2001-06-21

The web of human sexual contacts

F. Liljeros, C.R. Edling, L.A.N. Amaral, H.E. Stanley, Y. Aberg. 2001. "The web of human sexual contacts." NATURE, Volume 411, Issue 6840, pp. 907 - 908 (2). https://doi.org/10.1038/35082140
https://hdl.handle.net/2144/39918

The Web of Human Sexual Contacts

Many "real-world" networks are clearly defined [1] while most "social" networks are to some extent subjective [2, 3]. Indeed, the accuracy of empirically-determined social networks is a question of some concern because individuals may have distinct perceptions of what constitutes a social link. One unambiguous type of connection is sexual contact. Here we analyze data on the sexual behavior of a random sample of individuals [4], and find that the cumulative distributions of the number of sexual partners during the twelve months prior to the survey decays as a power law with similar exponents $\alpha \approx 2.4$ for females and males. The scale-free nature of the web of human sexual contacts suggests that strategic interventions aimed at preventing the spread of sexually-transmitted diseases may be the most efficient approach.

Recent studies of real-world networks [1] have formalized mathematically the "six-degrees of separation" concept put forth in the classic study of Milgram [5]. This so-called small-world phenomenon [6] refers to the surprising fact that networks have small average path lengths between nodes while preserving a large degree of "clustering" [3]. Small-world networks may belong to three classes—single-scale, broad-scale, or scale-free—depending on their connectivity distribution $P(k)$, where k is the number of links connecting to a node [7]. Scale-free networks—which are characterized by a power law decay of the cumulative distribution, $P(k) \sim k^{-\alpha}$ — may be formed due to preferential attachment, i.e., new links are established preferentially between nodes with high connectivities [8, 9].

We analyze data gathered in a 1996 Swedish survey of sexual behavior [4]. The survey—involving a random sample of 4781 Swedish individuals (ages 18–74 yr)—used structured personal interviews and questionnaires to collect information. The response rate was 59 percent, corresponding to 2810 respondents. Two independent analyses of non-response error reveal that elderly people, and especially elderly women, are under-represented in the sample; apart from this skewness, the sample is representative in all demographic dimensions.

Connections in the network of sexual contacts appear and disappear as sexual relations are initiated and terminated. To analyze the connectivity of this dynamic network, whose links may be quite short lived, we first analyze the number k of sex partners over a relatively short time window—the twelve months prior to the survey. Figure 1a shows the cumulative distribution $P(k)$ for both female and male respondents. The data follow closely a straight line in a double-logarithmic plot, consistent with a power law dependence. The data shows that males report a larger number of sexual partners than do females [10], but that both have the same scaling properties.

These results contrast with the exponential or Gaussian distributions—for which there is a well-defined scale—as was recently found for friendship networks [7]. Plausible mechanisms that could account for the observed structure include: (i) increased skill in getting new partners as the number of previous partners grows, (ii) different levels of attractiveness, (iii) the need to have many new partners to maintain self-image. Thus, the data are consistent with the preferential attachment mechanism. Perhaps, in sexual contact networks, as in other scale-free networks, "the rich do get richer [8, 9].

We next analyze the total number $k_{\rm tot}$ of partners in the respondent's life up until the time of the survey. This quantity is not relevant to the "instantaneous" structure of the network but may help elucidate the mechanisms responsible for the distribution of number of partners. Figure 1b shows the cumulative distribution $P(k_{\rm tot})$. For values of $k_{\rm tot} > 20$, the data follow a straight line in a double-logarithmic plot, consistent with a power law dependence in the tails of the distribution.

Our major finding is the *scale-free* nature of the connectivity of an objectively defined, non-professional, social network. This result shows that the concept of the "core group" considered in epidemiological studies [11] is somewhat arbitrary as there is no well-defined threshold or boundary separating the core group from other individuals (as there would for a bimodal distribution).

Our findings also have possible epidemiological implications. First, epidemics arise and propagate much faster in scale-free networks than in single-scale networks [6, 12]. Second, measures to contain or stop the propagation of diseases in a network must be radically different for scale-free networks. Specifically, the study of scale-free networks indicates that they are resilient to random failure, but are highly susceptible to destruction of the best connected nodes [13], while single-scale networks are not susceptible to attack even of the best connected nodes. Hence, the possibility that the web of sexual contacts has a scale-free structure indicates that strategic targeting of safe-sex education campaigns to those individuals with a large number of partners may have a significant effect in reducing the propagation of sexually-transmitted diseases.

