Preface

During the past one hundred years the dominance of a particular scientific discipline has been related to its new analytic methods: field equations in physics (1900-1960), information theory in signal analysis (1960-), molecular chemistry in biology (1980-) and now neurodynamics in neuroscience (1990-). Physicists have always thought that the most incomprehensible thing about the universe is that it is comprehensible. It is simply accepted that mathematical comprehension and worldly physics go hand-in-hand. With the new analytic methods, however, some physicists are today actually studying the conscious process itself. In contrast, others are developing concrete mathematical models that behave in the same way biological tissues or organisms do (Bazhenov et al. 1998). It is these new analytic tools that the modern physicists and neuroscientists are together playing with that constitute the subject matter of this series of manuscripts.

Before we go into the individual chapters though, we note a simple truism, everything that moves also oscillates. That is, some kind of feedback or foldback is necessary to keep the dynamics in bounds, else the motion would move the object off to infinity. This limitation on the motion can be achieved either with simple linear feedback or with the more complex nonlinear variety. The type may turn out to be very important, for reasons that we do not yet appreciate or comprehend. Until we get to this point of understanding about nonlinear dynamics in physics and biology, we can still muse over the concept and develop methods to study it, as is done in the chapters below. These new results may ultimately lead to a breakthrough in our understanding of the nonlinear oscillatory processes that appear to exist in the brain and what their roles are in conscious perception.

Before us in this series of chapters is the task of explaining the meaning of a brain oscillation. There are not only local microscopic components to the data, but more global macroscopic ones as well, and all of these must be integrated by logical synthesis in much the same way Wittgenstein (1950) achieved in his "Remarks on Colour". Perhaps an example is appropriate to lay out this integrative approach, and to do this we chose an old Japanese toy, the drinking bird.

The bird illustrated in Fig. 1 will manifest an oscillatory process because there are moments in which the amount of fluid in the head exceeds a threshold level and the bird tilts and drinks. Its motion is caused by two simple forces, gravity and heat. What makes this toy so interesting is that we can obtain the oscillatory movement with only a few external sources of energy, a simple fluid carrier, and a single nonequilibrium condition (unstable state that provides switching between two or more metastable states).

The experimental data we might collect on the bird will soon lead us to the conclusion that the frequency of the oscillatory drinking behavior is dependent on environmental humidity and temperature (i.e., the weather). The variables appear to be independent of one another and linear, a result which suggests Boyles laws are at work. The Lorenz equations, however, are also about a weather system, but they involve 3 inter-dependent variables whose reduced degrees of freedom make the system fractional in dimension and therefore nonlinear. So which is it for the bird, linear or nonlinear?

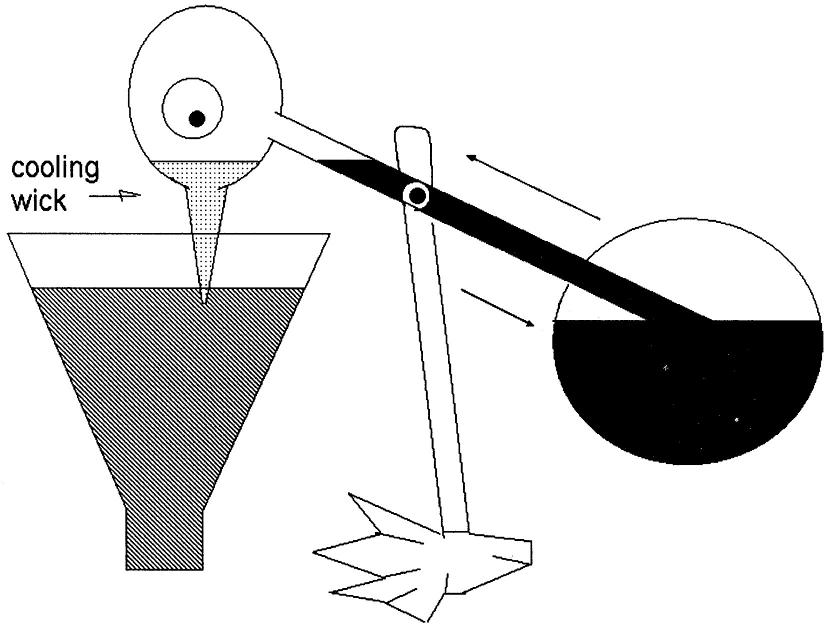

Fig. 1. Drinking bird as an oscillatory system (adapted after Gamow, 1961). Fluid in the tail is sucked up into the head when the gaseous volume is reduced in size by evaporative cooling. Once a threshold is passed the head falls over into the water to re-soak the evaporative cooling wicks. During the horizontal drinking, the gaseous volumes in the head and tail equilibrate, the fluid again makes the tail heavier, and the system resets.

