Conference on Complex Systems - CCS2025 Siena

# Marked Temporal Point Processes for simulating and capturing coordinated behaviour campaigns

Elisa Muratore[1,2,3], Letizia Iannucci[1], Riccardo Gallotti[2], Claudio Agostinelli[3], Mikko Kivelä[1]

1. Aalto University, Helsinki Finland
2. Bruno Kessler Foundation, Trento Italy
3. Trento University, Trento Italy

**Problem**:

- **Disinformation:**
  Deliberate attempts to mislead and manipulate people's perception.

$\Downarrow$

- **Coordinated Inauthentic Behaviours (CIBs):**
  Orchestrated campaigns amplifying misleading information through synchronized activities.

**Objective**: Simulate and capture coordinated inauthentic behaviours.

# The team

Elisa
MURATORE

Letizia
IANNUCCI

Claudio
AGOSTINELLI

Mikko
KIVELÄ

Riccardo
GALLOTTI

# Formalisation and data preprocessing

**CIBs detection** coincides with finding anomalous **users' clusters** or communities[1] :

$$Y := f(U \text{ users},\ H \text{ history}).$$

The activities' history $H$ is composed of **cascades** $C_s$.




[1] Lorenzo Mannocci et al. Detection and characterization of coordinated online behaviour: A survey, 2024

FONDAZIONE BRUNO KESSLER
Aalto University

# Formalisation and data preprocessing



**CIBs detection** coincides with finding anomalous **users' clusters** or communities[1]:

$$Y := f(U \text{ users},\ H \text{ history}).$$

The activities' history $H$ is composed of **cascades** $C_s$.

| Date | Content: Post (**P**) or Repost (**R**) | User |
|---|---|---|
| September 12, 2022 at 10:57 AM | **P** *Studies show that drinking bleach can cure COVID. Many hospitals are hiding this information to keep their profits up* | User A |
| September 17, 2022 at 05:50 PM | **R** *Studies show that drinking bleach can cure COVID. Many hospitals are hiding this information to keep their profits up* | **User B** |
| September 20, 2022 at 02:04 AM | **R** *Studies show that drinking bleach can cure COVID. Many hospitals are hiding this information to keep their profits up* | User A |
| November 15, 2022 at 07:05 PM | **R** *Studies show that drinking bleach can cure COVID. Many hospitals are hiding this information to keep their profits up* | User C |
| ... | ... | ... |

$\Downarrow$

Cs = [ ($t_1$ , $u_1$=User A ), ($t_2$ , $u_2$=**User B** ), ($t_3$ , $u_3$=User A), ($t_4$ , $u_4$=User C), … ]

[1] Lorenzo Mannocci et al. Detection and characterization of coordinated online behaviour: A survey, 2024

**Definition** MTPPs are $\{T_i : \Omega \to \mathbb{R}, M_i : \Omega \to \mathcal{K} \mid i \in \mathbb{N}\}$, stochastic processes $\{N_t^k\}^k$ whose realisations are sequences of arrival times and marks:

$$C_s := \{\ (t_1, m_1),\ (t_2, m_2),\ \ldots\ \}.$$

For example, a **mutually exciting Hawkes process** is a MTPP with

$$\lambda_k(t \mid H_t) := \frac{\mathbb{E}\left[dN_t^k | H_t\right]}{dt} = \mu_{\mathbf{k}} + \sum_{m=1}^{K} \sum_{t_{i,m}<t} \alpha_{\mathbf{k,m}} e^{-\beta_{\mathbf{k,m}}(t-t_{i,m})}.$$

- $\alpha_{k,m}$ excitation rate
- $\beta_{k,m}$ decay rate
- $\mu_k$ baseline rate

# Capturing and simulating coordinated behaviour

# Capturing: AMDN-HAGE extensions



AMDN-HAGE[2] integrates **MTPP**, **GMM** and **DL** to retrieve users clusters:

$$\log p_{\theta_a,\theta_b}(C_s, U \mid E) = \underline{\log p_{\theta_a}(C_s \mid U, E)} + \underline{\log p_{\theta_b}(U \mid E)}$$

We propose two extensions:

- Clustering techniques on <u>users' embeddings $E$</u>
- Clustering based on <u>users' influences</u>

[2] **Karishma Sharma et al.** Identifying coordinated accounts on social media through hidden influence and group behaviours, 2021

# Simulating: Initial dataset



## Twitter dataset

- Keywords like "vaalit" (elections), "eduskunta" (parliament), ...
- $5.2M$ tweets about the 2023 Finnish election
- $762$ remarkably active users ($159085$ accounts)

## Difficulties

- Absence of *ground truth*
- Wide number of existing *coordinated strategies*

$\Downarrow$

- Difficulties in performing a comprehensive study

# Simulating: Novel Framework



We propose a **simulation framework** leveraging *Hawkes Processes* where hyper-parameters can be selected depending on the scenario:

