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Editorial

Boolean Networks and Their Applications in Science and Engineering

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In recent decades, Boolean networks (BN) have emerged as an effective mathematical tool to model not only computational processes, but also several phenomena in science and engineering. For this reason, the development of the theory of such models has become a compelling need that has attracted the interest of many research groups in recent years. Dynamics of BN are traditionally associated with complexity, since they are composed of many elemental units whose behavior is relatively simple in comparison with the behavior of the entire system.

BN are a generalization of other relevant mathematical models, which appeared previously as cellular automata (CA), inspired by von Neumann and studied by Wolfram and others to explore the computational universe, or Kauffman networks (KN), proposed by Kauffman in 1969 for modeling gene regulatory networks. This gives an idea of the versatility of this new paradigm in applications to several branches of science (mathematics, physics chemistry, biology, ecology, etc.) and engineering (computing, artificial intelligence, electronics, circuits, etc.).

The aim of this special issue was to collect cutting-edge research on the different models of BN (deterministic and nondeterministic, synchronous and asynchronous, homogenous and non-homogenous, directed and undirected, regular and non-regular, etc.). Thus, several research groups in this field submitted their recent developments and future research directions concerning new models. In addition, original research articles showing some applications of BN in science and engineering were received.

Although fifteen manuscripts were submitted to the special issue, only nine of them were finally accepted for publication after the review process. These contributions are briefly described below.

In the paper "Predecessors Existence Problems and Gardens of Eden in Sequential Dynamical Systems", Aledo et al. deal with network models which are deterministic, asynchronously updated, homogeneous and defined over arbitrary (non-regular) undirected graphs, so extending the work on the synchronous case [1]. In particular, the local functions are restrictions of a global operator, given by a maxterm or minterm Boolean function; and the update order is a vertex indexed permutation. For these kinds of models, which are usually known as sequential dynamical systems (SDS) on maxterm and minterm Boolean functions, the authors solve the predecessor-existence problems algebraically. In addition, they give a characterization of the Garden-of-Eden configurations and provide the best upper bound for the number of such configurations.

The article "A Boolean network approach to estrogen transcriptional regulation" by Anda-Jáuregui et al. presents a dynamical model of gene regulation of the Estrogen receptor transcription network based on known regulatory interactions, to better understand the implications of deregulation of the Estrogen and Estrogen receptor regulatory networks. By using an adaptation to classical Boolean Networks dynamics,

the authors identify proliferative and anti-proliferative gene expression states of the network. They also identify key players that promote these altered states when perturbed. In addition, they model how pairwise gene alterations may contribute to shifts between these two proliferative states. Furthermore, they find that the coordinated subexpression of E2F1 and SMAD4 is the most important combination in terms of promoting proliferative states in the network.

The paper "Binomial representation of cryptographic binary sequences and its relation to cellular automata" by Cardel and Fuster-Sabater is devoted to studying some properties of binomial sequences. In particular, they show how any binary sequence whose terms are repeated periodically with period a power of two can be decomposed by some binomial sequences. Furthermore, the authors analyze other interesting properties, concerning their complexity and their relation with one-dimension CA following the rules 102 or 60. These CA can be seen as particular cases of deterministic synchronous BN whose dependency graph is a line graph, where the homogeneous evolution operator is given by the mentioned Boolean functions. Although there are some previous results relating Sierpinsky triangle and some linear CA, the interest and novelty of these results are due to the relations of these Boolean topics with binomial and binary sequences established in this paper, and their possible applications in cryptography.

In the paper "Effects of Anti-modularity and Multiscale Influence in Random Boolean Networks", Escobar et al., the authors extend work on modular BN [2] to measure novel aspects and define anti-modularity. Modular networks enhance the potential criticality of BN, while anti-modular BN turned out to be very similar to regular BN. Even when they have a peculiar structure given by anti-modularity, their dynamics resembles that of networks with random structure. A novel multi-scale model was also proposed, where the states of nodes at a higher scale are determined by lower scale BN and vice versa. Results showed that the statistical properties of the dynamics, such as complexity, are determined by the lower scale (upward causation), while the precise dynamics of the networks are determined by the higher scale (downward causation).

In the article "A Multilayer Structure Facilitates the Production of Antifragile Systems in Boolean Network Models" by Kim et al., the authors use Kim's model of multilayer BNs [3], where genetic dynamics are modeled at a lower layer and intercellular signaling at a higher layer, to show that the multilayer structure increases the probability of observing antifragile dynamics. That is, multilayer BN have the potential of benefiting from noise more than random BN. This suggests that a multilayer structure could be useful in different engineering systems.

In his work "Design of Fixed Points in Boolean Networks Using Feedback Vertex Sets and Model Reduction", Kobayashi provides methods for the design of fixed points in Boolean models of gene regulatory networks using model reduction and interaction graphs. His work includes an illustration of theory through a model for apoptosis, taken from Tournier and Chaves (2009) [4].

The article "Properties exploring and information mining in consumer community network: A case of Huawei Pollen Club" by Meng et al. is devoted to exploring properties and mining information in consumer community network. The consumer community network is constructed by Boolean retrieve programming and discussed in the methodology and empirical way based on the community data of Huawei P10/P10 Plus. The authors conclude that consumer community network is the important place that reflects product experiences and facilitates product innovation in future. Manufacturers can promote improvement and innovation of products by exploring effective information on the consumer community network, thus improving the experience level of consumers. On this basis, three strategies to improve information mining in consumer community networks are proposed.

In the paper "A Novel Antifragility Measure Based on Satisfaction and Its Application to Random and Biological Boolean Networks", Pineda et al. propose a general measure of antifragility. Antifragility occurs when a system benefits from perturbations [5]. Exploring random BN with this measure, the authors found that ordered dynamics are the most antifragile. Also, seven biological BNs exhibited antifragility.

The paper "Solutions to All-Colors Problem on Graph Cellular Automata" by Zhang and Chao provides solutions to the *All-Colors Problem*, which is a generalization of the *All-Ones Problem*. They proceed over some classes of graphs, dividing the study into two subproblems: *Strong-All-Colors Problem* and *Weak-All-Colors Problem*. In addition, they introduce a new kind of All-Color Problem, so called *k-Random Weak-All-Colors Problem*, which is interesting due to its applications to both combinatorial number theory and CA theory.

Conflicts of Interest

The editors declare that they have no conflicts of interest regarding the publication of this special issue.

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References

[1] J. A. Aledo, L. G. Diaz, S. Martinez, and J. C. Valverde, "Solution to the predecessors and gardens-of-eden problems for synchronous systems over directed graphs," *Applied Mathematics and Computation*, vol. 370, pp. 22–28, 2019.

[2] R. Poblanno-Balp and C. Gershenson, "Modular random Boolean networks," *Artificial Life*, vol. 17, no. 4, pp. 331–351, 2011.

[3] H. Kim and H. Sayama, "Robustness and evolvability of multilayer gene regulatory networks," in *Proceedings of the 2018 Conference on Artificial Life*, pp. 546-547, MIT Press, 2018.

[4] L. Tournier and M. Chaves, "Uncovering operational interactions in genetic networks using asynchronous Boolean dynamics," *Journal of Theoretical Biology*, vol. 260, no. 2, pp. 196–209, 2009.

[5] N. Taleb, *Antifragile: Things That Gain from Disorder*, Random House, New York, USA, 2012.