Network Science **8** (3): 399–417, 2020
doi:10.1017/nws.2020.5

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ORIGINAL ARTICLE

Egonets as systematically biased windows on society

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Special Issue Editors: Brea L. Perry, Bernice A. Pescosolido, Mario L. Small, and Ann McCranie

Abstract

A person's egonet, the set of others with whom that person is connected, is a personal sample of society which especially influences that person's experience and perceptions of society. We show that egonets systematically misrepresent the general population because each person is included in as many egonets as that person has "friends." Previous research has recognized that this unequal weighting in egonets leads many people to find that their friends have more friends than they themselves have. This paper builds upon that research to show that people's egonets provide them with systematically biased samples of the population more generally. We discuss how this ubiquitous egonet bias may have far reaching implications for people's experiences and perceptions of frequencies of other people's ties and traits in ways that may influence their own feelings and behaviors. In particular, these egonet biases may help explain people's tendencies to disproportionately experience and overestimate the prevalence of certain types of deviance and other social behaviors and consequently be influenced toward them. We illustrate egonet bias with analyses of all friends among 63,731 Facebook users. We call for further empirical investigation of egonet biases and their consequences for individuals and society.

Keywords: egonets, biased samples, friendship paradox, homophily, social psychology, risky behaviors, interpersonal comparisons, weighted samples, false impressions, social network theory

An egonet is an ego-centric network consisting of all of one person's (an ego's) ties with others. People receive considerably more influence and information from others in their egonets than from people in general. Each person's egonet provides a unique window on the larger social world that may influence him/her in its own way. Nevertheless, to the extent that egonets provide a systematically distorted view of the social world, that distortion can have a cumulative systematic impact on people across society. This paper shows the nature and extent of systematic distortion in egonets that may have considerable consequences for individuals, groups, and society. We present the theoretical underpinnings of this systematic bias in terms of egonets of generic "friends," and we explain that it applies equally to egonets of any symmetric ties with any types of relationships among any specific subsets of people. Furthermore, when the egonets misrepresent the population of people in terms of numbers of friends, they are also likely to misrepresent many other characteristics of people in society (e.g., moral and political views, normative and deviant behaviors) with the potential for further consequences on the people who experience these systematically distorted views from their own windows on the world.

One of the most consistent findings in research on social networks is a "homophily bias," that people's friends are more like themselves in many ways than people in general (Mcpherson et al., 2001). Thus, if people use their egonets as windows on the world, they are likely to get the impression that people in general are much more like themselves than they really are. Even as they see and know about people who are not their friends, they may nonetheless be especially

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influenced by their own egonets. There is increasing attention to egonets acting like echo chambers in reinforcing people's existing views of many things (c.f. Bakshy et al., 2015).

More homophily means that each egonet is more similar to its ego and likely to be less representative of the society as a whole than in the absence of homophily. However, if each person is connected to his/her own kind, that in itself would not lead egonets to exhibit any overall bias in any direction. Consequently, homophily bias in egonets affects which people experience which other people but does not affect the extent to which people are experienced by others on average.

In contrast, the overall egonet bias that we are describing in this paper misrepresents society in particular directions that might lead to systematic overall changes in social behavior. We suggest that this systematic egonet bias is pervasive, tends to be large, and is likely to have many varied effects across different types of people and ties that may not be well evident either to the people involved or to observers.

In this paper, we review previous findings showing why and how friends have more friends than people do on average and that people's own sets of friends, their egonets, have more friends per person than people do overall. We frame and prove the finding about egonets in a new more intuitive way that more directly shows how social networks with more positive assortativity (where people with more friends have egonets with more friends) have somewhat less of that upward bias than friends in general have. We show how this works using data from a large Facebook friend network. We then discuss how the systematic upward bias of egonets can have far reaching implications as it applies to all types of symmetric ties and all subnets of types of people, and it has indirect implications for many types of traits. To the extent that people are influenced by their egonets of friends and other ties and by the overall impressions that they get from their egonets, we suggest that these systematic biases can have large and important effects on their beliefs, attitudes, and behaviors.

We have divided the paper into the following sections:

1. A simple example illustrating the overall bias;
2. The logic of bias for friends
3. The logic of bias for egonets
4. Biased egonets in one large Facebook network
5. Implications and evidence for specific types of people and ties
6. The logic of egonet bias on traits
7. Applications to other types of ties, people, and traits
8. Caveats about variations among egonets
9. Systematic egonet bias for shared "social" behaviors
10. Discussion

1. A simple example illustrating the overall bias

Feld (1991) and Kumar et al. (2018) have shown the essential mathematical implications of how friends overrepresent people with many friends. In both of those papers, those findings were primarily used to show how people's own friends tend to have more friends than they themselves have. Following Feld (1991), Zuckerman & Jost (2001) were the first to refer to this surprising interpersonal comparison phenomenon as the "friendship paradox," and research on the friendship paradox has consistently shown that it is common for people's friends to have more friends than they do (e.g., Kooti et al., 2014). In this paper, we use some of the same logic of friends overrepresenting people with many friends to emphasize how egonets inevitably give people systematically biased impressions of the larger social world, irrespective of whether their own friends have more friends than they do.

Before going any further, we want to illustrate our central point with a simple example of 7 people with 18 friends, where we can calculate the mean number of friends of those 7 people,

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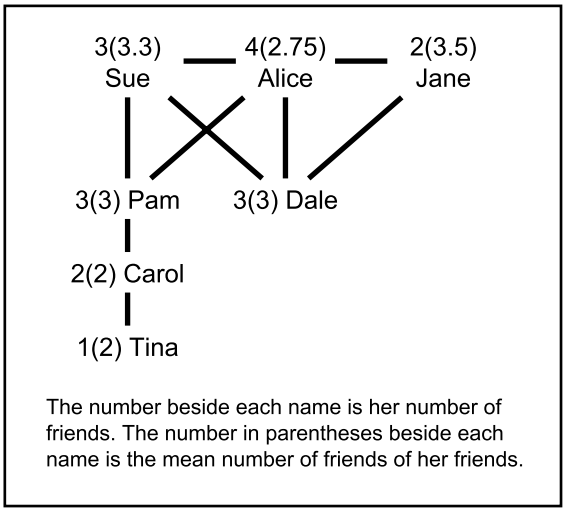


Figure 1. A small social network drawn from the example given in Feld (1991) of Coleman's Adolescent Society (1961) data of reciprocated friendships. This includes seven of the eight girls in the original example presented by Feld.

the mean numbers of friends of their 18 friends, the mean number of friends for each of their egonets (ranging from 1 to 4 friends), and the overall mean number of friends for all 7 egonets. This example includes seven of the eight girls in the example Feld (1991) drew from Coleman's Adolescent Society data (1961). This network is shown in Figure 1. The network of all eight would provide an adequate illustration and the size of the egonet bias is even greater for all eight, but we focus on the network of these seven because the three different means that we consider are more distinct. This example shows how the mean number of friends for egonets can be different from the mean for friends and the mean for people.

