BOOKS: COMPUTERS AND BIOLOGY

Get A Life

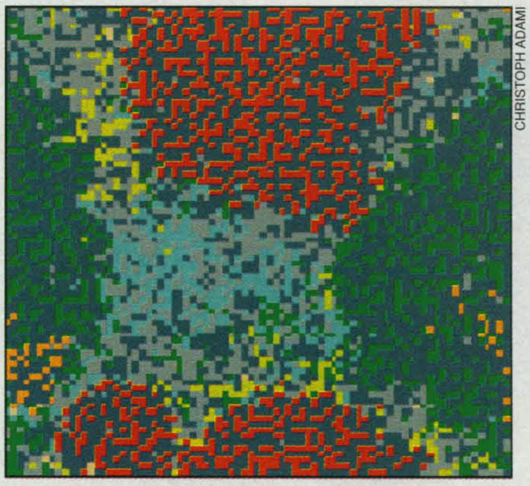
Richard E. Lenski

Introduction to Artificial Life. CHRISTOPH ADAMI. Telos (Springer), New York, 1998. xviii, 374 pp., + CD-ROM disc. $59.95. ISBN 0-387-94646-2.

Many people have heard about the fascinating experiments of Tom Ray, who devised an artificial world inside computers. There, programs self-replicate, mutate at random, compete for CPU time, and thus evolve by natural selection to become faster and more efficient replicators. Without deliberate programming, some complex phenomena emerge, including parasites that rely on host programs to be copied. But most biologists, I suspect, view such artificial creatures as amusing curiosities—not genuine life—unworthy of serious research. Christoph Adami aims to challenge this nucleic-acido-centric view of life.

Adami, whose training is in physics, begins by considering definitions of life. Not surprisingly, he favors definitions based on genetic processes (self-replication and mutation) and physical states (persistent low entropy), rather than physiology and biochemistry. He then describes hypothetical forms of artificial life (Turing machines and von Neumann automata) before turning to the genuine artificial life of self-replicating programs that dwell in computer memory. Several different "chemistries" (codes) have been devised for such life. One of these is "amoeba" (developed by A. N. Pargellis), which allows the spontaneous origin of artificial life—the emergence of self-replicating programs from random combinations of instructions. By contrast, Ray's "tierra" must be seeded with a progenitor made by God (the programmer), which already encodes self-replication (and which took longer than a day, or even a week, to create).

Several chapters then relate a range of physical and mathematical concepts—from statistical mechanics to fractal landscapes—to living and evolving systems, natural and artificial. Adami's explanations of these concepts are often enlightening, but it seemed to me that their use is mostly descriptive. They might not yield any new understanding of the mechanisms, or even the dynamics, of these systems. In some instances, he has rediscovered basic evolutionary theory and cast it in terms of physics instead of biology. For example, Fisher's fundamental theorem explains why a population experiencing rapid adaptation must transiently harbor substantial variation in fitness among individuals. Adami describes this relationship in terms of phase transitions triggering a transient increase in energy. More speculatively, Adami suggests that the quasi-equilibrium state between transitions reflects self-organized criticality; the cumulative effect of numerous small events (mutations) produces a hypersensitive condition in which one more event may then unleash a sudden avalanche of change. While this scenario is plausible, I suspect that the pattern of stasis and change in experiments with artificial life may instead simply reflect the dynamics of exponential growth integrated over many essentially independent events of varying size.



CHRISTOPH ADAMI

Evolution in a two-dimensional computer world. Populations of genotypically identical "creatures" labeld by color. The most fit (red) are expanding over all others.

The final chapters address further experiments with artificial life, specifically using a program called "avida" developed by Adami and his student Charles Ofria at Caltech. Among other topics, these experiments examine the process of speciation (that is, whether hybrid programs are functional) and the coevolution of genome size with mutation rate. Like tierra, avida has a complex instruction set, so it too must begin with a self-replicating progenitor. Also, both programs—like nature itself—select on the basis of phenotype rather than genotype. The "organisms" do not evolve to match some predetermined genetic sequence. Rather, they succeed by replicating quickly and efficiently, using whatever sequences they discover that allow them to do so. There are also important differences between avida and tierra. First, avidians live in a lattice where they interact only with neighbors. This structure slows, but does not stop, the spread of beneficial genotypes, thereby encouraging diversity and allowing wider exploration of the fitness landscape. Second, avida allows one to reward organisms for performing tasks (computational and logical) beyond mere replication. Thus, programs of some considerable size and complexity can evolve instead of ever smaller and faster replicators. Third, avida is intended specifically for research. By editing input files one can vary such parameters as the reward system and mutation rate; one can perform replicate experiments using random numbers; and one can produce outputs including the trajectory for average genome size and even the pedigree of every creature that existed during a run. One can also extract an individual creature to examine its program or inject it into another run.

In short, the book is an interesting and worthwhile contribution of a physicist who is intrigued by the special features of living and evolving systems. But what makes this book remarkable is the intellectual approach that the author advocates for research and, in fact, provides as software. The book includes a CD-ROM containing avida—in effect, a laboratory for studying artificial life. The program was easily installed on my Pentium 120 MHz machine with Windows 95 operating system; I did not even need to consult my teenage son. (It can also be used on UNIX platforms, but not on Macintosh.) A single run of 50,000 updates (but far fewer generations, since organisms live for many updates), with a population size of 3600 and an initial genome of length 31 (expanding to an average length of 103), required 12 hours. I was struck by the simple fact that the bacteria in my own research are parallel processors, so that in this same period of time, and in one tiny flask, a million organisms, each having a genome of 5×10^6 base pairs, can replicate themselves many times over. By contrast, a "time slicing" algorithm in avida simulates parallel processing of the competing programs although the processor performs the operations serially. Even with artificial life, one must carefully plan experiments in order

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to vary parameters systematically and obtain independent replicates within a reasonable time frame.

