gap junctions, their possible involvement in development and differentiation has been a frequent target of experimentation and speculation. Some of the latest episodes in this long story are presented in the final group of papers. With the exception of the lead-off paper on developing vertebrate limb, the various studies support the developmental importance of junctional communication. Evidence for communication compartments is reviewed for quite divergent species and related to developmental boundaries. Modulation of junctional selectivity as a function of developmental stage in insects and its possible mediation by L-glutamate is especially intriguing and brings one story at least closer to an understanding of mechanisms. In regenerating hydra, junctional involvement is strongly suggested by the effects of antibody blockade of junctional transfer, a method of "perturbation analysis" that is likely to appear more commonly in future investigations.

In all, the book provides the specialist a useful summary of most of the current themes in the gap junction field. For the generalist, the thoughtful introductions to each section give appropriate perspective to the specific experiments and models, the resolved conflicts and unanswered questions. Throughout, the impact of new technologies and approaches is evident and the prospects for exciting future discoveries are tantalizing.

At an earlier meeting, Lewis Wolpert stressed the "need" for gap junctions to answer the problems of limb patterning. Although his paper in the current book arrives at a less sanguine outlook for establishing a critical role for gap junctions in his own system, he once again sets the stage for the future when he says, "But it is early days, and exciting times are still to come." The contributors to this book would certainly agree.

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Chaos in Living Systems

From Clocks to Chaos. The Rhythms of Life. LEON GLASS and MICHAEL C. MACKEY. Princeton University Press, Princeton, NJ, 1988. xviii, 248 pp., illus. $45; paper, $13.95.

During the past several years a number of excellent books have been published on chaos and nonlinear dynamics. In most, some mention is made of applications in the life sciences, but for the most part the development is in terms of physical applications. This is hardly surprising. Physicists and chemists are generally able to carry out their experiments under cleaner conditions than their biological counterparts, and they can often amass considerably larger quantities of data. Thus the most convincing experimental evidence for chaos comes from physical systems—fluid dynamics, lasers, and chemical reactions such as the Belousov-Zhabotinskii system. At the same time, it has been remarked (A. Mandell, personal communication) that it is in biology that nonlinear science may ultimately find its most important applications. For it is in living systems that one sees overwhelming evidence of the complex behaviors—both temporal and spatial—that are grist for the dynamicist's mill. Indeed, one might argue that it is dynamical complexity that operationally distinguishes animate from inanimate matter.

From Clocks to Chaos provides a much-needed introductioin to complex dynamics from a biological point of view. Its authors, Leon Glass and Michael Mackey, have been major contributors to the field of biological dynamics for more than a decade. This book gives us an opportunity to view the role of chaos in biology through the eyes of pioneers.

Here are some specifics: The book is divided into nine chapters, of which the first provides an overall introduction. Chapter 2 develops some of the underlying mathematics—differential equations exhibiting stable equilibria and limit cycles; stability concepts; and period-doubling to chaos in the logistic map. Chapter 3 introduces the important problem of distinguishing noise from chaos. The authors point out that successive iterates of some chaotic difference equations have exponential probability distributions. Hence the observation of such a distribution cannot by itself be taken as evidence for a Poisson process. Here and throughout the book, biological observations provide the motivation, in this case data for miniature end-plate potentials in neuromuscular junctions. A second example of the "noise *vs.* chaos" problem is provided by cell cycle studies. Here, the authors argue that observations traditionally explained by models involving random transitions can be fit just as easily by deterministic models that generate chaos. The chapter concludes with a discussion of techniques, among them Poincaré maps, Lyapunov numbers, and fractal dimensions, for diagnosing chaotic behavior, and the stretching and folding in state space that induces sensitive dependence on initial conditions.

Chapter 4 reviews some models of biological oscillations, including the Hodgkin-Huxley equations, pacemaker models that can generate irregular as well as regular dynamics, models of mutual inhibition and sequential disinhibition, and systems with feedback and time delays. Among the specific physiological systems discussed are ventilatory control function, the pupil-control system in the eye, white blood cell production, and recurrent inhibitory control in the hippocampus. Often it turns out that by varying a parameter in the model one observes a transition from regular to irregular behavior.

In chapter 5, the authors turn their attention to physiological rhythms and the ways in which such rhythms can be affected by external stimuli. Among the topics considered are "soft" *vs.* "hard" excitation and the annihilation of rhythmic behavior that may occur when a limit cycle coexists with an attracting point.

