

Preface

In past years, dynamic consensus has attracted intensive research attentions and led to successful solutions of a large variety of distributed computation problems, including distributed formation control, distributed Kalman filter, decentralized control of swarm statistics, and synchronization of networked oscillators. Despite its great success, consensus algorithm, which updates the state by dynamically mitigating differences among agents, is mostly limited to the modeling of dynamic cooperation. It essentially lacks a mechanism to model dynamic competition in a distributed network, which desires the increase of peer differences and the enhancement of contrasts.

Research in many fields confirms the same importance of competition as that of cooperation in the emergence of complex behaviors. For example, it is revealed that competition and cooperation plays significant roles in the decision making in market economy and that the strategy chosen by the rational politicians consists of cooperation over competition in dealing with international relationships. Recent research in neuroscience found finds that control actions depend on transitory change in patterns of cooperation and competition between brain systems during cognitive control. Due to the fundamental significance of competition in the interaction of multi-agent systems, various models have been presented to capture this competitive nature. Among them, the winner-take-all (WTA) model, which refers to the competition of a group of agents that the one with the largest input finally remains activated, while all the other agents are deactivated, has been widely investigated and usually employed to model competition behaviors. Maass proves that a two-layered network composed of weighted averaging in the first layer and WTA in the second layer is able to approximate any nonlinear mapping in any desired accuracy. Following this results, the dynamic consensus with the capability for the computation of weighted averaging in a distributed way, and a distributed algorithm for the computation of WTA, will be able to constitute any nonlinear mapping in a distributed network.

In the past two decades, recurrent neural networks have received considerable studies in many scientific and engineering fields. Particularly, after the invention of the well-known Hopfield neural network, which was originally designed for

real-time optimization, the recurrent neural network, as a powerful online optimization tool with potential parallel implementations, is becoming an independent research direction in online optimization field. Remarkable advances have been made in the area of recurrent neural networks for online optimization. To a constrained optimization problem, early works often remove the explicit constraints by introducing a penalty term into the cost function and then design a recurrent neural network evolving along the gradient descent direction. This type of neural networks only converges to an approximation of the optimal solution. In order to obtain a recurrent neural network with guaranteed convergence to the optimal solution, later works introduce dynamic Lagrange multipliers to regulate the constraints. There exist various mathematical models for the description of the WTA competition. By following optimization-based formulation, WTA problem can be modeled as a constrained convex quadratic programming (QP) problem, and then, traditionally, gradient descent or projected gradient descent is employed to get the corresponding dynamic equations for online solution of the problem.

In this book, focusing on solving competition-based problems, we design, propose, develop, analyze, model, and simulate various neural network models depicted in centralized and distributed manners. Specifically, we define four different classes of centralized models for investigating the resultant competition in a group of multiple agents. For distributed competition with limited communication among agents, we present the first distributed WTA protocol and then extend it to the distributed coordination control of multiple robots. As for these models, the related theoretical analyses are given, and the corresponding modeling is illustrated. Computer simulations with various illustrative examples are performed to substantiate the efficacy of the proposed recurrent neural network models for solving WTA problems. Based on these successful researches, we further apply such a distributed WTA approach to distributed coordination control of multiple redundant robot manipulators. The corresponding results show the application prospect of the presented competition-based neural network approach to robot applications.

The idea for this book on solving competition-based problems was conceived during the classroom teaching as well as the research discussion in the laboratory and at international scientific meetings. All of the materials of this book are derived from the authors' papers published in journals, such as *IEEE Transactions on Automatic Control*, *IEEE Transactions on Neural Networks and Learning Systems*, *IEEE Transactions on Systems, Man, and Cybernetics: Systems, Neural Networks*. In fact, since the early 1980s, the field of neural networks has undergone the phases of exponential growth, generating many new theoretical concepts and tools (including the authors' ones). At the same time, these theoretical results have been applied successfully to the solution of many practical problems. Our first priority is thus to cover each central topic in enough details to make the material clear and coherent; in other words, each part (and even each chapter) is written in a relatively self-contained manner.

This book is classified into the following 6 chapters.