The seven girls with a total of 18 friends had a mean number of friends of 18/7 = 2.57. The 18 friends had a total of 52 friends and had a mean number of friends of 52/18 = 2.89. The seven egonets of the girls (with 1–4 people each) had its own mean numbers of friends of the people in that egonet. These seven egonets had an overall mean of 19.58/7 = 2.80. This example shows the relative values of these different means; friends have more friends than people do ($2.89 > 2.57$), and egonets have more friends than people do ($2.80 > 2.57$), but not as many more friends as friends do ($2.89 > 2.80$).

This example illustrates the unique egonet of each person. No single egonet represents the whole population very well. If the average of egonets was similar to the average for people, we would not anticipate any overall effect of influence through egonets. However, in this example, egonets have an average number of friends that is 12% more than the average for people (2.89 compared to 2.57). We show much larger differences in the New Orleans Facebook friendship network that we describe in a later section.

2. The logic of bias for friends

Feld (1991) showed that friends systematically overrepresent people with more friends by including each person as a friend of as many other people as that person has friends. Kumar et al. (2018) further showed that people's own set of friends, their egonets, on average necessarily have more friends than people generally have. They also showed that the average number of friends of egonets (the average of the average number of friends of the friends within each egonet) can be more or less than the overall average number of friends of friends (without taking account of whose friends they are). We provide a new expression of Kumar et al.'s (2018) findings that more intuitively shows how more positive assortativity on egonets (people with more friends have egonets with more friends), the less egonet bias than bias for all friends of friends. Nevertheless, unless

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everyone has exactly the same number of friends as all their friends have, people's egonets are always upwardly biased samples of people's numbers of friends.

In the rest of this section, we present and extend the basic mathematical findings of Feld (1991) and Kumar et al. (2018). We begin with some definitions and then show how the overall mean number of friends of friends must always be higher than the mean number of friends of people.

M_d—Mean degree (number of friends) for people. (D1)
V_d—Variance of the degree (numbers of friends) for people. (D2)
M_{df}—Mean degree (number of friends) for friends. (D3)

Note that there will generally be many more friends than there are people because each person has many friends, and each person counts as a friend as many times as they have friends.

Feld (1991) showed that the mean of the distribution of the numbers of friends for friends (M_{df}) can be calculated as a simple function of the mean and variance of the distribution of numbers of friends of people (M_d and V_d).

$$M_{\mathrm{df}} = M_d + \frac{V_d}{M_d} \qquad \text{(Theorem 1)}$$

The original proof by Feld is reproduced in Appendix A.

3. The logic of bias for egonets

In the previous section, we showed the extent to which friends overall have more friends than people do, on average. However, each person is exposed to the particular friends in his/her own egonet and to the mean number of friends of their own friends. We now consider the mean of the mean degree for all those egonets in the network, which we will call M_{de}.

All things being equal, we might expect that mean of all the means of the individual egonets would be the same as the overall mean for all friends of everyone. However, it is common in social networks for there to be some tendency for people with more friends to have friends with more friends (Newman, 2002). This particular type of homophily (with respect to numbers of friends) is often called "assortativity." Although it may not be obvious why the extent of assortativity would affect the mean for egonets, Kumar et al. (2018) showed that when there is no assortativity, the egonet mean is the same as the friend mean; however, as assortativity increases (the people with more friends have the friends with more friends), the egonet mean decreases from the mean for friends toward the mean for people. The mean for egonets is always strictly greater than the mean for people unless every friend of every person has exactly the same number of friends as the person has. Kumar et al. (2018) derived an expression for the mean number of friends of egonets as a function of the "inversity," the association between the numbers of friends of people, and the inverse numbers of friends of their individual friends.

We now introduce a simpler expression showing how the mean number of friends of egonets is a function of the assortativity of egonets, the correlation between the number of friends of a person, and the mean number of friends of his/her egonet. We first need to repeat and add some notation for the expression:

M_d—Mean degree (number of friends) for people. (D1)
V_d—Variance of the degree (numbers of friends) for people. (D2)
M_{df}—Mean degree (number of friends) for friends. (D3)
M_{de}—Mean of the mean degrees (number of friends) for all egonets. (D4)
$C_{d,de}$—Covariance between degree of a person and mean degree of his/her egonet. (D5)

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The following expression indicates how the mean number of friends for all egonets decreases from the mean number of friends of friends with the extent of assortativity.

$$M_{de} = M_{df} - \frac{C_{d,de}}{M_d} \qquad \text{(Theorem 2)}$$

Combining Theorems 1 and 2 gives the following expression that shows how the mean for egonets increases over the mean number of friends of people with the variance for people and decreases with assortativity.

$$M_{\mathrm{de}} = M_d + \frac{V_d - C_{d,\mathrm{de}}}{M_d} \qquad \text{(Theorem 3)}$$

This expression has the same substantive implications as that of Kumar et al. (2018). It shows that the egonet bias is equal to the friend bias in the absence of assortativity and declines as assortativity increases (i.e., as Kumar et al.'s (2018) "inversity" decreases). The size of the difference between the mean for the egonets and the mean for people is important because the greater the upward bias in the average egonet, the greater the likely consequences of that bias, such that people would think and behave as if other people did have more friends than those people actually have.

Most observers are not likely to be aware of systematic egonet bias and therefore tend to suggest other types of explanations for misperceptions of populations and the behaviors which are in response to systematic egonet biases. For instance, when social psychologists observe that people systematically over- or underestimate various population parameters (e.g., Nisbett & Kunda, 1985), they typically attribute this to cognitive biases, for example, false consensus, false uniqueness, or self-enhancement (Kitts, 2003). Ignoring the egonet bias explained in this paper disregards a large source of empirical bias in the information that people get to process.

Our essential point here is that systematic biases in egonets are likely to have systematic effects on people; however, the information from those egonets may be filtered by people's perceptions and cognitive processes; and the biases in people's actual experiences should be considered before looking for explanations in terms of cognitive distortions. Nevertheless, it is certainly possible that the types of cognitive biases suggested by social psychologists may be relevant on top of the actual biased experiences provided by egonets.

Before considering further implications and applications of this systematic egonet bias, we show the size of the egonet bias in one actual Facebook friendship network.

