Embedding-Based Node Clustering in Temporal Interaction Networks

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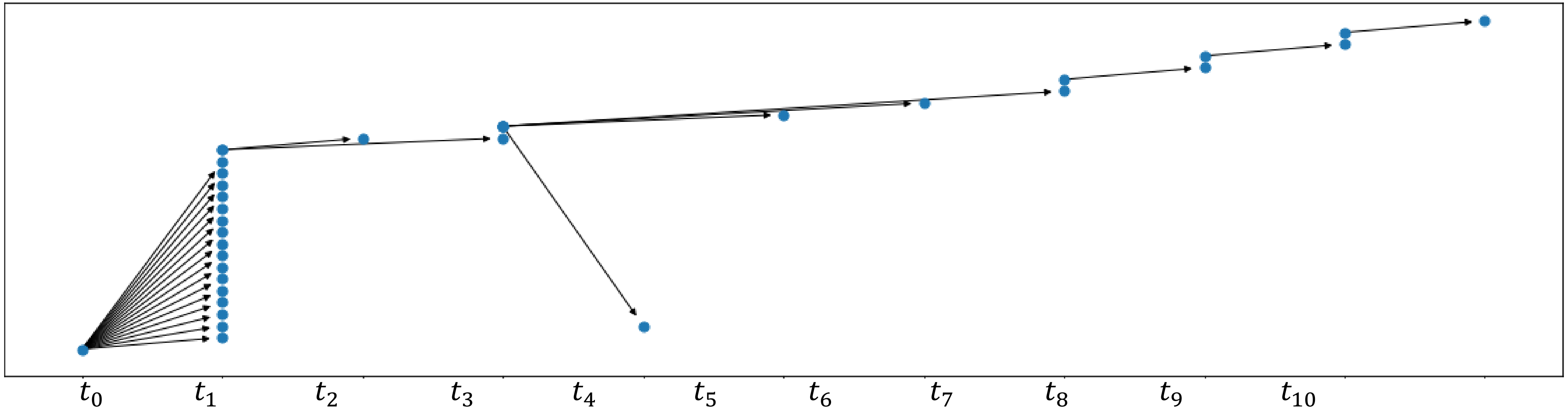
Temporal Data

- Radoslaw email dataset [1]
- It contains 167 nodes and 82.9K edges, where an edge represents and email exchange between two employees and each edge has a *time* attribute which corresponds to the timestamp the email was sent (57K unique emails)
  - Period covered is from January 1, 2010 to September 30, 2010
- It is also accompanied by the graph representing organizational hierarchy showing who supervises whom (without positions) [2]



[1] Datasets, K. O. N. E. C. T. (2015). The koblenz network collection. http://konect.uni-koblenz.de/networks/radoslaw_email

[2] Michalski, Radosław, 2020, "Manufacturing company email metadata and corporate hierarchy", https://doi.org/10.7910/DVN/6Z3CGX, Harvard Dataverse, V2, UNF:6:/mJDDYEUXZ0pb1bvKiKttA== [fileUNF]

Time-Respecting Node Embedding

- Continuous-Time Dynamic Network Embedding (CTDNE) [3] learns a time dependent network representation for a temporal interaction network $G = (V, E_T, \tau)$
  - Learns a temporal embedding by searching over the space of temporal random walks that obey time
  - Example: A random walk from node v_{i_1} to $v_{i_{L+1}}$

$$\{(v_{i_1}, v_{i_2}, t_{i_1}), (v_{i_2}, v_{i_3}, t_{i_2}), \dots, (v_{i_L}, v_{i_{L+1}}, t_{i_L})\}$$

where $t_{i_1} < t_{i_2} < \cdots < t_{i_L}$

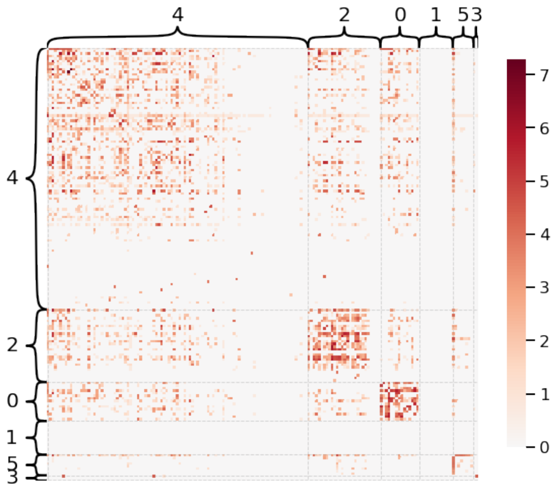
- Walks are biased towards edges that appear closer in time, i.e., the walks represent a (possible) chain of emails in a week
  - This is achieved using an exponential bias where given an arbitrary edge $e = (u, v, t)$, each temporal neighbor $w \in \Gamma_t(v)$ has probability of being selected given by

