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Ranking terrorists in networks: A sensitivity analysis of Al Qaeda's 9/11 attack

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ABSTRACT

All over the world, intelligence services are collecting data concerning possible terrorist threats. This information is usually transformed into network structures in which the nodes represent the individuals in the data set and the links possible connections between these individuals. Unfortunately, it is nearly impossible to keep track of all individuals in the resulting complex network. Therefore, Lindelauf et al. (2013) introduced a methodology that ranks terrorists in a network. The rankings that result from this methodology can be used as a decision support system to efficiently allocate the scarce surveillance means of intelligence agencies. Moreover, usage of these rankings can improve the quality of surveillance which can in turn lead to prevention of attacks or destabilization of the networks under surveillance.

The methodology introduced by Lindelauf et al. (2013) is based on a game theoretic centrality measure, which is innovative in the sense that it takes into account not only the structure of the network but also individual and coalitional characteristics of the members of the network. In this paper we elaborate on this methodology by introducing a new game theoretic centrality measure that better takes into account the operational strength of connected subnetworks.

Moreover, we perform a sensitivity analysis on the rankings derived from this new centrality measure for the case of Al Qaeda's 9/11 attack. In this sensitivity analysis we consider firstly the possible additional information available about members of the network, secondly, variations in relational strength and, finally, the absence or presence of a small percentage of links in the network. We also introduce a case specific method to compare the different rankings that result from the sensitivity analysis and show that the new centrality measure is robust to small changes in the data.

1. Introduction

In the last few years several instances of (almost successful) terrorist attacks have taken place in the West. For instance, think of Umar Farouk Abdulmutallab's attempt at blowing up a Detroit bound airliner (i.e., the 'underwear-bomber') or Quazi Mohammad Rezwanul Ahsan Nafis 2012 attempt at attacking the Federal Reserve Bank of New York. In the "war against terror" new laws are enforced that enable governments and intelligence agencies to retrieve and store increasingly larger amounts of personal data about individuals. These data contain among others information on both the characteristics of individuals, like financial means and affiliations, as well as data on the communication between these individuals, like financial transactions and email correspondence (cf. Lindelauf et al., 2013). As a result the amount of data that becomes available for the analysis and prevention of terrorist related incidents increases.

Traditionally such data are viewed and analyzed as network data, i.e., members of the network correspond to nodes and their interaction is modeled via links in the network. Standard centrality methods from the field of social network analysis, e.g., degree centrality (cf. Nieminen, 1964), betweenness centrality (cf. Freeman, 1977) and closeness centrality (cf. Borgatti and Everett, 2006), focus on finding key members taking only this network structure into account (cf. Wasserman and Faust, 1994; Everton, 2012). Recently, Lindelauf et al. (2013) introduced a game theoretic centrality measure that aids in the analysis of databases designed to detect terror threats by taking interactional information into account both on an individual and a coalitional level. This approach is in line with the game theoretic approach of measuring the quality of covert networks in Lindelauf (2011) and Lindelauf et al. (2009). In particular, context specific cooperative coalitional games are defined

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that reflect the situation at hand taking all available information about the network structure and the individual members and their relations into account. Next, the Shapley value (Shapley, 1953) is computed for the corresponding game to measure the importance of members of the network in order to construct a ranking of these members. A further advantage of using such a cooperative game theoretic centrality measure is that it allows for more flexibility in the sense that for each threat context a specific suitable game can be developed.

In this paper we further elaborate on the existing methodology introduced by Lindelauf et al. (2013). First, to each network we associate a monotonic weighted connectivity game. Here we relax the assumption of Lindelauf et al. (2013) that a coalition is only effective if all members of this coalition are connected in the network. In monotonic weighted connectivity games the effectiveness of a disconnected coalition is determined by the most effective connected subcomponent. This approach resembles reality more closely since partially connected coalitions may still pose a threat to the community. Subsequently, the Shapley value of the newly defined game is used to determine the importance of all members of the network and to construct a corresponding ranking.

Second, we revisit the case of Al Qaeda's 9/11 attack. We define an appropriate monotonic weighted connectivity game suitable to the network underlying the attack. This game incorporates information obtained from Krebs (2002) and Kean et al. (2002). Computing the Shapley value for this game leads to a ranking of the terrorists. Next, a sensitivity analysis is run to investigate the robustness of the ranking obtained. This is accomplished by slightly varying the data available on the members and the structure of the network.

To model individual strength the data on individuals are expressed as weights on the members of the network. In practice these weights are determined by an analyst that measures the importance, skills, or (financial) means available to a terrorist. Obviously, the determination of such weights may differ from one analyst to another. Therefore, we want to see how robust the derived ranking is with respect to small variations in the weights. Concerning the network structure itself, obviously not all interactional data between members may be completely known, i.e., some links may be missing or may be obsolete. Therefore we perform a second type of sensitivity analysis to see how robust our ranking is with respect to the addition or deletion of a small percentage of the links in the network. Finally, some of the interactions between members may be considered more important than others, i.e., the relational strength may differ for each interaction (e.g., email communication, exchanging explosive materials). Therefore we also perform a third type of sensitivity analysis to see how robust our ranking is with respect to changes in the weights assigned to interactions.