4. Biased egonets in one large Facebook network

There has been considerable research documenting the friendship paradox, showing that the large majority of people find that their egonets have more friends than they do (e.g., Ugander et al., 2011; Kooti et al., 2014; Kumar et al., 2018), but these researchers do not report the amounts of difference, which would indicate the extent to which egonets exaggerate the numbers of friends of people on average. Nonetheless, if nearly everyone has egonets with more friends than they have, that makes it likely that the mean egonet has more friends than people in general do.

As a dramatic example, Ugander et al. (2011) studied the entire network of Facebook friends as of May 2011, with 721 million active users and 68.7 billion friendships. The authors reported that 92.7% of users had friends with a mean number of friends greater than they had, and for 83.6% of users, most of their friends had more friends than they had. Those data are not available for reanalysis, but we are able to do further analyses on one large connected component of Facebook friends that were collected at a similar time period.

The New Orleans Facebook friend data used throughout this paper were collected in January 2009 by Viswanath et al. (2009). These data include the 52% of the Facebook users who were

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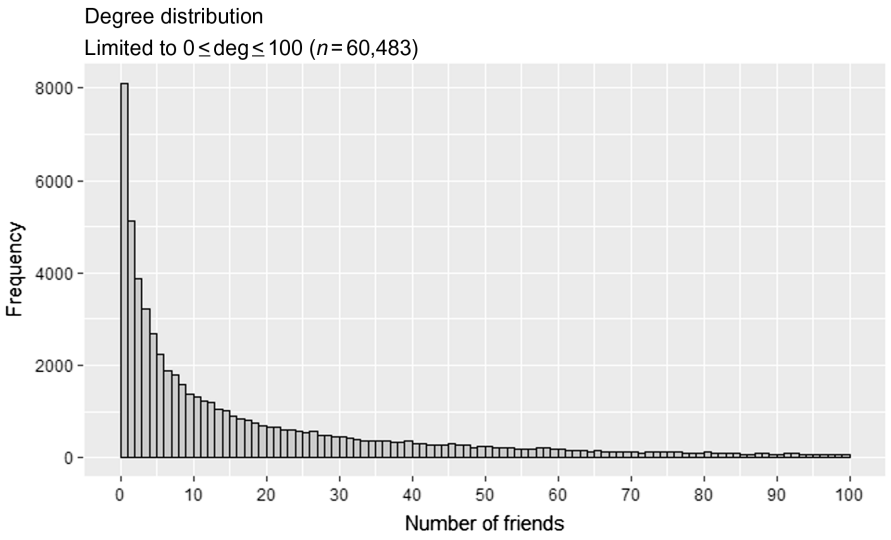


Figure 2. The degree distribution for the 60,483 Facebook users in the New Orleans regional dataset who had at most 100 friends.

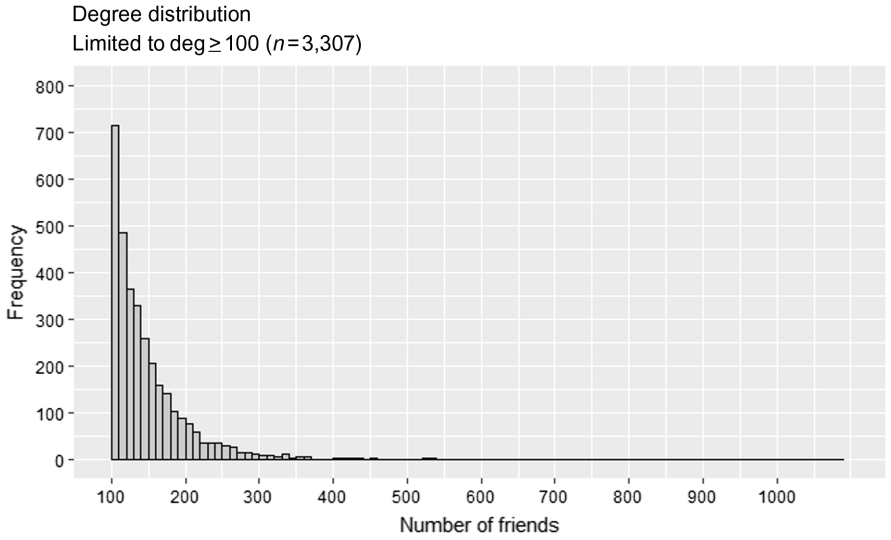


Figure 3. The degree distribution for the 3,307 Facebook users in the New Orleans regional dataset who had at least 100 friends.

connected to the New Orleans Regional Facebook Network at the time. There were 1,634,180 friends of the 63,731 Facebook users; that was a mean of 25.64 friends per person.

Figures 2 and 3 show the distribution of numbers of friends (a person's "degree") in this network. As is typical of social networks, this distribution is extremely skewed; 84% of people had less than 50 friends and yet only 106 people had more than 300 friends, and 1 person even had 1098 friends. We have divided the histogram into two separate parts (degree under and over 100) to better show the entire distribution.

We calculated the mean number of friends of the (1–1,098) friends in each egonet. Then, we calculated the mean of all those egonet means, which is 58.36 compared with the mean of 25.64

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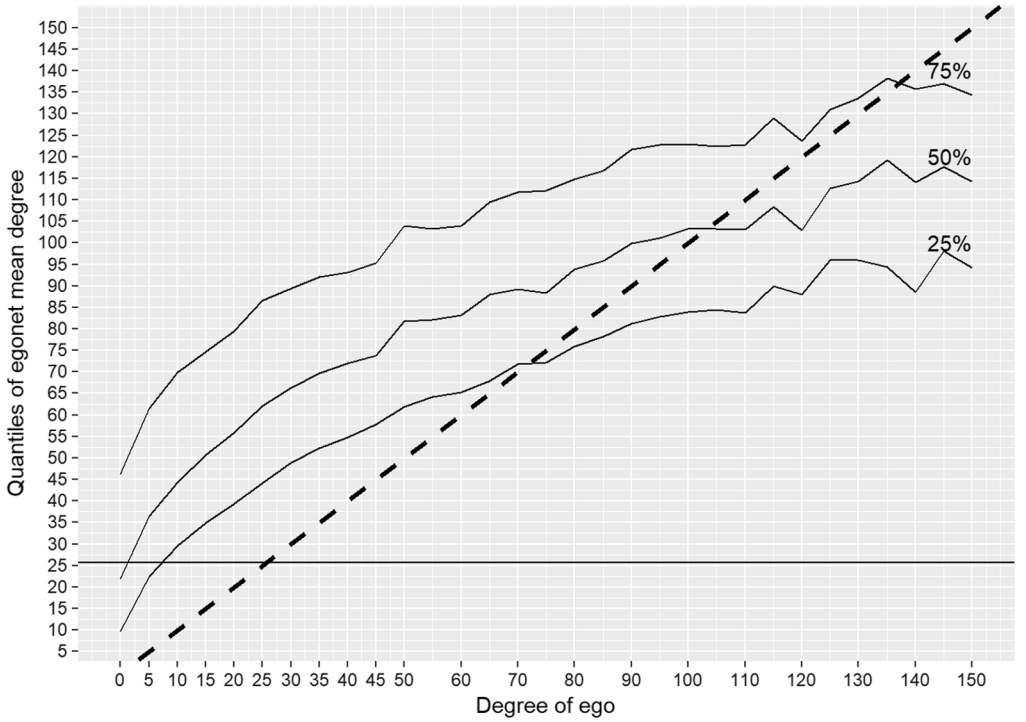


