Neurocomputing ∎ (∎∎∎∎) ∎∎∎–∎∎∎

Contents lists available at ScienceDirect

Neurocomputing

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

Contusion and recovery of individual cognition based on catastrophe theory: A computational model

Shuliang Lv [a], Ruixian Yang [b], Chuanchao Huang [a,*]

[a] School of Management, Huazhong University of Science and Technology, Wuhan 430074, China
[b] College of Information Management, Zhengzhou University, Zhengzhou 450001, China

ARTICLE INFO

Article history:
Received 28 February 2016
Received in revised form
5 April 2016
Accepted 2 May 2016

Keywords:
Individual cognition
Choice behavior
Resilience
Catastrophe theory

ABSTRACT

Originated in emergent behavior characterized by interactions between individuals and cognitive processes, sudden changes in behavior are common phenomena under the information pressure being perceived by individuals, particularly those whose cognition is weak to negative information. (Said behavioral changes are thus related to reactive individual behavior). To probe its underlying mechanism, we introduce an ICR model that accounts for the sudden changes in individual cognitions and behaviors. To ensure that our model is stable in different types of network environments, Verification results show that the model indeed accurately describes the various catastrophe paths of individual cognition. Exploration of our model also shows it can be applied in polarization of group behavior, and the confidence intervals of the resilience of individuals were analyzed to identify reversal patterns of polarized group behavior. As a discussion of the results, it shows that the proposed model has wonderful prospect to support neural network training in individual behaviors among networks.

1. Introduction

Over the past 30 years, the population of individuals who participate in online activities has increased sharply worldwide. This is particularly of interest in China, where the development of Internet technologies and online resources has been very rapid [1]. Via the Internet, "individuals" (as Internet users are referred to from here on,) can participate in social and political issues in an active and instantaneous manner [2]. This often results in online incidents that pose a concern for government and social organizations. Due to the massive amount of information available online, as well as its constant flow and ready access, individuals may find it difficult to make rational judgments regarding the information [30]. Individuals are, therefore, under gradually increasing levels of psychological stress that is likely to cause their opinions (and thus their behavior) to fluctuate.

Individual decision-making behavior corresponds to cognitive level [3,26], which can be affected by emotional and psychological stress. When psychological stress is strong enough to reduce individual cognitive level, irrational decisions readily follow [4,27]. Individuals with low cognitive level and difficulty making rational decisions who navigate an instant-access online information environment may show polarization and frequent reversal of their opinions [5]. Hence, in controlling the evolution of public opinion, it is important to explore the mechanism of change in the individual's cognition.

Human beings' behavior, which is related to their individual opinions, is generated by interaction between internal psychological factors and external environmental factors [31]. Studies have shown that cognitive level is closely related to psychological stress [6,29]. When individuals are exposed to crises and setbacks, the ensuing psychological stress may lower their level of cognition [7], thus reducing their ability to make decisions. However, it is crucial to note that individual cognition also has the property of "resilience" [8].

Resilience, originally a physics term, can be used to explain material properties; when a resilient material is deformed by pressure, it has the ability to restore itself to its original state. In the 1950s, resilience was brought into the field of psychology via a study on high-risk children in the Hawaiian Islands [9]. In psychology, resilience refers to the individual's ability to cope with setbacks by returning to his or her original mental and emotional state. Resilience, as a protective component of individual psychology, is now a commonly accepted concept with a well-established research framework [10].

Psychological resilience does have a limit beyond which the individual cannot adapt to external pressures. When pressure exceeds this threshold, resilience "bursts." At this point, the individual suddenly shifts his or her cognition and may even show "catastrophe" phenomena. Changes in cognition thus show nonlinearity and discontinuity properties. Catastrophe theory (CT)

* Corresponding author.

http://dx.doi.org/10.1016/j.neucom.2016.05.099
0925-2312/

Please cite this article as: S. Lv, et al., Contusion and recovery of individual cognition based on catastrophe theory: A computational model, Neurocomputing (2016), http://dx.doi.org/10.1016/j.neucom.2016.05.099

serves to analyze phenomena of discontinuous and sudden changes in the real world and is applicable to dramatic shifts in individual cognition. CT, first proposed by Thom in the 1970s [11], has since been widely applied to human psychological theories including cognition and opinion. Weidlich, for example, viewed changes in individual opinion as a nonlinear system and accordingly built a dynamic evolutionary model of collective opinion [12]. He found that change in human opinion (as evidenced in voting, for example) had the properties of "cusp catastrophe".

Stewart and Peregoy [13] illustrated the use of two catastrophe models, fold and cusp, to explain individual cognition mechanisms. They identified the distinguishing properties of catastrophic cognition through an experiment involving a group of multi-stable pictures. Based on descriptive analysis, they demonstrated a method of fitting observational data to the curved surface of the cusp catastrophe model. Compared to Flay's work [28], a real-world application of the cusp catastrophe theory was conducted, however, the applied object was in a simple environment (i.e., among all possible factors, only the picture changed).

By combining cognition theory and CT, we have extended current theoretical knowledge to establish a new model of cognitive resilience applied to network environments, group polarization, and individual opinions and behavior. The remainder of this paper is organized as follows: Section 2 introduces individual cognitive resilience and the cusp catastrophe model of individual cognition before establishing the proposed model of individual cognitive resilience. The model is modified in Section 3 to allow it to be adapted to different network environments; then its effectiveness and feasibility are verified. In Section 4, the model is used to explore the underlying causes of polarization and reversal of group behavior. Section 5 provides conclusions, describes limitations of this study, and makes recommendations for future research.

