What makes them tick?

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From Clocks to Chaos: The Rhythms of Life. By Leon Glass and Michael C. Mackey. Princeton University Press: 1988. Pp. 248. Hbk \$45; pbk \$13.95.

ONE OF the striking features of living systems is their cyclic nature, the processes from birth to death repeating through generations, annual cycles in populations or in growth of an individual, and through monthly and circadian rhythms. On a shorter timescale there are the periodicities of experimental physiology such as the repetitive discharge of neurons, the heart beat and the slower rhythms of breathing. In spite of the pervasiveness of periodicity biologists still look for steady states — periodic processes are replaced by their mean rates, and the failure to find steady population densities is blamed on the vagaries of the weather.

Such naive belief in equilibrium behaviour follows from the practical necessity of usually being able to record only one variable: if a single variable is evolving with time, it must approach some equilibrium value. Although only a single variable may be recorded, however, the processes determining the behaviour often depend on several of them. With the ubiquitous non-linearities of living systems two variables are enough to allow periodicity, and so it is not at all surprising that many biological processes are periodic.

From Clocks to Chaos is the first textbook of general physiology to start with this obvious premise, and to deal with examples using the mathematical methods of nonlinear dynamics. This approach could be a problem for readers from the physiological and clinical sciences, whose training is often deficient in mathematics, but the book is well planned, the mathematics being introduced gently and in contexts that will be familiar to these readers. It also includes an excellent mathematical appendix for those who abandoned mathematics at high school, together with carefully chosen problems that have been field-tested on medical undergraduates.

The authors work at a medical school and share the bizarre humour of medical students; for instance the example given for hard excitation (where a stable equilibrium and a stable periodic state co-exist, as just below a sub-critical Hopf bifurcation) is the sudden onset of bursting activity in pelvic floor musculature following orgasm. Other more

conventional examples come from all areas of membrane, cellular and systems physiology, and the generation, maintenance and responses to perturbation of oscillations are illustrated.

Part of the reluctance of experimental and clinical physiologists to accept the methodologies of nonlinear dynamics is that biological oscillations are not periodic: there is some irregularity, and so

an empirical classification into types A, B or C (or whatever) is easier and more sensible than talking about strictly periodic limit cycles. This irregularity can be produced by stochastic processes, which are described by probabilistic, non-deterministic equations, or can in fact result from deterministic nonlinear dynamics as chaos.

It is well known that stochastic processes, or noise, occur in physiology: examples include the time sequence of miniature end-plate potentials or of the intervals between nerve impulses. This subject has not generated great excitement and has been left to mathematically orientated biophysicists. However, ever since the appearance of Robert May's review article in 1976 (*Nature* 261, 459–467) there has been an enthusiastic, almost evangelical search for chaotic behaviour in biological systems and investigation of its possible significance. Attitudes to the subject range from those who believe that chaos is of little importance to those who think that chaotic dynamics is the driving force for evolution, adaptive behaviour

and even consciousness. The drift from analysis to speculation mirrors the increase in entropy illustrated by the statistical physicist's ditty that takes us from Shakespeare to Sinatra, via Sartre:

To be or not to be,

To be is to do

To do is to be

Doobie Doobie Doobie Doo;

from a detailed analysis of period doubling bifurcation sequences in one-dimensional return maps one soon ends up seeing period doublings and chaos everywhere.

Glass and Mackey do not follow this fuzzy-minded approach, but instead present a solid, methodical account of the dynamical behaviour of biological systems: chaos is an important but small

part of the behaviour. Their notion of a *dynamical disease*, where pathology is associated with abnormal dynamics, is not a superficial link between chaotic dynamics and pathophysiology; in some systems chaos appears to be normal, and periodicity pathological.

Although there are well-developed quantitative tests for identifying chaotic behaviour which have been applied to a variety of biological problems, they are sophisticated and not readily accessible to biological readers. The section in the book which deals with distinguishing noise from chaos is invaluable in allowing biologists to read, and assess, the chaotic literature on biological chaos. Spatial, as well as temporal, periodicities are considered.

Here an important clinical area of interest is the role of circulating spiral waves in two dimensions, as a mechanism in ventricular fibrillation. Because experimental measurements of spiral and scroll waves are only just beginning, some of the problems raised may be answered in the next decade.

So far I have considered the viewpoint of biologists, who have a real need for the methods expounded in this volume. It will also be invaluable to those applied mathematicians whose interests sometimes veer into physiology, as it provides a survey of problems in physiology in a language that they will readily appreciate. When *From Clocks to Chaos* is read by applied mathematicians, physiological research will benefit; when it becomes widely used in medical physiology courses, the shape of medicine will radically change from its present emphasis on structure and local mechanism to a more global appreciation of behaviour in an interacting, complicated dynamical system. □

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