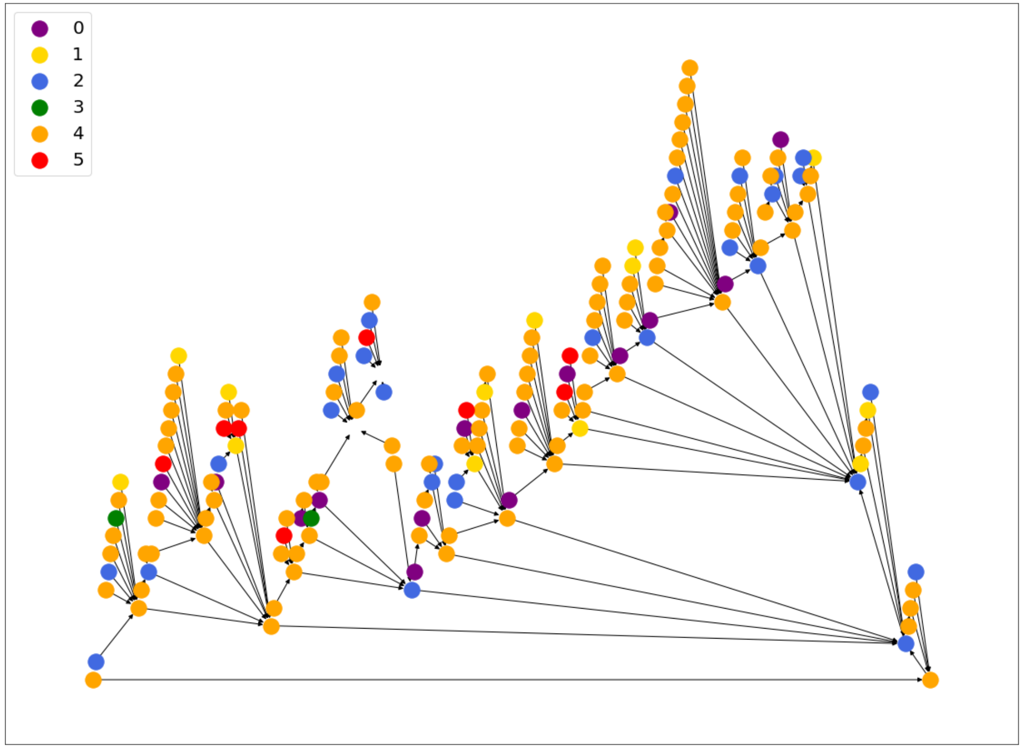
$$\Pr(w) = \frac{\exp[-(\tau(w) - \tau(v))]}{\sum_{w' \in \Gamma_t(v)} \exp[-(\tau(w') - \tau(v))]}$$

[3] Nguyen, G. H., Lee, J. B., Rossi, R. A., Ahmed, N. K., Koh, E., & Kim, S. (2018, April). Continuous-time dynamic network embeddings. In *Companion Proceedings of the The Web Conference 2018* (pp. 969-976).

Clustering

- Used Gaussian Mixture Model [4] to cluster the temporal embedding obtained from CTDNE
- The clusters assign nodes based on structural equivalence [5] which implies that the organization of the nodes is based on hierarchical roles in the network





[4] Pedregosa, F., Varoquaux, G., Gramfort, A., Michel, V., Thirion, B., Grisel, O., ... & Vanderplas, J. (2011). Scikit-learn: Machine learning in Python. *the Journal of machine Learning research*, *12*, 2825-2830.
[5] Fortunato, S. (2010). Community detection in graphs. *Physics reports*, *486*(3-5), 75-174.

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