MODELS OF EPIDEMIC PROCESSES IN SOCIAL NETWORKS: INFORMATION SUPPORT

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Abstract

This paper considers the varieties and peculiarities of content perception in social networks. It analyzes the data about communication topology and the probability of user's infection. The methodology of the representative sampling is suggested. The authors focused on discrete simulation of the epidemic process. In this connection, the topological models were used as a triadic predicate (vertex-arc-vertex) describing the incidence and communication strength of social network users. In this context, the matrices have been built: of the vertices degree, the weighted centrality of the network elements, and the specific balance of the content volume. These matrices characterize the topological properties of the weighted (taking into account the traffic of its arcs and vertices) of the network from which then the sampling takes place. This is due to the need to reduce the size of the network being analyzed and therefore its representative truncation is carried out, i.e. the conversion of the original data to a form suitable for later simulation of epidemics. The paper introduces a fairly detailed review of the variety of content circulating in social networks. For its intended purpose, content is divided into entertainment, useful, news, user, reputation, interactive, and commercial. Special attention is paid to destructions in content as well as the ways to draw attention to it. All of this constitutes an information base for modeling the diffusion processes of content in social networks. The above matrices serve this purpose. In addition, the paper introduces the results of the proposed methodology use in application to the development of information support required for the modeling of social networks. In

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In this context, an example of a three-dimensional illustration of the source network and its representative sample by level of specific traffic is given. The issue of the mutation of the distribution law of vertices degrees during representative sample was discussed. In the discussion of the results obtained in the paper, the directions of further improvement of the methodology have been formulated, which could be used as a basis for other researchers. First of all, they are the following: structural and parametric details of social networks descriptions, comprehensive research of the content constructs and ways of its promotion in the network, taking into account the change dynamics of analyzed network parameters, and users participation in several information communities at the same time. This would greatly enrich the information support for social networks modeling.

**Keywords:** Social network, epidemic, content, probability of infection, representative sample of data.

1. **Introduction**

Social networks - today's the most powerful webcaster (billions of active and passive users). User - network subject who is objectively interested in maximizing his popularity in the society and in obtaining the most useful information through network services. And herein lies the phenomenon of the snowballing growth in the number of social networks of different intended purpose and their users, as well as the fierce competition in this information space. In fact, we are talking about battle of contents for the information and psychological preferences of the masses of socially and economically active people, covering a third of humankind. The stakes are very high and therefore the technological sophistication of designing and distributing content in social networks exceeds expectations. And here, the basic issue is the tool issue - a set of tools for step-by-step modeling of content diffusion in social networks based on the probabilistic parameters of its perception. That is, there is an urgent need for a tool to predict the network success of content that both active users and many social network researchers want to use. In this regard, appropriate information support is required.

In social networks, the content exists in the following forms [I, II]:

1. Text: post (any article or posting online), article, subject in discussions, document.
2. Image: picture, comic, drawing, photograph, info graphic (this is a graphical way of information, data, and knowledge submission, the purpose of which is to deliver complex information quickly and clearly), meme (unit of cultural information, meme can be any idea, symbol, manner or way of action, consciously or unconsciously transmitted from person to person through speech, writing, video, rituals, gestures, and so forth), GIF-file (the popular format of animated graphic images).
3. Audio: music, podcasts (audio or video files in form of broadcast and telecast in the Internet (broadcasting in the Internet) of specific topics and periodicity.)
4. Video: movie, screenshots, event recording, webcast, interviews.

In this case, the content is divided into entertainment, useful, news, user, reputacion, interactive, and commercial [I-III]:

1. Entertainment: humor, memes, quotes, entertainment sets (video, images, gifs), riddles (puzzles), greetings, facts from celebrities lives, stories, parables, poems, prose, sets (albums) of beautiful and high-quality photos, collections of music, success stories.

2. Useful: training videos, podcasts, articles, interviews with opinion leaders, useful info graphic (intelligence cards), instructions, FAQ (frequently asked questions), books (electronic, audio, etc.), recordings of webinars training, seminars, conferences, lectures, intensive courses, workshops (training event under the guidance of an expert), translations of foreign articles, scientific articles and achievements, analysis of common mistakes, and the discrediting of myths.