Figure 4. Median and quartiles of egonet mean degree, by the ego's degree. A diagonal dashed line shows the points where ego's degree is equal to egonet's degree. For instance, the 25% quantile intersects the dashed line where 75% of egonets have a higher mean degree than the ego. The solid horizontal line indicates the mean degree in the population.

for people. Thus, people's egonets are providing people with extraordinarily biased samples of other people's numbers of friends. Egonets include people with more than twice as many friends on average as people generally have.

This is the overall average effect of egonet bias for the network as a whole. With an egonet mean much higher than the mean for people, we also expect most people will have egonets with an average of more friends than the mean for people; those expectations were strongly supported in these data; 73.06% of the 63,731 egonets had more friends on average than the mean for people.

There was positive assortativity, a clear tendency for people with more friends to have egonets with more friends, the correlation between the number of friends of people, and the mean number of friends of their egonets was 0.40. That association is evident in Figure 4. The figure shows the first quartile, median, and third quartile of the mean number of friends in egonets of people with each number of friends. All these quartile lines start low and go up for people with more friends. Nonetheless, most people even with relatively few friends themselves have egonets with mean numbers of friends greater than the average person has. For the purposes of comparison, Figure 4 shows a horizontal line at the mean number of friends of people. The figure shows that most people with only 10 friends themselves have egonets with more than the average numbers of friends (25) for people. The figure also shows that among people who have 25 friends (about the mean for people), 75% of them have egonets with at least an average of 44 friends; 50% have egonets with at least an average of 62 friends; and 25% of them have egonets with an average of more than 86 friends. Those few people whose egonets have an average of fewer friends than the average for people are heavily concentrated among those with less than five friends themselves.

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Our focus in this paper is on the impact of egonet bias relative to the population as a whole. However, as an aside and to show consistency with other studies, we can also examine the friendship paradox, comparisons of numbers of friends of people's egonets with the numbers of friends that people have themselves. In this figure, the "self line" is a dotted line showing what the means of egonets would be if they were *equal* to the number of friends of their egos. As one might expect, nearly everyone with the fewest friends has egonets with more friends than they have; but, it should be more surprising to see that more than 75% of people with 70 friends have egonets with more friends than they do. Maybe even more surprising is that more than half of people with 100 friends have egonets with more friends than they do. Overall, 90.8% of all the people in these data have egonets with more friends than they have, which is a very similar proportion to that found in the definitive Facebook friend study discussed above.

5. Implications and evidence for specific types of people and ties

The upward bias in egonets applies to any particular type of symmetric tie and any particular set of people. It is crucial to carefully consider the particular biases of particular types of egonets. For example, if we are looking at egonets of strong ties, then those tend to overrepresent the numbers of strong ties of people, but not necessarily overrepresent weak ties; your close friends are likely to have more close friends than people in general, but they may not have more acquaintances than people in general. If we are looking at egonets among farmers, then the egonets of farmers tend to overrepresent the numbers of ties to farmers, not to accountants.

5.1 Applications to particular types of ties

The logic which applies to friends applies to any type of symmetric tie, for example, "strong ties," "people you socialize with," or "people you encounter every day." The logic only depends upon there being variation in the numbers of such ties in the population of people, where the greater the variation relative to the mean, the greater the difference between the mean numbers of ties for people and for those to whom they are tied in this way. Thus, it follows that your strong ties have more strong ties than people generally do, and your weak ties have more weak ties than people generally do.

We can use additional data on Facebook wall-posts from the New Orleans Facebook data to illustrate some of these effects. These data included records of all the public posts made by any of these users on another users' Facebook walls during a period before the final data collection. When one user posts on another's wall, the post is visible to all of the Facebook friends of the recipient.

These data allow us to determine which friendships involve mutual posting. We refer to these as "posting" relationships. For the 31,082 people who have any posting partners, people have a mean of 5.01 posting partners. We can determine the mean number of posting partners for each of their egonets of posting partners; we find that their posting partner egonets have a mean of 10.04 posting partners. Thus, people's posting partners have more posting partners than people with any posting partners generally do.

The particular application to posting partners may not be very substantively important, but this is presented as an illustration of the same phenomenon that exists for sex partners, drug partners, drinking partners, etc., which have much more obvious import. It is well recognized that people's attitudes and behaviors are disproportionately influenced by their friends' attitudes and behaviors. For example, Maxwell (2002) and Otten et al. (2009) show evidence of friends' influence in behavior for smoking cigarettes and marijuana, and for drinking. Prinstein et al. (2003) show the same for engagement in oral sex. There is also evidence that people's impressions of what other people do more generally are influenced by their egonets. For example, both Lewis et al. (2007) and Otten et al. (2009) report that having smoking friends is associated with overestimating the prevalence of smoking.

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5.2 Applications to particular types of people

The logic described above applies equally well to relationships within any particular subsets of people. Specifically, that would include subsets that can be defined by particular contexts (in a neighbourhood, workplace, church, etc.), characteristics (e.g., gender, race, illness, hobby, and stage of life), or behaviors (using drugs, eating meat, and watching movies).

In the above section, we looked at posting partners. Now, we can look at friendships among people who post. We refer to them here as "posters"; 63% of all users in the dataset were posters. Such people have many more poster friends than they have posting partners because they and their poster friends do not necessarily post to one another. As we predict, the egonets of posters have many more poster friends on average than posters themselves have; we find that posters have a mean of 28.89 poster friends, while their mean egonet has a mean of approximately twice that many, 56.36 poster friends.

Again, we recognize that the particular application to people who post is not especially substantively compelling. However, we believe that it seems more important that people in a neighbourhood find that their neighbours know more neighbours than they do; people find that their gym friends have many more gym friends than they do; African Americans find that their African American friends have many more African American friends than they do; opera buffs find that their opera buff friends know many more other opera buffs than they do, etc. The general point is that biased egonets can lead people to have experience with people who are generally better embedded in each one of their communities than people generally are.

