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An Eigenmodel for Dynamic Multilayer Networks

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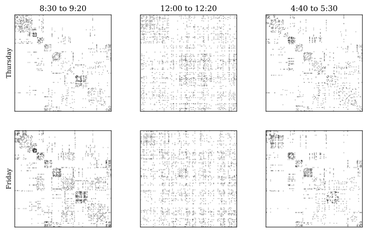
Introduction / Motivation

Dynamic Multilayer Networks

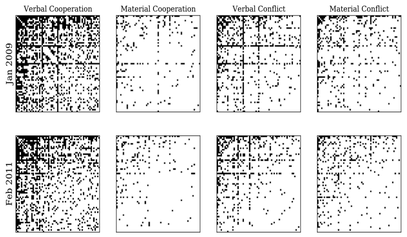
Many complex systems found in nature are dynamic and consist of multiple correlated relations:

- Social networks, social media, international relations, etc.

Data: K time-indexed adjacency matrices, $\mathbf{Y}_t^1, \ldots, \mathbf{Y}_t^K$, where $\mathbf{Y}_t^k \in \{0,1\}^{n \times n}$ for $1 \le t \le T$ and $1 \le k \le K$, e.g.,



Face-to-face contacts at a primary school



International relations between nations

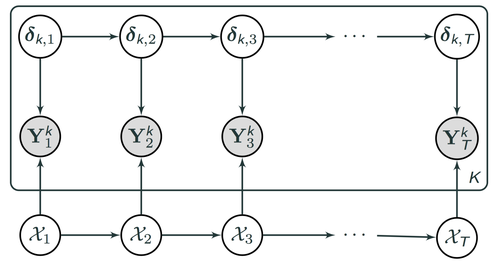
Approach

The Model

$$Y_{ijt}^k \overset{\text{ind}}{\sim} \text{Bernoulli}(P_{ijt}^k)$$

$$\text{logit}(P_{ijt}^k) = \delta_{k,t}^i + \delta_{k,t}^j + \mathbf{X}_t^{i\,\mathrm{T}} \Lambda_k \mathbf{X}_t^j$$

- $\delta_{k,t}^i \in \mathbb{R}$: sociality, varies by time and layer.
- $\mathbf{X}_t^i \in \mathbb{R}^d$: latent vector, shared by all layers but varies over time.
- $\Lambda_k = \text{diag}(\lambda_K) \in \mathbb{R}^{d \times d}$: diagonal homophily matrix, varies across layers.



Latent variables evolve via a Markov process

Variational Inference

Introduce a new structured mean-field approximation to the posterior that maintains temporal dependencies:

$$q(\boldsymbol{\theta}) = \left[\prod_{h=1}^{d} q(\lambda_{1h})\right] \left[\prod_{k=2}^{K} q(\lambda_k)\right] \left[\prod_{k=1}^{K}\prod_{i=1}^{n} q(\delta_{k,1:T}^i)\right] \left[\prod_{i=1}^{n} q(\mathbf{X}_{1:T}^i)\right] q(\tau^2) q(\sigma^2) q(\tau_\delta^2) q(\sigma_\delta^2)\,.$$

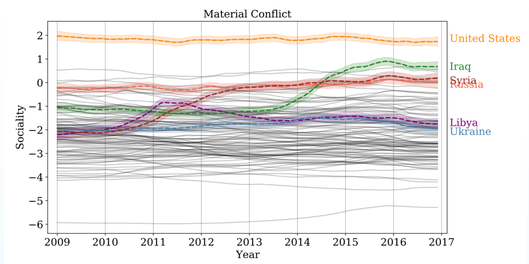
Derived a closed form coordinate ascent variational inference algorithm (CAVI) leading to efficient inference.

Results

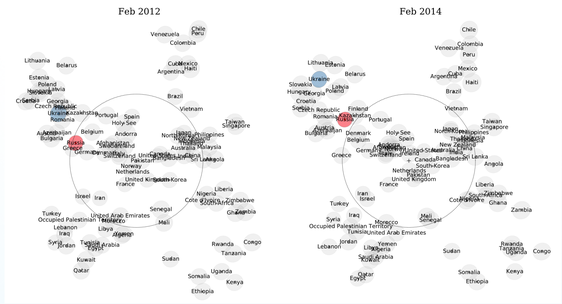
Analysis of ICEWS Networks

Eight years during the Obama administration of monthly relational data taken from ICEWS.

- Y_{ijt}^k = 1 : country i and country j had a {verbal cooperation, material cooperation, verbal conflict, material conflict} on the tth month.



The nations' socialities reveal global conflicts: Arab Spring in Libya (2011), Rise of ISIL in Syria (2013 — present), The American-led intervention in Iraq (2014).

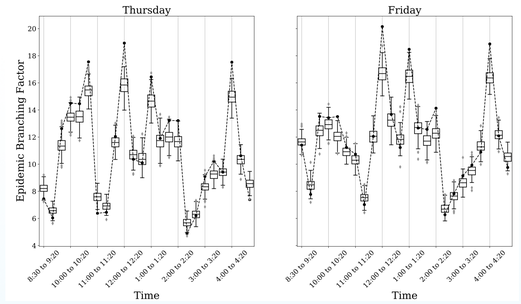


Latent positions reflect the nations' geographic location. The latent space reflects regional events such as the Crimean Crisis between Russia and Ukraine (2014).

Challenges

Quantifying R_0 in Face-to-Face Contact Networks

Y_{ijt}^k = 1 : individual i and individual j within 5 ft for more than 20 seconds during the tth 20 minute interval on {Thursday, Friday}.



*Uncertainty quantification of the epidemic branching factor R_t. The network model **underestimates sudden changes in network structure**.*

Next Steps/ Future Work

- Allow inference on larger networks through stochastic optimization.
- Explore non-stationary state-space models to better model non-smooth changes.
- Extend the VB algorithm beyond binary ore real-valued dyads, e.g., count data.

Scan me to download the full paper.

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