We thank M. Buchanan, G. Franzese, S. Mossa, and C. M. Roman for helpful suggestions and discussions, and especially G. Helmius for making the survey data availble to us. FL and YÅ thank STINT(97/1837) and HSFR(F0688/97), and CE thanks HSFR(F0624/1999) for support. LANA and HES thank NIH/NCRR (P41 RR13622) for support.

REFERENCES

[1] Strogatz, S. H. *Nature* **410**, 268–276 (2001).

[2] Kochen, M. (ed.), *The Small World* (Ablex, Norwood, NJ, 1989).

[3] Wasserman, S. & Faust, K. *Social Network Analysis* (Cambridge University Press, Cambridge, 1994).

[4] Lewin, B. (ed.), *Sex i Sverige. Om sexuallivet i Sverige 1996 [Sex in Sweden. On the Sexual Life in Sweden 1996]* (National Institute of Public Health, Stockholm, 1998).

[5] Milgram, S. *Psychol. Today* **2**, 60–67 (1967).

[6] Watts, D. J. & Strogatz, S.H. *Nature* **393**, 440–442 (1998).

[7] Amaral, L. A. N., Scala, A., Barthélémy, M., & Stanley, H. E. *Proc. Nat. Ac. Sci USA* **97**, 11149–11152 (2000).

[8] Simon, H. A. *Biometrika* **42**, 425–440 (1955).

[9] Barabási, A.-L. & Albert, R. *Science* **286**, 509–512 (1999).

[10] Laumann, E. O., Gagnon, J. H., Michael, R. T. & Michaels, S. *The Social Organization of Sexuality* (University of Chicago Press, Chicago, 1994).

[11] Hethcote, H. W. & Yorke, J. A., *Gonorrhea Trasmission Dynamics and Control* (Springer Verlag, Berlin, 1984).

[12] Pastor-Satorras, R. & Vespignani, A. *Phys. Rev. Lett.* **86**, 3200–3203 (2001).

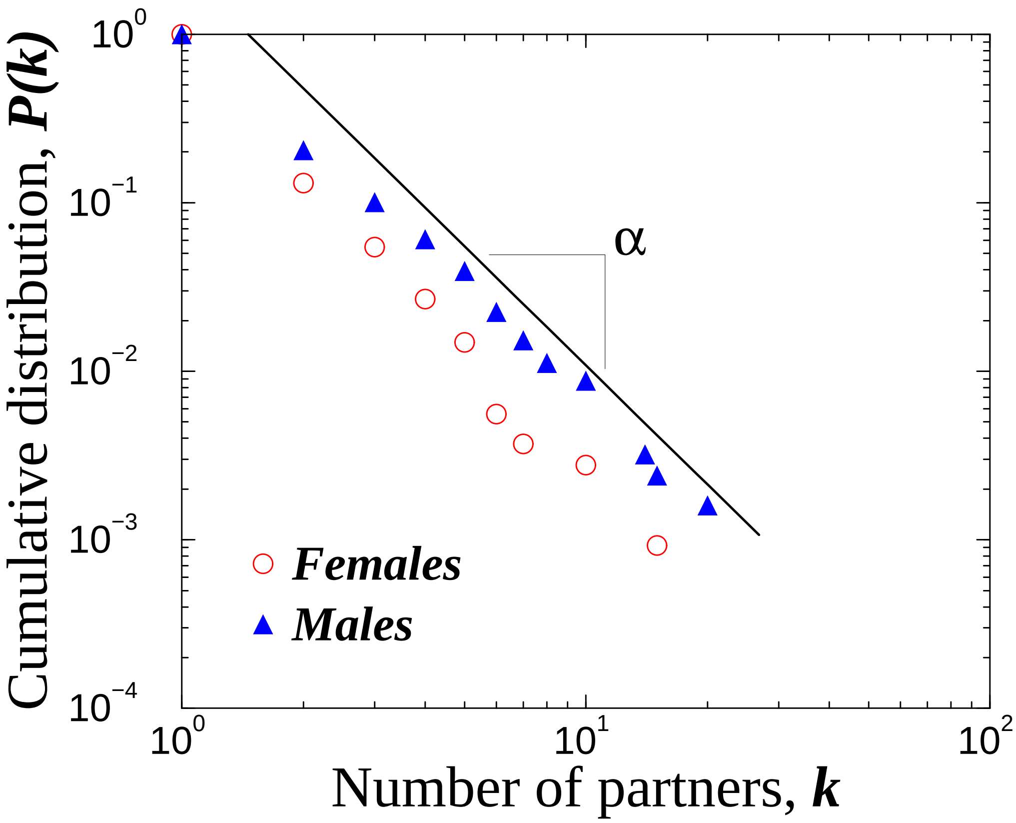
[13] Albert, R., Jeong, H., & Barabási, A.-L. *Nature* **406**, 378–382 (2000).

