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Modeling Community-Driven Bursty Dynamics

Temporal networks,Collaborative burstiness, Community dynamics,Privacy-preserving modeling, Cross-platform communities

Extended Abstract

In fragmented and encrypted digital environments, coordinated activity often unfolds without observable structural connections, posing a major challenge for detecting communities and coordinating groups across different networks. Traditional approaches which rely on explicit connections, whether direct or indirect, are often hindered by fragmented data, multi-platform environments or deliberately concealed adversarial links.

We introduce a generative model to explain the emergence of *collaborative burstiness*, where similar bursty patterns arise among community members. Importantly, these shared temporal dynamics enable the inference of latent community structure even when explicit links are sparse or entirely absent. This model builds on the "network of networks" framework [1] and considers latent community members as bridges, implicitly linking seemingly disconnected networks (see panel A, Fig. 1 for motivation). It models external events which propagate as shock waves through this interconnected structure, while influencing coordinating entities across networks and triggering their actions. These actions, even if not simultaneous, often exhibit similar bursty patterns (panel C, Fig. 1). While previous studies primarily modeled human burstsiness based on isolated individuals, disregarding environmental effects [2], we offer a broader perspective, attributing coordinated bursty behavior to shock waves traversing the network of networks.

Formally, we model the latent community structure using a weighted stochastic blockmodel $A_w \in \mathbb{R}^{n\times n}$, where each block corresponds to a latent real-world community and encodes the strength of interaction among its members. At each iteration of the model target and source node are selected by:

- **Source Selection.** A source node v_{source} is chosen with probability proportional to $A_w \cdot z$, where $z[i]$ is a recency counter for node i, holding the number of time steps since its last activity. This captures the idea that recent activity in one member can stimulate others community members into action.

- **Target Selection.** A target node v_{target} is chosen following the mechanism in [3]:

$$P(v_{target}) \propto \lambda A_w \cdot d + (1-\lambda) A_{rand} \cdot d$$

  where $\lambda \in [0,1]$ controls the strength of community-based vs. random selection, represented by $A_{rand} \in \mathbb{R}^{n\times n}$, a uniform interaction matrix. This allows the model to simulate both community-specific and background activity. Preferential attachment [4] is applied to favor nodes with higher existing degree, represented by $d[i]$ the degree of node i.

Furthermore, we demonstrate the coordination detection performance on two empirical use-cases: across different financial platforms and across different social platforms. The model consistently outperforms state-of-the-art structural and temporal baselines (panel C, Fig. 1). Finally, our model simulations reproduce the empirical findings and reveal a transition point in structural density below which the bursty model significantly outperforms structure-based models in identifying coordinating communities (Panel D, Fig. 1).

Beyond the specific task of community detection, our results highlight temporal patterns, and burstiness in particular, as a fundamental axis of network inference. Modeling actors through the dynamics of their actions, rather than only through structural or semantic ties, opens new directions for analyzing behavior in multi-platform, privacy-constrained, and adversarial settings.

Ethical Considerations Our approach relies on temporal activity patterns rather than content or personal identifiers, thereby reducing privacy risks and aligning with data protection principles. While such tools can advance theoretical understanding of networks and support the detection of coordinated inauthentic behavior, financial misconduct, and influence campaigns, safeguards are essential to prevent their misuse for unwarranted surveillance of legitimate communities.

References

[1] Jianxi Gao et al. "Robustness of a network of networks". In: *Physical review letters* 107.19 (2011), p. 195701.

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[3] Brian Karrer and Mark EJ Newman. "Stochastic blockmodels and community structure in networks". In: *Physical Review E—Statistical, Nonlinear, and Soft Matter Physics* 83.1 (2011), p. 016107.

[4] Albert-László Barabási and Réka Albert. "Emergence of scaling in random networks". In: *science* 286.5439 (1999), pp. 509–512.

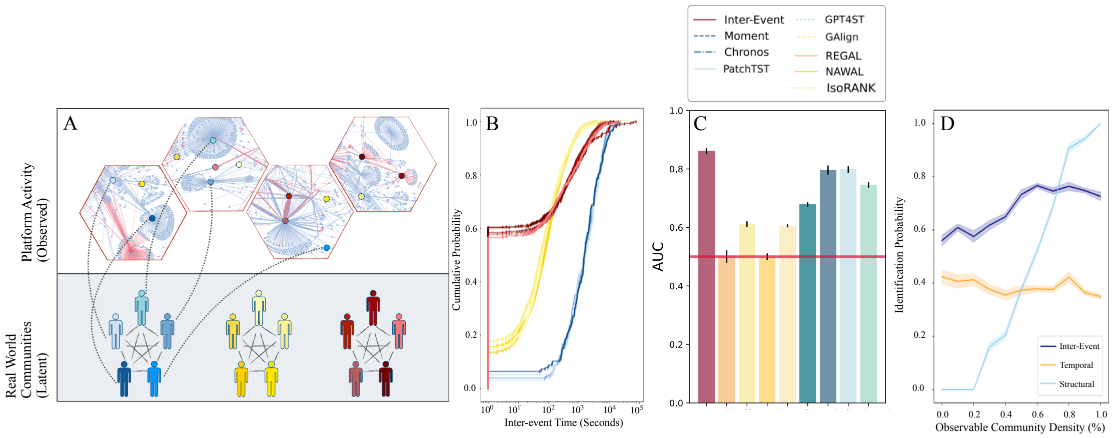

Figure 1: **Collaborative burstiness for coordination detection.** Panel A presents a graphical description of three real-world latent communities acting on four different observable networks, without explicit links between community members. Panel B presents bursty activity dynamics for each latent community member, manifesting the collaborative burstiness, as community members share similar dynamics. Panel D: coordination detection performance of the inter-event bursty model, surpassing temporal and structural baselines. Panel F: effect of intra-community edge density on coordination detection, with the Inter-event model robustly outperforming structural baselines when density falls below 70%.