3. The news includes market news (of the industry), company news, event reports, important business dates, vacant positions, market trends, interviews.

4. The user content type is represented by the following: product test drives, albums (customer-product, services), product-services reviews, articles from users on any topic, guest posts (comments), video from users, event video, user questions.

5. Reputation content include reviews (texts, photos, videos) media references to business, achievements, prizes, diplomas, business behind-the-scenes, how the product is created (story, video, audio), expert opinion, insights.

6. The interactive content form provides for involvement the user into any business direction. These can be polls, discussions, on-line chats, advices to each other, provocations.

7. The commercial type includes the photograph of goods with descriptions and prices, promotion actions, competitions, contacts, and new goods (services).

It is worth taking into account that content can have both positive and negative (destructive) effects on social network users. Several destruction objectives are allocated [IV]:

1. The intrapersonal object is represented by: bodily characteristics (e.g. hair, skin, etc.); individualized needs (e.g., in food, sleep, etc.) and values (e.g., healthy lifestyles, education, etc.); nature of mental phenomena (e.g. changing cognitive, emotional states parameters through alcohol, narcotic substances). The destructive orientation of texts is implemented in pushing for manipulating the intrapersonal object, change its properties (for example, forgo sleep, food, scars, tattoos), including its destruction.

2. As the intrapersonal object are: specific individuals, small social groups (e.g. educational, sportive, occupational groups); communications and relationships with specific people and small social groups represented in the form of social roles (e.g. son, daughter, father, mother, member of the collective). The destructive orientation
of the text is found in the implementation in its semantics of negative assessment of the particular person, social group, communications and relationships with them, including through the depreciation of characteristics, incitement to destruction.

3. The metapersonal object of destruction includes social institutions, their activities, representatives and attitude to it (institutions of management, education, healthcare, etc.); norms of social regulation (legal, religious, political, cultural and other). The destructiveness is tracked in incitement to global social facilities destruction according to political, religious, ethnic and other types of signs. The means of implementation here are quite extensive, that allows mark down as destructive texts the extremist appeals aimed at arousing feelings of hatred and enmity.

The following objectives of objects conversion are also allocated [IV] and the following examples are provided: "the destructive orientation of the suicidal act can be accompanied by a desire to replenish and restore the relationship between the family members experiencing loss." The destructive purpose of the text with threats against a particular person may imply a deconstructive orientation as well (modification with the aim of creating an object with different properties) — a desire to "change" the other, to form the necessary behavior. Reconstruction objective (focus on the recovery of the object, its properties, characteristics) of extremist text is usually combined with the theme of the object restoration (freedom of "Motherland" from various "invaders"), accompanied by incitements self-denial for the sake of struggle, indicating the necessity to be reborn, to become a "superhuman".

Today, there are many ways to attract users' attention to content. The most popular for social networks is SMM (social media marketing) marketing - a set of activities to use social media as channels to promote companies and solve other business challenges. Undoubtedly, the obvious advantage of SMM promotion is that, thanks to the capabilities of social networks as well as their classification, it is possible to effect accurately on the target audience by selecting the platforms where the audience is most represented. We mean the possibility of giving weight to demographic, psychographic and behavioural characteristics of consumers [V].

As an example, let's take the research of Buzzsumo company engaged in analytics of social channels and content marketing. In 2014, it conducted a number of studies when analyzed 100 million articles for eight months. Thus, several principles of content popularization were identified [I]:
1. Long content gets more reposts and the user gets familiar with it through a personal computer, and short content that does not require a high concentration of attention - through the mobile device, respectively.
2. The text along with an image gives a greater number of reposts.
3. Depending on the emotional content, its reposts were distributed as follows: fear - 25%, laughter - 17%, entertainment - 15%, anger and sadness - 7%, rage - 6%, empathy - 15%, other - 15%.
4. The most popular contents are the posts containing: lists, info graphic, instructing articles (how to make ...), video.
5. The content transmitted by the "leader of opinion" may also be the most popular, since people got used to take information from verified sources or from users with high reputation.

