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Book Review: *Statistical Physics of Spin Glasses and Information Processing*

Statistical Physics of Spin Glasses and Information Processing. Hidetoshi Nishimori, Oxford Science Pubiications, Oxford University Press, 2001.

This book summarizes and extends a series of lectures given by the author at the Tokyo Institute of Technology and several other universities and, in fact, is a revised and translated edition of a book published in Japanese in 1999. Its object is to provide a unified formal basis for several multidisciplinary fields, exemplified by error-correcting codes, image restoration, neural networks, and optimization problems. It summarizes formalism based on the replica method, introduced first in the context of spin glass theory, as the underlying formal similarity between the disparate topics. It takes advantage of a formal link between information processing and a statistical mechanical analysis of strongly disordered systems, and spin glasses in particular. To a reader, such as myself, uninitiated in the recent developments in these fields this venture is bound to generate some interest. It is in deed a delight to see how Shannon's information theory, based on the notion of entropy, and subsequent developments based on his seminal work, can be united with the statistical mechanics of disordered systems through the universality of the replica method, amply and successfully applied to both fields. The book is not conceived as a comprehensive treatise for any of the subjects it deals with; it is mostly a compendium of the replica methods in different contexts and thus unavoidably a bit formal in its endeavors and terse in its style. Different topics in information processing problems are introduced at a very fast pace and are presented in a very condensed way. Each chapter also contains a bibliographical note that should direct the uninitiated reader to more introductory and comprehensive expositions of the different problems in information processing. Only chapters that dealt with subjects that I already knew something about were easy to follow and I could appreciate the connection between that part of the information processing and the theory and methodology of spin glasses. The book is written at a fairly advanced level and should be suitable for advanced graduate students and researchers

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working in related fields. It's style is however a bit too compressed to make for interesting reading for physicists working in other fields but interested in learning about the recent advances in information processing and its relation to the physics of disordered systems.

The book is broadly composed of two parts. Apart from the first chapter, which gives a short introduction to the mean-field theory of phase transitions, the first part of the book consists of four chapters, giving a very good introduction to the theory of spin glasses as well as the formal structure of the theory of disordered systems. The chapter on the mean-field theory of spin glasses sets the stage for spin glass theory by dealing with the Edwards–Anderson model, the Sherrington–Kirkpatrick model, the replica method and the replica symmetric solution. The chapter on replica symmetry breaking introduces the problem of the stability of the replica symmetric solution and consequent replica symmetry breaking. It introduces the full replica symmetry breaking solution and discusses its formal underpinnings, such as ultrametricity and its physical significance, and discusses the rich structure of the phase diagram that emerges from replica symmetry breaking. The first part of the book ends with a chapter on the gauge theory of spin glasses that introduces a different type of argument meant to asses the reliability of predictions of the mean-field theory of spin glasses for realistic conditions. The gauge theory of spin glasses places some strong constraints on the exact phase diagram of spin glasses in realistic finite dimensional systems. Because of its close relation to the Bayesian method frequently used in statistics and information processing problems it appropriately sets the stage for the second part of the book dealing with applications of the replica method in different contexts of information processing.

The second part of the book is dedicated to applications of the replica method in different information processing contexts. Most of the chapters in this part of the book (except the last one) first establish the relation of the problem to the replica method and then show how this connection can lead to fundamental and interesting insights regarding different facets of information processing itself. Each of the five chapters starts with a fast-paced introduction to the problem, with a bibliographical note for readers who might need a gentler introduction to the subject, and its reformulation in the language of the replica method. The first of these is a chapter on error-correcting codes, which addresses the problem of reconstructing a message transmitted through a noisy channel. The problem of decoding a noisy message is formulated through the application of the Bayes formula in a way that allows for a very illuminating application of the spin glass theory developed in the first part of the book. The following chapter deals with image restoration. This problem can also be formulated rather simply: given a noisy image how do we reconstruct the original? Again the Bayes formula provides a link to the spin glass theory and the replica method.

The preceding chapters are followed by one on associative memory. This is probably the chapter that many physicists will connect with. The seminal work of Hopfield, that eventually lead to intensive application of the spin glass theory and the replica method in this context, has been widely publicized in the general physics community. The presentation in the book is condensed but very informative and broad. To its credit, the book does not venture to make any sweeping generalizations about workings of the central nervous systems, a fashion all too readily followed by many workers in the field of information processing. The chapter on learning using the notion of perceptrons develops some aspects of associative memory theory further, dealing with the way a student perceptron may learn from a teacher perceptron in setting up its couplings to get the expected response. Again the Bayesian formulation leads the way to the formulation of the problem in terms of the replica method.

The last chapter deals with optimization problems. Among these are the number partitioning problem, the graph partitioning problem, the knapsack problem, the satisfyability problem and the simulated annealing method. The replica method does not provide such a clear underpinning of this chapter as in the other ones. The author basically shows how general methods of Gibbsian statistical mechanics can be useful in the context of optimization problems. A good outline and analysis is given to the simulated annealing method, a generic method for dealing with optimization problems.

The replica method obviously provides scaffolding and is the unifying principle behind most of the subject matter. This necessarily emphasizes a formal tone. Ideally, the reader should probably already know something about the phenomenology that it describes in formal terms. This is the only caveat I have with this book. Furthermore it is not intended to be an exhaustive treatise on all of its many subjects as readers unfamiliar with these subjects will have trouble following the formal arguments. The book should nevertheless be welcome reading for advanced specialists working in any of these fields. For a general reader it will certainly be worthwhile to see the unity in all these different subjects provided by the theory of disordered systems and to gauge the long road that the information processing has paved following the work of Shannon some fifty years ago.

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