Do the Young Live in a “Smaller World” Than the Old? Age-Specific Degrees of Separation in a Large-Scale Mobile Communication Network

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That any two persons are separated by a relatively small number of intermediary contacts—the “small-world” phenomenon—is a surprising but well established regularity in human social networks. To date, network science has ignored the question of whether the small world phenomenon manifests itself in similar ways across dyadic classes defined by individual traits, such as age or sex. To address this gap in the literature, we explore the phenomenon of “age-specific small worlds.” Rather than asking whether two random individuals are separated by a small number of links, we ascertain the extent to which individuals in specific age groups live in a small world in relation to individuals in other generational classes. We use data from a large-scale mobile communication network built from billions of voice calls and short messaging events approximating interaction patterns at a societal scale. We observe the average global distance between any random pair of users is 9.52, corresponding to nine-and-a-half degrees of separation. More importantly, we show that there is a systematic relationship between age and the average path distance connecting that person to others, with some age groups falling below this average quantity while others falling above. Young people live in the “smallest world,” being separated from other young people and their parent’s generation via a comparatively small number of intermediaries. Older people live in the “least small world,” being separated from their same age peers and their younger counterparts by a relatively large number of intermediaries. Middle age-people fall in between, being sociometrically close to both younger and older generations. However, there exists no significant difference of this age-effect on small world size between men and women. In all these results demonstrate that age-group heterogeneity of the small world can be traced to well-known social mechanisms affecting the way that age interacts with overall volume of connectivity and the relative prevalence of kin ties and non-kin ties, and may have important implications for our understanding of information cascades, diffusion phenomena, and the localized spread of fads and fashions.

I. INTRODUCTION

A. Background

The fact that any one individual may be capable of reaching any other person via a relatively short chain of network intermediaries is a surprising property of human social networks [28]. This “small world phenomenon” was first documented in a series of classic experiments conducted by Travers and Milgram in the 1960s [28, 37], with a more recent large-scale Internet-based replication using a cross-nationally diverse population producing results encouragingly close to those of the original study [11].

More recently, with the increasing availability of large-scale network data built from digitally recorded traces of human communication [13, 21], the existence of the small-world phenomenon has been successfully established using observational data obtained from large-scale systems featuring millions of actors and billions of links [4, 15, 24]. One attractive feature of this approach is that it allows for direct calculation of the average number of links separating any two individuals at very close to the whole network level (e.g. the largest connected component in the system). This helps to overcome the key limitation of first generation research on the small world: namely reliance on indirect inference from completed chains obtained from the initial subset of seed nodes. Instead, in large-scale small world research the average of all shortest paths in the network can be calculated directly, although not without computational cost [4, 23].

While useful for demonstrating the robust existence of an important property of social networks, a focus on global estimates of the existence of the small world property has to rely on averages taken over all nodes in the network irrespective of node attributes. The disadvantage of this approach is that it may hide structured heterogeneity in the extent to which different node classes are actually well-represented by the average. This becomes more relevant when we consider that persons tend to select contacts with similar social characteristics as themselves [21, 27], a tendency that is reproduced in the sort of electronic telecommunication platforms that have been the subject of recent attention [3, 12, 19]. Because links are not assigned randomly to node-classes, neither are the number of intermediaries separating a given person from others of the same (or different) class.

In this respect, it may be more meaningful to investigate the existence of more targeted realizations of the small world phenomenon, especially with respect to node
classes defined by socially significant node attributes such as age, gender, and in some contexts, race and social class. As a first step in this direction, in this paper we investigate the phenomenon of “age-specific small worlds.” Rather than asking whether any two randomly chosen individuals are separated by a small number of intermediaries, we ascertain the extent to which individuals in the same age group tend to live in a small world in relation to individuals in the same or other generational clusters. We select age as a focal attribute because it is one of the two (gender being the other one) most powerful traits structuring interaction and sociability in human groups.

B. Age, Social Networks, and the Small World

What sort of pattern should we expect to observe in terms of the relative strength of the small world phenomenon across age groups? Sociological research on the connection between the age and kin structure, as well as the relationship between non-kin connectivity and life course transitions can be of help in developing some expectations in this regard. Consider the (idealized) model of the connectivity structure between age and kin groups shown in Figure 1. In the figure, shapes represent three generational groups arranged from younger (on the bottom) to older (on the top). The green edges connecting the shapes represent (idealized) connections among persons who belong to the same age group but who are not biologically related (non-kin ties). The red edges represent (idealized) connections among persons from different age groups who share a biological relation (kin ties). The thickness of the edge indicates the expected relative prevalence and strength (e.g., typical communication frequency) for those ties. For the sake of simplicity, cross-generation non-kin ties are not drawn.

