# Identifying the Transition of Interactions in Virtual Communities of Social Networking Services to Chaotic Dynamics

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### Abstract

The diversification of communication channels influenced by the development of information and communication technologies has made social networking services particularly popular among users. They provide actors with many tools not only for effective communication and networking in virtual communities but also for self-organization and coordination of interactions in real life. As a result of the diffusion of boundaries in the information space, social networking services have become an object of threats to the information security of the state. The experience of information operations against information security of the state has shown that because of targeted information impact on virtual communities of actors can occur chaotization of processes of their interaction. The result of such impact is a transition of such processes from online to real life in the form of mass civil protests. With the constant growth in the number of threats and the emergence of new methods of destructive information impact, the problem of their early detection and effective counteraction becomes particularly important. It is known that the transition of virtual community to deterministic chaos is characterized by increasing levels of entropy in the system. In this article, we use the kernel density estimation of the entropy distribution of the actors' interaction parameters in the social networking services to determine its dynamics to identify growth periods, preceding the system's transition to chaotic dynamics. Determination of the nature of entropy function's variation from time will make it possible to determine the moments of application of controlling influence on information space of the social networking services and actors, which will ensure reduction of the system's degrees of freedom with its subsequent transition to a given state of information security. In this state the structure of virtual communities' changes because of the self-organization of actors, providing information exchange in communities, which is resistant to destructive impact. Application of the proposed approach will improve the effectiveness of countering threats to state information security in the social networking services.

### Keywords

Social networking services, chaotic dynamics, kernel density estimation, entropy, Rössler attractor

## 1. Introduction

The growing influence of social networking services on social communication processes has turned them into a leading channel of communication [1-5]. Under these conditions, social networking services have become not only a leading source of information due to a high degree of trust in the content of the services but also an instrument of covert influence on social

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and political processes in the state [6-8]. Threats to information security of the state in social networking services of a communicative nature are connected to the realization of the needs of individuals, society and the state for the creation, consumption, dissemination, and development of national strategic content. Threats in social networking services may be aimed at influencing the mental and emotional state of actors, influencing their freedom of choice, calling for separatism, the overthrow of constitutional order, violation of territorial integrity, discrediting state authorities, supporting, accompanying, or activating criminal or terrorist activity, etc. [9, 10]. In the conditions of globalization of the national information space, absence of state borders in virtual information environment, constantly growing number of threats to information security of the state, the problem of modelling actors' interaction in virtual social networking services communities becomes especially topical. Research into processes of interaction between actors in the information space of the social networking services, considering the influence of threats, will make it possible to systematically counteract destructive information influence, which remains uncontrollable [11, 12].

Analysis of recent research and publications [13-15] has shown that one of the promising approaches to modelling social networking services as a class of complex dynamic systems is dynamic chaos theory. It allows considering key properties of social networking services – high sensitivity to initial conditions, as well as openness, nonlinearity, non-equilibrium and dissipativity of interaction in virtual communities. When interaction in social networking services turns to chaotic dynamics under the influence of information operations, not only the prediction of such interaction of actors becomes impossible, but also the system's behavior itself changes uncontrollably.

Such behavioral features can occur not only in the virtual space of the social networking services but can also be reflected in the actions of citizens in real life. Therefore, within the framework of solving the problem of modelling actors' interaction in virtual communities of services, not only the synthesis of control actions but also the point in time at which such a measure is implemented, is of particular importance. This approach will make it possible to suppress chaotic dynamics of interaction and form prerequisites for effective counteraction to threats to state information security in the social networking services [11, 15, 16].

The purpose of the article is to determine a point in time for effective implementation of the control action, followed by the transition of virtual communities of actors in the social networking services from chaotic interaction with a given state, in which the levelling of destructive information influence the actors is ensured.

To achieve the goal, the following tasks are required:

1) Formalize the interaction of actors in virtual communities of social networking services under the influence of threats using irregular attractors.

2) Estimate system entropy using kernel density estimation of actor interaction parameters in social networking services.

3) Identify existing precursors of chaotic dynamics of actors' interaction in the social networking services and give practical recommendations for their early identification.

