Activity Dynamics in Collaboration Networks

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Motivation

Websites often struggle to keep users active and become self-sustaining.

- For example, Editors in Wikipedia!

Problem: We lack the tools to properly analyze, model and simulate activity in online collaboration networks.

Model based on two opposing principles:

- Without incentives, users tend to lose interest to contribute and thus, systems become inactive.
- People are susceptible to actions taken by their peers.

Goal: Analyze and manipulate dynamical parameters to model and simulate activity in collaboration networks.

Activity Dynamics

Modeled as *dynamical system* on a network

- Nodes represent users
- Edges represent collaboration

Model configuration with two basic activity mechanisms in online collaboration networks:

- **Activity Decay Rate** λ, which postulates how fast a user loses interest to contribute,
- **Peer Influence Growth Rate** μ, postulating to what extent a user is influenced by the actions taken by her peers.

Dynamics and parameters are the same for each user in the population.

Activity Dynamics Model

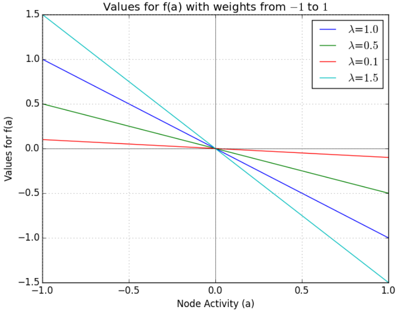
Activity is represented as

- a continuous real-valued variable x_i
- evolving on node i of the collaboration network
- over relative time τ.

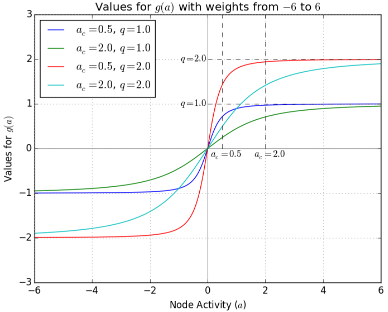
The general time evolution equation can be written as:

$$\frac{dx_i}{d\tau} = \underbrace{f_i(x_i)}_{\text{Intrinsic Activity Evolution}} + \overbrace{\sum_j A_{ij} \underbrace{g_i(x_i, x_j)}_{\text{Influence of j on i}}}^{\text{Extrinsic Peer influence}}, \quad (1)$$

Intrinsic Activity Decay & Peer Influence



(a) Intrinsic Activity Evolution

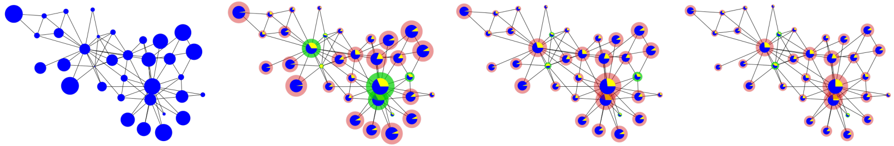


(b) Extrinsic Peer Influence

$$\frac{dx_i}{d\tau} = \underbrace{-\frac{\lambda}{\mu} x_i}_{\text{Intrinsic Activity Decay}} + \overbrace{\sum_j A_{ij} \frac{x_j}{\sqrt{1 + x_j^2}}}^{\text{Peer influence}} \qquad (2)$$

Activity Evolution Example

Evolution of *Intrinsic Activity (blue)* and *Peer Influence (yellow)* over time.



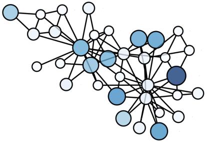
(a) At Time t_0 (b) At time t_1 (c) At time t_2 (d) At time t_3

Linear Stability Analysis

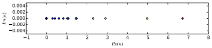
Master Stability Equation

$$\kappa_1 < \frac{\lambda}{\mu} \quad (3)$$

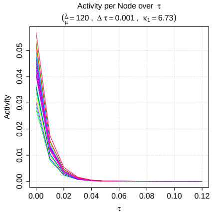
Stability Example:



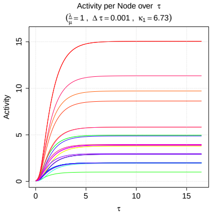
(a) Zachary's Karate Club Network



(b) Adjacency Spectrum ($\kappa_1 = 6.726$)



