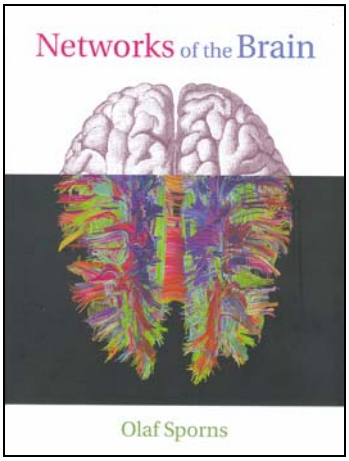


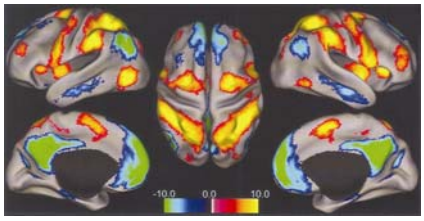
Networks of the Brain. Olaf Sporns. The MIT Press, 55 Hayward Street, Cambridge, MA 02142-1493, USA. 2011. xi + 412 pp. Price: £29.95.

Recent years have seen 'networks' emerge as a key theme in the scientific arena, propelled by runaway successes such as 'six degrees of freedom' in the realm of ideas, and Google or Facebook in the realm of technology and commerce. The academic thrust has come from several disparate disciplines. There has been the traditional activity in statistical physics concerned with percolation and allied models[1] with its focus on critical phenomena. A parallel activity in economics and sociology, motivated by networks of human agents or organizations, has focused on quantifying and measuring parameters related to 'influence' of individual agents, ease of information propagation, and more importantly, 'strategic' aspects related to decisions made by the agents forming the network[2,3]. The explosive growth of the internet, the World Wide Web and social networks such as Facebook has brought in engineers and applied mathematicians; the latter looking at generative models and gross properties of large random graphs[4], the former for the associated algorithms, such as search and ranking[5]. This flurry of activity has also highlighted a need for an overarching 'network science' that unifies and subsumes the different strands, and a considerable activity along these lines is already on[6]. Then there are the biological networks. These are not a single category, but several categories. For example, there are evolutionary networks[7]. And then there are the neural or 'brain' networks, the theme of the book under review. Any spiel about networks mentions without fail these networks in the same breath as socio-economic, physical and engineered networks. What is often left unsaid is that they are a different kettle of fish in terms of the difficulty of the exercise. This is because for one, the level of complexity is orders of magnitude higher. Also, any such study cannot separate itself from the empirical results, and these at present, while numerous, are still too inadequate to be conclusive. As it stands, the subject interlaces experiments with advanced signal processing techniques to glean what one can from the available experimental results, backed by computational models as a 'second front'. The book under review brings this out only too well.

Following an introductory chapter that serves as a prelude and overview along with some motivating issues that suggest the need for a network view, the author gives in chapter 2 an overview of basic terminology and concepts of networks. Beginning (as always) with Euler's Königsberg bridge problem, he introduces some essential graph theoretic notions, followed by the more sophisticated ones relevant for the present study. The latter include clustering and modularity that allow the network to be viewed as an interconnection of sub-networks, possibly with further such subdivisions leading to multiple 'scales'. Then there are global features such as degree distribution, average path length and so on, each reflecting some intuitive notion about how well connected the network is. Further, there are measures of significance for individual nodes, the so-called centrality measures, that identify which nodes are more critical according to a given criterion. There is also a brief discussion of popular categories of networks such as regular, random, small world and scale-free, along with some generative models such as preferential attachment. These notions are illustrated in the specific context of measured data for a certain region of a macaque cerebral cortex. The description throughout this chapter (and others for that matter) is purely verbal and eschews any equations or mathematical symbols, successfully hiding the non-trivial mathematics that lies underneath, a trait which will go a long way towards making this book non-intimidating for the mathematically unsophisticated readers.

Changing tracks in the next chapter, the author then describes the other side of the problem, that of biological measurements and data interpretation. He is careful to underscore the key issues of multiple spatio-temporal scales as well as the essential difference between structural and functional networks, reflecting respectively the actual physical connections and the causal relationships (one may think of a loose analogy with internet versus the World Wide Web). He describes both the experimental methodologies such as perturbative methods, as well as statistical techniques such as those based on temporal precedence and/or correlation. He is emphatic in particular about the fact that the massive complexity of the object under study belies the limitations of any purely analytic study and therefore the need for large-scale computational models and simulations. The next chapter continues in a similar vein, spelling out the attempts to localize brain functions right from phrenology on, and building it up to a network perspective, discussing *en passant* issues of variability, diversity, randomness, etc. that are an integral part of brain networks. Chapter 7 gives an additional perspective on experimental methods for mapping the 'wiring' of the brain, dubbed the brain's connectome, describing at length the single success story, that of *Caenorhabditis elegans*.