## 2. Modelling actors' interaction in social networking services based on irregular attractors

In the case of transition of social networking services actors' interaction to deterministic chaos, it is characterized by the high sensitivity of virtual communities to changes in system parameters and the action of disturbances, in particular destructive information influences. Even if the interaction of actors in the social networking services is formalized by deterministic models, in a state of deterministic chaos, their communication turns into random and unpredictable processes (Figure 1).

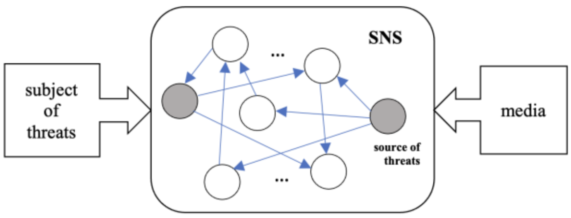



**Figure 1**: Social networking services as a target of threats

To describe the interaction of actors in the social networking services when the system transitions to chaotic dynamics, it is advisable to use irregular attractors. Even though social networking services is a dissipative system, which can be either open or non-equilibrium, using the irregular attractors is appropriate.

The features of irregular attractors are the complex geometric structure of the set of states of the system they describe. Such attractors are characterized by a simultaneous combination of both stability and instability. Therefore, irregular attractors provide a high degree of adequacy in describing the interaction of actors in the social networking services, which are taking place under the conditions of information confrontation. Such attractors include Lorenz attractors, Rössler attractors, and others [17, 18].

## 2.1. Rössler chaotic system

In general terms, the actors' interaction in the social networking services using the Rössler irregular attractor is formalized as a system of differential equations [19]

$$\begin{cases} \dfrac{dI(t)}{dt} = \gamma R(t) + \theta Z(t); \\ \dfrac{dR(t)}{dt} = \xi I(t) + \mu R(t); \\ \dfrac{dZ(t)}{dt} = a + I(t)Z(t) - bZ(t), \end{cases} \quad (1)$$

where $I(t)$ is the destructive information influence, which is carried out by the opposing group in the social networking services information space; $R(t)$ is the function which characterizes the actors' ability to critically perceive the content and determines the level of information resistance to destructive information influence; $Z(t)$ is the function that determines the actor's level of readiness for active actions in real life, which is induced by destructive information influence $I(t)$, $Z(t) > 0$; $\gamma$ is a parameter that determines the level of destructive information influence on actors aimed at overcoming their information resilience and is related in inverse relation to $\theta$, $\gamma < 0$; $\theta$ is a parameter of actor's readiness level to move to active actions in real life; $\xi$ is an information influence that is performed using strategic communication channels and is aimed at building information resilience in actors, $\xi > 0$; $\mu$ is a parameter that determines the actors' prior experience in identifying threats in the social networking services; $a$ is an integrative parameter that determines the actors' ability to switch to active actions as a result of destructive information influence and is formed as a result of individual characteristics; $b$ is a parameter that determines the actors' ability to switch to chaotic dynamics under the influence of destructive information influence.

To simulate the interaction of actors in the SIS based on the synthesized model (1) were used the tools of *Google Collaboratory* environment and programming language *Python*. The bifurcation diagram of the system of differential equations (1) at values of parameters $\gamma = 1$, $\xi = 1$, $\theta = 1$, $\mu = 0.2$, $a = 0.2$, $b = \{1; 10\}$ is constructed, which is presented in Figure 2.