Considering the principles of destructive content generation, it is also important to consider the importance of the number of posts. It should also be taken into account that depending on the type of social network you choose, the optimum number of posts that do not allow the user to "be tired" from this content type is changed, and still remain interested in it. For communications networks, from 5 to 10 posts per day are optimal; for media share networks - at least 1 update per 2-3 days; in discussion forums - at least two posts per day [I-III].

Therefore, when you create content, you should consider things such as: the content of the post interesting to the public; tone of the letter; frequency of writing posts of different content on some topics and the number of reposts of the same information for a certain period of time; content format; audience features: age, hobbies and other [IV].

Probabilistic parameters for content perception, which determines the breadth of its diffusion (popularity) in the social network depend on the listed features.

II. Methodology for Building Models

Topologically, the social networks are a set of nodes connected by communication links. Networks can be classified by the direction of links between vertices (oriented, unoriented, bipartite), by the weight of the rib and the multiplicity, which characterizes the time frames and vertices labels, as well as object types represented by the nodes and references. Thus, the social network can be represented as a graph \( G (X, A) \), in which \( X \) is a set of vertices (agents) and \( A \) is a set of edges representing the interaction of the agents.

Hence, the social networks can be preset with the appropriate data, the format of which corresponds to a triadic predicate consisting of two vertices connected with edges and to its weight characteristics:

\[
\Gamma(x_i, x_j, a_{ij}) \Leftrightarrow \Gamma(i, j, \delta(a_{ij})),
\]

where \( i \) and \( j \) are the numbers of vertices \( x_i \) and \( x_j \) in the network; \( \delta(a_{ij}) \) - the weight of the arc \( a_{ij} \) linking \( x_i \) and \( x_j \) and directed from \( i \) to \( j \).
Let's define the weight of the arc as the transfer of a certain volume of filler $V$ and its value $C$ in the network to unit of time:

$$\delta(a_{ij}) = \frac{\partial [CV]}{\partial t} = C \cdot V',$$

where $V'$ refers to the intensity of information exchange.

It should be clarified that under $V'$ we understand the amount of the information transmitted (in case with social networks, it is a private message - post) or the number of actions between two users (pcs) per unit time.

Thus, the triadic predicate is presented in the following form:

| $x_i$ | $x_j$ | $\delta(a_{ij})$ |
|-------|-------|------------------|
| $x_k$ | $x_i$ | $\delta(a_{kl})$ |
| $\vdots$ | $\vdots$ | $\vdots$ |
| $x_{k+s}$ | $x_{l+r}$ | $\delta(a_{k+s,l+r})$ |
| $\vdots$ | $\vdots$ | $\vdots$ |
| $x_n$ | $x_m$ | $\delta(a_{nm})$ |

Since the triadic predicate is a sample of a network, it is necessary to clarify a particular feature of its presentation: vertices can be connected not only between each other but also can form loops, that is, the vertex can be connected with itself. Thus, a triadic predicate can have the same vertex at the first and second place.

It is appropriate to normalize each value of edge weight relative to the total weight of all edges in the network. Thus, we will get the specific value of the traffic between two vertices. As a result of the transformations, the triadic predicate will obtain the following form

$$\Gamma(i,j, \frac{\delta(a_{ij})}{\Sigma_{ij}\delta(a_{ij})})$$

A similar operation is also appropriate to conduct with the weight of the vertex (the total traffic passing through it).

Then, the data obtained by researchers at the University of Koblenz-Landau [5] have been used in the form of the triadic predicate described above, where on the first and second places the vertex number (user) is indicated, and on the third place - the number of interactions between these users. It should be noted that the statistics received do not take into account the number of messages transferred because of the inability to track personal correspondence.
Qualitatively, the source data which includes the weight characteristics in the triadic predicate, can be presented in the form of Table 1 for each network.

