about physiological mechanisms and dismiss their investigators as "watchmakers" and where neuroethologists, taking comfort in their "hard" data, tend to dismiss their sociobiological colleagues as philosophers. This is a book that should be read by advanced undergraduates and graduate students in neuroethology and biobehavioral science programs. I can also recommend it for anyone who has ever wondered, upon hearing crickets or katydids sing on a hot summer's night, how or why they do it. My main reservation about the book is actually a hope that the publisher will read this and bring it out as an affordable paperback.

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The Mathematics of Infection

Infectious Diseases of Humans. Dynamics and Control. ROY M. ANDERSON and ROBERT M. MAY. Oxford University Press, New York, 1991. viii, 757 pp., illus. $115.

Even as we near the end of a triumphant century for science, infectious diseases remain a threat to humans everywhere. Many such diseases have had a long association with humans and are thoroughly understood in biomedical terms, with effective vaccines at hand; some, like AIDS, are of relatively recent experience. Studies of infectious disease fall loosely into three categories: laboratory, field, and mathematical. Communication between these areas is improving but remains generally poor. Laboratory work focuses on the machinery of the parasite, with the golden prize being a vaccine or some other effective prophylactic. Fieldwork is an often urgent blend of epidemiological study and health-care delivery. Mathematical work ranges from the study of simple, general models to detailed statistical analysis of particular data sets. For those afflicted by disease (and there are millions, predominantly children, every year) the overriding concern is an integration of existing knowledge that allows effective use of scarce resources in the field. On the other hand, planners with longer time horizons can anticipate the development of new knowledge as well as improvements in infrastructure and political support.

What does mathematical work contribute to the ultimate objective of eliminating, or controlling, infectious disease? The answer depends on the distance between the mathematics and the facts. For most infectious diseases of humans, the facts consist of serial observations, what are called event-histories, recording the health of individuals in populations at risk. These event-histories are detailed, microlevel data, and they vary greatly in quality and completeness between diseases and countries. Closest to the data are statistical analyses that deal with the exploration of causal linkages (via probabilistic models) and with forecasting at different levels of aggregation (from community to country). At a greater remove are large-scale simulation models that attempt to mimic, in essential (but computationally tractable) detail, the course of an infectious disease over time in a population. Farthest from the facts are simple, "strategic" mathematical models, often inspired by theoretical population ecology and genetics, that attempt to elucidate the basic dynamic processes that determine the pattern of disease in space and time. Such strategic models are the subject expounded by Roy Anderson and Robert May in this large and important book.

The central goals of the mathematics that Anderson and May describe are qualitative insights of two kinds. First, if a common dynamic underlies all infectious disease processes, such processes can usefully be analyzed with a common set of qualitative and quantitative concepts and tools. They will also share qualitative static and dynamic properties. Second, any particular infectious disease is distinguished by a wealth of special biological, ecological, sociological, and other characteristics. As a way of coping sensibly with such detail, the mathematical modeler seeks to identify those features that are truly significant in determining the statics and dynamics of the particular disease.

The core of this book effectively synthesizes the burgeoning mathematical literature in a way that focuses on the basic insights obtainable from the theory. The book focuses on deterministic models; stochastic models are mentioned only occasionally. The authors make a pedagogically useful, if biologically loose, distinction between macroparasites (most flukes and worms) and microparasites (everything else). In this book, macroparasites are those for which it is important to keep track of individual parasite loads and infected individuals must be treated as a heterogeneous group. The first half-dozen chapters on microparasites bring together the work of many people in the last two decades; key concepts are identified (such as basic reproductive rate, thresholds, and herd immunity), many otherwise tedious formulas are compactly derived, and the important consequences of the key mathematical ideas are crisply explained. A valuable effort is made to illustrate the mathematical conclusions by reference to the specific details of particular infectious diseases. A later set of chapters does the same job for macroparasites. This material is likely to become the standard reference for mathematical modelers in this field, and should also be most useful to people entering the field and as a textbook in courses.

Standing somewhat apart from this core is approximately a third of the book, dealing with sexually transmitted diseases, various aspects of heterogeneity, and features peculiar to developing countries. There is an interesting discussion of sexually transmitted diseases, including AIDS, focusing on the need for certain kinds of data and on the special modeling strategies that appear fruitful. This work is still in its early stages; however, modeling has had an important early role in the scientific discourse surrounding AIDS.

The material on genetic and spatial heterogeneity and on developing countries makes a start on some important issues, but is not as well developed. This is a reflection of the literature, which has largely focused on the simplest genetic, spatial, and demographic assumptions. Many assumptions that underlie the models in this book are most appropriate to developed countries. For many diseases, especially childhood diseases, the pattern of prevalence is very different in developed and developing countries. Several diseases that are no longer a concern in developed countries have become serious problems in developing countries. The book makes a start, but a very sketchy one, at identifying critical assumptions that may need to be modified.

Another aspect of infectious disease in developing countries that is not addressed here is the widespread occurrence of multiple disease in the same individual. It is very likely that there is a strong historicity to the health status of children who are exposed to multiple parasitic infections. Data analysis and even simple probabilistic modeling are very difficult in such cases. These problems pose an important challenge for mathematical modelers.

The authors repeatedly stress the importance of keeping the theory in close touch with the facts, and they have pulled together an impressive amount of data that illustrate the value of their mathematical models. This is an important contribution, the beginning of a critical evaluation of the successes and failures of mathematical models as tools for qualitative understanding and as policy inputs. Nevertheless, any reader will be struck by the absence of a systematic methodology for model estimation and testing. This is a long-standing problem in mathematical biology and a weakness in this kind of theory: many parameters are difficult to define operationally and even more difficult to estimate.

One reason for this is that dynamic mod-

els such as are used in this book are "coarse-grained": they apply in some averaged sense to a population of intrinsically heterogeneous individuals. One of the central challenges in the field, I believe, is to connect the fine-grained data from individual event-histories to the coarse-grained world of dynamic models. Epidemiologists and demographers have begun work on this problem, starting at the data end of things, but their work is not discussed or referenced in this book. The poor connection between data and models is particularly noticeable in studies of disease in developing countries. Data for developing countries are often available only for small regions and short time spans; careful analysis of epidemiological and demographic information is essential in order to make useful assumptions about heterogeneity, contact patterns, age dependence of transmission, and the like. This book, with its notable emphasis on data, should help draw much-needed attention to these matters.

The book briefly mentions a new trend in simple mathematical models, in which strong nonlinear effects are hypothesized to drive the time course of disease over a chaotic trajectory. Chaotic dynamic models, at this point, are much further removed from the data than are the models in this book. Existing methods for the study of observed chaos require time series of observations that are impossibly long by any sensible epidemiological standard. From a practical standpoint it is difficult to be other than skeptical about the utility of models in this field that involve chaotic dynamics.

The most important transition for mathematical modeling in applied science is from studying itself to making an effective attack upon the practical problems that inspired it. This book shows that mathematical epidemiology has surely begun that transition. On this and many other counts, readers can be grateful to Anderson and May for their talent and industry in writing this book.

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