The figure is meant to encode a series of relevant empirical generalizations taken from work on age, social interaction, and kinship in anthropology and sociology. First, note the declining strength of within-generation, cross-kin connection as we move up from the youngest to the older generation. This encodes the idealized fact that sociability and frequency of interaction decline almost linearly with age. In regards to young people, sociological work on the subject shows that, free from the demands of work, childcare, and other mid-life responsibilities, young people are better able to devote relatively larger amounts of time to within-generation socializing outside the family, increasing their connectivity within this age stratum. In addition, younger individuals tend to spend the majority of their time inhabiting social institutions (such as schools) that encourage same-generation non-kin peer group formation and promote sociable interaction. Middle aged individuals, while continuing to have active dispositions and capacities for socializing with same-age non-kin others experience a variety of negative shocks that lead to a decline in connectivity in relation to younger persons. These include transition into marriage, full-time employment, and parenthood.

Second, with regards to kin ties, note the relatively strong links linking younger individuals to the parental generation, follow by relatively weaker link connecting parents to their parents, and the tenuous links connecting younger people to the older generation. This generalization is supported by research in anthropology and sociology highlighting the distinctive nature of kin ties and their transformation as societies transition into economic and cultural modernity. First, this research shows that because the bulk of informal socializing outside of the family occurs within generations, kin ties are the primary link connecting individuals across generations. Kin ties are distinctive because they are largely fixed at birth and as such display less variation in prevalence and strength across individuals and groups. Social norms dictate that parents must be connected to their children and to their own parents. Consistent with this idea, Social scientific studies show that kin ties represent a substantial portion of reported “close” confidants among middle-aged adults. However, sociological research also shows that the structure and strength of kin ties has undergone significant transformations as Western (and later non-Western) societies began to industrialize in the 18th and 19th centuries. The most significant social transformation in this regard is the shift towards a “conjugal” (bi-generational) form of family organization.
The PDF of the distances between pairs of users with different gender; (b) The cumulative distribution function (CDF); (c) The PMF of the distances between males and females in Mobile network. (d) The CDF in the Mobile Network.

Figure 2. Distributions of distances (the shortest path lengths). (a) The probability mass function (PMF) of the distances in the Mobile, CALL, and SMS networks, respectively; (b) The cumulative distribution function (CDF); (c) The PDF of the distances between pairs of users with different gender in the Mobile network, i.e., female (F) and male (M); (d) The CDF in the Mobile Network.

across the world’s most economically developed societies, far from tri or quad-generational co-residential living arrangements in which grandparents co-resided with both their children and grandchildren. In this respect, the modal household becomes the bigenerational residence containing only parents and children. In Figure 2, this is indicated by the thick vertical lines linking the circle (parent) and triangle (children) generation, and by the relatively thinner vertical links connecting the circle and square (grandparent) and the even thinner lines connecting the triangle and square.

C. Implications for Age-Specific Small Worlds

Because the small world property is premised on the relative connectivity of persons, the existence of combined age and kin effects on social connectivity should result in predictable consequences for the relative extent to which individuals of different age groups live in a small world. Generally, the less connected the members of a given age group are to others of a given node class (e.g. same or different generation), the less likely they are to be able to reach those others via a small number of intermediaries. This proposition has three main set of empirical implications.

First, younger individuals should live in the smallest of worlds, especially with respect to same-generation others. In addition, given the existence of relatively strong ties to their parental generation (via the bi-generational household residence mechanism), they should also be separated by a relatively small (but larger than the same-generation quantity) number of intermediaries from members of the parental generation (and vice versa). However, relatively fractured attachments to the grandparent’s generation, given produced by the same bigenerational household process, should put young people at a longer sociometric distance from their most elder counterparts (and vice versa). Second, middle-aged individuals should be in the next “least small” world tier with respect to same-generation peers. That is, their separation from same-generation others should be larger than that of corresponding to their children. Middle-aged individuals, should also be relatively close to members of the parental generation via intermediary kin ties. Finally, older individuals should live in the “least small” world with respect to same-generation peers, as ties to same-generation others are selectively pruned leaving only attachment to younger generation kin as their primary source of sociability.

