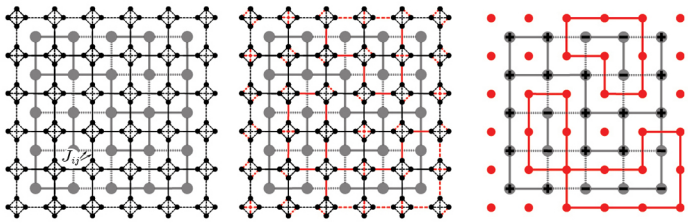
Spin Glass Theory and Far Beyond

Replica Symmetry Breaking After 40 Years



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This volume is dedicated to Miguel Virasoro, our dear friend, who has helped this field reach so far beyond what one could have expected.

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Preface

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About sixty years ago, the anomalous magnetic response of some magnetic alloys drew the attention of theoretical physicists. It soon became clear that their understanding would require to develop a new branch of statistical physics for disordered and strongly interacting systems. As physical materials, spin glasses were found to be as useless as they were exotic. They were nevertheless recognized as paradigmatic examples of *complex* systems.

Theoretical efforts to describe spin glasses took speed with the complete formulation of *replica symmetry breaking* by Giorgio Parisi in 1979 [1, 2] and the discovery of its physical content in the following years. The book *Spin glass theory and beyond* [3] (familiarly known as the *Beyond*), published in 1987, presented the concepts and consequences of replica symmetry breaking, as well as a first look at some applications that one could foresee at that time. Indeed, in the introduction to that book, the authors wrote "We are firmly convinced that the techniques developed for spin glasses: the replica theory, the TAP approach and the cavity method can be applied to a myriad of other problems that otherwise are difficult to handle". It turns out that the set of ideas and techniques that originated from spin glasses have since given rise to an intellectual *cornucopia* [4]; it has led to a huge number of applications to problems as diverse as neural networks, amorphous solids, biological molecules, social and economic interactions, information theory and constraint satisfaction problems.

In 2019, some of us co-organized a conference to celebrate the 40th anniversary of the complete formulation of replica symmetry breaking theory. Within this context, the idea emerged of inviting colleagues to participate in a collective effort at writing a new book, the *Far Beyond* that would give an idea of the development of the field after the release of the *Beyond*. Of course, the recognition of the importance of these ideas by the Nobel committee in 2021 gave further momentum to the project, and eventually led to its completion.

This book aims at presenting an overview of the broad scope of applications of spin glass theory. We tried to invite as many as possible of the researchers that have contributed to these applications over the last decades, and we asked them to present the connection between spin glasses and their own research field in a pedagogical way, having in mind a reader with a good scientific background (not necessarily in physics), but generally unfamiliar with the specific field. We have striven for an encyclopedic work, in which a reader can find a general description of the ideas, together with a set of references to a more technical and complete discussion. The reader who wants to follow the technical developments, or get deeper into one of the presented subjects, is invited to study first some of the available textbooks, e.g. [3, 5–8].

The book is organized into thematic chapters. Some chapters contain a single contribution, coauthored by a small set of colleagues. Other chapters contain several distinct (but related) contributions, each written by one or a few authors. In the latter case, we added a short introductory paragraph to describe the contributions and their articulation. In the spirit of an encyclopedia, each chapter can be read independently of the others, so the reader can pick those chapters that are closer to their interests.

A final chapter, written by Giorgio Parisi, describes his own perspective on the state and direction of the field.

We are grateful to all the hundred and one authors who accepted to embark on this challenging endeavor with us.

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