Table 1: Interpretation of matrix elements of the social networks connectivity

| Social network type                      | Social network | The physical nature of the weights of network graph arcs                           |
|-----------------------------------------|----------------|-----------------------------------------------------------------------------------|
| Networks for communication              | VKontakte      | Number of reposts to own page per unit of time (per year) [5-9]                    |
|                                         | Google +       |                                                                                   |
|                                         | Facebook       |                                                                                   |
| Media Networks                          | SoundCloud     | Number of audio recordings added to own page per unit of time (per year) [5,10]     |
| Share                                   | YouTube        | Number of audio recordings added to own page by means of repost per unit of time (per year) [5,11] |
|                                         | Flickr          | Number of viewd photos and videos per unit of time (per year) [5,12]               |
| Networks for reviews and insights       | Rate& Goods    | Number of reposts of goods insights per unit of time (per year) [5,13]             |
|                                         | Foursquare     | Number of comments per unit of time (per year) [5, 14, 15]                        |
|                                         | Tourout        |                                                                                   |
| Discussion forums                       | 4PDA           | Number of comments per unit of time (per year) [5,16-18]                           |
|                                         | xda-developers |                                                                                   |
|                                         | Reddit         |                                                                                   |
| Social publishing                       | Blogger        | Number of reposts per unit of time (per year) [5,19]                               |

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| Platforms                  | Network Type                        | Description                                                                 |
|---------------------------|-------------------------------------|-----------------------------------------------------------------------------|
| Social publishing platforms | Tumblr                              | Number of reposts per unit of time (per year) [5,20]                        |
|                           | LiveJournal                         | Number of reposts per unit of time (per year) [5,21]                        |
| Networks of social bookmarks | Digg                                | Number of bookmarks per unit of time (per year) [5,22]                     |
|                           | Slashdot                            | Number of articles per unit of time (per year) [5,23]                      |
|                           | BibSonomy                           | Number of co-authored papers per unit of time (per year) [5,24]            |
| Networks of interests     | Advogato                            | Number of joint projects per unit of time (per year) [5,25]                |
|                           | Last.fm                             | Number of music tracks played by coincidence per unit of time (per year) [5,26]|
|                           | Scientific Collaboration             | Number of jointly written articles per unit of time (per year) [5,27]      |

The table shows the physical nature of the vertices interaction for the networks under consideration. This data represents the unweighted network traffic, and therefore all data should be converted to the specific traffic (2).

To describe the processes of modeling information diffusion in the network, you need to build the matrix of the network vertices degrees (Figure 1), where the diagonal of matrix holds the values of the degrees of all arcs outgoing from vertices. At the intersection of the column and row, the matrix will have 0:
This matrix is required to build a layered model of the network graph. Further, to describe the content diffusion model, it is necessary to create a vertex-adjacency matrix.

To get the adjacency matrix, it is necessary to convert the data of the triadic predicate. At the intersection of the row and column set 0 subject to the vertex does not have a link with the other vertex corresponding to numbering in the predicate, and set 1 subject to there is a link between the vertices. The diagonal in this matrix will contain zeros. Figure 2 provides an example of the vertex-adjacency matrix of the network created according to the above principle.

As you can see from Figure 2, the values at the intersection of rows and columns are not asymmetrical relative to the diagonal line. This indicates that vertices can contain not only one edge with another vertex, but a bi-directional link as well. This matrix is required for description of the network's epidemic processes.
For representativeness of sample from the multi-dimensional network, let's define the unit weight of vertices and arcs. To do this, the values obtained should be normalized by the sum of the weights of all the arcs on the network:

$$\bar{x}_i = \sum_{i \neq j} \delta(a_{ij}),$$

(3)

that is, on the total traffic of the user relative to the entire network traffic. Then in this case, the normalized value obtained will show the specific weight of the arcs $a_{ij}$:

$$\delta(\bar{a}_{ij}) = \delta(a_{ij}) \frac{\sum_{i \neq j} \delta(a_{ij})}{\sum_{i \neq j} \delta(a_{ij})},$$

(4)

where (4) will characterize the degree of its weighted (according to value volume) centrality. Hence, the matrix of weighted centrality of the network, whose elements are the normalized values of weights of the arcs and vertices, wherein in the diagonal of the matrix the specific weights of the vertices are located, and in the columns and rows respectively the specific weight of the incoming and outgoing arcs is shown in Figure 3.

