Nurse. "It may not be possible or even necessary to explain all cellular phenomena in terms of precise molecular interactions."

Participants argued that genetic redundancy poses a similar challenge to reductionism. Researchers who have created genetically modified organisms in which a single gene has been deleted or blocked, known as "knockouts," have often been surprised to find that some other gene can take over at least part of its function. "Some mouse knockouts have turned out to be messy," says Nurse. These lessons have forced researchers to look harder at how genes map onto the form, or phenotype, of developing organisms, particularly their behavior. Biologist Sydney Brenner, of the Molecular Sciences Research Institute in La Jolla, California, argues that studying genes can help researchers understand how organisms are put together, but may not be helpful in describing some of the ways they function. "You can map genes onto behavior, but [the map] doesn't give you a causal explanation," he says.

Participants in the conference agreed that reductionism has a future in biology—but only as one approach among many. A growing number of questions will require other approaches. Some delegates felt that a deeper understanding of the role of information may yet throw a spanner in the grand reductionist scheme and that Nagel may be right in his suggestion that additional principles are needed. Asks biochemist Max Perutz of Cambridge's Laboratory of Molecular Biology: "Will there be new laws of biology?"

–Nigel Williams

COMPUTER SCIENCE

Model Explains Internet 'Storms'

Every cyber-junkie knows that the Internet is a crowded place. As computers send volumes of data from server to server, phone lines fill up, causing Internet traffic jams—and making Web browsers chug away in fruitless attempts to retrieve information. Then, moments later, the congestion abates. On page 535, two physicists present mathematical and computer models that point to the causes of these Internet "storms." The explanation, say the researchers, lies not in technology but in social behavior: Millions of users who have no incentive to economize flood the Internet with data, clogging it, and then get discouraged, relieving the congestion—all at roughly the same time.

The researchers, Bernardo Huberman and Rajan Lukose of the Xerox Palo Alto Research Center in California, aren't the first to recognize that the Internet tends to be overused because most users pay a flat rate for unlimited access. Instead, their achievement is to show exactly how these incentives lead to the spates of congestion seen on the Internet, says Kenneth Steiglitz, a computer scientist at Princeton University. "You look at the Internet and say, 'My god, it's a mess; nobody's going to understand it,' but Huberman gets qualitative insights into very complicated problems," says Steiglitz. Huberman himself thinks these insights might eventually point to ways to unclog the Internet.

He explains that everyone who logs onto the Internet faces a "social dilemma" like the one posed by a group dinner in which the bill will be split evenly. If you are in a selfish mood, you might order a lobster, hoping that your friends will economize and choose the salad. Because the price of the lobster gets split among the whole group, you would pay little for a sumptuous meal. But your friends see no reason why they should settle for salad while you order shellfish. They order the pricey lobster as well, placing a heavy demand on the lobster chef and leaving the whole group with a hefty bill.

The Internet is like one big, expensive dinner where no one expects to pay his share, says Huberman. Because of flat-rate pricing, people have no incentive to limit the size of their downloads, their Web meanderings, their e-mail, or their Internet chatting. As everyone consumes bandwidth—just as when everyone consumes lobsters—there is a price to pay: in this case, congestion. "Individually, their actions are rational, but collectively they're suboptimal," says John Bendor, a political scientist at Stanford University. The result of this collective display of self-interest, adds Lukose, is "overusing and degrading the value of resources. That's the tragedy of the commons."

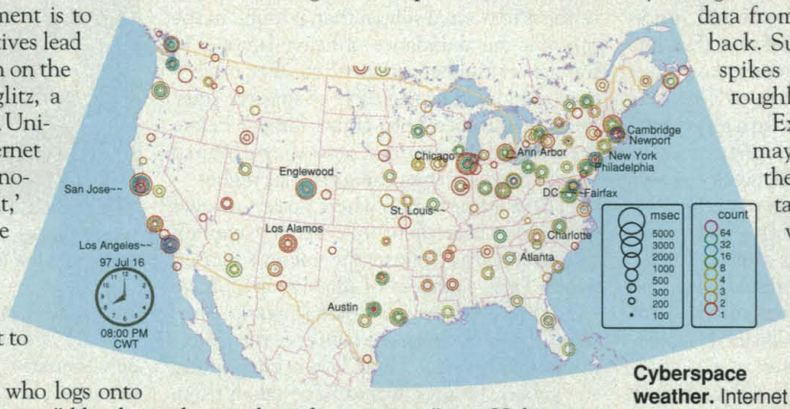
But unlike the gradual deterioration of other common resources—for example, the atmosphere, where countries see no incentive to reduce greenhouse-gas emissions if other countries don't cut back as well—the Internet's congestion is sporadic. "There are short spikes of congestion," says Huberman, "on the order of seconds or tens of seconds." To explain this behavior, he and Lukose created a mathematical model of Internet use in which each user behaves rationally, overusing the Internet most of the time but logging off when congestion becomes too great.

The model borrows from statistical mechanics, a branch of physics that deals with the collective effects of many simple objects, such as molecules or magnetic spins. It predicted the statistical properties of the network delays as many agents—each representing an Internet user—logged on and off. The result was a so-called lognormal distribution, which resembles a skewed bell curve, indicating "latency"—the extra time it takes to send a packet back and forth—on the horizontal axis and how often a user would encounter each latency on the vertical axis. Most of the time, the latency fell on the hump of the distribution, and the delays were small. But every so often—on the tail of the distribution—the delays spiked in an Internet storm as a large number of users put a load on the system at the same time.

To see what this statistical behavior would mean in the real world, Huberman and Lukose wrote a computer model based on the equations. By plugging in values for such things as the network bandwidth, the number of users, and how much congestion it takes to discourage a user, they were able to simulate congestion on an actual network. They also tested the mathematical model's predictions by timing how long it took to send packets of data from Stanford to England and back. Sure enough, they measured spikes of congestion distributed roughly in a lognormal curve.

Explaining Internet storms may prove easier than controlling them, because doing so will entail changing the behavior of vast numbers of users. "As the size of the group grows, it gets tougher to produce collective levels of common good," says Bendor. The answer, Huberman thinks, will lie in new pricing schemes, such as a pay-per-packet scheme or a priority-pricing method (the Internet equivalent of Federal Express). Huberman hopes to put his model to work studying the effects of various changes in incentives on Internet congestion. But one thing is already clear, he says. "I don't think the idea of a [flat-rate] Internet will go on forever."

–Charles Seife



SOURCE: MIDS

Cyberspace weather. Internet delays, as measured round trip between Austin, Texas, and hosts around the United States.

Charles Seife is a writer in Riverdale, New York.