

## Contagion on the Internet

**To the Editor:** Computer viruses are designed to be pests, proliferating in uncontrolled ways and causing severe damage to electronic data. These malignant programs, which amplify between files and computers, are strikingly similar in virulence, modes of spread, and evolutionary pathways over time to the microbes that cause infectious diseases. Both biological viruses and these virtual viruses are transmitted from host to host. Computer viruses are a human invention; however, their development follows a well-recognized biological route. Relatively harmless ancestors gradually or step-by-step evolve into "pathogens;" the host develops adaptive defense mechanisms, which in turn select for new virus "variants;" eventually, equilibrium is reached between infection and host defenses. Comparing "virtual microbes" with their biological counterparts can help us control both.

The term "computer virus" is loosely used to describe computer "malware," an umbrella term that includes the following categories. 1) Viruses. A computer virus is a program that implants a version of itself in any program it can modify. The modified program, once run, attempts to modify other programs directly associated with it. Computer viruses spread by sharing data on infected disks or diskettes. Unlike their biological counterparts (which are fast and very infectious), computer viruses spread slowly and infrequently between computers. 2) Worms. A worm is a self-contained program that replicates itself and sends copies to any connected computer, with little or no user interaction. Unlike biological worms (which spread slowly), computer worms spread rapidly and without much user interaction between computers of a network, including the Internet. (In view of the contagiousness of biological worms and viruses,

the terms should have been reversed.) 3) Trojan horses. A Trojan horse is a program concealing harmful code that usually makes a computer or network available to unauthorized users in an appealing or unsuspecting package. A virus, worm, or Trojan horse can be latent (then also called a logic bomb) and become active only after a certain period.

Each class of computer malware has hundreds of variants, and many variants have several slightly modified versions, paralleling microbial diversity. Worms, such as the infamous "ILOVEYOU" worm in 2000, may employ a universal message of gratification to entice users. Their wide dissemination parallels the spread of socially transmitted diseases (e.g., influenza) that have the potential to infect everyone susceptible. In contrast, computer viruses (spread by sharing data on infected diskettes) parallel sexually transmitted diseases, whose spread is related to specific behavioral practices. Viruses or worms that are spread undetected but are activated at a later date (as was the case with the Michelangelo virus, discovered in 1991 and still around) resemble latent microbes, such as HIV. Denial-of-service attacks, which block access to a server by an onslaught of messages, are the equivalent of toxins, since neither can reproduce in their host and are only harmful above a critical concentration. Spam (unwanted but harmless e-mail), the curse of computer users with slow modems through expensive telephone connections, resembles bacterial commensals that can injure the host only under specific conditions.

Biological viruses can mutate rapidly, create novel pathogenic and transmission routes, and develop antigenic variation to evade host immunity. In the computer world, worms exhibit similar behavior. Once a worm has been transmitted successfully, variants quickly emerge. These variants cause damage in similar ways but evade detection and impediments installed to provide "immunity" to the

original "strain." Therefore, knowledge of biological infections can be used to predict and anticipate highly virulent computer infections.

Although the computer user has some recourse against computer viruses, the costs may be high. As with biological viruses, good hygienic practice is helpful. Just as they should wash hands frequently, avoid exposure to people with colds, or use condoms to protect against infectious diseases, computer users should mistrust (and thus not open) files received through unexpected channels or with unknown extensions or subject lines, request confirmation from the sender before opening attachments, and regularly back up hard disks to reduce the risk of losing data. The consequences of such actions in terms of time, disk space, and efficiency illustrate a biological truth: immunity has cost. Effective antiviral barriers are impediments to communication. Moreover, virus protection programs are only as good as the last virus recognized, providing only partial protection at best. Computer users have not always taken inconvenient precautions, even in view of serious consequences. ILOVEYOU was a worm that used the same mechanism of spread as Melissa, which had been released a year earlier. Yet, ILOVEYOU turned out to be even more destructive than Melissa.

Biological immune disorders in which host defenses turn against the host and actually cause damage are known as autoimmune diseases. Computer autoimmune disorders parallel their biological counterparts. Recently, a warning (defense mechanism used by computer users) turned out to be a not-so-harmless hoax. The hoax warning stated that certain files were infected by a computer virus. Heeding the warning, unsuspecting computer users removed the affected utility files from their computers' operating systems. The harm mediated by this "host defense" was relatively small in this particular case, resembling the discomfort of allergies, in which immune responses to benign