![Matrix of the weighted centrality of the network elements](image)

Fig. 3: Matrix of the weighted centrality of the network elements

For the oriented network, in the case of determining the weighted centrality of the vertex $x_s$, it is possible to use the sum of the weights of incoming and outgoing arcs:

$$\sum_i \delta(a_{si}) + \sum_j \delta(a_{js}).$$

(5)
The value obtained in (5) should be normalized according to the total weight of the network arcs. As a result we will obtain the normalized value characterizing the degree of this vertex centrality:

\[ \delta(\bar{x}_s) = \frac{\sum_i \delta(a_{si}) + \sum_j \delta(a_{js})}{\sum_{i,j} \delta(a_{ij})}. \]  

(6)

The obtained square matrix of the weighted centrality of the network vertices elements (Fig. 3) can be converted to a diagonal view (Fig. 4).

\[
\begin{array}{cccc}
  & s & n \\
  i & \bar{x}_i & \cdots & 0 \\
  \vdots & \vdots & \ddots & \vdots \\
  s & 0 & \cdots & \bar{x}_s \\
  \vdots & \vdots & \ddots & \vdots \\
  n & 0 & \cdots & 0 \\
  & & & \cdots & \bar{x}_n \\
\end{array}
\]

Fig. 4: Diagonal matrix of the weighted centrality of the network vertices

This matrix can be useful for vertices selection by the value of their traffic.

To determine whether the vertex is an authoritative user, i.e. with more specific weight among the authors of certain topics (more users refer to this user), or the vertex is the center node that makes references to author's pages (users), let's calculate for it the difference between the weights of the outgoing and incoming arcs:

\[ \delta(\bar{B}_s) = \frac{\sum_i \delta(a_{si}) - \sum_j \delta(a_{js})}{\sum_{i,j} \delta(a_{ij})}. \]  

(7)

The specific value obtained (7) will characterize the role of the network vertex (subject) [34]:

- at \( \bar{B}_s > 0 \) - the content accumulator (authoritative user);
- at \( \bar{B}_s < 0 \) is the content battery (central node).

The larger the module \( \bar{B}_s \), the more its role-oriented function is. This is the practical application of the diagonal matrix of the specific balance of traffic in the network vertex (Figure 5).

Thus, it makes sense to convert the resulting square matrix of weighted centrality of network elements into a diagonal matrix of the specific balance of the content value volume in the network vertices where along the diagonal the role functions will be located for each vertex in the form of the positive value for the network content generator, and in the form of negative value - for the content accumulator, respectively:

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Fig. 5: The diagonal matrix of the traffic specific balance in the network vertices.

This matrix is useful for detecting attack targets in the network.

III. Results of the Proposed Methodology Application

The multi-dimension of many social networks that make difficult their modeling clearly requires a representative sample of data. Suppose for the network a directed linked graph is set \( G = (V, E, U) \) with a non-negative real-valued weighting function on the vertices \( V \) represented by the diagonal matrix of weighted centrality \( W(\delta(x)) \). It is required to re-sort the matrix so that you could easily remove the vertices with the lowest specific traffic.

The sampling principle is in reducing the tasks on the original network graph of the large dimensionality to the task on the graph of small dimensionality. This approach requires that the following conditions be met:

(a) authenticity - sample should retain the properties of the source network;

(b) accuracy - the sample with the specified accuracy must retain the primary parameter of the source network - traffic.

The reduction in network dimensionality is multi-layered and consists of a consistent approximation of a weighted centrality \( W(\delta(x)) \) to the specified value of the total traffic.

At the first stage it is necessary to re-assort a matrix of the weighted centrality so that the weight of its diagonal elements were located in descending order, i.e. for the matrix of weighted centrality \( W(\delta(x)) \) having the form of
the condition will be fulfilled:
\[ \delta(x_i) > \delta(x_{i+1}) > \cdots > \delta(x_s) > \delta(x_{s+1}) > \cdots > \delta(x_k) > \delta(x_{k+1}). \]

After such levelization of the matrix elements we will have the location of its elements in descending order from the vertex with the highest specific traffic to the vertex with the smallest specific traffic.

Next, you need to determine the total network traffic. It will be defined as the sum of all diagonal elements of the matrix:

\[
V^1 = \sum_{i=1}^{n} \delta(x_i),
\]

where \( V^1 \) is the volume of network traffic, \( n \) is the number of network vertices.

