Preface

Social learning is a timely and highly relevant topic that addresses themes such as the study of opinion formation and propagation over networks, or how cooperating agents (e.g., humans, robots, or sensors) affect one another and make decisions based on decentralized observations.

Many complex cognitive systems are made up of individual agents whose activities are the result of sophisticated "social" interactions with other agents. Consider how people build their opinions about a particular phenomenon. The opinions form through repeated interactions with other people, whether in person or virtually (e.g., over a social network). A diffusion mechanism occurs, by which ideas, information, and even false news spread throughout the network. Nature provides many other examples of cooperative learning in the form of biological networks.

Social learning occurs in man-made systems as well, in the form of multi-agent decision-making procedures. One example is a robotic swarm deployed over a hazardous area for a rescue operation. Multi-agent decision-making can be critical in this scenario, as some robots operating in adverse conditions (e.g., with limited visibility or partial information) would only be able to complete their task by cooperating with other robots that have better access to critical information.

The primary focus of this text is on techniques for information diffusion and decision-making over graphs, as well as the examination of how agents' decisions evolve dynamically in response to interactions with neighbors and the environment. There are at least two reasons why research on social learning is important. On one hand, it provides for a more in-depth explanation of the fundamental cognitive mechanisms that enable opinion formation and the dissemination of knowledge (or disinformation) across graphs. On the other hand, the study of social learning is important for the design of reliable distributed decision-making strategies, which encounter applications in a range of settings involving highly dynamic environments, nonstationary data and uncertain models, untrustworthy or malicious agents, sparsely connected graphs, and restricted communication.

The text provides a unifying framework and a comprehensive presentation for understanding and developing social learning strategies. The treatment starts from the theory of optimal single-agent learning, to arrive gradually at the foundations of social learning by multiple agents connected through a graph, whose structure can induce interesting and diversified phenomena. For example, we will see how connected graphs enable agreement across the agents, whereas a "mind control" mechanism emerges over weakly connected graphs, where the network is split into influencers and influenced agents.

After a detailed illustration of the traditional techniques, the focus is shifted to recent advances and trends in social learning. For example, we will show that traditional strategies produce stubborn agents, which oppose new states of information and are reluctant to respond to changes in the environment. We then explain how to endow social networks with adaptation and learning capabilities to detect these drifting situations. We also present methodologies to deal with the sharing of incomplete or partial information, and we explain how to design social machine learning solutions where the agents rely exclusively on data.

The text relies on various powerful tools, such as stochastic convergence, large deviation analysis, martingales, and the Rademacher complexity. The necessary elements to understand and use these tools are collected in the appendices.

Acknowledgments

We are indebted to many Ph.D. students and post-doctoral associates for their contributions to social learning, as well as for their input at various stages of this project, either through feedback on earlier drafts or through conversations that deepened our understanding of the topics. In particular, we are grateful to (in alphabetical order): Marco Carpentiero, Michele Cirillo, Ping Hu, Mert Kayaalp, Malek Khammassi, Kostas Ntemos, Hawraa Salami, Augusto Santos, Valentina Shumovskaia, Stefan Vlaski, Bicheng Ying, and Xiaochuan Zhao.

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April 2025