Chapters 6 and 7 continue the discussion of possible responses to perturbations. Both chapters begin with a review of experimental results. In chapter 6, the focus is single-pulse stimulation. Here the emphasis is on phase resetting. The authors distinguish between the two major types of this behavior, and there follows a discussion of the topological theories that have been advanced to account for the observations. Chapter 6 also includes a discussion of some of the difficulties entailed in using the topological theory to interpret data. In chapter 7, the focus shifts to periodic stimulation and the complex sequence of phase-locked and chaotic behaviors that can ensue when a nonlinear oscillator is subjected to varying degrees of periodic forcing. Among the experimental systems discussed is the periodically stimulated chick embryo heart cell preparation whose behavior has been analyzed in detail by Guevara, Glass, and their associates. This chapter also contains a review of apparent phase-locking in clinical situations: respiratory-locomotory coupling, ectopic cardiac pacemakers, and artificial ventilator-respiration coupling.

Chapter 8 takes up the matter of oscillations in space and includes some recent results on wave propagation in two and three dimensions. A major part of this chapter concerns cardiac fibrillation and its possible relation to rotating spiral waves. Finally, in chapter 9, the authors take up the idea of "dynamical diseases," by which they mean pathologies that result not from structural abnormalities *per se* but from abnormal temporal behavior. In cases such as chronic myelogenous leukemia, they suggest that understanding the dynamics in the absence of intervention may be crucial for efficacious treatment. The book concludes with a mathematical appendix, including problem sets, and an extensive bibliography.

As the foregoing summary should evidence, *From Clocks to Chaos* is an ambitious attempt to explore the application of an exciting branch of modern mathematics to real biological problems. Not all of the issues raised are resolved with anything approaching finality, and, indeed, a cynic might argue that none of them are. But it is clear that Glass and Mackey, together with their fellow theoretical biologists of the 1970s and '80s, have forever changed the ground rules for discussion of some measurable fraction of biological problems. In this reviewer's not unbiased opinion, that fraction is sure to grow in the coming decades as biologists concentrate more and more on comprehending how the machinery of life is set in motion and the circumstances that maintain it thus.

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Evolutionary Mechanisms

Mutation, Developmental Selection, and Plant Evolution. EDWARD J. KLEKOWSKI, JR. Columbia University Press, New York, 1988. xiv, 373 pp., illus. $55.

Plants (and some animals) lack a segregated germ line, yet often contain hundreds of thousands of meristems and live hundreds of years. Such conspicuous features of plant growth raise several questions: how often do somatic mutations arise? what effects do they have on somatic and reproductive tissues? does selection operate within or among meristems? what mechanisms might allow the usually deleterious effects of such mutations to be minimized? These questions are too important to have been overlooked, but this book is the first systematically to explore the causes, control, and implications of somatic mutation at all levels of biological organization. With this goal, the author leads the reader through a seemingly unlikely combination of topics, ranging from RNA retroviruses, supernumerary B chromosomes, and inverted repeats in chloroplast DNA to the fates of mutant cells within stratified meristems and mutant genes within populations. Such breadth is anomalous for one author in this age of specialization and represents a special strength of the book, as well as occasionally a weakness.

The book begins with reviews of the nature and organization of genetic information and the mechanisms and rates of mutation. Though some of this information is only tangentially relevant to the arguments presented later, these sections provide an accessible overview of modern molecular genetics as well as expose our ignorance of basic quantities like mutation rates per cell cycle in long-lived perennials. To discuss the fates of somatic mutations Klekowski next describes the structural organization and patterns of cell division in various types of plant meristems. Thorough reviews of the relevant morphological literature are combined with simple mathematical models to predict the probability that cells with or without a handicap will be retained and the likely spatial patterns of the resulting chimeras. These form the foundation for intriguing speculation regarding the likelihood that selection occurs among cells within a meristem or among meristems within a branched individual. The potential for such selection to occur depends, of course, on how somatic mutations are expressed (or hidden), the subject of the next chapter. The reader is again made aware of an absence of empirical data, this time on the extent of genetically based phenotypic variance among branches or ramets within a genet.

Do plants have an extraordinary ability to tolerate somatic mutations? By virtue of their relatively simple development and their fixed cell walls and consequent cell immobility, plants resist many of the conspicuous developmental effects of mutations that plague animals, such as teratomas and metastatic cancers. In addition, they seem to have evolved a number of contrivances (including diploidy itself) to minimize the somatic expression of deleterious mutations, described in a chapter entitled "Mutation buffering." For example, plants might reserve particular meristems (short shoots, for example) or parts of meristems ("méristème d'attente") with reduced mitotic activity for reproduction, resembling the segregated germ line in higher animals. Even this trick, however, cannot protect meristems against ultimately accumulating errors in protein synthesis, causing aging analogous to that of bacteria in a chemostat. Furthermore, the short-term solution of shielding mutations by diploidy or cross-feeding of meristem cells only postpones the day of reckoning, transforming the problem to one of accumulated individual and population mutational load. (That solving problems created by mutations on one level often causes problems at a higher level of biological organization is a recurring theme.) The extent of this load in ferns, gymnosperms, and several flowering plants and its evolutionary conse-