Book Review

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Adaptive Networks: Theory, Models and Applications. T. Gross and H. Sayama (Eds.). (2009, Springer Verlag.) £108, $159, 332 p., 162 illus., 15 in colour, hardcover. ISBN: 978-3-642-01283-9.

Over the past decade, networks have become an important paradigm for understanding natural and engineered systems. From cells and brains, through companies and computers, to ecosystems and power grids, it has emerged that almost everything either is, or is embedded in a complex network of interactions [3]. The popularity of network theory is easy to understand. By abstracting away much of the complicated morass of real world detail surrounding a complex system, a network representation brings into sharp relief the fundamental patterns of interaction between the system's key elements. Investigating the statistical properties of these networks has provided new insights into a diverse range of systems. As revealing as this approach has been, it is clear that real world networks are more than just static topologies. Networks in the real world change dynamically, in response to both external stimuli and internal processes, and it is upon this class of *adaptive* networks that the present volume focuses.

There are two different ways that a network can be dynamic: First, its nodes may be associated with state properties that change over time, such as the activity level of a gene, or the political affiliation of an individual. Second, its topology may change as nodes enter or leave the network and the pattern of interactions between nodes changes. There exist many models of systems in which each of these types of dynamic process occur independently. For example, random Boolean network models of gene expression, and preferential attachment models of network growth. However, in many real world systems both the state and the topology undergo dynamic changes. Furthermore, state and topology may change in ways that influence one another. For example, it has been observed that both peer selection and peer influence play a role in determining adolescent smoking behaviour [1]. The propensity of an individual to adopt a particular behaviour will be influenced by whether their neighbours exhibit that

behaviour. Thus network topology affects state. Simultaneously, the principle of homophily predicts that individuals will preferentially associate with those who exhibit similar behaviour to themselves. Thus state affects topology. Numerous models presented both in this volume and elsewhere suggest that adaptive networks can display topologies and behaviours that are more complex, and more similar to those observed in real world systems, than those of their non-adaptive counterparts.

Recognising that the concept of mutual feedback between a network's state and its topology has found independent expression in a range of research domains, Gross and Sayama have assembled a collection of contributions spanning mathematics, physics, computer science, biology and social science. Both empirical and theoretical studies are represented (with an emphasis on the latter), and the contributions include both previously published and novel research, as well as several more review-oriented chapters. The selection of material is comprehensive: topics that I expected to see covered in such a volume were well represented, plus I learned of new concepts and models that I had not previously encountered. Indeed, given the breadth of contributions, readers of *Artificial Life* with an interest in networks are likely to find something relevant to their own particular domain. The volume would also serve as a good introduction to, and overview of, research on adaptive networks for someone entering the field. That said, the contributions for the most part represent cutting-edge research: the volume does not aim to be a general introduction to networks as a whole, and the reader without some familiarity with basic concepts in network theory may find the going heavy.

Adaptive Networks contains fourteen invited contributions, plus an introductory chapter by the editors. While the research presented in many chapters has previously appeared in leading journals, I was pleased to see that the authors

of each contribution had taken the opportunity of republication to expand their papers with the inclusion of additional results and discussion. The volume is therefore more valuable than just a collection of reprints. In addition, several of the chapters serve as useful reviews of specific topics, such as Do and Gross's overview of opinion formation and epidemic models. While generally an impressive collection, a couple of minor flaws detract. Some of these are perhaps an unfortunate side effect of collected volumes, such as the lack of an index and global list of references, and a need for better proofreading in some chapters. Colour figures are present in some chapters; however, in other chapters the conversion of figures to grayscale detracts from the information they provide. Also, I would have liked to see a more adventurous synthesis of the insights presented in each chapter; perhaps a conclusion that built upon the brief outline presented in the introduction to summarise the current state of the field and outline the most important open challenges.

Turning to content, the contributions are divided into five sections; the first concerns empirical studies of real networks, and the remaining four sections, while empirically motivated, present studies of a more theoretical nature. The three empirical studies in the first section focus on scientific citation networks, telephone and email communication networks, and the transport networks embodied in mycelial fungi. These studies highlight the importance of novel approaches to interpreting temporal network data to better understand how their structure is both generated and maintained. The second section focuses on the capacity of adaptive networks to self-organise towards critical states. These theoretical studies make inroads towards eliciting a more general understanding of the types of behaviour of which adaptive networks are capable. The third section concerns contact processes, such as the spread of opinions or epidemics, on adaptive networks. The fourth covers the dynamics of various games

played on adaptive networks. The models described in these two sections extend methodologies (contact processes and evolutionary graph theory) that are well established when considered on static network structures, but raise new and interesting questions with adaptive topologies. The final section describes several graph-rewriting approaches to modelling adaptive networks based on concepts arising from computer science. These approaches build upon cellular automata and generative grammars to propose novel protocols for representing networks with dynamic state and topology.

In their introduction, the editors suggest that we are within reach of a unifying "theory of adaptive networks", and identify several common issues and themes touched on by the contributors to this volume. One unifying concern is the impact of timescale separation between the dynamic processes affecting network topology and those affecting the states of nodes. In the extreme, when the timescales on which these processes occur differ by enough orders of magnitude, there may be little interplay between them, and it may indeed be appropriate to consider each type of dynamic behaviour independently, as has traditionally been the approach. For example, each time network topology changes, system state will converge to a new dynamic attractor. In some circumstances, when there is mutual feedback between system state and the topological changes that occur, separation of timescales can also lead to self-organised criticality, resulting in the spontaneous emergence of complex network structures. This result suggests that mutual influence between state and topology may be a necessary factor to take into account when seeking to explain the topology of real world networks. As the separation of timescales between dynamic processes decreases, system behaviour becomes increasingly complex and difficult to analyse.

A second common theme is the emergence of differentiated roles in adaptive networks consisting of initially homogeneous individuals. This differentiation

may be functional (related to the state of a node) or structural (related to its topological position). An example of the former is the the coupled map models described in the chapter by Ito and Kaneko, nodes spontaneously separate into leaders and followers, which exert, respectively, strong and weak influences on their neighbouring nodes. An example of the latter mode of differentiation is provided in the chapter by Holme and Ghosal, which describes a model of the diplomat's dilemma in which a population of individuals attempt to simultaneous maximise centrality and minimise degree. Three topologically distinct classes of individual emerge, corresponding to those who have managed to achieve one or other of their aims, and the privileged few who manage to simultaneously achieve both.

Although not mentioned explicitly, a third theme that emerges throughout the volume is the extent to which adaptive networks exhibit readily observable *mesoscopic* dynamics. At a macroscopic, or population, level, adaptive networks often display stable aggregate properties (such as degree distribution or characteristic path length) despite continuing dynamism at the microscopic, or individual, level. Between these macro and micro levels, it is also possible to discern the presence of a meso level, consisting of entities known as groups, communities or modules. These groups of nodes may be distinguished functionally or topologically and undergo dynamic change at a rate slower than that of individual nodes, but faster than that of the population as a whole. An example of this is the social groups identified in the chapter by Palla and colleagues. The detected patterns of group affiliation change over time as new groups are formed, individuals join and leave existing groups, and old groups disappear. Groups have functional importance in a wide variety of social and biological systems. A diverse range of algorithms have been proposed for identifying community structure in static network topologies [2], and adaptive network models are a

promising avenue for better understanding the dynamic behaviour of groups.

Overall, *Adaptive Networks* is a solid collection that brings together diverse facets of an exciting and growing field with many opportunities for further research.

References

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