INTRODUCTION

It is widely recognized that the birth of modern science dates to the moment when Galileo first timed physical processes taking place in space. In biology, it is only recently that scientists have felt the need for experimental and mathematical methods describing the development of living organisms in terms of dynamic processes. When we analyze the development of self-replicators, we see that they develop their characteristic patterns and self-similarity through processes that resemble a set of oscillators, operating on different time scales. The periodic behavior of these large scale processes and the relations between them both depend on information processing and on local activity. The end result is the steadily increasing complexity we observe in all biological development processes. Physiological rhythms are essential to the life of the organism. Some are maintained for its whole life and even a brief interruption signifies death. Others only operate for short periods of time - some under the control of the organism, some not. Rhythms interact with each other and with the external environment. In most cases, abnormal and new rhythms are associated with serious pathology. To understand the typical rhythms of living organisms, we have to integrate mathematics and physiology. One important approach is non-linear dynamics. Non-linear dynamics allow us to study biological observables as a func-
tion of time. Time series for physiological variables show four distinct classes of
dynamic behavior: steady state, oscillations, chaos and noise. These are the same
behaviors we observe in 2-D CAs, as described in previous chapters. “Steady state”
is a way of describing homeostasis - the tendency of biological organisms to maintain
the stability of their internal environment (for example, in terms of the presence of
specific molecules). It also refers to a solution for an equation that is a constant. More
technically, homeostasis is the ability of a system or living organism to adjust its
internal environment to maintain a stable equilibrium, thanks to regulatory processes
that come into operation when external conditions change. The investigation of the
processes that maintain physiological variables within a narrow range of values is
a lively area of physiological research. Many physiological phenomena - such as
the beating and electrical activity of the heart - are approximately periodic. Other
cyclical behaviors - such as breathing, sleep, the menstrual cycle - are equally
familiar. Less well-known oscillatory behaviors include insulin release, release of
male and female sex hormones, peristaltic waves in the intestine, and the electrical
activity of the cortex and the autonomous nervous system. Each of these physiologi-
cal oscillations is associated with a periodic solution to a mathematical equation.
Of course, the phenomena we observe in physiology are highly variable; we never
observe a perfect steady state or a perfectly regular oscillation. Even in systems
we class as stationary or periodic, there are always fluctuations around the stable
value or the regular cycle. There are also systems whose behavior is so irregular
as to escape classification. For instance, blood pressure tends to be maintained at
a constant value, but is nonetheless subject to fluctuations, reflecting the activity
and emotional state of the organism. What is more, some physiological rhythms
influence (and are influenced by) other rhythms. In arrhythmia, for instance, heart
beat accelerates during inhalation. This is a relatively simple phenomenon. When
we measure the electrical activity of the brain with an electroencephalogram, the
situation becomes more complex. The instrument measures mean electrical activity
in localized areas of the cortex and shows how this activity fluctuates over time. In
many cases the fluctuations are fairly irregular. Understanding this irregularity is a
difficult task. Mathematics has two distinct methods for studying irregularities in
physiological rhythms. The first is to consider them as noise - the result of random
processes such as the opening and closing of ion channels in neurons or in heart
cells. The second is to apply the concept of chaos - an explanation for apparently
random fluctuations in deterministic systems. We can observe chaos even in the
absence of noise from the environment. Associated concepts include sensitivity to
initial conditions and perturbations, strange attractors, multiple routes to chaos and
the fractal boundaries of basins of attraction (for a review see Bilotta et al., 2007).
Attempts to describe physiological rhythms in mathematical terms have led to the
development of several models, including those incorporated in modern cardiac
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