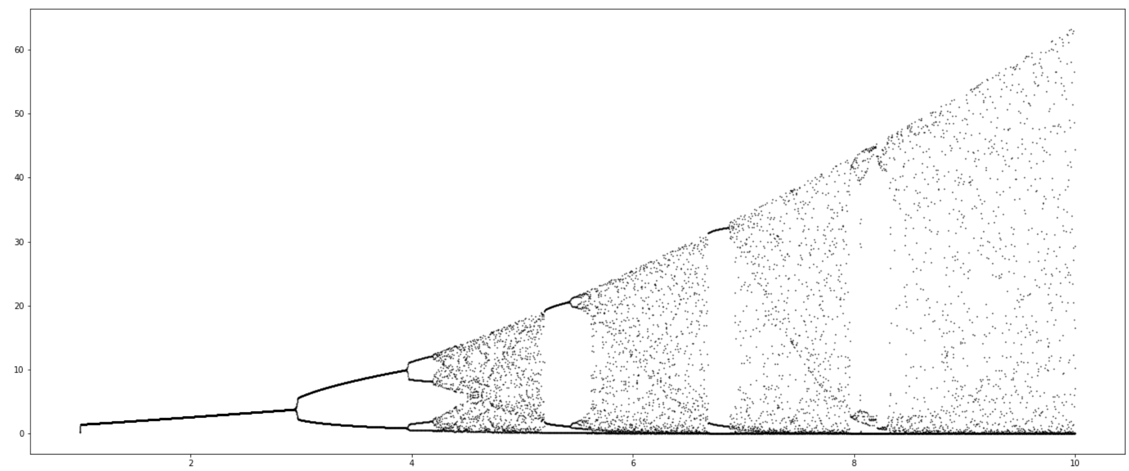



**Figure 2**: Bifurcation diagram of the Rössler attractor

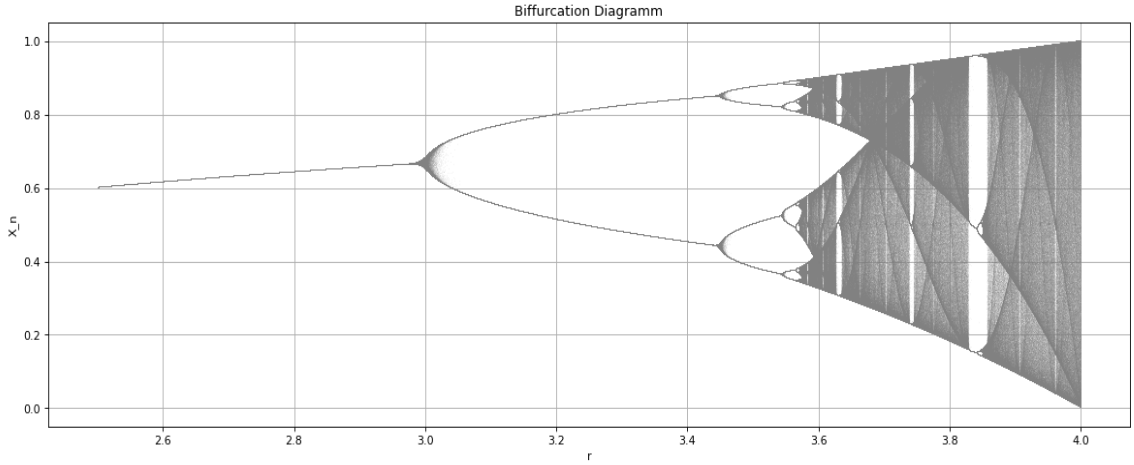
Rössler bifurcation diagram is similar in nature and behavior to the logistic transformation bifurcation diagram (Figure 2 a, b) [20, 21]

$$x_{n+1} = rx_n(1 - x_n). \quad (2)$$

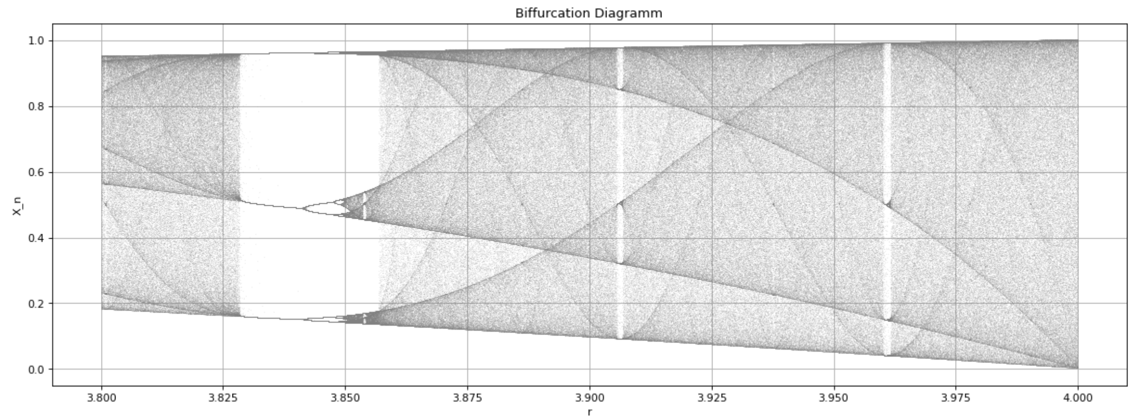
## 2.2. Determination of the chaotization metric of the system based on entropy

To simplify the calculations, we further analyze the behaviour of Rössler system in the $Z$-plane based on the analysis of the bifurcation diagram of the logistic transformation.

