRP is only about 20%. Node’s rank, WRP [influence], and POCC [connectedness] are all important.
Experiment: Predicting Vertex Replacement

- Result considered correct if it was within $\delta = 2\%, 3\%, 4\%, 5\%$ of the most probable answer

<table>
<thead>
<tr>
<th>Setting</th>
<th>Dataset</th>
<th>$\delta = 2%$</th>
<th>$\delta = 3%$</th>
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In 80% of the cases, one of the top 3 people predicted by us turned out to be the true replacement, based on historical data.
Experiments: Who to Remove

- Difficult to measure.
- Asked experts to evaluate.
- Experts scored answer on a 1-5 scale.

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