Then, if you set the traffic percentage equal to 5% that can be lost in the result of the sample from, we will get the network of the representative traffic

\[
V'_0 = 0.95 \cdot V^1 = 0.95 \cdot \sum_{i=1}^{n} \delta(x_i),
\]

To obtain the representative sample, you need to summarize successively the elements \( \delta(x_i) \) of the weighted centrality matrix \( W(\delta(x_i)) \) until the loss of traffic meets the 5% condition

\[
\sum_{i=1}^{n} \delta(x_i) \rightarrow V'_0.
\]
Now it is necessary to zero out all elements of the weighted centrality matrix $W(\delta(x))$ that turned to be below the elements for which the traffic summary was the preset value $V'_0$.

The proposed method of representative sampling is appropriately to illustrate graphically. Let's set the network vertex positions as abscissa and ordinate axes, and the specific traffic of vertices will serve as applicate axis. Let's indicate the network contour (Fig. 6) as a solid line.

![3-D illustration of the source network](image)

**Fig. 6:** 3-D illustration of the source network

In fact, when a representative sample is received, the indicated contour will shift along the applicate axis upward. The procedure is illustrated on Fig.7, where the sample contour is indicated with a solid line. In this case, Fig. 6 and 7 reflect the decrease in normalized specific traffic from 1 to 0.95 and the decrease in the number of vertices from 720 to 610 along the contour.

Let $N$ is the number of vertices of the source network, and $N_\#$ is the number of vertices of the representative sample. Then the process of obtaining a representative sample can be called the network truncation with a rate of sample scale equal to:

$$Q = \frac{N_\#}{N}$$
Source network truncation with the traffic maximum retention obviously reduces in the sample the proportion of low-degree ones compared to the original network. In this case, the law of the degrees distribution is undergoing some changes (Fig. 8).

![Fig. 7: Three-dimensional illustration of the representative sample](image1)

![Fig. 8: Law mutation of the degree distribution of the vertices during representative sample](image2)

It is worth noting that the vertices of the high centrality during obtaining a representative sample do not undergo changes, so it is appropriate to speak of the segment where the type of distribution law is maintained (Fig. 8). It is quite extensive and the lost vertices do not make a significant distortion in the heterogeneous nature of the studied network.

**IV. Discussion of the Results**

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The methodologies proposed in this work should be considered as the development of the risk-analysis methodology [28-34] on social network space. The emphasis on discrete modeling, which allowed eliminating a number of contradictions inherent with the traditional epidemic models, gave a number of theoretically and practically original results. However, the authors visualize the direction of further improving the "Netepidemic", which, in the first approximation, can be formulated as follows:

1. First of all, the models proposed need to be thoroughly detailed for the individual types of social networks in both their parametric and structural content. The technological differences and moderation techniques specific to each network should certainly be reflected in the modeling of the content distribution processes.

2. Content, as the main "hero" of information diffusion in the networks under consideration, should also be subject to in-depth research. Its design largely determines the qualities of the expected popularity on the network, such as: visibility, susceptibility, etc. Therefore, the information and psychological aspects of building the content to be distributed, including the preferences of the intended audience and the intended effect of its reaction, clearly require its formalization.

3. The ways of content promotion in network should be in accordance with its information structure. The time, place, and frequency of injecting content in the network largely determine its popularity. Therefore, these technological features of the information diffusion in social networks clearly require the careful study and formalization.

4. In the considered models of information diffusion, the social network often acts as a stationary object. In reality, however, it is a living organism in which, depending on the observation time, both the number of the users in population and the quantity and quality of the links between them change significantly. In cases, where it is not possible to ignore this phenomenon (for example, long-term information and psychological operations), it is necessary to justify and introduce amendments to the epidemic process models, taking into account the dynamics of the network.

5. Modern users of the virtual space, usually are registered in several social networks. Thus, information diffusion via these users also exists between the networks, and the appropriate internet content distribution models should take it into account.

The identified directions can be useful for researchers of social networks as a guide to practical development. The characteristics of weighted centrality of the network elements use is fundamental. It is they which provide the most objective picture of users interaction through their specific traffic. They also take into account integrally the degree of vertex and the network popularity of their respective users, which is particularly important for modeling the content diffusion processes. This is the main significance of the results obtained in the paper.
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