Furthermore, we want to give some indication of the potential for very broad and diverse implications of systematic egonet bias by suggesting the possibility of an important effect of systematic egonet bias for certain types of deviant behavior. Specifically, we suggest that systematic egonet bias may be important for deviant behaviors that are shared and where the participants may be especially responsive to their perceptions of the numbers of others involved. For example, people may be less afraid of getting into trouble for drug use if they think larger numbers of other people are using drugs. The relevant egonet bias is in terms of people who use drugs and their drug partner friends. Specifically, the drug partner friends of drug users have more drug partner friends on average than drug users generally do. As a consequence, drug users who use their egonets of drug partner friends as indicators of the numbers of other drug users out there are likely to overestimate their prevalence. There is considerable research showing that people, on average, and especially people who use drugs more themselves tend to overestimate the numbers of drug users (e.g., Martens et al., 2006). Other research has similarly shown that the overestimation of prevalence of cigarette smoking is more extreme for those who smoke and for those whose friends or family smoke (Otten et al., 2009). We recognize that there may be many further complexities in these processes of experience, perception, sharing of information, and the effects of that information; nevertheless, we believe that systematic egonet bias in the network of deviant partners may be an important neglected aspect of those processes.

We have just elaborated and illustrated the essential phenomenon that egonets composed of particular types of people with particular types of ties overrepresent the numbers of those types of ties among those types of people. However, that says nothing about whether those egonets misrepresent numbers of anything else we now turn to the general logic underlying egonet bias regarding ties, people, and traits that are not the bases of the egonets themselves.

6. The logic of egonet bias on traits

We begin by considering egonet bias for a generic trait. Traits will be overrepresented among friends to the extent that people with more friends have those traits (i.e., people with those traits have more friends). In fact, it is straightforward to modify the fundamental expression showing how the mean number of friends of friends misrepresents the mean number of friends of people

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to show how the mean traits of friends misrepresent the mean traits of people. We need additional notation for discussing the various means for traits:

M_t—Mean trait for people. (D6)
M_{tf}—Mean trait for friends as many times as they are a friend. (D7)
M_{te}—Mean trait for egonets. (D8)
$C_{d,t}$—Covariance between degree and traits for people. (D9)

We remind the reader that M_d is the mean number of friends for people.

The following expression, Theorem 4, shows how the mean trait for friends is biased relative to the mean trait for people

$$M_{\text{tf}} = M_t + \frac{C_{d,t}}{M_d} \qquad \text{(Theorem 4)}$$

Appendix B includes a derivation/proof for this expression. Thus, if the covariance is positive, then the mean trait for friends is greater than the mean trait for people, and if the covariance is negative, then the mean trait for friends is less than the mean trait for people.

We now consider the egonet bias for traits. We have shown above that the egonet bias for numbers of friends is less than the friend bias when people with more friends have egonets with more friends. Considering egonet bias for traits, the relevant population characteristic is the extent to which people with more friends have *egonets* with more of the trait. Note that this is different from the extent to which people with more friends have more of the trait themselves.

We now need additional notation for the covariance between the number of friends of a person and the traits of that person's egonet.

$C_{d,te}$—Covariance between degree and the mean trait of a person's egonet. (D10)

The following expression, Theorem 5, shows how the mean trait for egonets is a function of the mean trait for friends and the covariance between the number of friends of people and the traits of their egonets.

$$M_{\text{te}} = M_{\text{tf}} - \frac{C_{d,\text{te}}}{M_d} \qquad \text{(Theorem 5)}$$

Appendix B includes a derivation/proof for this expression. Theorems 4 and 5 can be combined to provide a single expression showing how the bias for egonets on that trait has a function of the two different covariances.

$$M_{\text{tf}} = M_t + \frac{C_{d,t} - C_{d,\text{te}}}{M_d} \qquad \text{(Theorem 6)}$$

As discussed above, the size and direction of the bias for the friend bias on a trait are determined by the covariance between degree and the trait. There may be situations where the covariance between degree and the mean egonet trait is largely determined by the covariance of degree with the individual trait, dampened by reduced assortativity of degree. If so, the egonet bias on the trait will be in the same direction as the friend bias on the trait but reduced in size, and it will be most reduced in size when there is most assortativity of degree. However, homophily on that trait (the association between the trait of a person and the mean trait of that person's egonet) can also affect the covariance between degree and the egonet trait, in addition to any effects of assortativity of degree. Both the directions and relative sizes of these covariances can vary across networks for many reasons, and this is a subject worthy of further theoretical and empirical investigation.

In the next section, we consider some of the potential broad applicability of this type of egonet bias that goes beyond the types of people and ties that determine the egonets. This type of bias

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may not only be important for many things ordinarily regarded as "traits" (e.g., gender, height, income, and drug use), but it can also apply to the numbers of other types of ties to other kinds of people than those that define the particular egonets. For example, when one is considering egonets of neighbours, whether egonets of neighbours know more accountants than people in general depend upon whether there is a positive correlation in the population between the number of neighbours one knows and the number of accountants they know; the number of accountants they know is just another "trait."

7. Applications to other types of ties, people, and traits

7.1 Egonet biases regarding other types of ties

In general, knowing that someone has a strong tie to you does not tell you whether that person tends to have more or less weak ties to other people than people generally do. To anticipate those types of biases, one needs more information about the association between numbers of strong and weak ties in the larger network. Each network may have a different structure in regard to these associations. This depends upon the nature of the ties, social organization, preferences, constraints, etc. One needs to know the relevant correlations to anticipate the nature of the biases in egonets with regard to numbers of any kinds of ties other than those that define the particular egonet.

We can illustrate this phenomenon with the New Orleans Facebook data, differentiating posting partnerships from other friendships. The question is whether egonets of other friendships have more or less posting partners than people generally do. To determine what to expect, we calculate the relevant correlation between the numbers of posting partners and the numbers of other friendships for all people. We find that for all people, the correlation between the number of posting partners and the number of other friends is 0.57. In the data, people have an average of 2.45 posting partners. We find that friends have an average of 7.65 posting partners, and egonets have an average of 5.01 posting partners. Because the correlation is positive, we see that friends overrepresent the frequencies of posting partners. And, because there is a certain amount of assortativity, egonets overrepresent posting partners slightly less than do friends overall.

