Biological Physics of the Developing Embryo

Gabor Forgacs and Stuart A. Newman
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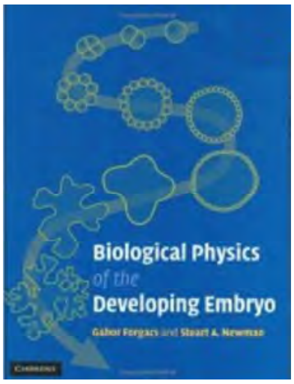

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In the quest to understand the mechanisms that underlie developmental processes, much attention has been focused on the contribution of the regulation of gene expression. While it is undeniable that genetics plays a central organisational role during development, the fact cannot be escaped that living systems are equally subject to the laws of physics as any physical system, as illustrated beautifully by D'Arcy Thompson in his classic work *On Growth and Form* (Thompson, 1917).

In some cases, "physical" considerations can be seen as predominantly providing general constraints on genetically specified mechanisms. For example, the limited diffusibility of morphogens in cellular tissues imposes an upper limit on the size of domain that can be patterned by a simple diffusion gradient established by a localised source (Crick, 1970). However, living systems constitute a rather special class of physical systems, due to the fact that they maintain themselves in highly organised states that are far from thermodynamic equilibrium. It has long been appreciated that physical systems far from equilibrium often posses spectacular capacities to generate complex spatiotemporal order from random conditions (Nicolis & Prigogine, 1977). Indeed, many non-living systems exhibit spontaneous patterning that is strikingly reminiscent of that seen in developing embryos (Turing, 1952; Ball, 2001). It is therefore essential when attempting to discover the fundamental logic of developmental processes to consider the extent and nature of the role played by physics.

There is no shortage of textbooks devoted to developmental biology, but it is remarkably rare to find any substantial treatment of physical considerations. In producing an excellent guide to the physics of developing embryos, Forgacs and Newman have therefore done the developmental biology community a great service. After a brief introduction to some relevant basic physical mechanisms — diffusion, osmosis and viscoelasticity — the reader is taken on a tour of key morphogenetic events such as the formation of compartments and lumens, gastrulation and neurulation, and mesenchymal condensation. In these events that are so important in shaping the embryo, the central role played by physical forces is particularly clear and a little physics goes a long way. The emphasis throughout is on the developmental processes, with physics being introduced as and when necessary.

An interesting feature of the book is the inclusion of a substantial amount of material on models of genetic/biochemical networks and pattern formation. Topics covered include models for oscillatory cell states, such as those involved in the cell cycle and somitogenesis, gradient formation, lateral inhibition, and cellular calcium waves following fertilisation. These models are posed in the mathematical formalism of dynamical systems, and a brief clear introduction is provided that allows some of the main points of interest to be described.

An appealing feature of both these chapters and those on morphogenesis is that the authors have chosen a selection of recent models that provide clear illustrations of physical effects, rather than opting for some of the more well developed “classic” models. Many of these models are currently being refined and elaborated, and so the descriptions provided here can be used by the interested reader as an entrée into the current research literature. This fact could prove invaluable if the book is to be used as a textbook for an advanced undergraduate or postgraduate course.

The book concludes with a chapter that explores the links between physical and genetic approaches to development, by considering developmental mechanisms in an evolutionary context. Recent theoretical studies of genetic networks are described that provide new quantitative insight into traditional evo-devo concepts such as canalization (Waddington, 1942). This material suggests an overall scheme of how the relative importance of physical and genetic factors can change during evolution. While these studies are quite preliminary, they provide an important broader perspective in which to consider the preceding material in the book.

Presenting models of complex biological systems to a mixed audience involves a delicate balancing act between accessibility and over-simplification. Thanks partly to excellent schematic illustrations, and in large part to the clarity of presentation, the book achieves this balance. Importantly, the authors avoid trivialising the biology and provide a very extensive and up to date bibliography (a particularly strong point for readers coming from a non-developmental biology background). Some equations are unavoidable, but the authors have taken care to ensure that the logical flow of the text can generally be followed by skimming over the equations. The mathematics required is fairly elementary, and its inclusion should not seriously discourage anybody from reading this book. Each chapter is fairly well self-contained, making it possible to dip into the book to explore particular areas of interest.

The lack of depth in the mathematics means that this is not a book from which to learn the practicalities of constructing quantitative models of development. But this is quite appropriate, as there are many excellent sources from which to learn the necessary mathematical techniques. As the authors state in their introduction: “What will be required of the scientist of tomorrow is the ability to speak the language of other disciplines. The present book attempts to help the reader to become at least bilingual.” Not only does this book have the potential to achieve that, but by highlighting the additional insight that can be gained into familiar developmental events by consideration of physics it also provides the necessary motivation to do so.

Ball, P. (2001). *The Self-Made Tapestry: Pattern Formation in Nature*. Oxford University Press.

Crick, F. (1970). Diffusion in embryogenesis. *Nature* **225**, 420–422.

Thompson, D'Arcy W. (1917). *On Growth and Form*. Cambridge University Press.

Nicolis, G. & Prigogine, I. (1977). *Self-Organization in Nonequilibrium Systems*. John Wiley & Sons.

Turing, A. (1952). The chemical basis of morphogenesis. *Phil. Trans. Roy. Soc. London B* **237**, 37–72.

Waddington, C.H. (1942). Canalization of development and the inheritance of acquired characters. *Nature* **150**, 563–565.

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