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** $\lambda$, which postulates how fast a user loses interest to contribute,
- **Peer Influence Growth Rate** $\mu$, 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 $\tau$.

The general time evolution equation can be written as:

$$\frac{dx_i}{d\tau} = f_i(x_i) + \sum_j A_{ij} g_i(x_i, x_j),$$

(1)
Intrinsic Activity Decay & Peer Influence

(a) Intrinsic Activity Evolution

(b) Extrinsic Peer Influence

\[
\frac{dx_i}{d\tau} = -\frac{\lambda}{\mu} x_i + \sum_j A_{ij} \frac{x_j}{\sqrt{1 + x_j^2}}
\]

(2)
Activity Evolution Example

Evolution of \textit{Intrinsic Activity (blue)} and \textit{Peer Influence (yellow)} over time.

(a) At Time $t_0$  
(b) At time $t_1$  
(c) At time $t_2$  
(d) At time $t_3$
Activity Dynamics in Collaboration Networks

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Empirical Illustration

Illustrate Activity Dynamics model on empirical datasets.

<table>
<thead>
<tr>
<th></th>
<th>StackExchange Datasets</th>
<th></th>
<th>Semantic MediaWiki Datasets</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>History</td>
<td>Bitcoin</td>
<td>English</td>
<td>Math</td>
</tr>
<tr>
<td>Users</td>
<td>682</td>
<td>1,299</td>
<td>7,893</td>
<td>35,476</td>
</tr>
<tr>
<td>Edges</td>
<td>5,179</td>
<td>5,528</td>
<td>83,457</td>
<td>477,133</td>
</tr>
<tr>
<td>$\kappa_1$</td>
<td>54.33</td>
<td>43.88</td>
<td>162.04</td>
<td>303.58</td>
</tr>
<tr>
<td>Posts &amp; Replies</td>
<td>12,496</td>
<td>12,295</td>
<td>151,028</td>
<td>986,996</td>
</tr>
<tr>
<td>Weeks</td>
<td>52 + 3</td>
<td>52 + 3</td>
<td>52 + 3</td>
<td>52 + 3</td>
</tr>
</tbody>
</table>

- Fit $\lambda/\mu$ 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 $T$

\[
J\left(\lambda, \mu \right) = \frac{1}{T} \sum_{k=0}^{T-1} \left[ \sum_{i} x_i(k+1) - \sum_{i} \hat{x}_i(k+1) \right]^2 \tag{4}
\]
Simulation of Activity Trends

(a) Bitcoin StackExchange Activity

(b) Bitcoin StackExchange Ratios

\[ \Delta \tau = 0.01, \ \kappa_1 = 56.67 \]
System Mass & Activity Momentum

System Mass

- Measures system stability or inertia to changes in activity.
- Is represented by $\frac{1}{\rho}$, where $\rho$ is the standard deviation of $\frac{\lambda}{\mu}$, normalized over $\kappa_1$.

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.

<table>
<thead>
<tr>
<th>Dataset</th>
<th>AVG Activity (last month)</th>
<th>$\rho$</th>
<th>System Mass</th>
<th>Activity Momentum (last month)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Math SE</td>
<td>19,255 (70,130)</td>
<td>0.0115</td>
<td>86.65</td>
<td>1,668,446 (6,076,765)</td>
</tr>
<tr>
<td>English SE</td>
<td>2,952 (13,751)</td>
<td>0.0344</td>
<td>29.07</td>
<td>85,815 (399,742)</td>
</tr>
<tr>
<td>Bitcoin SE</td>
<td>246 (782)</td>
<td>0.0762</td>
<td>13.12</td>
<td>3,228 (10,260)</td>
</tr>
<tr>
<td>History SE</td>
<td>248 (1,110)</td>
<td>0.0554</td>
<td>18.10</td>
<td>4,489 (20,091)</td>
</tr>
<tr>
<td>15MW</td>
<td>1,999 (4,702)</td>
<td>0.0506</td>
<td>19.76</td>
<td>39,500 (92,912)</td>
</tr>
<tr>
<td>NeuroLex</td>
<td>668 (1,131)</td>
<td>0.0532</td>
<td>18.80</td>
<td>12,558 (21,263)</td>
</tr>
<tr>
<td>Nobbz</td>
<td>12 (270)</td>
<td>0.0802</td>
<td>12.67</td>
<td>152 (3,421)</td>
</tr>
<tr>
<td>Beachapedia</td>
<td>54 (228)</td>
<td>0.0547</td>
<td>18.28</td>
<td>987 (4,168)</td>
</tr>
</tbody>
</table>
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 a 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?

Thanks!