Posting partners and other friends is merely an illustration of a phenomenon involving much more important types of relationships. For example, it could be important to know whether people's egonets of non-family friends have more or less family relationships than people in general. That will depend upon the correlation between the numbers of friends and family in the relevant population. For example, Rözer et al. (2016) find that strong family contacts restrict contact with neighbours and colleagues. This implies that people's neighbours and colleagues have less family relationships than people in general.

7.2 Egonet biases regarding other types of people

We can now consider whether egonets of one type of person have more or less relationships with other types of people than those first type of people generally do. For example, from our earlier discussion, we know that the Irish egonets of the Irish always have more Irish friends than the Irish generally do. However, whether the Irish egonets of the Irish have more or less Asian friends than the Irish generally do depends upon the overall network correlation among the Irish between numbers of friends who are Irish and the number who are Asian. If there is a positive correlation, then egonets of the Irish will exaggerate the number of Asian friends the Irish typically have, but if there is a negative correlation, these egonets will underrepresent the number of Asian friends the Irish typically have.

We can show this with further analysis of the New Orleans Facebook data. We consider two kinds of people, those who post ("posters") and those who do not ("non-posters"). The correlation between people's numbers of poster and non-poster friends is 0.89. Consequently, even though

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posters have an average of 5.37 non-poster friends, their poster friends have a much larger average of non-poster friends (13.45), and their egonets of posters also have a larger number of non-poster friends an average (10.42) than posters generally do. Thus, if posters use their poster friends and egonets of posters to estimate how many non-poster friends posters generally have, they would greatly overestimate the numbers of non-poster friends of posters.

Similarly, even though non-posters have an average of 10.45 poster friends, their non-poster friends have an average of 61.80 poster friends, and their egonets have an average of 46.72. Non-poster friends of non-posters have many more poster friends than non-posters have; and their egonets of non-posters also have more poster friends than non-posters generally do. It is interesting to note that if posters find their egonets overestimate relationships with non-posters, then it will also be true that non-posters will find that their egonets of non-posters will similarly overestimate relationships with posters. When there is a positive associating with numbers of friends with different types of people, each type will have egonets that overestimate the amount of the cross-type relationships.

As noted before, our illustration from the Facebook data are just that and further investigations of more egonet biases of other types of intergroup relations (e.g., between whites and blacks in America) might reveal some more consequential egonet biases.

7.3 Egonet biases regarding other traits

We now consider applications to the overrepresentation of particular traits in egonets. To the extent that a person's number of friends is correlated with particular traits, those traits will be misrepresented among egonets. Such misrepresentation was recognized by Eom & Jo (2014) in their consideration of what they called the "generalized friendship paradox," referring to the tendency for people to find that their friends have more of those traits than they do. Similarly, Lerman et al. (2016) described the "majority illusion" as a phenomenon where people misperceive the distribution of traits in a population as the result of bias in people's egonets. These are recognitions that at least under some conditions, egonets will provide biased samples that give people the impression that there are greater or lesser amounts of certain traits in the general population than there actually are.

We have used the New Orleans Facebook data to illustrate the effects on other types of ties and persons above, but those data unfortunately do not include any other types of traits. On the other hand, we are fortunate to have an even more dramatic illustration with regard to other types of traits in the definitive study of all Facebook friendships at one point in time (Ugander et al., 2011). Among other things, that study reports that people who sign on Facebook more often have more Facebook friends than other people, and most people find that their Facebook friends sign on to Facebook considerably more than they do.

The overrepresentation of traits that are correlated with having more ties can have some interesting consequences. For example, you might well find that that your acquaintances at your gym are in especially good physical shape. Your acquaintances at the gym are likely to be people who have a lot of acquaintances there and likely to have acquired them by having gone to the gym a lot. And people who have gone to the gym a lot have likely experienced the most benefits of working out at the gym and so be in particularly good shape, even if the average person who goes to the same gym is not in such good shape.

7.4 Some reasons one might expect correlations between numbers of friends and other traits

There are three general reasons why we might expect certain characteristics will be positively correlated with numbers of friends: (1) Some characteristics can *cause* people to have more friends; (2) Other characteristics can be consequences of having more friends; and (3) There are likely to also be other factors that cause having more friends that also cause other characteristics. To the

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extent that people with more friends tend to have certain characteristics for any of these reasons, people will find that they have a higher proportion of their own friends with these characteristics than existing in the overall population. For example, people tend to have friends who are very experienced, are especially outgoing, confident, successful, and physically attractive.

In real-world friendship networks, many personality traits have been linked to having a large number of friends. Staiano et al. (2012) give an extensive meta-analysis, showing that people with more friends consistently score higher on psychological measures of extraversion and agreeableness. Feiler & Kleinbaum (2015) show that among an incoming MBA cohort, people's friends are more extraverted than they are. Grund (2014) shows that among students in 14 U.S. schools, friends were better intermediaries and more powerful in terms of network position than individuals in general. Tong et al. (2008) show through experiment that Facebook users are perceived as more attractive and extraverted if they have a higher friend count.

8. Caveats about variations among egonets

The central logic of this paper concerns the comparison between the distribution of characteristics of friends in egonets and of people in general. The argument is that people with lots of ties are overrepresented and those with few or no ties are underrepresented in egonets. We believe that these biases have pervasive influences on the biases people generally experience in their egonets. However, there are many reasons why each person's egonet does not include a representative sample of the distribution of all friends in the network. People's egonets are selected from particular contexts that organize people's activities, meeting, and mating (Feld, 1984). Each context tends to be disproportionately homogeneous in particular respects, and people select and are selected by others on various criteria that reflect the particular context and characteristics of the individual him/herself. Individual egonets vary widely from one another, and the overall biases that we have been describing are likely to be very unevenly distributed among egonets.

Also, selection and overrepresentation biases may interact in complex ways that are difficult to anticipate or take into account. For example, the particular carpenters that academics know are likely to be unrepresentative of carpenters more generally because the carpenters who know a lot of academics may be very unusual carpenters; they themselves may be disproportionately highly educated, living or working in upper middle-class residential areas, more politically liberal, and/or just particularly like academics.

Particular circumstances can greatly affect the way that particular egonets are affected by the general overrepresentation biases that we have been discussing. Nevertheless, while it is ultimately an empirical issue, these biases may have pervasive influences on the experiences of people in nearly all social networks.

9. Systematic egonet bias for shared "social" behaviors

Research has shown that it is common for people to overestimate certain important types of behaviors, for example, alcohol use (Berkowitz, 2005; Perkins, 2003, 2002), smoking (Sussman et al., 1988), sexual activities (Scholly et al., 2005), and use of drugs (Perkins et al., 1999).