Chapter 1—In this chapter, we investigate a simple discrete-time model, which produces the winner-take-all competition. The local stability and global stability

of the model are both proven theoretically. Simulations are conducted for both the static competition and the dynamic competition scenarios. The numerical results validate the theoretical results and demonstrate the effectiveness of the model in generating winner-take-all competition.

Chapter 2—In this chapter, different from the model presented in Chap. 1, we present a continuous-time dynamic model, which is described by an ordinary differential equation and is able to produce the winner-take-all competition by taking advantage of selective positive–negative feedback. The global convergence is proven analytically, and the convergence rate is also discussed. Simulations are conducted in the static competition and the dynamic competition scenarios. Both theoretical and numerical results validate the effectiveness of the dynamic equation in describing the nonlinear phenomena of winner-take-all competition.

Chapter 3—In this chapter, a class of recurrent neural networks to solve quadratic programming problems are presented and further extended to competition generation. Different from most existing recurrent neural networks for solving quadratic programming problems, the proposed neural network model converges in finite time and the activation function is not required to be a hard-limiting function for finite convergence time. The stability, finite-time convergence property, and the optimality of the proposed neural network for solving the original quadratic programming problem are proven in theory. Extensive simulations are performed to evaluate the performance of the neural network with different parameters. In addition, the proposed neural network is applied to solving the k -winner-take-all (k -WTA) problem. Both theoretical analysis and numerical simulations validate the effectiveness of our method for solving the k -WTA problem.

Chapter 4—In this chapter, we make steps in that direction and present a simple model, which produces the winner-take-all competition by taking advantage of selective positive–negative feedback through the interaction of neurons via p -norm. Compared to models presented in Chaps. 1–3, this model has an explicit explanation of the competition mechanism. The ultimate convergence behavior of this model is proven analytically. The convergence rate is also discussed. Simulations are conducted in the static competition and the dynamic competition scenarios. Both theoretical and numerical results validate the effectiveness of the dynamic equation in describing the nonlinear phenomena of winner-take-all competition.

Chapter 5—When it comes to distributed networks, Maass’s theorem poses great appeal for distributed WTA algorithms provided that the distributed weighted averaging could be addressed using consensus. Unfortunately, as presented in Chap. 1 through Chap. 4, there is no existing distributed WTA algorithm available, which significantly blocks the exhibition of the computational power of WTA over dynamic networks. In this chapter, we make progress along this direction and present the first distributed WTA protocol with guaranteed global convergence. The convergence to the WTA solution is proved rigorously using Lyapunov theory. The theoretical conclusions are supported by numerical validation.

Chapter 6—In this chapter, as an application of the competition-based models investigated in previous chapters, the problem of dynamic task allocation in a distributed network of redundant robot manipulators for path-tracking with limited

communications is investigated, where k fittest ones in a group of n redundant robot manipulators with $n > k$ are allocated to execute an object tracking task. The problem is essentially challenging in view of the interplay of manipulator kinematics and the dynamic competition for activation among manipulators. To handle such an intricate problem, a distributed coordination control law is developed for the dynamic task allocation among multiple redundant robot manipulators with limited communications and with the aid of a consensus filter. In addition, a theorem and its proof are presented for guaranteeing the convergence and stability of the proposed distributed control law. Finally, an illustrative example is provided and analyzed to substantiate the efficacy of the proposed control law.

In summary, this book presents models producing the WTA competition in centralized and distributed manners and further applies these models to distributed coordination control of multiple robot manipulators (showing its application prospect). This book is written for graduate students as well as academic and industrial researchers studying in the developing fields of neural dynamics, computer mathematics, time-varying computation, simulation and modeling, analog hardware, and robotics. It provides a comprehensive view of the combined research of these fields, in addition to its accomplishments, potentials, and perspectives. We do hope that this book will generate curiosity and also happiness to its readers for learning more in the fields and the research and that it will provide new challenges to seek new theoretical tools and practical applications.

At the end of this preface, it is worth pointing out that, in this book, a new and inspiring direction on the competition-based neural network as well as its applications is provided. This opens an avenue to study distributed competition over a connected network with any possible topology. It may promise to become a major inspiration for studies and researches in neural dynamics, robotics, and dynamic decision making. Without doubt, this book can be extended. Any comments or suggestions are welcome. The authors can be contacted via e-mails: shuaili@polyu.edu.hk and jinlong@lzu.edu.cn.

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