II. RESULTS

A. Nine-and-a-half Degrees of Separation in Mobile Communication

We begin by establishing whether we can observe “small world” effects in our three large-scale electronic communication networks. Figures 2(a) and 2(b) show the distributions of geodesic distances between all pairs of users. Here we observe that the modal distances between Mobile (voice calls plus text messaging), CALL (voice calls only), and SMS (text messaging only) users are 9, 12, and 11, respectively. Further, over 95% pairs of users can be reached within 15 steps in each network. The average distances between two users are 9.52, 12.53, and 10.89 in three networks, which correspond to nine-and-a-half, twelve-and-a-half, and eleven degrees of separation, respectively.

These estimates are larger than those obtained via indirect experimental strategies (which are contaminated by selection on completed chains) or in online social media environments. In this last case, available ties may reflect only a selected portion of an individual’s total network (e.g. excluding kin for young people and over-representing same age peers) and include an “excess” number of ties that the individual need not spend time, energy or resources to actively maintain (as in electronic communication networks).

Further, we investigate the small-world effect between people of different gender. In particular, we would like to answer the question of whether females live in a smaller world than males. In Figures 2(c) and 2(d) we report the distributions of distances between two females (F-F),
one female and one male (F-M), and two males (M-M) in the Mobile network. Accordingly, the average distances are 9.62, 9.51, and 9.41, respectively. The overlapping of the three distance distributions indicates that females and males live in the similar scale of small worlds. More surprisingly the distances between opposite-gender people are in accordance with those between same-gender, although previous studies show that the interactions between women and men are consistently more intense and frequent in different communication channels [12, 23].

B. The Young Live in A Smaller World

We proceed by examining the question of whether there exist systematic variation in age-specific small worlds taking the estimates of the average shortest path connectivity for all pairs of users in the Mobile (voice call plus text messaging) network shown in Figure 2 as our overall reference point ($\mathcal{L} = 9.52$). We also computed estimates separately for the SMS and CALL networks but since these tell a similar story, we show only those for the combined Mobile network for simplicity. The results of this analysis are shown in Figure 3. The results are consistent with expectations. Average shortest path connectivity increases steadily with age, being smaller than expected for young individuals, about average for those of middle age and higher than expected for older individuals. These results do not seem to be vary appreciably by gender. Note the observed “hinges” in the age/average geodesic distance curve, at about ages 30 and 50 which correspond closely to the major life transitions noted in the sociological and anthropological literature [39].

Figure 4 shows a heatmap plot of the average shortest path connectivity across age groups. As expected, the small world advantage of younger individuals comes from their relative closeness to their same age counterparts (blue shaded area in the lower left-hand corner) coupled with their relative closeness to individuals in their parent’s generation (about 20 to 30 years older). This is consistent with sociological work suggesting that the first pattern is due to the formation of non-kin same generation ties (although ties to siblings in the same generation are also included here), while the latter are due primarily to kin ties to parents (and indirectly to other members of the parental generation).

Surprisingly, middle-aged individuals end up being sociometrically closer to their younger counterparts (offspring generation) than they are to their own generation. This is consistent with sociological research pointing to the disruption of same-generation non-kin ties with middle-aged life transitions, and the relative stability and durability of kin ties to offspring given their non-elective (ascriptive) status [34, 39]. Finally, as shown in the red-shaded area in the upper-right hand corner of the plot, older individuals live in the “least small” of the world and this is due primarily to their relatively large sociometric distance from members of the same-generation and that of their immediately preceding (offspring) age group. This is consistent with work showing steady decline in sociability and connectivity with in elective (non-kin) ties leaving older persons with non-elective (kin) ties as their only source of connectivity [26].

Figure 5 shows a heatmap illustrating what happens when we shuffle the demographic attributes of each vertex in the network while leaving both the network structure and the proportion of vertices belonging to a given age group intact while computing the average shortest path distances across age groups for fifty different realizations of the reshuffled network (see Material and Methods for details). As shown by the homogeneous coloring across the figure, age-group differences in average shortest-path distances to members of other age groups disappear, and all age groups converge to the average geodesic distance
Figure 5. **Shuffled average degrees of separation across age groups.** The spectrum color represents the average shortest path lengths between two people of age indicated by x- and y-axes.