It is known from analysis of sources [22, 23] that a marker of chaotic dynamics appearance in a system is a senior Lyapunov exponent. Despite the developed mathematical apparatus associated with the study of dynamical systems and their behaviour based on Lyapunov exponents, this approach has an analytical character. In practice, it leads to post-analysis based on a statistical retrospective analysis of the system parameters.




(a) the control parameter $r \in (2.5; 4)$;




(b) the control parameter $r \in (3.8; 4)$;

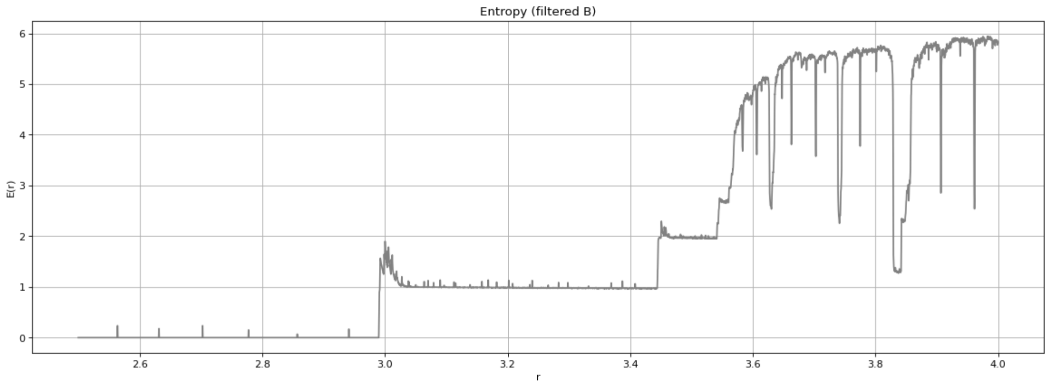
**Figure 3**: Bifurcation diagram of the logistic transformation

It is well known that the bifurcation diagram in its physical sense describes possible states of the system depending on the control parameter $r$ [24-26]. Each "slice" of the bifurcation diagram $\{X_i(r)\}$ describes a set of system states $x_{ij} \in X_i(r)$, $j \in (1; inf)$ is the number of system states in the $j$-th "slice" of the bifurcation diagram. We will determine the entropy of the system based on a preliminary analysis of the probability density of states $S_{ij}$, for this purpose we use the mathematical apparatus *KDE* (*Kernel Density Estimation*) [27]. Therefore, we transform the sequence of "slices" into the sequence of estimates of kernels of normalized probability density distribution – $p_i(x)$.

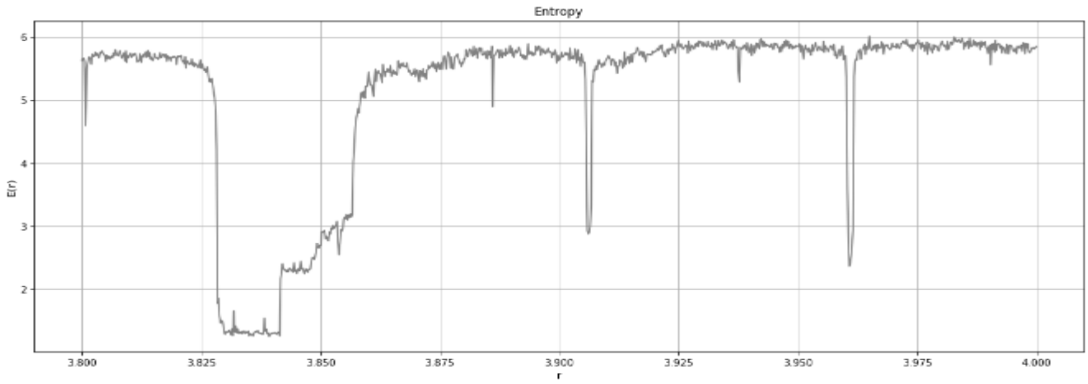
To determine the entropy of the system at known values of the probability density distribution, we use the expression for Shannon's entropy [28]

$$E_i = -\int p_i(x) log_2\big(p_i(x)\big)dx. \tag{3}$$

Thus, for each set of states $X_i(r)$ the entropy $E_i$ is obtained. The variation of the entropy value is shown in Figure 4.