Fredrik Liljeros[1], Christofer R. Edling[1], Luís A. Nunes Amaral[2], H. Eugene Stanley[2], and Yvonne Åberg[1]

[1]Department of Sociology, Stockholm University, S-106 91 Stockholm, Sweden

[2]Center for Polymer Studies & Dept. of Physics, Boston University, Boston, MA 02215,

USA


Cumulative distribution, P(k)
10^0
10^−1
10^−2
10^−3
10^−4
α
Females
Males
10^0
10^1
10^2
Number of partners, k

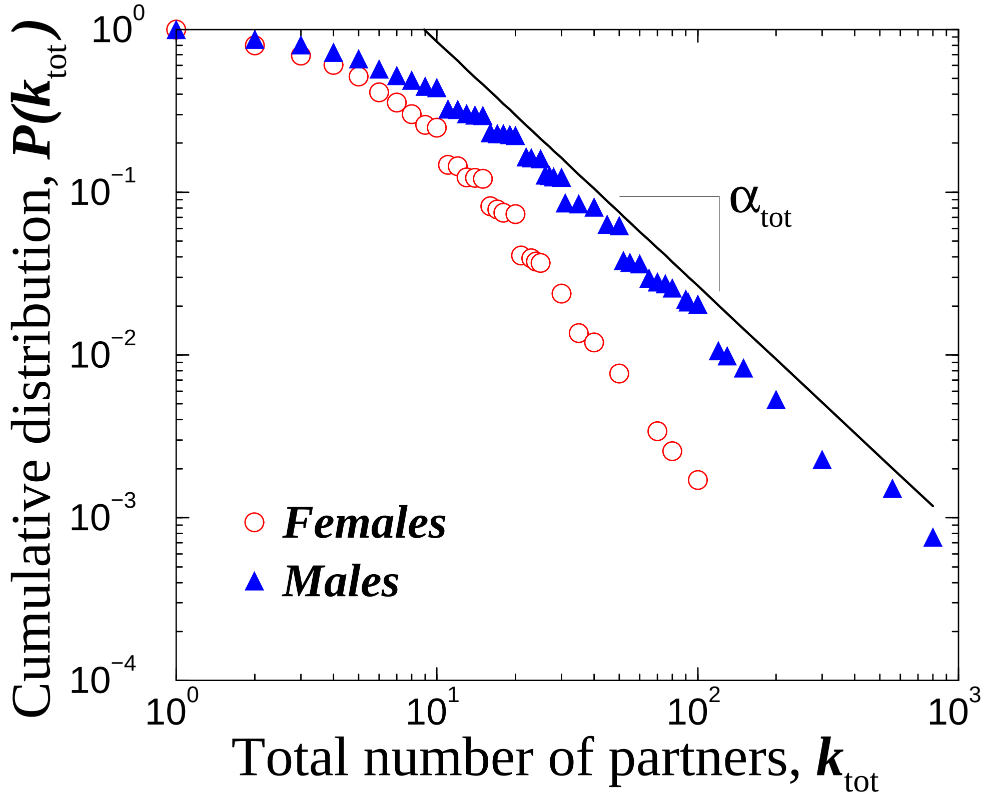


FIG. 1. Scale-free distribution of number of sexual partners for females and males. **a**, Distribution of number of partners k in only the previous year. Note the larger average number of partners for male respondents. This difference may be due to "measurement bias"—social expectations may lead males to "inflate" the number of sexual partners. Note that the two distributions are both linear, indicating power law scale-free behavior. Moreover, the two curves are roughly parallel, indicating similar scaling exponents. For females, we obtain $\alpha = 2.54 \pm 0.2$ in the range $k > 4$, and for males, we obtain $\alpha = 2.31 \pm 0.2$ in the range $k > 5$. **b**, Distribution of the total number of partners $k_{\rm tot}$ over all years since sexual initiation. For females, we obtain $\alpha_{\rm tot} = 2.1 \pm 0.3$ in the range $k_{\rm tot} > 20$, and for males, we obtain $\alpha_{\rm tot} = 1.6 \pm 0.3$ in the range $20 < k_{\rm tot} < 400$. These two estimates agree within statistical uncertainty.