The sensitivity analysis compares the rankings obtained by slightly perturbing the data to the ranking found for the unperturbed data using a tailor-made comparison method on rankings. For an overview on general comparison methods on rankings we refer to Su et al. (1998) and Fagin et al. (2003). We find that the ranking based on the new game theoretic centrality measure is robust to small changes in the data.

The structure of this paper is as follows. Section 2 formally associates a monotonic weighted connectivity game to each network on the basis of data on characteristics of individuals and interactions. Subsequently, using the Shapley value, a game theoretic centrality measure and a corresponding ranking is defined. In Section 3 we perform a sensitivity analysis of this centrality measure using data of Al Qaeda's 9/11 attack. In Section 4 we summarize the main conclusions of the sensitivity analysis.

2. A new game theoretic centrality measure

A network can mathematically be represented by a graph $G=(N, E)$, where the node set N represents the set of members of the network and the set of links E consists of all relationships that exist between these members. The existence of a relationship between member i and j is denoted by $ij \in E$. For a coalition $S \subseteq N$, the subnetwork G_S consists of the members of S and its links in E, i.e., $G_S=(S, E_S)$ where $E_S=\{ij \in E | i, j \in S\}$.

A cooperative game in coalitional form is a pair (N, v), where N denotes the finite set of players and v is a function that assigns to each coalition $S \subseteq N$ a value $v(S)$, which can be interpreted as the effectiveness of the coalition. By definition $v(\emptyset)=0$. The central issue is how to adequately allocate $v(N)$, the effectiveness of the grand coalition, over all players. Thus, implicitly measuring to what extent each player is responsible for the total effectiveness of the grand coalition. The Shapley value (Shapley, 1953) of a cooperative game (N, v) allocates $v(N)$ by averaging marginal contributions of a player to the different coalitions.[1]

Following Lindelauf et al. (2013) the idea is to create a game that takes into account the structure of the network $G=(N, E)$, individual strengths (e.g., special skills) of the members of the network, summarized by $\mathcal{I}=\left\{w_i\right\}_{i \in N}$ with $w_i \geq 0$, as well as the relational strength (e.g., communication) between members of the network, summarized by $\mathcal{R}=\left\{k_{ij}\right\}_{ij \in E}$ with $k_{ij} \geq 0$. A coalition $S \subseteq N$ is called a connected coalition if the network G_S is connected, otherwise S is called disconnected. We define a *monotonic weighted connectivity game* (N, v^{mwconn}) with respect to network $G=(N, E)$ based on $\mathcal{I}$ and $\mathcal{R}$ in the following way. For a connected coalition S we define

$$v^{\mathrm{mwconn}}(S)=\begin{cases} f(S, \mathcal{I}, \mathcal{R}) & \text{if } \ |S|>1, \\ 0 & \text{otherwise}, \end{cases} \tag{1}$$

where f is a context specific and tailor-made non-negative function depending on S, $\mathcal{I}$ and $\mathcal{R}$ which measures the effectiveness of coalitions in the network. It can be chosen to best reflect the situation and information at hand. For a coalition S that is disconnected we define

$$v^{\mathrm{mwconn}}(S)=\max_{T \subset S, \ T \text{connected}} v^{\mathrm{mwconn}}(T). \tag{2}$$

Observe, that the value of each disconnected coalition is based on the most effective connected component of this coalition. For the purpose of this paper we define $f(S, \mathcal{I}, \mathcal{R})$ by

$$f(S, \mathcal{I}, \mathcal{R})=\left(\sum_{i \in S} w_i\right) \cdot \max_{ij \in E_S} k_{ij}. \tag{3}$$

This specific choice can be motivated for terrorist cells in which we need to focus on the total operational strength of the cell as well as the most prominent line of communication between members. The operational strength of a cell increases when its individual members exhibit special skills or posses ample financial means, which is reflected by the corresponding weights of the members of the cell. Proper coordination of the cell further increases its ability to act, which is reflected by considering the maximal relational strength present between members of the cell. These latter members can be considered as the coordinators of the attack, whereas the other members can be considered to be the facilitators of the attack.

[1] Let $\sigma=\sigma_1\sigma_2\cdots\sigma_N \in \Pi$ be an ordering of the players in the grand coalition N. If player i is at position k, i.e., $\sigma_k=i$, then its marginal contribution $m^\sigma(i)$ is defined as $m^\sigma(i)=v(\{\sigma_1, \ldots, \sigma_k\})-v(\{\sigma_1, \ldots, \sigma_{k-1}\})$, i.e., the extra value that player i contributes to the already established coalition $\{\sigma_1, \ldots, \sigma_{k-1}\}$. Since the marginal contribution depends on the ordering σ, we average over the set of all possible orderings Π, resulting in the Shapley value of player i: $\varphi_i(v)=(1/n!)\sum_{\sigma \in \Pi} m^\sigma(i)$.