(a) the control parameter $r \in (2.5; 4)$;




(b) the control parameter $r \in (3.8; 4)$;

**Figure 4**: Shannon's entropy for the logistic mapping at different values of the parameter $r$

## 3. Modelling results

The analysis of the bifurcation diagram and entropy suggests the following:

1. Local maximums of entropy are observed at bifurcation points, which is interpreted by a temporal increase in uncertainty. It can be related to an abrupt change in the behaviour of social networking services' actors because of destructive information influence on virtual communities [29, 30]. Actors need some transition period to form their viewpoint on the events in the information space to further interact with other actors and virtual communities.

2. The life cycle of the virtual community of actors in social networking services is followed by changes in indicators of their interaction from stationary (characterized by a decrease in entropy value) to chaotic dynamics (entropy growth). The result of passing the bifurcation point by the system is structural changes in virtual communities – the number of participants, creation of new associations, interaction through likes, reposts and distribution of given content.

3. The transition of actor interactions in the social networking services to chaotic dynamics is accompanied by a rapid increase in the value of entropy

$$\frac{dE}{dt} \gg M.$$

4. In the field of chaotic dynamics of actors' interaction in the social networking services, the entropy of the system tends to the maximum, as the probability density distribution approaches uniformity. If the number of states of the virtual community of actors is $N$, then under the conditions of transition to chaotic dynamics $N \to \infty$. In this case, the probability of being the virtual community in one of these states is defined as uniform distribution

$$p = \frac{1}{N}$$

Then the entropy is defined as

$$E = -\sum_{i=1}^{N} p_i \log_2 p_i = -\sum_{i=1}^{N} \frac{1}{N} \log_2 \frac{1}{N}.$$

From where

$$E(N \to \infty) = \lim_{N\to\infty} \left( -\sum_{i=1}^{N} \frac{1}{N} \log_2 \frac{1}{N} \right) =$$

$$= \lim_{N\to\infty} \left( -N \frac{1}{N} \log_2 N \right) = \lim_{N\to\infty} \log_2 N.$$

## 4. Practical guidelines

Considering the results of the modelling of actor interactions in virtual communities, the following practical recommendations for identifying precursors of chaotic dynamics are given:

1. Applying Rössler chaotic system for modelling actors' interaction in social networking services under the destructive information influence and conduct of information confrontation allows describing the transition of citizens' potential to active actions in real life. Therefore, it is reasonable to apply the proposed approach to modelling interactions in virtual communities when developing and improving the subsystem of information space monitoring within the framework of the state information security system in the social networking services.

2. The simulation of virtual communities in the social networking services based on the chaotic Rössler system is appropriate for monitoring the interaction of groups of actors created and/or managed by an opposing force. Actors of such virtual communities are potentially used to participate in mass protests and unrest in real life. Therefore, timely identification of signs of their transition to chaotic dynamics based on entropy indicator (3) will allow responding in advance to changes in the situation in the social networking services information space.

## 5. Conclusions

Simulation of actors' interaction in the social networking services based on irregular attractors investigates the processes of transition of communication in the information space of services into chaotic dynamics, in which associations of actors become unmanageable. The application of irregular attractors helps considering the effect of destructive information influence on actors in the social networking services in the conditions of information confrontation. To achieve this, interaction in the information space of services is modelled using the Rössler irregular attractor, which enables the formalization of interaction not only online but also the transition of actors to acts of defiance in real life. For early detection of signs of transition to chaotic dynamics, we propose to use the kernel density estimation of the entropy distribution of interaction parameters of actors in the social networking services to determine its dynamics to identify periods of growth. Thus, the analysis of entropy value dynamics changes indicates a transition of virtual community to chaotic dynamics and promptly applies methods of its suppression.

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