Figure 6. **Z-score of the shuffled results.** The spectrum color represents the Z-score values.

for all pairs in the Mobile network ($L \approx 9.5$). This suggests that, consistent with our account, differences across age groups in “small worldness” emerge as a result of systematic preferences for within and cross-generation social attachments [27].

Figure 6 shows a heatmap of the distribution of Z-scores obtained from comparing the observed average geodesic distances across age groups against what we would have expected by chance (from the fifty reshuffled realizations of the network as given in Figure 5). The results confirm that younger individuals live in smaller worlds in relation to same generation peers and older generation contacts than we would expect by chance, while older individuals live in larger than expected small world in relation to same generation peers and members of the immediately preceding generation (middle-aged individuals).

A key implication of sociological and anthropological work on age and social networks is that the cross-age-group connectivity distribution is systematically different for older and younger persons and the pattern should be consistent with one in which same-generation non-kin sociability steadily declines and is replaced by cross-generation kin-based sociability. Figure 7 plots the proportion of ages for each age group that link them to same generation (plus or minus five years difference), older generation (between 20 to 30 years older) and younger generation (between 20 to 30 years younger) groups. All rates are calculated from the mobile electronic communication network.

The findings replicate the idealized pattern depicted in Figure 1 suggesting that these are the mechanism behind the age-specific small world effects that we observe. Younger individuals (e.g. between the ages of 20 and 35) have relatively high rates of communicative interaction with both their same age peers and those in the immediately preceding (parental) generation. However, as we move up along the x-axis, we see a steady decline in same-generation sociability and its gradual replacement by cross-generation sociability (20 to 30 years younger). This is indicative of attrition in same-generation ties for older individuals and their replacement with cross-generation ties to the immediate kin (child) generation. The two lines cross at about 60 years of age, which is close to the institutionally mandated time for retirement from work activity in industrialized Western societies (such as the one from which the Mobile network originated), providing further support for the model.
III. DISCUSSION

Previous work has shown the “small world” property to be a counter-intuitive but robust signature of human social networks. The classic work by Milgram [28] as well as more recent replications using email chains [11] used experimental strategies aimed at inferring average network diameter from the average length of completed chains. More recent work using social media and electronic communication data allow for the computation of average shortest paths at a societal or even “planetary” scale [4, 13, 23]. However, most of this work remains focused on the small world property as a feature of the entire network, but has not looked at vertex-level heterogeneity in the existence of this property.

In this paper, we ask the question whether age which, other than sex, is one of the few universal characteristics that has been shown to structure human interaction in human societies [32], can be considered a vertex-level property that generates differences in the extent to which people live in more or less small worlds. Using a large-scale mobile communication network that approximates the volume of communication of a large-scale industrialized society, we ask not whether any two random individuals are separated by a relatively small number of intermediaries. Instead, we ask whether individuals in different age groups live in more or less small worlds in relation to members of other groups.

Our results reveal systematic heterogeneity in the extent to which people of different ages can be said to live in “more or less” small worlds. The pattern of this heterogeneity is, in its turn, predictable from well-known regularities uncovered in anthropology and sociology related to the relationship between age, sociability, changing structure of generational living arrangements in modern societies, and the relative rates of kin-based and non-kin-based connectivity throughout the life-course (see Figure 1). Younger individuals live in the smallest of worlds, both in relation to same-age peers and cross-generation consociates, while older individuals live in the “least small” of worlds, being particularly likely to be separated by a larger number of intermediaries from same-generation peers.

These results have important implications because the small world property of human social networks lies behind a variety of phenomena associated with processes of cultural transmission, the emergence of information cascades, and other diffusion processes. As a rule, shortest connectivity paths between persons facilitate the fast spread of information and thus contribute to the large-scale adoption of novel beliefs, behaviors, practices, and products [30–33]. Our results thus imply that in any given modern society, due to their greater sociometric proximity to both same-generation and cross-generation others, younger persons are more likely to serve as the most effective seeds and most likely conduits for the rapid spread of novel information, behaviors, practices, and any other element that may be subject to “contagion” and diffusion dynamics than older individuals. This is consistent with work in sociology and marketing showing that such phenomena as fads, fashions, and information/behavior cascades occur more frequently among the young [14], and that members of older generations are generally dependent on younger individuals to keep abreast of novel behaviors, products, and activities [14]. Our work thus reveals that these long-standing observations have an intuitive basis in the sociometric location of the young in relation to the old.