Researchers have considered many possible processes that could produce such systematic overestimates in particular situations, but these situational explanations cannot account for the very general findings of overestimates of certain types of behaviors across varied situations. For example, Osgood et al. (2013) find with regard to alcohol use, people who use alcohol have more friends than others; thus, people are likely to overestimate the prevalence of alcohol use. However, we should not expect that people who use alcohol, or who engage in any of these other behaviors, will generally have more friends than others; in fact, it is a classic finding that "deviants" have fewer friends than others (Festinger et al., 1950). Situational processes may be important factors in many

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situations, but we suggest that one should consider the inevitable egonet biases as a baseline before considering situational factors.

We suggest that that many of these behaviors are "social" in the sense that people who engage in more of the behaviors tend to engage in those behaviors with more other people. For example, people who drink more tend to drink with more other people. People who engage in more casual sex engage in such activity with more other people. Thus, numbers of drug partners, sex partners, drinking partners, etc. are used as indicators of the extent of these various behaviors. Therefore, systematic biases in egonets of these types of partners lead to systematic biases in people's estimates of the extent of these types of behaviors. We consider drug partners as an example to illustrate how this generally works.

As shown earlier with regard to generic friends, egonets of drug partners (pairs of people who do drugs together) necessarily overrepresent people who have more drug partners, which would lead people to experience and overestimate the numbers of other people's drug partners and the amount of drug use that would go with that. The overrepresentation of numbers of drug partners in egonets of drug partners will always occur, irrespective of other situational factors, including whether people who use drugs have more or less generic friends than other people.

It is worth noting people with no drug partners themselves have no egonets of drug partners from whom to derive biased impressions of others' numbers of drug partners. Nevertheless, those who do have egonets of drug partners have biased experiences with people with more drug partners, which inflates their experiences, perceptions, and estimates of numbers of drug friends. This in turn contributes bias to the average experiences, perceptions, and estimates for the whole population.

A tendency for people with small egonets not to rely on their egonets as windows on the world might help explain another common finding that people who smoke and drink more tend to overestimate these behaviors of others more (Chassin et al., 1991; Sussman et al., 1988; Perkins, 2005). We expect that people with minimal relevant egonets (e.g., few smoking partners or drinking partners) are less likely to rely on those egonets for estimating the numbers of other people's numbers of relevant partners; therefore, their estimates will be based upon other information that does not necessarily include the systematic biases of egonets. Furthermore, when there is assortativity/homophily on numbers of behavioral partners, people with more partners themselves will have egonets with more of those partners and consequently be especially likely to overestimate the numbers for other people.

Researchers have collected information on numbers of people's friends who drink, smoke, etc. (Berkowitz, 2005; Perkins, 2005; Chassin et al., 1991), but we are not aware of research that has collected data specifically on social behavior partners that could show the extent to which systematic egonet bias in those specific egonets contributes to people's biased experiences and estimation of these behaviors. It would be useful for future studies to include data on the networks of these types of partners, people's estimates of numbers of such partners of others, and their estimates of the extent of the behaviors of others.

The most straightforward implication of this overrepresentation in these social behavior networks is a tendency for people to be influenced to act more like their own egonets, which would tend to increase these behaviors. In addition, people's overestimates of the behaviors of other people generally might act as norms that encourage more of those behaviors.

In addition to explaining why and which people overestimate these types of behaviors, we may also be able to help predict the overall extent of overprediction. In earlier sections, we showed that the greater the variation in the numbers of friends, the greater the overall bias of egonets. When applied to social behavior partner networks, more variation among people implies greater overrepresentation of the behaviors relative to actual prevalence. That greater overrepresentation could lead to increasing those behaviors both from the direct influence of the egonets and from the perceptions of the social norms.

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10. Discussion

An egonet provides an important window on the social world for each person. Even as people are aware that the social world contains a lot more than they can see through their own friends and associates, people's best efforts to supplement their own egonet information are unlikely to give them a full accurate picture (see Smith, 2015, for a discussion of the challenges of inferring accurate full network information even by combining information from many egonets.). It is reasonable to suppose that people are affected by their experiences with their own egonets as well as by the impressions that they get from their own egonets and likely to be affected by biases in those egonets even with taking account of supplementary information.

We began by reminding readers of the homophily bias, that your friends overrepresent people like yourself. This is the most widely recognized bias in egonets. Then, we devoted most of this paper to showing multiple different manifestations of the systematic bias that results from friends being included in as many egonets as they themselves have friends. Specifically, we emphasized that all types of symmetric relationships with all kinds of people are overrepresented in egonets in comparison to their presence in the general population. And, we discussed how all kinds of other traits that are related to the numbers of ties people have are similarly misrepresented in egonets. Further research should explore how biases in egonets affect people's experiences, beliefs, understandings, and behaviors.

First, further theorizing might clarify, modify, and extend the theoretical arguments that we have presented here. In particular, our considerations have raised questions about how the systematic egonet bias that we have highlighted interacts with the homophily bias. For example, when a trait is associated with having more ties, more assortativity leads to more homophily on that trait and more homophily on that trait increases assortativity. There might be circumstances where people with the most ties are more or less homophilous on a trait than other people; and the homophily on any trait of those with the most ties has disproportionate effect on the homophily of everyone else on that trait. It could also be important to understand how both systematic egonet bias and homophily are related to the formation and change of egonets over time.

Second, we suggest that it would be very useful to have further empirical work that can determine the nature and extent to which these biases are actually experienced in egonets of people in various contexts. There is need for empirical research on the extent of such bias as actually manifest in various real networks. Specifically, it may be useful to directly measure particular types of symmetric relationships that have not generally been measured (e.g., drug use partners) where systematic egonet bias may have particularly important effects on people's experience and perceptions of particular types of behaviors (e.g., extent of drug use). Research including such measures may provide some systematic explanation for some consistent empirical findings (e.g., overestimation of the extent of drug use) that researchers have been able to only partially explain with situational factors. And, it would seem especially useful to further explore the nature of various types of egonets on the Internet, as people increasingly experience and perceive the social world through those egonets as well as through egonets offline.

Finally, it is important to both theoretically and empirically explore where, when, how, and how much people's beliefs, understandings, attitudes, and behaviors are actually affected by their biased egonets and the impressions that they derive from those egonets about the larger social world. Whether people are aware of the distributions of others in their egonets or not, they are inevitably disproportionately influenced by the people with whom they relate in one way or another.

In addition, it would be good to know more about the extent to which people are aware of characteristics of people in their egonets, the extent to which their impressions of their egonets are accurate, the extent to which those impressions affect their image of the larger social world, the extent to which those images affect their beliefs and attitudes about people and society, and the extent to which any or all of this might affect their own behaviors toward others and society.

