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The structure and vulnerability of a drug trafficking collaboration network

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ABSTRACT

Prior research has established that collaboration networks exhibit heavy-tailed degree distributions, assortative degree mixing, and large clustering coefficients. Using court record data, we assess these properties in a collaboration network among heroin traffickers. Consistent with prior research, we find an exponential degree distribution and strong local clustering. However, the traffickers mix dissortatively by degree rather than assortatively. Using a graph sampling method, we show that a consequence of dissortative mixing is that targeted vertex removals have a greater impact on the connectivity and cohesion of the trafficking network. We also note the importance of degree mixing for characterizing and identifying topological weaknesses.

1. Introduction

Many criminal endeavors are complex and demand a large degree of collaboration and coordination. Criminals rely on each other for tasks that cannot be performed alone, such as the trafficking of drugs and humans, money laundering, fixing sports events, and rigging markets. In this regard, however, criminals are not unique. After all, many non-criminal endeavors are just as complex. What makes criminal collaboration extraordinary is that, in most cases, criminals operate under the constant threat of detection and the punitive consequences that this entails.

Much research has focused on how these extraordinary conditions shape the structure of collaboration in criminal networks. For instance, it has long been proposed that, in order to remain covert, criminal networks adopt particular topological features, such as greater sparsity and decentralization (Baker and Faulkner, 1993; Krebs, 2002; Kenney, 2007; Williams, 2001). Further work has addressed the trade-off between efficiency and security in criminal networks (McCormick and Owen, 2000; Morselli and Petit, 2007; Lindelauf et al., 2009). This work has, in part, motivated research into the vulnerability and disruption of criminal networks (Ayling, 2009; Duijn et al., 2014; Morselli, 2010; Malm and Bichler, 2011).

Meanwhile, there has been a great deal of interest in the structure of collaboration networks in non-criminal domains, such as academia, music, and business. It is recognized that such collaboration networks typically share three properties in common (Ramasco et al., 2004). First, the vertex degree distribution is heavy-tailed (Newman, 2001b; Barabási et al., 2002; Guimerá et al., 2005) such that a minority of actors have a disproportionately large number of collaborators. Second, the degree of connected vertices is positively correlated (Newman, 2005; Chang et al., 2007). Well-connected actors tend to work with other well-connected actors, while the poorly-connected work with the poorly-connected. Third, collaboration networks exhibit strong local clustering. Actors who share at least one mutual partner are more likely to become partners themselves, whether as a matter of choice or chance, than would be the case if vertices were randomly connected (Watts and Strogatz, 1998; Newman, 2001a; Moody, 2004).

However, while these properties are routinely examined in collaboration networks outside of the criminal networks literature, whether collaboration among criminals shares the same three properties has not been addressed directly. Although studies on criminal networks often consider degree and clustering coefficients, they seldom characterize the degree distribution formally, and degree mixing is typically overlooked entirely.

Yet, there are good reasons to be interested in whether collaboration between criminals exhibits the same topological properties as collaboration elsewhere. First, such comparison provides a systematic means of identifying irregularities in the structure of criminal networks. Research on clandestine networks has drawn criticism for lacking empirical benchmarks against which to assess whether the observed properties are, in fact, exceptional (Varese, 2012; Crossley et al., 2012). By drawing on empirical results in the wider literature on collaboration networks, such benchmarks are made explicit.

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Second, the combination of the topological properties, and in particular degree mixing, are interesting in their own right. It has long been known that assortatively mixed networks are more robust to the removal of high degree vertices, whereas this strategy is considerably more effective in dissortative networks (Newman et al., 2002). In light of growing research interest in disrupting criminal networks, degree mixing is therefore a property of particular relevance.

In this paper, we examine the degree distribution, degree mixing, and clustering of a heroin trafficking network. We remain agnostic about how these properties should manifest in the network, and instead simply evaluate each property in turn. We find that the trafficking network has a heavy-tailed degree distribution, which may be classified as either exponential or log-normal. Additionally, the network exhibits strong local clustering. However, unlike other collaboration networks, the traffickers mix dissortatively by degree. Traffickers with a large number of collaborators tend to be connected to traffickers with relatively few, and vice versa.

The dissortative mixing has substantial consequences for the vulnerability of the network to targeted vertex removals. We demonstrate this by analyzing the impact of vertex removals on the heroin trafficking network under different mixing configurations using a graph sampling method. In variants of the trafficking network which are more assortative, but where the degree distribution is preserved, the impact of targeted vertex removals on the cohesion and connectivity of the network diminishes. Conversely, targeted vertex removals have a greater impact in more dissortative variants of the network. Thus, the property on which the trafficking network deviates from other types of collaboration network appears to be critical for its robustness to attacks.

