Interplay of dynamicity and connectivity in temporal networks

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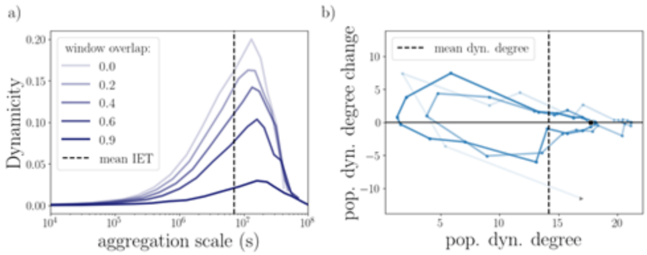

Figure 1: a) Average measure of edge-level temporal changes across consecutive time windows as a function of the scale of aggregation. Intermediate scales of aggregation are able to maximize the degree of temporal changes, or the dynamicity of the network. b) Average population trajectory in the space defined by the change in degree of a node along a single time step and the degree of the same node in the first window of the time step. We find that the population follows a clockwise cyclic trajectory (from triangle to square) that is symmetric about the x axis.

The spread of traffic, pathogens, and information on temporal networks is governed by both connectivity and dynamics which can be observed at different scales of aggregation. However, a fundamental trade-off arises: short observation windows preserve dynamicity but weaken connectivity, whereas long windows enhance connectivity while suppressing temporal variability. Although temporal data are usually observed at exogenous timescales of interest, our analysis of 39 social and informational networks reveals an endogenous observation scale at which local activity is maximally dynamic (see Fig. 1a). Strikingly, this scale coincides with high global connectivity, uncovering a regime in which dynamicity and connectivity coexist. At this timescale, connectivity is both highly intermittent and system-spanning.

We show that this characteristic scale is reproduced by a simple uncorrelated renewal-process model, indicating that detailed temporal correlations are not required for its emergence. The model further demonstrates that heterogeneity in node degree and inter-event time (IET) distributions promotes the coexistence of connectivity and dynamicity, and that these distributions largely determine the relevant timescale.

After aggregating the data at this optimal scale [1], we examine the evolution of connectivity across the 39 temporal networks. Despite bursty, heterogeneous, and highly variable individual interactions [2,3], social and informational networks exhibit remarkable stability at the system level. To understand how seemingly erratic individual behavior gives rise to stable collective dynamics, we analyze degree evolution and find a self-regulating mechanism: nodes tend to gain degree when poorly connected and lose degree when highly connected. At the population level, this produces a balance between positive and negative degree changes, indicating system-wide stability (see Fig. 1b).

Overall, by interpolating between static and temporal limit representations of complex networks through rolling time windows, our results showcase universal structures in temporal networks that involve both the temporal and topological components, as opposed to structures such as scale-free degree distributions in static networks and bursty behavior of human activity in temporal networks [4]. Moreover, our results bring to light the coexistence of flexibility and persistence in the interaction patterns of temporally connected systems guaranteed by heterogeneity. This aligns with the idea that criticality is favored by heterogeneity, and is a desirable regime for systems to evolve in as it simultaneously offers robustness and adaptability [5, 6].

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