

sionate infanticide of children with irremediable or serious disabilities or, even worse, the killing of violent individuals because of their danger to society. He also disparaged molecular biology, the nature and potential of which he did not really understand. And he suffered from the common affliction of eminent scientists late in their careers in believing that science had now come to an end.

Sexton, a barrister-at-law, has painted a convincing portrait of Burnet and is to be congratulated on his generally accurate exposition of the scientific issues. Personally, I would like to have seen a greater emphasis on the descriptions and

implications of self-tolerance and clonal selection at the expense of detailing Burnet's more trivial encounters with royalty. Nevertheless, the book brings alive the nature of the scientific quest and shows the excitement that a man of Burnet's genius can bring to the evolution of broad ideas, as well as how these ideas can spark off whole generations of scientists. Would that we could all have such an impact. □

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Electric fishnets

Max Westby

Neural Nets in Electric Fish. By Walter F. Heiligenberg. MIT Press: 1991. Pp. 179. \$50.50, £33.75.

FIRST a word of warning that may come as a disappointment to the artificial-intelligence community and a relief to others. This book has *nothing* to do with neural nets. No hidden layers or back-propagation here, this is strictly neural circuitry. The title is misleading given current usage and has already led to the inappropriate inclusion of this book in a series of strictly computational neuroscience publications.

It is 15 years since the publication of Heiligenberg's last monograph on electric fish, and a great

deal of research has subsequently been carried out on these fascinating animals. His latest book is even more narrowly focused on the highly esoteric piece of behaviour known as jamming avoidance, and deals nearly exclusively with one genus, *Eigenmannia*.

Several species of fish use their electrical sensitivity not only to detect distortions of self-generated weak electric fields for object detection and navigation, but also to detect other electric fish in electrocommunication. These two functions can come into conflict — the jamming avoidance response has evolved to overcome this. The response was first described in high-frequency-wave-type species by A. Watanabe and K. Takeda in 1963. They showed that individual fish will shift the frequency of their normally invariant quasi-sinusoidal, roughly 500-hertz discharge away from that of another fish (or a signal generator) discharging within a few hertz of their own frequency. They hypothesized that this

behaviour enabled the fish to avoid interference by maintaining a private channel for electrolocation.

Ten years later, Heiligenberg came on the scene with an engineering approach in which he used Fourier analysis to measure the gain and phase of electrolocating fish tracking swinging objects in the presence of jamming electric fields. Only then did it become possible to move beyond the supposition that jamming stimuli caused a deterioration in tracking performance and to characterize exactly the nature of the response. This

comparisons) at the two ears, although our acuity is an order of magnitude worse than that of *Eigenmannia*.

Perhaps the classic case of a widespread principle in neuroscience for which electric fish are an extremely good model is the principle of 'efference copy'. This principle is used extensively in the mammalian central nervous system, particularly in motor control. Here, a comparison of the intended behaviour (motor command) with actual results, through sensory feedback, is a crucial component of sensorimotor learning such as skilled reaching, grasping and locomotion.

Similarly, African mormyrid electric fish use a copy of their efferent discharge command signal to elaborately gate the electrosensory input. In this way, the fish can sort out its own self-induced electrical input from that generated by its neighbours. Unfortunately, this phenomenon is not covered in Heiligenberg's book because *Eigenmannia* does not use it. Indeed, it is the fact that this fish does not use efference copy that makes the study of its jamming avoidance response so challenging. To avoid jamming, the fish must be capable of determining both the magnitude and the sign of the difference between the

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Charge card: Yuppie Alex's conclusions concerning the neuroethology of the electric eel.

rigorous approach, coupled with elegant and innovative experimental techniques, is the hallmark of his work. As it developed, unsuspecting biologists soon had no choice but to grapple with such concepts as trajectories in the amplitude-phase plane.

In this book, Heiligenberg basically tells the history of his prolific research output over the past 20 years. He is at pains to justify the narrow focus of the book, but succeeds in doing so. The phase-comparison system of *Eigenmannia* can resolve time differences of one microsecond, a remarkable feat for any nervous system, given the amount of jitter inherent in neural transmission, and a problem of general importance for other sensory systems, especially hearing, where high temporal acuity is vital for the recognition of species-specific sounds, including the distinctive features of human speech. The spatial localization of sound sources also requires time-difference measurements (among other

frequency of its own and its neighbour's discharge. The goal of the research is thus to understand the neuronal mechanism behind the response. The second half of the book is devoted to this topic and is riveting reading.

Heiligenberg takes one through this research as though it were a detective story, introducing one with enthusiasm to the battery of behavioural, electrophysiological and anatomical techniques that have allowed the almost complete description of the neuronal basis of a species-typical behaviour. This experimental work will be remembered as a classic of modern neuroethology along with that on the discrimination by toads between predators and prey, and the book is an elegant example of the power of the neuroethological approach at its very best. □

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