Information Sciences 320 (2015) 26–61

Contents lists available at ScienceDirect

Information Sciences

journal homepage: www.elsevier.com/locate/ins

Online social contagion modeling through the dynamics of Integrate-and-Fire neurons

Ilias N. Lymperopoulos *, George D. Ioannou

Department of Management Science and Technology, Athens University of Economics and Business, 47a Evelpidon Str., Athens 11362, Greece

ARTICLE INFO

Article history:
Received 21 May 2014
Received in revised form 23 April 2015
Accepted 2 May 2015
Available online 11 May 2015

Keywords:
Online social contagion
Collective behavior
Synchronization
Integrate-and-Fire neuron
Online social network
Neural network

ABSTRACT

We introduce a novel model capturing the dynamics of the online social contagion. We adopt a neuroscience perspective and consider the online social networks analogous to networks of Integrate-and-Fire neurons. The dynamics of the model is driven by three sources of positive or negative influence: The individuals' self-generated bias, the interpersonal online interactions, and the external environment stimulus. The model explains the online activity growth and the activity propagation patterns in relation to the interaction network, the endogenous and exogenous influence, and the individuals' activation mechanism. Through simulation experiments and validation against empirical data from Twitter, we demonstrate that the model captures the relationship between the dynamically changing internal and external influence and the ensuing online activity. As such, it can accurately reproduce collective activity patterns arising from the online users' response to various kinds of stimuli. The model can be generalized to handle a wide class of contagion phenomena.

1. Introduction

- On May 15, 2011 thousands of people rallied in 59 cities across Spain initiating a series of protests known as the 15 M movement. What did make this mobilization coordinated, fast, and popular?
- During the typhoon Bopha in the Philippines, and the Hurricane Sandy in the U.S. in 2012, people voluntarily responded en masse to organize their emergency units. How did this wave of cooperation propagate through people and make them participate in this self-organized help network?

These are a few examples where social contagion driven by the pervasive nature of the online social networks, led to the appearance of collective phenomena. Such phenomena abound in physical, biological, cognitive, social and economic systems [48,98], thus implying the universality of the underlying network dynamics [11]. In chemistry, macroscopic spatio-temporal patterns arise in oscillating reactions [24]. In biology, multiple cells act in unison to perform muscle contraction, and billions of interconnected brain neurons give rise to thoughts, feelings, percepts and purposes [47]. In society, interacting people form social groups with economic, professional, political, religious and cultural activities [16].

The presence of a network connecting the individual parts of a system is essential for the appearance of collective phenomena [3]. This network is a complex one, in that it comprises a large number of interdependent elements interacting

* Corresponding author.
E-mail addresses: eliasliber@aueb.gr, eliasliber@hotmail.com (I.N. Lymperopoulos), ioannou@aueb.gr (G.D. Ioannou).

http://dx.doi.org/10.1016/j.ins.2015.05.004
0020-0255/

through intricate and multiple ways [12]. The most complex of all are the social networks, due to the multiplicity of social interactions and the complexity of the human cognitive system [51]. The advent of the social web increases their complexity even more. The interdependence of individuals becomes deep and dense, and the transmission of information almost instantaneous. Nevertheless, the enormous complexity of the online social interactions do not necessarily entail chaos and unpredictability. On the contrary, phenomena of collective behavior often appear through the dynamics of social contagion [17].

