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PII: S0167-2789(16)30362-1
DOI: http://dx.doi.org/10.1016/j.physd.2017.05.002
Reference: PHYSD 31911

To appear in: *Physica D*

Received date : 15 July 2016
Revised date : 3 May 2017
Accepted date : 8 May 2017

The Influence of Canalization on the Robustness of Boolean Networks

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Abstract

Time- and state-discrete dynamical systems are frequently used to model molecular networks. This paper provides a collection of mathematical and computational tools for the study of robustness in Boolean network models. The focus is on networks governed by k-canalizing functions, a recently introduced class of Boolean functions that contains the well-studied class of nested canalizing functions. The variable activities and sensitivity of a function quantify the impact of input changes on the function output. This paper generalizes the latter concept to c-sensitivity and provides formulas for the activities and c-sensitivity of general k-canalizing functions as well as canalizing functions with more precisely defined structure. A popular measure for the robustness of a network, the Derrida value, can be expressed as a weighted sum of the c-sensitivities of the governing canalizing functions, and can also be calculated for a stochastic extension of Boolean networks. These findings provide a computationally efficient way to obtain Derrida values of Boolean networks, deterministic or stochastic, that does not involve simulation.

Keywords: k-canalizing function, Derrida value, Boolean network, nested canalizing function, stability

1. Introduction

The robustness of dynamic networks has long been an important topic of investigation in a wide range of contexts, using various definitions of the concept [1, 2]. Due to the important role of stochasticity in the dynamic behavior of biological networks, in particular gene regulatory networks, the concept of robustness has been studied extensively in this context [3]. Since the introduction of Boolean and logical network models to the study of the properties of gene regulatory networks [4, 5], time- and state-discrete dynamical systems have become an increasingly popular representation of molecular networks [6, 7, 8]. For the most part, these consist of Boolean networks and various generalizations thereof. Questions regarding the robustness of molecular networks, modeled in the time- and state-discrete dynamical systems framework, frequently involve the relationship between structural features of the network and its resulting dynamics. One commonly used measure of the robustness of such a network is the so-called Derrida value of the network, a measure of how perturbations propagate through the network [9]. This measure can then be related to network

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[1]Supported by NSF Grant CMMI-0908201 and US DoD Grant W911NF-14-1-0486