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REVIEW ARTICLE

The Damage Spreading Method in Monte Carlo Simulations: A Brief Overview and Applications to Confined Magnetic Materials

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Abstract. The Damage Spreading (DS) method allows the investigation of the effect caused by tiny perturbations, in the initial conditions of physical systems, on their final stationary or equilibrium states. The damage $(D(t))$ is determined during the dynamic evolution of a physical system and measures the time dependence of the difference between a reference (unperturbed) configuration and an initially perturbed one. In this paper we first give a brief overview of Monte Carlo simulation results obtained by applying the DS method. Different model systems under study often exhibit a transition between a state where the damage becomes healed (the frozen phase) and a regime where the damage spreads arriving at a finite (stationary) value (the damaged phase), when a control parameter is finely tuned. These kinds of transitions are actually true irreversible phase transitions themselves, and the issue of their universality class is also discussed. Subsequently, the attention is focused on the propagation of damage in magnetic systems placed in confined geometries. The influence of interfaces between magnetic domains of different orientation on the spreading of the perturbation is also discussed, showing that the presence of interfaces enhances the propagation of the damage. Furthermore, the critical transition between propagation and nonpropagation of the damage is discussed. In all cases, the determined critical exponents suggest that the DS transition does not belong to the universality class of Directed Percolation, unlike many other systems exhibiting irreversible phase transitions. This result reflects the dramatic influence of interfaces on the propagation of perturbations in magnetic systems.

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Contents

1 Introduction

One of the most interesting challenges in the theory of dynamic systems is the understanding of the dependence of the time evolution of physical observables on the initial conditions, because very often a small perturbation in the initial parameters could completely change their behavior [1]. Within this context, it is interesting to study the time evolution of such perturbations in order to investigate under which conditions a small initial perturbation may grow up indefinitely or, eventually, it may vanish and become healed.

In order to understand this behavior, Kauffman introduced the concept of Damage Spreading (DS) [2]. In order to implement the DS method in computational simulations [3, 4], two configurations or samples S and S', of a certain stochastic model, are allowed to evolve simultaneously. Initially, both samples differ only in the state of a small number of sites. Then, the difference between S and S' can be considered as a small initial perturbation or damage.

The time evolution of the perturbation can be followed by evaluating the total damage or "Hamming distance" defined as

$$D(t)=\frac{1}{N}\sum_i D_i(t)=\frac{1}{N}\sum_i 1-\delta_{S_i(t),S_i'(t)}, \tag{1.1}$$

where $D_i(t)$ is the damage of the site labeled with the index i at time t, $\delta_{S_i(t),S_i'(t)}$ is the delta function and the summations in Eq. (1.1) run over the total number of sites of the system N.

By starting from a vanishing small perturbation $D(t=0)\to 0$, one may expect at least two main scenarios, namely: a) $D(t\to\infty)\to 0$ and the perturbation is irrelevant because the damage heals; or b) $D(t\to\infty)$ assumes some non-zero value, and the damage spreads.