For some variations in humidity and temperature, the bird may appear to be governed by a linear oscillatory process. If the system is examined to its fullest extent, however, and the dynamics cover all possible locations in the variable-space, then it will become quite apparent that the birds drinking behavior is not linear. Why? Because the actual weather is not described by a linear process (e.g., the ideal gas laws), but rather by a nonlinear or chaotic system, one with an extreme sensitivity to initial conditions. The lesson here is that although the system is simple and its behavior may appear to be linear, its total behavior can be quite complex, especially under certain circumstances or regimes.

The bird metaphor holds for the firing behavior of a neuron in the brain. At first glance there appear to be synaptic potentials produced by a variety of ionic channels that when summed go above a critical threshold to cause an action potential followed by a reset. But are the neurons really this simple and linear? Neurons, unlike toy birds, do not ever work in isolation. They are interconnected to other neurons, usually in a massively parallel manner. To investigate the connectivity, a lot of neuronal firings will have to be recorded at the same time, and this is hard to do. If one therefore looks for an ensemble recording of many neuronal synaptic potentials and their firings, then the field potential recorded from the extracellular space can be shown from first principles to be just such a composite measure.

Although examination of this ensemble field potential is like looking at the ripples on the top of a barrel of fish, something important may be in this global data. Although one cannot tell what any particular fish is doing (i.e., microscopic data), if the fish go through sleep-wake cycles together or for some other reason become cooperative with one another (macroscopic data), then it is easy to tell when they are in one of their various interconnected modes. This interconnectivity adds yet another element of complexity to the local data and appears to create large scale nonstationarities.

Besides the hidden nonlinear oscillations and the global nonstationary features of the local microscopic data, there is a third important attribute of neurons there are malleable use-dependent changes in both the cable properties (e.g., dendritic spines) and synaptic gains (e.g., long-term potentiation or depression). These use-dependent changes continuously change the thresholds in the system and may be nonstationarities in the system. The question is, are these global and local changes nonlinearities (i.e., expected, but initial-condition-dependent, aspects of the system) or are they nonstationarities (i.e., generated by a different system). At this moment in the development of neurodynamics we cannot tell whether an abrupt change is a rare nonlinearity or an adventitious nonstationarity. Only when we completely understand the system will we know.

Some neural networks contain all of these newly discovered features of neurons (i.e., nonlinear oscillations, parallel connectivities, global and local nonstationarities). Simulation studies invariably show that no single interneuron contains all of the information (i.e., as may an input or output neuron) and none of them is essential to the learning that takes place as the network adapts to its stimulus environment. For example, the backpropagation model has the massive parallel connections, an error term that is fed back to modify globally all synaptic efficacies (and thresholds), and a nonlinear sigmoid function to modify the feedback dynamics. This network can learn over tutored trials to give at its output, say, the sine of an input number.

Two interesting results are noted in these simulations. Removal of any one interneuron (hidden unit) does not produce much of an affect on the result evoked by an input number. Furthermore any one of the interconnected interneurons is capable of participating in the system. These two features commonly seen in the hidden units are also observed in real tissues. They are called mass action and equipotentiality, respectively, in the real interneurons. In conclusion, mathematicians are finding phenomena in the simple nonlinear models (i.e., learned perceptual behaviors) that are associated with epiphenomena (mass action, equipotentiality) also found in the real biological tissues.

