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Universal patterns in egocentric communication networks

Quantitative sociology, personal networks, tie strength. communication dynamics, modelling

Extended Abstract

Social networks are key to the exchange of ideas, norms, and other cultural constructs in human society [1], influencing the way we communicate, support each other, and form enduring communities. Decades of research have focused on regularities in the patterns of relations among individuals, as well as the drivers and mechanisms behind their origin [2]. One particularly prominent feature of social networks is the diversity of tie strengths [3], where strong ties are typically embedded within social groups while weak ties are crucial for the cohesiveness of the network as a whole [4]. At the micro level, ego networks—the sets of social ties between an individual (the ego) and their family, friends, and acquaintances (the alters)—commonly feature a small core of close relationships. These close relationships are associated with high emotional intensity and they are surrounded by a larger number of weaker ties. The emergence of this characteristic structural pattern has been associated with constraints on maintaining social relationships, which include limited information processing capacity, social cognition, and time availability [5].

Studies of human communication via mobile phones have shown that in line with the above picture, there is a consistent, general pattern in egocentric networks where a small number of close alters receive a disproportionately large share of communication. Data on the frequency of mobile phone calls and text messages also indicate that within this general pattern, there are clear and persistent individual differences [6]: some people repeatedly focus most of their attention on a few close relationships, while others tend to distribute communication among their alters more evenly. These differences are stable in time even under high personal network turnover. However, the mechanisms that generate such heterogeneity of tie strengths, its individual-level variation, and the generality of this pattern beyond mobile-phone-mediated communication, have not yet been established.

Here, we explore multiple sets of data on recurring social interactions between millions of people to study heterogeneity in ego network tie strengths and its individual variation, and to shed light on the mechanisms behind this heterogeneity. These large-scale data sets contain metadata on different types of time-stamped interactions (Fig. 1a), from mobile phone calls to social media, spanning a time range from months to years. They are likely to reflect different aspects of social behaviour: e.g., mobile-phone calls between friends, work-related emails, and messages on an Internet forum or dating website serve different purposes and may or may not reflect social relationships that also exist offline. Using social networks reconstructed from the interaction records in our data, we measure the distribution of tie strengths in a massive number of egocentric networks, focusing on how this distribution varies between individuals (Fig. 1b). We compare observations across several datasets representing different channels of communication and use our observations to construct a minimal, analytically tractable model of egocentric network growth that attributes heterogeneity in tie strengths and its individual variation to the balance between competing mechanisms of tie reinforcement (Fig. 1c).

We find systematic evidence of broad variation in the distributions of tie strengths in ego networks across all communication channels, including those channels that do not necessarily reflect offline social interactions. The majority of ego networks have heterogeneous tie strengths with varying amounts of heterogeneity, while a minority of individuals distribute their contacts in a homogeneous way (Fig. 1d). With the help of our model of egocentric network evolution, we attribute the amount of heterogeneity to a mechanism of cumulative advantage [7], similar to proportional growth and preferential attachment. Homogeneity, in turn, is associated with effectively random choice of alters for communication. The balance between these two mechanisms determines the dispersion of tie strengths in an egocentric network. This balance is captured in our model through a single preferentiality parameter that can be fitted to data for each ego. The distributions of fitted values of this parameter are remarkably similar across different datasets, indicating universal patterns of communication in channels that are very different in nature (Fig. 1e). Similarly to social signatures [6], we also observe that at the level of individuals, the preferentiality parameter is a stable and persistent indicator of the distinctive way people shape their network on the particular channel (Fig. 1f).

Our results are significant from several points of view. We show that personal network structure is universal. The context and the reasons behind social interactions may differ, but they effectively translate into mechanisms of tie reinforcement that yield similar outcomes. This point of view resonates with the concepts of complexity sciences: there are emergent outcomes that do not strongly depend on the details of interactions. It is also significant to social network studies, where the emergence of macro-level network structure from the micro level of social interactions is a key question. Thus, our results provide new insights into the driving mechanisms of tie strength heterogeneity in social networks and have implications for the understanding of social network structure and individual behavior.