**Authentic**

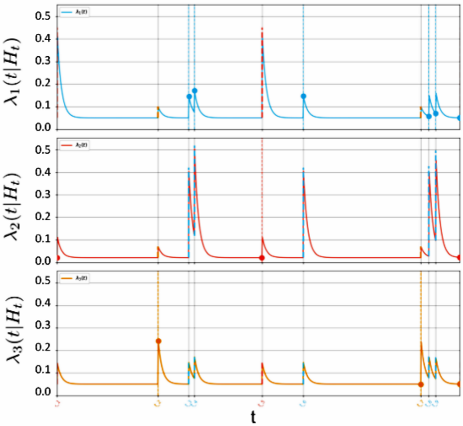
$$\mu_i \sim \Gamma(\mu, \sigma_\mu^2)$$
$$\alpha_{i,j} \sim \Gamma(\alpha, \sigma_\alpha^2)$$
$$\beta_i \sim \Gamma(\beta, \sigma_\beta^2)$$

**Inauthentic**

$$\mu_i = c_\mu \mu Z$$
$$\alpha_{i,j} = c_\alpha \alpha Z$$
$$\beta_i = c_\beta \beta Z$$

Interactions percentage controlled by $p$

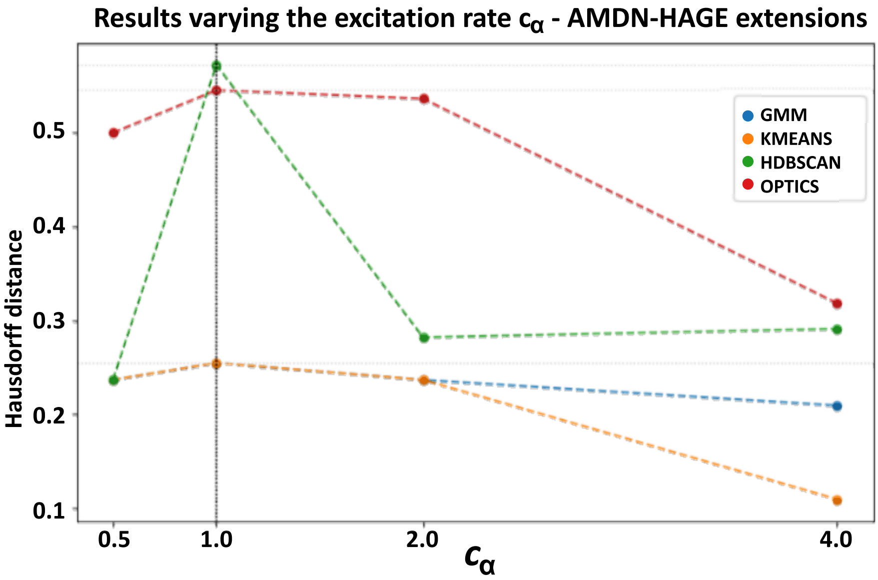
**Simulation of users' activities**



# Results

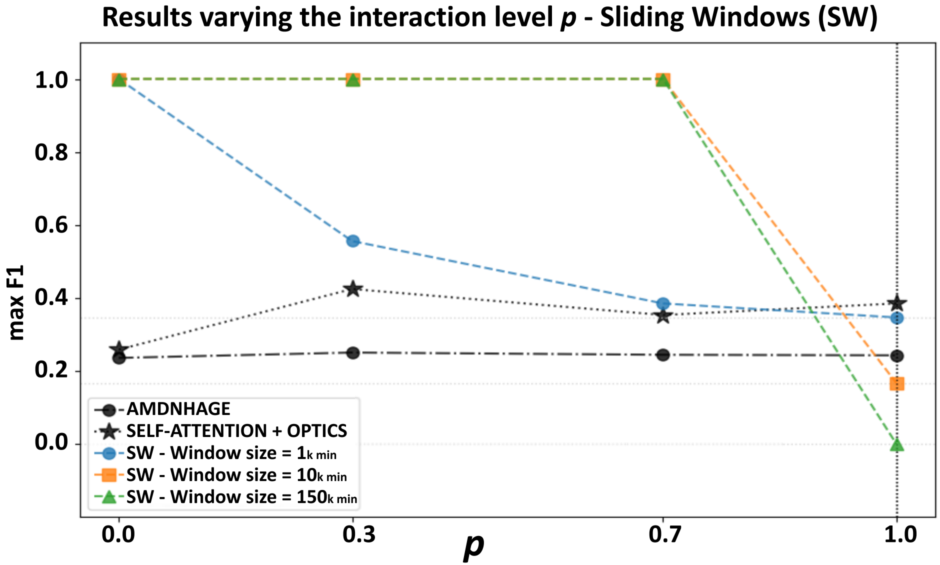
# Framework: the excitation rate varies





# Framework: the interaction percentage varies





# Conclusions

# Conclusions



- Enhanced coordination **detection methods**
- Simulation framework for **systematic evaluation**