The increasing use of the online social networks and the ample availability of empirical data are instrumental in elucidating the mechanisms of behavioral phenomena appearing in the online ecosystem. To gain more insights into their dynamics, our study adopts a neuroscience perspective and draws inspiration from the structural analogy between the brain and the online social networks. Recent developments in neuroscience have yielded an enormous amount of knowledge on the brain dynamics, thereby leading to the construction of realistic model neurons. Such a model is the leaky Integrate-and-Fire neuron [35,28]. Simplistically, when a leaky Integrate-and-Fire neuron is excited above a certain threshold, an electric pulse – the action potential – is emitted and delivered to the dendritic trees of the neighboring neurons through synaptic connections. This pulse can either cause excitation, thus bringing the receiving neurons closer to their firing threshold, or inhibition, with the opposite effect. Apart from the received pulses, the excitation of a leaky Integrate-and-Fire neuron is also affected by its self-dynamics and its sensory input conveying stimulation from the external environment [96]. By analogy, we model the online social contagion as a dynamical process whereby the users' activity is regulated by the dynamically evolving impact of three sources of positive or negative influence, that is, their self-generated bias (e.g. preferences), their online interactions, and the external environment stimulus. As in the case of Integrate-and-Fire neurons, the positive influence causes excitation leading to an individual's activation when a threshold is exceeded, whereas the negative influence causes inhibition, thus deterring the activity propagation. The study of the online social contagion from an open systems perspective whereby the dynamics is not only affected by the internally generated influence, but also by the external environment, opens new opportunities for the investigation of the dynamical coupling between the online social networks and the surrounding context, be it economic, political, technological, or societal.

Through the proposed isomorphism this study aims to introduce an overarching modeling approach capturing the dynamics of:

- The stimulation mechanism, through which the influence originating from the individuals' self-dynamics, their interaction and the external environment, diffuses in online social networks.
- The stimulus processing, whereby the incoming influence accumulates, but also dissipates, thus dynamically changing the level of the individuals' susceptibility to social contagion.
- The individuals' activation mechanism, by means of which behavioral changes occur.

To the best of our knowledge, our study is the first to simultaneously include all the aforementioned factors into a single model explaining the online activity growth, the activity propagation patterns, and the emergence of collective behavior. Furthermore, it is the first to propose an isomorphism between the properties of the leaky Integrate-and-Fire neurons and the behavioral characteristics of individuals. Although the potential of neural networks as modeling tools of social interaction has been noticed in the literature of computational sociology [84], as of yet there has been no transfer of such an approach to the online social contagion. In this regard, our study fills a gap between the neuroscience perspective on social dynamics, and the creation of a validated, highly flexible online social contagion model of a multidisciplinary conceptual and practical relevance.

To demonstrate the capacity of the proposed model to describe and reproduce online social dynamical processes, we validate it against two Twitter datasets. The first one contains messages created during the initial phase of the mass protests of the 15 M movement in Spain [40]. This dataset is particularly relevant to the purposes of our study, as it enables the investigation of the evolution of Twitter activity in a context combining both internal and external sources of influence. The internal sources relate to the online users' self-dynamics and their interaction, while the external ones pertain to the mass media coverage of the events and the popular support for the demonstrations. Through simulation experiments we aim to reproduce the 15 M online activity patterns with a view to explaining how the internal and external excitation result in synchronized collective behavior and oscillatory activity propagation. The second dataset relates to a high profile event which took place in the world cup of 2014. The detection of synchronized activity and the replication of its qualitative features, provide evidence of the suitability of the proposed model for the study of all forms of online activity patterns.

The rest of the paper proceeds as follows. In Section 2 we review research on social contagion and compare the proposed method with the state-of-the-art. In Section 3 we elaborate on the modeling framework and proceed to its mathematical formulation which translates the dynamics of the leaky Integrate-and-Fire neurons – in the form provided by Vogels [96] – into the dynamics of the online social contagion. Section 4 describes the model implementation and validation methods. Section 5 presents the results of the study through a comparative examination of the simulated and the real activity patterns, thus providing qualitative and quantitative evidence of the validity of the proposed approach. Section 6 discusses the findings, their practical implications, and provides directions for future research. The study closes with the concluding remarks in Section 7. In addition, the paper contains two appendices. The first one briefly covers the fundamental theoretical background dealing with the function of the leaky Integrate-and-Fire neurons. The second one describes the dynamical states of networks of this type of neurons. This material can be used as a reference for examining the similarity in activity patterns between networks of leaky Integrate-and-Fire neurons and online social networks.