2. Individual cognitive resilience (ICR) model

2.1. Cognitive resilience and CT

Chaju pointed out that changes in external pressures have sizeable impact on the individual cognitive level [14]. Experimental results have shown that different types of pressure have different influences on individual cognition. Therefore, pressure has nonlinear effects on cognition, as depicted in Fig. 1 [15].

Different amounts and types of psychological pressure (represented here as "*A*," "*B*", and "*C*") lead to different paths of change in individual cognition. Under Pressure *A*, individual cognition shows the fastest decline; in other words, individual cognition has lower resistance to Pressure *A* than *B* or *C*.

Cognition Theory considers individual cognition to be composed of roughly three parts: confirmation of problems, mastery of events, and recovery of confidence. As discussed above, research has shown that external pressure affects individual emotions, memory, and cognitive level [7]. The effect of pressure on individual cognition follows Yerkes-Dodson's law, through which the relationship between individual cognition and external pressure forms an "inverted U" shape [16].

Individual behavior (which we also refer to here as "individual opinion") is instantly formed based on cognition when rapid (even seemingly instinctual) decision-making is called for within a network environment. In this situation, the individual's psychological activity (and thus behavior) may show a sudden "jump", which can be represented by the cusp catastrophe model [13]. The cusp catastrophe model is applied to systems in which continuous changes in certain factors cause the state of the system itself to show discontinuous changes. These changes take the system in

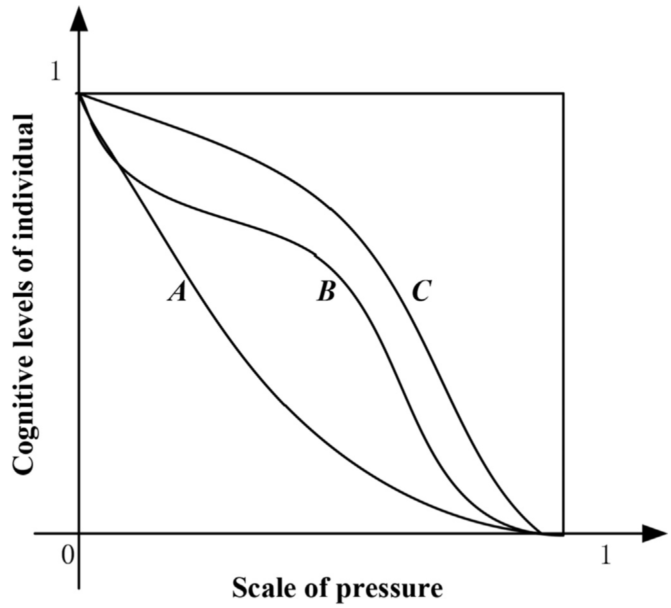

Fig. 1. Influence of pressure on individual cognition.

and out of equilibrium states, as the system is always driven toward an equilibrium state with minimum energy. The cusp potential function of the system is as follows:

$$V(f, u, v) = \frac{1}{4}f^4 + \frac{1}{2}\alpha{\cdot}u{\cdot}f^2 + \beta{\cdot}v{\cdot}f \qquad (\alpha > 0, \beta < 0) \tag{1}$$

When Eq. (1) is used to describe an individual's psychological activity and behavior, α and β are parameters corresponding to the context he or she stays in at that time [17] and f is his or her cognition level, which, again, may suddenly change; u and v are continuous variables that drive f to change continuously. As defined by Sheridan and Abelson [18], u reflects "organizational commitment" and v is "job tension". As defined by Sheridan [19], u is "group cohesion" and v is the "external environment". In this study, similarly, we define u as individual internal psychological factors (including individual propensity, stubbornness, and sensitivity to information) and v as external environmental factors (e.g., the pressure on the individual from other individuals or social organizations).

According to cusp catastrophe theory, u is referred to as a normal variable while v is a splitting variable. The normal variable determines when the sudden change in f happens, and the splitting variable regulates the scale of this change. The equilibrium state can be described by Eq. (2) after taking the derivative of Eq. (1):

$$\frac{\partial V(f, u, v)}{\partial f} = f^3 + \alpha{\cdot}u{\cdot}f + \beta{\cdot}v = 0 \tag{2}$$

and Eq. (3) is the first derivative of Eq. (2):

$$3f^2 + \alpha{\cdot}u = 0 \tag{3}$$

In CT, the singularity set (i.e., two cusp shaped lines) on the control plane is the simultaneous solution of Eqs. (2) and (3):

$$4{\cdot}\alpha^3{\cdot}u^3 + 27\beta^2{\cdot}v^2 = 0 \tag{4}$$

According to Eq. (2), we graphed behavior surface f (cognition change) as shown in Fig. 2. (The program code is given in Appendix A).

Fig. 2 covers two parts: The upper portion is behavior surface f, where lines $A \to A'$ and $B \to B'$ show the possible paths of cognition change; the lower portion, the control plane, shows the changing

Please cite this article as: S. Lv, et al., Contusion and recovery of individual cognition based on catastrophe theory: A computational model, Neurocomputing (2016), http://dx.doi.org/10.1016/j.neucom.2016.05.099