How the backpropagation model achieves the correct answer is not easy to fathom. Each interneuron carries a little piece of the correct answer and all interneurons interact by having a global affect on the synaptic gains of all others. How does the system sort all of this out? How does it decide what interneouron will have what sized piece of the right answer? How does the same neuron contribute to the correct answer for all inputs? The simple way to answer this set of complex questions is to say that the system self-organizes. This is sort of like saying a group of musicians learns how to play music together (self-organizes) by being interconnected either by their own hearing, as in a small ensemble, or by a conductor, as in a larger orchestra. Self-organization may be another of the epiphenomena that accompanies a modern neural network.

One of course must also mention the precursors to discovery and invention. The cortical gamma-activity that is the focus for the study of cognitive and conscious processes, and a major theme of this series of manuscripts,

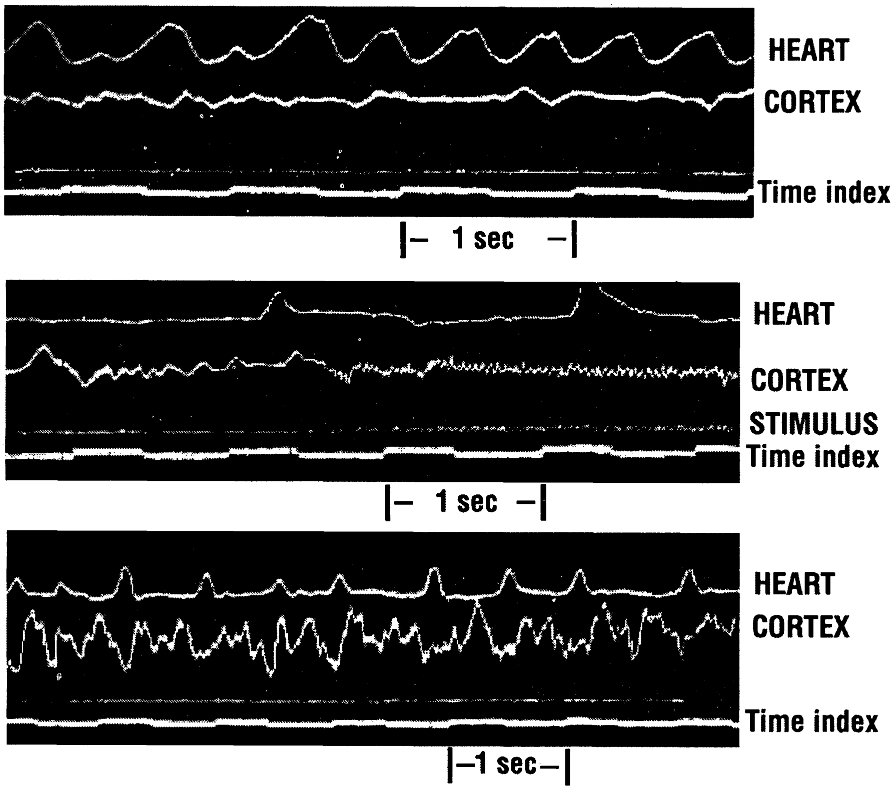

Fig. 2. Cortical activity from a dog's brain. No stimulus applied (upper), electric stimulus applied (middle), and epileptic activity induced (lower). About 5 s of the EEG is shown. Adapted after (Cybulski and Jelenska-Macieszyna, 1914).

was clearly observed in the brain waves when it was first recorded, as shown in Fig. 2. By just looking at the data, however, one could not readily figure out how Wittgensteins synthesis might proceed. A lot had to be learned about electrical generators in the brain. It had to be discovered that the nonlinearity in the error feedback is what made the backpropagation model work better than its predecessors. The time was not ripe for understanding the significance of the gamma-activity until its importance in perception began to be demonstrated. And finally, it was not until the PC came along to make the laborious calculations that the nonlinear dynamics of a real neural system could be analyzed or the iterative events in a neural network calculated. As we shall soon see in the chapters that follow, the dynamical tools are now at hand to apply to the gamma-activities that appear to underlie perception and the conscious state. We are at the dawn of a new era in which physics and psychology are converging to investigate the same biological events.

We are very grateful to Editors of Acta Neurobiologiae Experimentalis and to their Editor-in-Chief, Dr. Andrzej Wrobel, for the invitation to collect the series of articles covering such an interesting topic as the (nonlinear) neurodynamics of the conscious state.

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