Listing 19.1 The getRate method.

```
public void getRate(double[] state, double[] rate) {
   // generalized coordinates
   double x1 = state[0];
   double vx1 = state[1];
   double x2 = state[2];
   double vx2 = state[3];
   double y1 = y(x1);
   double y2 = y(x2);
   double yp1 = yp(x1);
   double yp2 = yp(x2);       // first derivative
   double ypp1 = ypp(x1);
   double ypp2 = ypp(x2);     // second derivative
   // displacements
   double Lx = x2-x1, Ly = y2-y1;
   double L = Math.sqrt(Lx*Lx + Ly*Ly);
   // L0 is equilibrium length of spring
   double keff = k*(1-L0/L);               // effective spring constant
   // net applied force on particle 1 in x direction
   double fx1 =  keff*Lx;
   double fy1 =  keff*Ly-g*m1;
   double fx2 = -keff*Lx;   // net applied force on particle 2
   double fy2 = -keff*Ly-g*m2;
   // elements of diagonal matrix (J^T M J)^-1:
   double a11 = 1/(m1*(1+yp1*yp1));
   double a22 = 1/(m2*(1+yp2*yp2));  // other matrix elements are zero
   // elements of vector J^T F^(a):
   double b1 = fx1 + yp1*fy1;
   double b2 = fx2 + yp2*fy2;
   // elements of vector J^T M J du/dt:
   double c1 = m1*yp1*ypp1*vx1*vx1;
   double c2 = m2*yp2*ypp2*vx2*vx2;
   rate[0] = vx1;
   rate[1] = a11*(b1 - c1);
   rate[2] = vx2;
   rate[3] = a22*(b2 - c2);
}
```

The complete program can be downloaded from the ch19 directory.

19.5 ■ WHAT ARE COMPUTERS DOING TO PHYSICS?

There is probably no need to convince you that computers are changing the way we think about the physical world. The question, "How can I formulate this problem for a computer?" has lead to new insights into old problems and is allowing us to consider new problems.

What will be the effect of computers in physics education? The most common use of computers has been to assist students to understand topics that have been in the curriculum for many years. So far the computer has not qualitatively changed the way we learn nor the topics we study. Will computer simulation and numerical analysis make analytic methods less important? Has this happened already? Should calculus retain its traditional importance in the curriculum? Do we understand a natural phenomenon when we are able to construct a computer model that allows us to make predictions that agree with experiment? Is it necessary to obtain at least some analytic results? What do you think should be the role of computers in education?

Computers and the visual images produced by computer models can be very seductive. However, we need to remember that the goal of science is to understand nature. Theory and experiment have been the traditional routes to this end, and computation has become a third and complementary route. Although we have stressed the importance of computation in this text, it is important to stress its complementary role. We must not let the rapid advances of computer technology and the easy availability of information overshadow our ultimate goal of gaining more knowledge and a deeper understanding of natural phenomena.

REFERENCES AND SUGGESTIONS FOR FURTHER READING

It would be impossible to list even a small subset of references to areas of physics and related disciplines that we have not discussed. Also, the development of algorithms and applications in areas we have discussed is evolving rapidly. Many references to other applications and current developments can be found in archival journals. An important site for recent developments is <http://arxiv.org/>, an e-print service in physics, mathematics, nonlinear science, computer science, and quantitative biology operated by Cornell University. The magazine, *Computing in Science and Engineering*, <http://cise.aip.org/cise/>, especially the Departments on Education, Scientific Programming, and Computer Simulations, regularly feature articles that are generally accessible. The *American Journal of Physics*, <http://scitation.aip.org/ajp/>, also has articles on computers and physics. We encourage readers to regularly visit our website, <http://www.opensourcephysics.org/sip>, where new developments will be listed and discussed, as well as http://opensourcephysics.org> for updates of the Open Source Physics library.

Several references relevant to this chapter are given in the following.

Eric Bonabeau and Laurent Dagorn, "Possible universality in the size distribution of fish schools," Phys. Rev. E **51**, R5220–R5223 (1995). The authors apply a model originally developed for river networks to the size distribution of schools of fish. See also Kjartan G. Magnüsson, "Can physics save fish stocks?" Physics World **13** (2), 21–22 (2000).

Marek Cieplak, Achille Giacometti, Amos Maritan, Andrea Rinaldo, Ignacio Rodriguez–Iturbe, and Jayanth R. Banavar, "Models of fractal river basins," J. Stat. Phys. **91**, 1–15 (1998), or cond-mat/9803287.

A. K. Dewdney, "Computer Recreations," Sci. Am. **251** (12), 14–22 (1984). A discussion of the Wa-Tor model. Also see R. E. Durrett and S. Levin, "Lessons on pattern formation from planet WATOR," J. Theor. Biology **205**, 201–214 (2000).

David Eberly, *Game Physics* (Morgan Kaufmann, 2004).

Zvonko Fazarinc, Saša Divjak, Dean Korošec, Aleš Holobar, Matjaž Divjak, and Damjan Zazula, "Quest for effective use of computer technology in education: From natural sciences to medicine," Computer Applications in Engineering Education **11** (3), 116–131 (2003). The authors discuss some of the reasons for the relatively low impact of computer technology on university education. Also see Zvonko Fazarinc, "A viewpoint on calculus," Hewlett–Packard Journal **38** (3), 38–40 (1987).