With chapter 6, the book returns to primarily network science issues, discussing attempts to identify motifs and modularity in brain networks and their apparent 'small world' structure. These studies raise the question regarding the evolutionary underpinnings of such structures: if they have emerged and stayed, there must be good reasons for evolution to prefer them. This question is deliberated at length in chapter 7. Brain networks are embedded in a physical medium, viz. a body. Thus a link in a structural network (a neuron, say) has physical attributes such as length that affect its functional role as they dictate



Anticorrelated task-positive and task-negative networks in the human brain.

signal propagation delays and so on. High connectivity means rapid communication, but it also entails longer links with concomitant energy and delay costs, lack of robustness, and so on. This favours a modular structure which is more robust and economical. It has been proposed that the preponderance of small-world networks is because they strike a balance between several competing requirements, such as cost of wiring versus communication delays (I cannot resist pointing out at this juncture the last chapter of a book by a major thinker of the last century, which presaged much of the current thinking on complex systems[8]). The author makes a convincing case based on such considerations for evolutionary roots of the observed attributes of brain networks.

Chapter 8 addresses a distinctive phenomenon: the spontaneous activity in a brain at rest. After reporting the experimental results on this theme, the author highlights the important observations such as the relationship between 'hubs' in the functional network associated with spontaneous activity and the underlying structural network, and also speculates on the cognitive role of this activity. The latter theme is developed further in the next chapter, which makes a case for cognition as an 'emergent' network phenomenon. It discusses the possible role of the modular hierarchical and recurrent structure, particularly the latter, in cognition, discussing at the same time issues such as dynamic reconfiguration of the functional networks and their variability. Chapter 10 discusses a special topic intimately connected with brain studies and whose understanding is of great value to humankind – brain diseases such as Alzheimer's, schizophrenia and autism. The chapter spells out possible network implications of these diseases. The following chapter discusses network growth and development in humans, describing both models and experimental results.

The last three chapters address the final frontiers in this line of work. Chapter 12 is devoted to the role of dynamics, underscoring the fact that the brain is a *dynamic* network and this aspect thereof is crucial to its functioning. Whereas the functional network picture would view the brain in terms of 'frozen' cause–effect relationships, a dynamic view expands the possibilities a lot more: a dynamic system allows one to think also in terms of a map from initial condition to equilibrium behaviour, or in the case of external inputs, from input *process* to equilibrium behaviour. Then there is the possible coupling of dynamical systems, sometimes across the same spatio-temporal scale, at other times across scales, leading to an array of critical phenomena, metastability, emergent behaviour and so on. This naturally leads to the broader theme of complexity, which is taken up in the next chapter. After describing various notions of complexity such as those that quantify the minimum effort needed to specify a structure on the one hand, to those that try to capture where in the spectrum ranging from deterministic regularity to statistical regularity the system is poised, it makes a case for studying the brain as a complex system, highlighting its evolutionary *raison d'etre*: to survive in and adapt to a complex and not fully predictable environment. It also makes a case for computational models to aid the intuition in this pursuit. The final chapter faces the ultimate issue: brain as it is situated in a body, which in turn is situated in its social environment. Here the author falls back on the studies in robotics, a field which confronts these issues with great immediacy, and draws parallels with brain networks.

The book, as the author himself says, is one long argument to make a case for a network view of the brain. He draws upon an amazing repertoire of experimental work, statistical analysis, computational models, etc. at times also borrowing from artificial intelligence and robotics. The scholarship that has gone into writing this book is impressive. It is a true bird's eye view of what's out there, squeezed between the covers of a single accessible book. The style is engaging, I particularly enjoyed the way he begins each chapter with a quotable quote from a scientist whose work is relevant to the theme of the chapter and takes it on from there, with a little bit of history at the beginning, and a status report along with some speculation for future at the end. The topic is truly interdisciplinary and that reflects in the style, which, as already mentioned, is sans excessive technical jargon of any kind that would turn away an interested non-specialist. The book is an open invitation to jump into the fray and take on any of the multitude of questions begging for an answer.

1. Grimmett, G., *Probability on Graphs*, Cambridge University Press, Cambridge, UK, 2010.
2. Easley, D. and Kleinberg, J., *Networks, Crowds and Markets*, Cambridge University Press, Cambridge, UK, 2010.
3. Jackson, M. O., *Social and Economic Networks*, Princeton University Press, Princeton, NJ, 2008.
4. Chung, F. and Lu, L., *Complex Graphs and Networks*, American Mathematical Society, Providence, RI, 2006.
5. Langville, A. N. and Meyer, C. D., *Google's PageRank and Beyond: The Science of Search Engine Rankings*, Princeton University Press, Princeton, NJ, 2006.
6. Newman, M. E. J., *Networks: An Introduction*, Oxford University Press, Oxford, UK, 2010.
7. Nowak, M. A., *Evolutionary Dynamics*, Harvard University Press, Cambridge, Massachusetts, 2008.
8. Simon, H., The *Sciences of the Artificial*, MIT Press, Cambridge, Massachusetts, 1996, 3rd edn.

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Annual Review of Physical Chemistry, 2010. Stephen R. Leone, Paul S. Cremer, Jay T. Groves, Mark A. Johnson and Geraldine Richmond (eds). Annual Reviews, 4139 El Camino Way, P.O. Box 10139, Palo Alto, California 94303-0139, USA. Vol. 61. xii + 499 pp. Price: US$ 84.

In the early days of our graduate studies in the physical chemistry department of the Indian Association for the Cultivation of Science, Calcutta, we were told by our mentors that the articles in the latest volumes of the *Annual Review of Physical Chemistry (ARPC)* presented the current status and direction of research in the subject. Since then, it became a craze for many of us to look forward to the arrival of the latest volume of *ARPC* in the library every year. When *Current Science* approached me to review the present volume with the offer that I can retain the book at the end of the job, I immediately agreed.