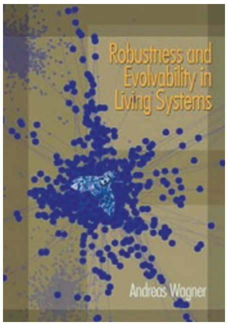
Robustness from top to bottom



Robustness and Evolvability in Living Systems

By Andreas Wagner

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Reviewed by Hiroaki Kitano

Robustness is one of the fundamental properties of living systems that is observed ubiquitously among different species and at different levels. In *Robustness and Evolvability in Living Systems*, Andreas Wagner attempts to provide a conceptual framework for understanding robustness in biological systems. The main thrust of his argument is that robustness against mutation can be explained by the existence of multiple solutions to a particular biological problem. Mutations can thus be selectively neutral. Wagner argues that "a neutral space is a collection of equivalent solutions to the same biological problems. It can also be thought of as a set of alternative configurations of a biological system, configurations that solve the same problem." This idea is developed to explain the robustness of living organisms at different levels. Chapter 1 discusses "robustness below the gene level" and describes how the neutral space concept can be applied to explain robustness against changes in DNA, RNA and amino acid sequences. Chapter 2 discusses "robustness above the gene level," providing examples from fly, sea urchin and worm developmental and metabolic networks. Chapter 3 reconciles examples in Chapters 1 and 2 into a unifying perspective of neutral space, as well as developing arguments on evolvability and robustness. Chapter 4 is about "robustness beyond organisms," extending the arguments to ecology and self-organization.

This book is interesting to read because it coherently describes robustness by using the concept of neutral space from the level of genetic sequence to organism and beyond. It is very insightful to present one concept throughout different levels of living systems, explaining seemingly isolated phenomena with a unifying view. The book is generally easy to read for anyone who has a basic knowledge of biology, especially population genetics. At the same time, you should not expect technical details of arguments, as it is intended solely to provide a conceptual framework for robustness. You will come away from this book with an overall perspective on robustness based on the neutral space concept, but for those wanting more, there are numerous references listed at the end of the book.

Although the book is interesting and insightful in many respects, there are significant drawbacks. The major problem is the book's narrow focus on robustness against mutation. Robustness against environmental perturbation is totally excluded from the discussion. This is unfortunate, as a number of interesting and important properties of biological systems that are widely recognized as robust are not included.

There are four basic mechanisms that enable a system to be robust against various perturbations: systems control, fail-safe by means of redundancy and diversity, modularity and decoupling, which isolates low-level perturbations from functional-level properties. For example, bacterial chemotaxis is one of the textbook examples of robustness against environmental perturbation in which perfect adaptation is maintained against various concentrations of ligand. Robustness of bacterial chemotaxis is achieved by negative feedback, which is a form of systems control. Negative feedback is one of the major means to enhance the robustness of the system against various perturbations and is central to any discussion of the engineering of the system. Unfortunately, bacterial chemotaxis is only briefly mentioned, and feedback control not at all. By the same token, modularity is not discussed in any depth.

The account of robustness and its trade-offs mainly focuses on redundancy of genes versus efficient coding that potentially fosters faster replications. Although this is certainly one of the trade-offs that exists, other kinds of trade-offs that may be more interesting and important are missing. For example, diseases such as type 2 diabetes are the results of trade-offs in which individuals have adapted to be robust against near-starvation, high–energy use and hostile, highly pathogenic environments but now have to cope with an abundant and high-energy food supply, coupled with a sedentary lifestyle. The current lifestyle is problematic because feedback control to cope with a sustainable oversupply of nutrients has not been well developed. This trade-off is due to a feedback control scheme acquired through evolution. In the field of engineering, Bode's integral formula clearly demonstrates the trade-off between robustness against noise and distortion attained by negative feedback, and fragility in terms of the risk of unwanted oscillations. Perhaps it is not fair to criticize the exclusion of this material, as the author himself clearly states that the focus of the book is on robustness against mutation. Nevertheless, it is important to point out that there are many other issues of robustness that are outside the scope of the book.

Such problems aside, the book is enjoyable to read and insightful. I am particularly pleased with Wagner's attempt to bring broad issues into perspective and provide a unifying view of these phenomena from genes to organs and beyond. ■

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