CHAPTER

19 Epilogue: The Unity of Physics

We emphasize that the methods we have discussed can be applied to a wide variety of natural phenomena and contexts.

19.1 ■ THE UNITY OF PHYSICS

Although we have discussed many topics and applications, we have covered only a small fraction of the possible computer simulations and models of natural phenomena. However, we know that the same algorithms can be applied to many kinds of phenomena. For example, the Monte Carlo methods that we applied to the simulation of classical liquids and to the analysis of quantum mechanical wave functions have been applied to the transport of neutrons and problems in chemical kinetics. Similar Monte Carlo methods are being used to analyze problems in quark confinement. Indeed, the increasing role of the computer in research is strengthening the interconnections of the various subfields of physics and the relation of physics to other disciplines.

We have also emphasized that the computer has helped us think of natural phenomena in new ways that complement traditional methods. For example, consider a predator-prey model of the dynamics of fish (minnows) and sharks. Assume that the birth rate of the fish is independent of the number of sharks, and that each shark kills a number of fish proportional to their number. If we assume that $F(t)$, the number of fish at time t, changes continuously, we can write

$$\frac{dF(t)}{dt} = [b_1 - d_1 S(t)]F(t), \tag{19.1}$$

where $S(t)$ is the number of sharks at time t, and b_1 and d_1 are parameters independent of F and S. To obtain an equation for the rate of change of the number of sharks, we assume that the number of offspring produced by each shark is proportional to the number of fish eaten by the shark. If we also assume that the death rate of the sharks is constant, we can write

$$\frac{dS(t)}{dt} = [b_2 F(t) - d_2]S(t). \tag{19.2}$$

Equations (19.1) and (19.2) are known as the *Lotka–Volterra* equations. They can be analyzed by standard methods and solved numerically using simple algorithms. Why is the dynamical behavior of (19.1) and (19.2) cyclic?

In the Lotka–Volterra model, the numbers of predator and prey are assumed to change continuously and their spatial distribution is ignored. We now summarize an

alternative model that can be simply expressed as a computer algorithm. The model is a two-dimensional cellular automaton known as *Wa-Tor*.

1. Fish and sharks are placed at random on the sites of a lattice with the desired concentrations. The fish and sharks are assigned random ages.
2. At time (iteration) t, consider each fish sequentially. Determine the number of nearest neighbor sites that are unoccupied at time $t - 1$ and move the fish at random to one of the unoccupied sites. If all the nearest neighbor sites are occupied, the fish does not move.
3. If a fish has survived for a time that is equal to a multiple of `fbreed`, the fish has a single offspring. The new fish is placed at the previous position of the parent fish.
4. At time t, consider each shark sequentially. If one or more of the nearest neighbor sites at time $t - 1$ is occupied by a fish, the shark moves at random to one of the occupied sites and eats the fish. If not, the shark moves to one of the unoccupied sites at random.
5. If a shark moves `nstarve` times without eating, the shark dies. If a shark survives for a multiple of `sbreed` iterations, the shark has a single offspring. The new shark is placed at the previous position of the parent shark.

What is the dynamical behavior of Wa-Tor? Do the Wa-Tor and the Lotka–Volterra equations exhibit similar behavior? Is the Wa-Tor model more realistic than the Lotka–Volterra equations? Which approach would be easier to explain to a nonexpert? Which approach is more flexible? See the references for suggestions for the numerical values of the parameters.

19.2 ■ SPIRAL GALAXIES

In addition to making it easier to investigate complex nonlinear problems and more realistic systems, the computer has reinforced one of the contemporary themes in physics, the unifying role of collective behavior. Systems composed of many individual constituents can exhibit common properties under certain conditions, even though there might be differences in the nature of the constituents and in their mutual interaction. The behavior of a system near a critical point is probably the best example of collective behavior in a familiar context. In the following, we discuss an example of collective behavior in the context of the structure of spiral galaxies.

The internal structure of a galaxy has traditionally been studied using Newtonian dynamics. This point of view is very useful but is complemented by thinking about the large scale structure of a galaxy using ideas from statistical mechanics. Because we only briefly summarize this alternative point of view here, we encourage you to explore the properties of the percolation-based model of Schulman and Seiden by running `GalaxyApp`, a simple version of their model, which can be downloaded from the ch19 directory.

The basic assumption of the model is that even though a region of the galaxy might have the necessary ingredients for star formation, nothing happens if it is left alone. However, if a shock wave from a supernova passes through the gas, there is a good chance that a star will be formed. The supernova is itself the result of an earlier nearby star formation. The