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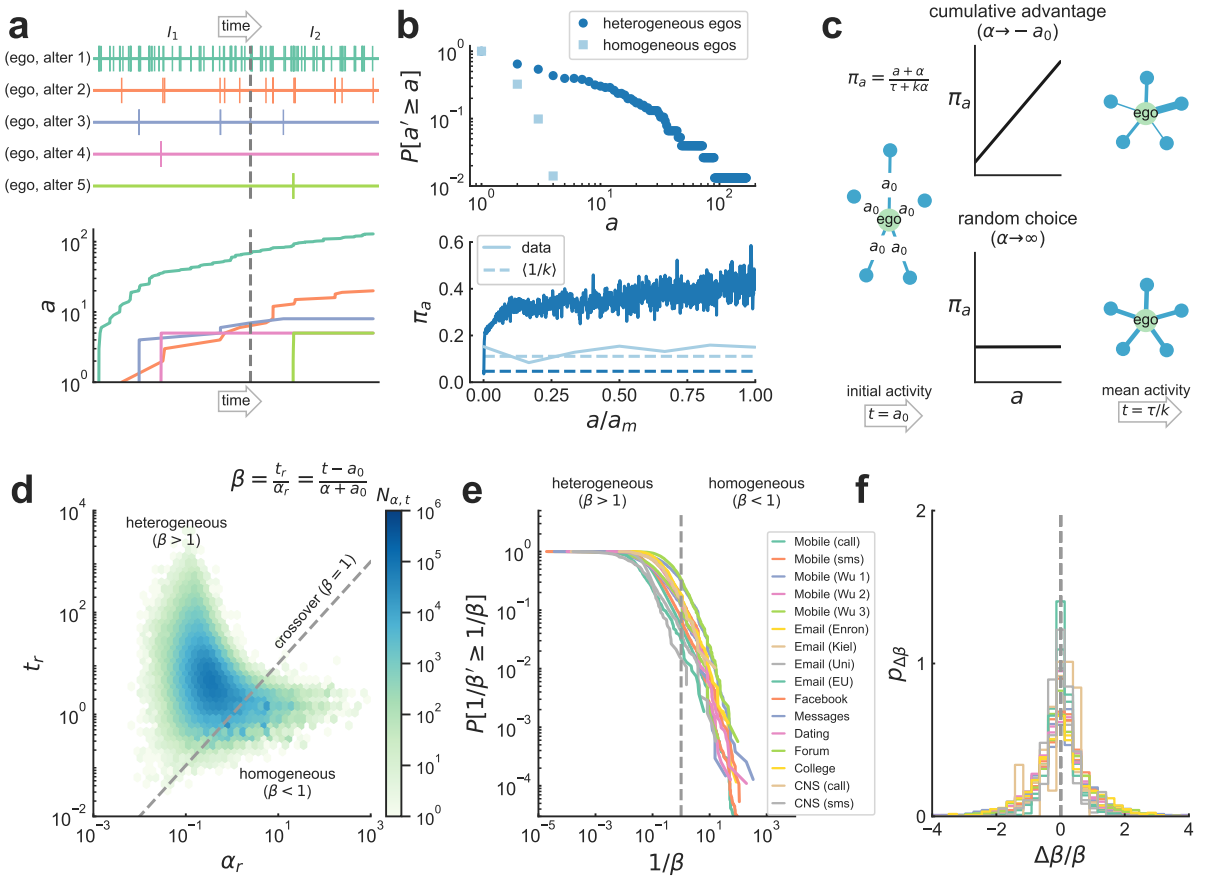

Figure 1: **(a)** Real-time contact sequence between an ego and its k alters (top) and time evolution of communication activity a with each alter (bottom), for selected ego in a mobile call dataset. Times are relative to the length of the observation period, so close-by events appear as single lines (top) or sudden increases in a (bottom). The sequence is divided into two consecutive intervals with the same number of events (I_1 and I_2). As time goes by, some alters accumulate more events than others. **(b)** (top) Complementary cumulative distribution (CCDF) $P[a' \geq a]$ of number of alters with at least activity a for selected egos in an online forum dataset. Egos distribute activity among alters either homogeneously or heterogeneously. (bottom) Probability π_a that an alter with activity a is contacted, averaged over time and subsets of heterogeneous or homogeneous egos, and the average baseline $\pi_a = \langle 1/k \rangle$ when communication events are distributed randomly (each value of a corresponds to at least 50 egos and is normalized by the maximum activity a_m in the subset). For heterogeneous ego networks, the increasing tendency indicates cumulative advantage where alters with high prior activity receive more communication. **(c)** In a modeled ego network of degree k, alters begin with activity a_0 and engage in new communication events at event time τ with probability π_a, where a is the alter's current activity and α a parameter interpolating behavior between cumulative advantage ($\alpha \to -a_0$, top) and random choice ($\alpha \to \infty$, bottom). These dynamics lead to an ego network with mean alter activity (i.e. time) $t = \tau/k$. **(d)** Heat map of the number $N_{\alpha,t}$ of egos with given values of $\alpha_r = \alpha + a_0$ and $t_r = t - a_0$ in a mobile call dataset. Most egos (93%) have a heterogeneous social signature. On the other side of the crossover $\beta = 1$, a few egos (7%) have more homogeneous tie strengths. **(e)** CCDF $P[1/\beta' \geq 1/\beta]$ of rate $1/\beta$, estimated for 6.57M egos in 16 datasets of calls, messaging, and online interactions. All systems show a diversity of social signatures, with 66–99% egos favouring a few of their alters, and 1–34% communicating homogeneously. **(f)** Distribution $p_{\Delta\beta}$ of relative preferentiality change $\Delta\beta/\beta$ when estimating β in two consecutive intervals of activity (I_1 and I_2), for all studied datasets. Persistence of social signatures is systematic across communication channels.