The remainder of this paper is structured as follows. In Section 2 we briefly review previous research on the structure of collaboration networks and criminal networks. In Section 3, we describe the data. In Section 4 we outline the methods for evaluating each property in the network, along with the graph sampling method for generating networks with varying degree mixing configurations, and the measurements used to assess the impact of vertex removal. In Section 5 we present the results, before concluding in Section 6.

2. Previous research

2.1. Topological features of collaboration networks

Studies on the structure of collaboration networks abound. Here, we focus on three topological features that feature regularly in these studies: clustering, a heavy-tailed degree distribution, and assortative degree mixing. In an early study, Watts and Strogatz (1998) used data on the co-appearance of actors in movies and found that when an actor i has appeared in a movie with another actor j, and i has also appeared with a third-actor k, it is far more likely than one would expect by chance that j and k will have also appeared in a movie together. This clustering phenomenon is now a routine finding in social networks, and is a feature of co-authorship among scientists (Newman, 2001a,b) and social scientists (Moody, 2004), in collaboration among jazz musicians (Gleiser and Danon, 2003), and in the Broadway musical industry (Guimerá et al., 2005).

Second, collaboration networks often exhibit a heavy-tailed distribution of degree. Newman (2001a) demonstrated a heavy-tailed distribution in co-authorship networks among physicists, biomedical researchers, and computer scientists. Across disciplines, a minority of authors has a disproportionately large number of co-authors, while the majority has few. The heavy-tail in degree persists outside of scientific co-authorship. For example, collaboration among jazz musicians and in the Broadway musical industry also exhibit a heavy-tailed distribution of vertex degree. Moreover, this property holds for collaboration networks among organizations. Butts et al. (2012) show that a network of inter-organizational collaboration, developed in response to Hurricane Katrina, has a characteristic right-skewed distribution of degree, while collaboration among firms in the biotechnology industry is characterized by a small number of high-degree firms and much larger group of poorly-connected firms (Gay and Dousset, 2005).

Table 1
The clustering coefficient c, degree assortativity r, and degree assortativity error σ_r in several collaboration and criminal networks.

Network		c	r	σ_r
a	Network Science	0.638	0.462	0.072
b	Condensed Matter Physics	0.636	0.186	0.004
c	High Energy Physics	0.442	0.294	0.019
d	Astrophysics	0.639	0.235	0.005
e	Jazz	0.617	0.020	0.026
f	Students	0.636	0.366	0.113

Barabási and Albert (1999) propose that preferential attachment is part of the explanation for this pattern of inequality. Preferential attachment is often associated with a power law in the tail of the degree distribution (Barabási and Albert, 1999; Albert et al., 1999), such that the probability that an actor has precisely x collaborators abides by $P(x) \sim x^{-\alpha}$, where the α scaling parameter relates to the extent of inequality in the number of collaborators per vertex. This work, along with Huang et al. (2008) and Moody's (2004) research on academic collaboration, point to a power law in the tail of degree. Moreover, using dynamic data, Newman (2005) shows that the growth of a co-authorship network is consistent with preferential attachment.

The third property typical of collaboration networks is the positive correlation in the degree of connected actors. Newman (2003a) demonstrates that the partners of academics, movie actors, and businesspeople who have large vertex degree are likely to have many partners themselves, calling this property "degree assortativity." Chang et al. (2007) and Ramasco and Morris (2006) show the degree–degree correlation holds in the movie actor network for both weighted and unweighted degree, while Ramasco et al. (2004) finds assortative degree mixing in company co-directorships. We reanalyze some of the aforementioned networks and report the local clustering coefficient c, assortativity r, and standard error for the assortativity coefficient σ_r in Table 1.[1]

All of these networks are, of course, qualitatively different in kind. The scientific collaboration networks are made up of thousands of actors partitioned into smaller co-authoring teams, where the high-performing teams cluster into a large component (Newman, 2001a; Guimerá et al., 2005). In contrast, those in the Broadway musical industry are divided into somewhat larger teams on a show-by-show basis, where actors cross-over or belong to several teams (Guimerá et al., 2005). Movie actors and jazz musicians assemble around records and movies, respectively. However, in spite of these differences, all of the networks exhibit the clustering, heavy-tailed degree, and assortativity characteristics. Whatever the specific purpose of collaboration, whether producing jazz records, co-authoring papers, or operating a business, similar patterns emerge. A minority of actors represents a large portion of the collaborative activity, well-connected actors tend to work with other well-connected actors, and cooperation is more likely between actors who share a mutual partner.

[1] The network data used in Table 1 were obtained from the Network Data Repository (Rossi and Ahmed, 2015).