Conflict of interest. Authors have nothing to disclose.

https://doi.org/10.1017/nws.2020.5 Published online by Cambridge University Press

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Appendix A. Proofs about egonet bias in degree

Throughout this appendix, we denote by P the set of all people in the social network. We denote by N the number of people in the social network. We denote by $F(i)$ the set of people who are friends of person i, and by $d_i = |F(i)|$ the number of friends person i has. Unless otherwise specified, summations are over the entire network, denoting by i the summation index. Notation necessary for the following proofs is summarized in Table A1.

Theorem A1.

$$M_{df} = M_d + \frac{V_d}{M_d}$$

Because V_d and M_d are non-negative, this expression implies the important observation that friends on average have more friends than people do on average (as first shown by Feld (1991)).

Proof of Theorem 1. Using a standard calculation formula for variance (c.f. Ross, 2010),

$$V_d = \frac{\sum d_i^2}{N} - \left(\frac{\sum d_i}{N}\right)^2$$

Furthermore, the mean degree for friends takes the average degree over all $\sum d_i$ friends. Because each person is counted as many times as they have friends, the total number of friends of friends is $\sum d_i^2$. This leads to a simpler expression for M_{df}:

$$M_{df} = \frac{\sum d_i^2}{\sum d_i}$$

With these two expressions, we can prove Theorem 1:

$$\begin{aligned} M_d + \frac{V_d}{M_d} &= \frac{\sum d_i}{N} + \frac{\frac{\sum d_i^2}{N} - \left(\frac{\sum d_i}{N}\right)^2}{\frac{\sum d_i}{N}} \\ &= \frac{\sum d_i}{N} + \frac{\sum d_i^2}{\sum d_i} - \frac{\sum d_i}{N} \\ &= \frac{\sum d_i^2}{\sum d_i} \\ &= M_{df} \end{aligned}$$

□

Theorem A2.

$$M_{de} = M_{df} - \frac{C_{d,de}}{M_d}$$

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Table A1. Notation, definition, and description of each quantity of interest in regards to egonet bias in number of friends

Notation	Definition	Description
M_d	$\frac{\sum d_i}{N}$	The mean number of friends, averaging over each person in the network.
V_d	$\frac{\sum (d_i - M_d)^2}{N}$	The variance of number of friends (degree) in a social network.
M_{df}	$\frac{\sum_{i \in P} \sum_{j \in F(i)} d_j}{\sum_{i \in P} d_i}$	The mean degree for friends, averaging *over each friend* in the network. Each person is counted in this average as many times as they are a friend—that is, by their degree.
de_i	$\frac{\sum_{j \in F(i)} d_j}{d_i}$	"Egonet mean degree": The average of number of friends among the friends of person i.
M_{de}	$\frac{\sum de_i}{N}$	The mean of egonet mean degree in the network.
$C_{d,de}$	$\frac{\sum (d_i - M_d)(de_i - M_{de})}{N}$	The covariance between degree and the egonet mean degree in the network.

Proof of Theorem 2. Using a standard calculation formula for the covariance (c.f. Ross, 2010),

$$C_{d,de} = \frac{\sum d_i de_i}{N} - M_d M_{de}$$

Note also that

$$\begin{aligned} \frac{\sum d_i de_i}{N} &= \frac{\sum_{i \in P} d_i \left(\frac{\sum_{j \in F(i)} d_j}{d_i} \right)}{N} \\ &= \frac{\sum_{i \in P} \sum_{j \in F(i)} d_j}{N} \\ &= \frac{\sum d_i^2}{N} \\ &= M_{df} M_d \end{aligned}$$

Combining this result with the above expression for $C_{d,de}$ and rearranging yields the result

$$M_{de} = M_{df} - \frac{C_{d,de}}{M_d}$$

□

Appendix B. Proofs about egonet bias in traits other than degree

The proofs in this section are directly analogous to those in Appendix A. Before continuing, we present the needed definitions to analyze the bias on some numerical trait of people in the network. We denote by t_i the value of this trait for person i. Notation necessary for the following proofs is summarized in Table A2.

Theorem A4.

$$M_{tf} = M_t + \frac{C_{d,t}}{M_d}$$

Proof of Theorem 4. The proof of Theorem 4 is analogous to the proof of Theorem 1, recognizing that (c.f. Ross, 2010)

$$C_{d,t} = \frac{\sum d_i t_i}{N} - \left(\frac{\sum d_i}{N} \right) \left(\frac{\sum t_i}{N} \right)$$

and another exercise in algebra

$$\begin{aligned} M_t + \frac{C_{d,t}}{M_d} &= \frac{\sum t_i}{N} + \frac{\frac{\sum d_i t_i}{N} - \left(\frac{\sum d_i}{N} \right) \left(\frac{\sum t_i}{N} \right)}{\frac{\sum d_i}{N}} \\ &= \frac{\sum t_i}{N} + \frac{\sum d_i t_i}{\sum d_i} - \frac{\sum t_i}{N} \\ &= M_{tf} \end{aligned}$$

□

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Table A2. Notation, definition, and description of each quantity of interest in regards to egonet bias for a given trait

Notation	Definition	Description
M_t	$\frac{\sum t_i}{N}$	The mean of t, averaging over each person in the network.
M_{tf}	$\frac{\sum_{i \in P} \sum_{j \in F(i)} t_j}{\sum_{i \in P} d_i}$	Mean of t, averaging *over each friend* in the network. Each person is counted in this average as many times as they are a friend—that is, by their degree.
te_i	$\frac{\sum_{j \in F(i)} t_j}{d_i}$	"Egonet mean t": The average of trait t among the friends of person i.
M_{te}	$\frac{\sum te_i}{N}$	The mean of egonet mean t across the population
$C_{d,te}$	$\frac{\sum (d_i - M_d)(te_i - M_{te})}{N}$	The covariance between degree and the egonet mean t in the network.

Theorem A5.

$$M_{te} = M_t - \frac{C_{d,te}}{M_d}$$

Proof of Theorem 5. The proof of Theorem 5 is directly analogous to the proof of Theorem 2. We recognize that we can express $C_{d,te}$ as follows (c.f. Ross, 2010)

$$C_{d,te} = \frac{\sum d_i te_i}{N} - M_d M_{te}$$

And show, analogous to the proof of Theorem 2 that

$$\frac{\sum d_i te_i}{N} = M_d M_{tf}$$

and combining these expressions, we get the result. □

Cite this article: Feld S. L. and McGail A. (2020). Egonets as systematically biased windows on society. *Network Science* **8**, 399–417. https://doi.org/10.1017/nws.2020.5

https://doi.org/10.1017/nws.2020.5 Published online by Cambridge University Press