Some users may feel a bit constrained by what cannot be done with avida. The software precludes sexual recombination of programs, and does not allow rewards to vary in space (which would provide opportunities for the evolution of stable communities composed of many programs, each filling a distinct niche). Of course, avida itself may evolve as features are added to subsequent versions. Updates and related information can be obtained from a web page (http://www.krl.caltech.edu/avida). Other users may object to the simplicity of tasks that are rewarded, limitations in the instruction set, and so forth. Still others may reasonably ask whether results can be extended to real organisms. In extrapolating from the genetics of bacteria to animals, Jacques Monod is said to have quipped that "What is true for *E. coli* is also true for elephants, only more so." Is what is true for avidians also true for real organisms, or is it less so? It will be interesting to see.

EVOLUTION

Knowledge from the Flies

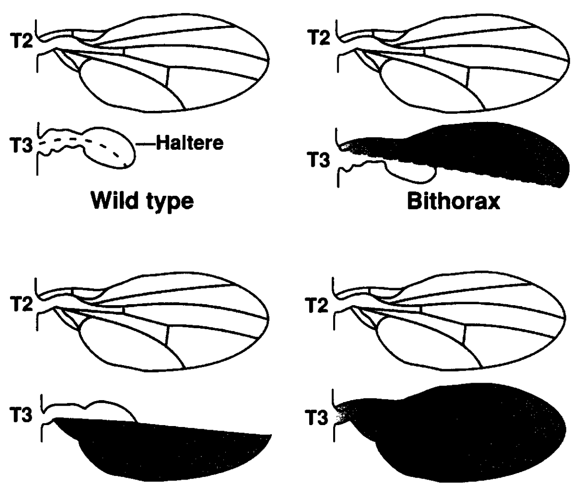
Walter F. Eanes

Progress and Prospects in Evolutionary Biology: The *Drosophila* Model. JEFFREY R. POWELL. Oxford University Press, New York, 1997. xiv, 562 pp., illus. $70. ISBN 0-19-507-691-5.

As one of several so-called biological models, the fruit fly genus *Drosophila* has contributed to more fields than any other group. Nowhere is this more evident than in evolutionary biology, where many contemporary principles and hypotheses have their origin in *Drosophila* studies dating back to the 1920s. In no other group of organisms can evolutionary questions be attacked with such precision and sophistication. For these reasons, *Drosophila* population geneticists are a particularly self-critical lot.They tend to emphasize how much we do not know, and to forget just how much we have discovered. Jeffrey Powell's book, *Progress and Prospects in Evolutionary Biology: The* Drosophila *Model*, corrects these oversights. It is a succinct review of the contributions these wonderful organisms have made to many themes in evolutionary biology.

Powell's mentor Theodosius Dobzhansky, along with Chetverikov, Morgan, Sturtevant, and Muller, introduced *Drosophila* into the study of evolution over seven decades ago. The sheer volume of references that have appeared in the last decade alone make it clear that evolutionary studies in *Drosophila* continue to expand, furthered by the gains *Drosophila* enjoys as a model in other fields including molecular biology, developmental biology, neurobiology, and behavior.

Powell devotes the initial chapters to a historical and philosophical overview of genetic variation in natural populations, the topic to which *Drosophila* has contributed the most in evolutionary biology. He discusses the levels of variation that have been traditionally examined: visible mutations, lethals, allozymes and polygenic variation. Subsequent chapters detail such topics as chromosomal inversions, speciation, ecological genetics, phylogenetics, genome evolution, molecular evolution, and development. Although this is a book on evolution, the chapter on ecology is a useful addition. It emphasizes just how much more ecological work is needed to better understand evolution in this genus. The informative chapter on speciation outlines the complex data from and arguments surrounding the large body of genetic work that has emerged quite recently, and it is nice to have all of this in one place. Powell acknowledges that the chapter on development, mainly a review of the contribution of *Drosophila* to studies of development, was the most difficult to write. Despite the enormous contribution *Drosophila* has made to developmental biology, extending these discoveries into an evolutionary context within the genus has so far proved rather unsatisfactory.



Two sets of wings. In wild-type *Drosophila*, the second (T2) and third (T3) thoracic segments in adults have a wing and a haltere. Flies with two mutations (in the *bithorax* and *postbithorax* genes) have four wings, the evolutionarily primitive state in flying insects.

JEFFREY POWELL

The final chapter returns to issues raised in the introduction and summarizes just how far we have come and where efforts should now be directed. Most of the quest to characterize genetic variation in population genetics has been technology driven. Powell is right in stating that, with the development of large-scale DNA sequencing methods, the goal of characterizing genetic variation has been taken to the limit. As he says, the discipline must now turn away from simply describing pattern, direct its efforts toward understanding processes, and once again become experimentally oriented. Furthermore, efforts to understand the historical impact of natural selection can only be considered in the context of changing population size, as in models now emerging in population genetics.

Although evolutionary studies have focused on a large number of *Drosophila* species, I am pleased to see everyone's favorite lab organism, *Drosophila melanogaster*, finally getting top billing. According to folklore, Dobzhansky maligned this species as a "garbage can species," and 25 years ago only a handful of population geneticists focused on it. Nevertheless, the new understanding of its ancestral structure in Africa and the discovery of endemic island relatives have moved this species to the forefront of many studies of the genetics of speciation. This is very important because the explosive development of this species as a model in cell and developmental biology significantly facilitates understanding the genes that generate the differences between species.

Powell emphasizes his own favorite issues, subjects of his reviews in recent years, and occasionally takes the opportunity to rebut studies that conflict with his own work. This is the author's license. The impact of Dobzhansky's work in his former

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