(c) Activity Evolution $\frac{\lambda}{\mu} > \kappa_1$



(d) Activity Evolution $\frac{\lambda}{\mu} < \kappa_1$

Empirical Illustration

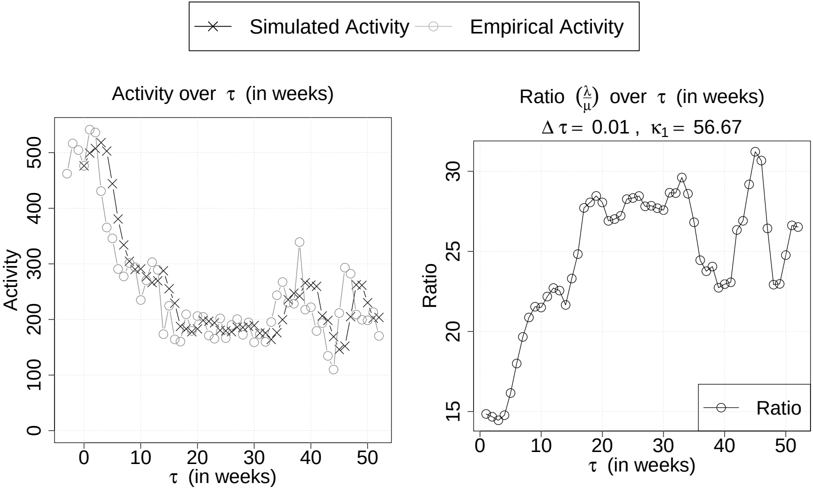
Illustrate Activity Dynamics model on empirical datasets.

	StackExchange Datasets				Semantic MediaWiki Datasets			
Dataset	History	Bitcoin	English	Math	Beachapedia	Nobbz	NeuroLex	15MW
Users	682	1,299	7,893	35,476	16	36	112	394
Edges	5,179	5,528	83,457	477,133	38	125	383	772
κ_1	54.33	43.88	162.04	303.58	6.71	11.46	18.4	19.97
Posts & Replies	12,496	12,295	151,028	986,996	2,718	603	33,792	102,521
Weeks	52 + 3	52 + 3	52 + 3	52 + 3	52 + 3	52 + 3	52 + 3	52 + 3

- Fit λ/μ using sliding window of 4 weeks and predict week 5.
  - Formulated as least squares cost function, which calculates the error of the sum of activity over multiple data points k over a certain period of time T

$$J(\frac{\lambda}{\mu}) = \frac{1}{T} \sum_{k=0}^{T-1} \left[\sum_{i}^{n} x_i(k+1) - \sum_{i}^{n} \hat{x}_i(k+1) \right]^2 \quad (4)$$

Simulation of Activity Trends



(a) Bitcoin StackExchange Activity (b) Bitcoin StackExchange Ratios

System Mass & Activity Momentum

System Mass

- Measures system stability or inertia to changes in activity.
- Is represented by $\frac{1}{\rho}$, where ρ is the standard deviation of $\frac{\lambda}{\mu}$, normalized over κ_1.

Activity Momentum

- The higher the *Activity Momentum* of a collaboration network, the more force is needed to “stop” the system.
- Activity Momentum is System Mass multiplied with Activity.

Dataset	AVG Activity (last month)	ρ	System Mass	Activity Momentum (last month)
Math SE	19, 255 (70, 130)	0.0115	86.65	1, 668, 446 (6, 076, 765)
English SE	2, 952 (13, 751)	0.0344	29.07	85, 815 (399, 742)
Bitcoin SE	246 (782)	0.0762	13.12	3, 228 (10, 260)
History SE	248 (1, 110)	0.0554	18.10	4, 489 (20, 091)
15MW	1, 999 (4, 702)	0.0506	19.76	39, 500 (92, 912)
NeuroLex	668 (1, 131)	0.0532	18.80	12.558 (21, 263)
Nobbz	12 (270)	0.0802	12.67	152 (3, 421)
Beachapedia	54 (228)	0.0547	18.28	987 (4, 168)

Conclusions

- We have presented a simple dynamical system to model activity in online collaboration networks
- The model is based on two well-studied and opposing principles.
  - Intrinsic Activity Decay.
  - Peer Influence.
- System Mass & Activity Momentum can be used to characterize online collaboration networks.
  - System Mass as metric for stability.
  - Activity Momentum as a metric for robustness.

Future Work

- Extend the Activity Dynamics Framework to
  - handle evolving network structures
  - calculate activity dynamics per user
  - suggest optimal intervention strategies
- Use our model to (automatically) learn the collaboration network!

Questions?

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Walk, S., Helic, D., Geigl, F., & Strohmaier, M. (2016). Activity dynamics in collaboration networks. ACM Transactions on the Web (TWEB), 10(2), 11.

Thanks!

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