- Importance of the **objective**

  ⇒ Different methods may excel depending on the CIB nature

  ⇒ Careful consideration of the data features and detection goals

# Thanks for your attention!

**Email:** emuratore@fbk.eu

**Bluesky:** @elisamurators.bsky.social

Aalto University

FONDAZIONE BRUNO KESSLER

# AMDN-HAGE clustering recovery



- Each user $u_j$ is clustered into group $i$ s.t.

$$\hat{i} := \text{argmax}_i \; p_{\theta_b}\left(z_{i,j} \mid E_{u_j}\right) = \text{argmax}_i \; \frac{p\left(E_{u_j} \mid \mu_i, \Sigma_i\right)}{\sum_{k=1}^{N} p\left(E_{u_j} \mid \mu_k, \Sigma_k\right)}$$

where $z_{i,j} = 1$ represents the event that the user $u_j$ is from group $i$

- Usage of KMEANS on embeddings since coordinated users behaving similarly are expected to have close embedding vectors

Self-attention user-to-user matrix $A_{\text{TOT}} \in \mathbb{R}^{|U|\times|U|}$

- Each row corresponds to a user who performs an action
- Each column represents the influence he receives from other users

The weights are updated as:

$$A'_{\text{TOT}}[i,j] = A_{\text{TOT}}[i,j] + \sum_{\{k|m_k=u_i\}} \sum_{\{h|m_h=u_j\}} A_X[k,h]$$

where $A_X[k,h]$ is the influence that $(m_k,t_k)$ has received by $(m_h,t_h)$

# Simulating: Hybrid dataset



## Authentic

- $5.2M$ tweets about the 2023 Finnish election
- $762$ remarkably active users ($159,085$ accounts)
- Keywords like “vaalit” (elections), “eduskunta” (parliament), ...

## Inauthentic

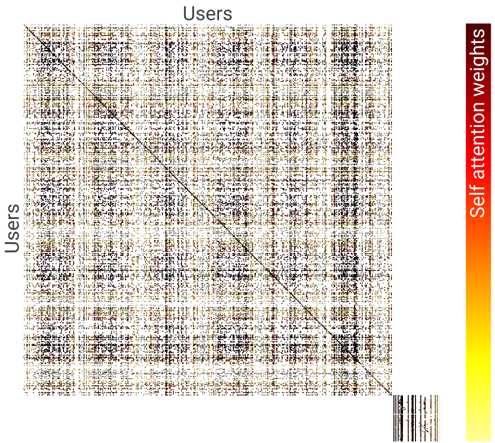
- $100$ coordinated users
- Uniform distribution of timestamp
- About $5\%$[3] of the real dataset activities

[3] Andrew M. Guess and Benjamin A. Lyons. MDOP, 2020.

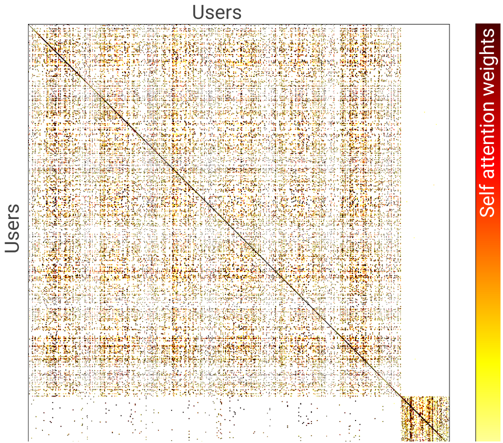
# Hybrid dataset: self-attention matrix



## Non-Interacting scenario




## Interacting scenario



# Framework: Modelling interactions

$$
(\alpha_{i,j})_{i,j} =
\begin{array}{cc}
 & \text{influencer} \\
 & \begin{array}{cc} \text{authentic} \qquad\qquad\qquad & \text{inauthentic} \end{array} \\
\text{influenced} \begin{array}{c} \text{authentic} \\ \\ \\ \text{inauthentic} \end{array} &
\left(\begin{array}{ccc|ccc}
\alpha_{i,j} & \cdots & \alpha_{i,j} & 0 & \cdots & 0 \\
\vdots & \ddots & \vdots & \vdots & \ddots & \vdots \\
\alpha_{i,j} & \cdots & \alpha_{i,j} & 0 & \cdots & 0 \\
\hline
c_\alpha \alpha I Z & \cdots & c_\alpha \alpha I Z & c_\alpha \alpha Z & \cdots & c_\alpha \alpha Z \\
\vdots & \ddots & \vdots & \vdots & \ddots & \vdots \\
c_\alpha \alpha I Z & \cdots & c_\alpha \alpha I Z & c_\alpha \alpha Z & \cdots & c_\alpha \alpha Z
\end{array}\right)
\end{array}
$$

## Results via GMM, KMEANS, HDBSCAN and OPTICS