Our results also imply that greater sociometric isolation of older individuals will result in their being the last to hear or be exposed to novel “viral” practices, beliefs, and objects of any dispositional “conservatism” that may come with advanced age [10]. Thus even older individuals who may be potentially open to new experiences and be likely candidates for the adoption of innovations, will be at a structural disadvantage. However, our argument and results do suggest that if older persons do experience exposure it is more likely to come from cross-generational next of kin ties (most likely children) than from non-kin same-generation peers. In this respect, the existence of various “generation gaps” in attitudes, behaviors, and practices may be as much of a product of the qualitatively distinct social structural position of the young and the old as it is of cohort-based, period-based, or aging-dynamics.

In this paper, we have provided a model and a set of tools for how to investigate heterogeneity in “generic” properties of large-scale networks across vertex attributes. Future work can build on our current effort and examine the extent to which heterogeneity in the small world (and other well-defined network properties) that have been primarily investigated irrespective of the categorical attributes of vertices in human social networks do vary in a structured way according to those attributes, while outlining the implications of this variation for our understanding of important structural and dynamics processes in such networks.

IV. MATERIALS AND METHODS

A. Mobile Phone Networks

We use a mobile phone data comprised of more than 1 billion voice call and short messaging records spanning in two consecutive months in 2008 [12, 16]. To represent the human communication behavior in networks, we place an edge between two users if and only if they have reciprocal communications within the two-month observation time window [32]. In this way we construct a call network from voice calls, a messaging network from short messages, and a mobile network from both channels. Further we extract the giant component as the experimental network from each network [32]. The resulting mobile, call, and messaging networks (referred to as Mobile, CALL, and SMS) contain 5,324,963, 4,295,638, and 2,369,078 nodes, and
10,410,903, 7,893,769, and 3,330,086 undirected edges, respectively.

In the resulting Mobile, CALL, and SMS networks, 89.19%, 99.93%, and 87.16% of nodes are associated with the corresponding users’ gender and age information. We calculate the shortest paths between all pairs of users and report the results between those with known gender and age attributes. The demographic distributions of users in the Mobile network and the Europe population are presented in Figure 8. Overall there are 45% of female users and the remaining 55% of male users, and both female and male users between the ages of 18 and 55 are strongly overrepresented in the Mobile network compared to the true population, while teenagers and seniors on the other hand are underrepresented.

B. Shortest Paths in Large Networks

In this work, rather than employing the sampling and probabilistic methods used in previous work [4, 23], we instead leverage a large computing cluster to determine the average shortest paths between all pairs of users, that is \( n \times (n - 1)/2 \) pairs, where \( n \) is the number of users in each network. In total, we compute the shortest paths between \( 1.4 \times 10^{13}, 9.2 \times 10^{12}, \) and \( 2.8 \times 10^{12} \) pairs of users in the Mobile, CALL, and SMS networks, respectively, and more essentially, record the length of the shortest path between two users specified by their gender and age information.

C. Null Model

We validate the statistical significance of the differences on shortest path lengths between users of different age and gender groups. The idea of the statistical test is to compare the gender- and age-based shortest path length \( x \) from the data to those \( \{ \hat{x} \} \) provided by a null model, wherein the users’ gender and age are randomly shuffled. In this article, we leverage a classical null model that was used in attributed networks [19]. On the null model, we first randomly assign users’ gender and age on the underlying structure of the communication networks, and then compute the lengths of the shortest path between pairs of users of randomly allocated gender and age. The random assignment of users’ gender and age and following computation of shortest paths in the network are simulated for fifty times. Accordingly, we calculated the mean \( \mu(\hat{x}) \) and standard deviation \( \sigma(\hat{x}) \) of the shortest path lengths \( \{ \hat{x} \} \) on the null model. We use Z-score to examine the gap between the real data \( x \) and the randomly shuffled results \( \{ \hat{x} \} \) on the null model.

\[
Z(x) = \frac{x - \mu(\hat{x})}{\sigma(\hat{x})}
\]

A Z-score of 0 indicates that there exists no difference between the real data and the null model. A positive (negative) Z-score represents that the empirical data is above (below) the null model result. \(|Z(x)| \geq 3.3\) (corresponding to \( p \)-value \( \leq 0.001 \)) represents that the observation from the empirical data is extremely statistically significant.

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