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Doing Science on the Network: A Long Way From Gutenberg

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Millions converse daily on a system of linked computers that shrinks space and time.

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A POTENT catalyst to scientific advance is quietly working its way through the world of research, promising to speed the pace of innovation and discovery. In science, as in many other realms, computer networks are having a revolutionary influence. In forging

intimate new ties among researchers around the globe, the computer is rapidly replacing old intellectual traditions with new ways of doing science.

Worldwide, up to four million scientists are thought to be wired into the rapidly expanding maze of interconnected networks, which now number 11,252 and are known as the Internet, or sometimes just the net. Thousands of scientists hook up for the first time every day.

This patchwork of electronic conduits can link a lone researcher sitting at a computer screen to such things as distant experiments and supercomputers, to colleagues on faraway continents in a heretofore impossible kind of close collaboration, to electronic mail, to mountains of data otherwise too expensive to tap, to large electronic meetings and work sessions, to bulletin boards where a posted query can prompt hundreds of replies and to electronic journals that disseminate findings far and wide.

Moreover, all this can happen with blinding speed at a fraction of the cost of other types of communication. All it takes is a personal computer and a phone line.

"It's the most fundamental shift since Gutenberg," said Dr. Larry Smarr, an astrophysicist who directs the National Center for Supercomputing Applications at the University of Illinois.

"The Internet is basically a space and time destroyer," he said. "It shrinks distance and time to zero. It's as if all the world's scientists were in one room, available at one computer. Needless to say, this is having a profound impact on the way science is done."

Dr. Stephen S. Wolff, head of networking at the National Science Foundation, the Federal agency that runs the nation's top science network, said the emerging era meant "you can be physically isolated without being intellectually isolated," adding, That's a profound change."

The shift is clear to Dr. Brendan D. McKay, a computer scientist at the Australian National University in Canberra. Three years ago over the networks he got an electronic query about his work from Dr. Stanislaw Radziszowsky, a mathematician at the Rochester Institute of Technology. Since then, the two have exchanged more than 1,000 messages over the networks in a partnership undaunted by a distance of thousands of miles. While one works, the other sleeps.

"The ability to communicate very rapidly and cheaply with anyone anywhere has revolutionized collaboration," Dr. McKay said in a telephone interview. Thousands of Australian researchers, he added, are linked into the global net. "Everybody's starting to use them," he said.

A hint of the emerging power of the networks occurred in March as a robot from the Woods Hole Oceanographic Institution explored the bottom of the Gulf of California. More than a mile down, surrounded by inky darkness, the robot scrutinized hot vents and bizarre life forms. Instantly, its raw data were flashed over a tether to a surface ship and then, via satellite, to computer networks and researchers around the globe.

A very different realm is to be explored by environmental scientists at the Polytechnic University of New York. Over the networks, they are preparing to hunt for treasures of environmental data hidden inside hundreds computers around the world, such as those at the Environmental Protection Agency in Washington, the World Health Organization in Geneva and the National Aeronautics and Space Administration, which has voluminous satellite data. The scientists' aim is to open such out-of-the-way archives to routine analysis.

The study of the social repercussions of this electronic upheaval has just begun. However, early analyses suggest that the revolution is improving productivity as it breaks social and geographic barriers.

"The old means of distributing information were very unfair," said Dr. Paul Ginsparg, a physicist at the Los Alamos National Laboratory in New Mexico, who in 1991 founded an electronic publication available on the networks.

"When I was at Harvard, I'd get preprints by virtue of being on a very select mailing list," he said, referring to manuscripts of articles scheduled to appear in journals. "The rest of the world, the postdocs, would have to wait to get their stuff months later. In a field that's rapidly developing, that means everything."

Over the networks, Dr. Ginsparg says, his electronic preprints of physics articles are now read in Argentina, Australia, Austria, Belgium, Brazil, Britain, Bulgaria, Canada, Chile, China, Colombia, Costa Rica, the Czech Republic, Denmark, the Dominican Republic, Finland, France, Germany, Greece, Guatemala, Hong Kong, Hungary, Iceland, India, Ireland, Israel, Italy, Japan, Mexico, the Netherlands, New Zealand, Norway, Poland, Portugal, Russia, Singapore, South Africa, South Korea, Spain, Sweden, Switzerland, Taiwan, Thailand, the United States, Uruguay, Venezuela and Yugoslavia.

"The nets are growing in an explosive way," said Dr. Radziszowsky of the Rochester Institute of Technology. "They were not that popular a few years ago, but now more and more people are realizing their tremendous power. They're a tool of greater capability than anything before." Barring Electronic Junk Mail

Indeed, so many people are now putting so much material on the networks that data

overload and psychological burnout are hot topics. Emerging aids include the introduction of human editors similar to those at print journals, computer programs that pinpoint desired data, and electronic islands that bar the equivalent of hooligans, junk mail and brassy salesmen.

"Dealing with the Internet is like dealing with a fire hose," said Susan K. Kubany, president of Omnet Inc., a private company in Boston whose network for oceanographers prides itself on decorum and civility.

"Much of the beauty and wonder of Internet and its resources, if you look on the horizon, could become a horrific problem. Systems and people will shut down. I know people who have stopped using Internet because they get 500 messages a day."

"We believe that giving people tools and resources is important, not just data," she added. "We manage our net very carefully for the benefit of the community."

At its heart, the research enterprise has always been a social process, despite the myth of the scientist as a lone genius at work in isolation. Moreover, the speed with which ideas are communicated has often been a basic regulator on the pace of scientific progress.

In the 17th century, at the start of the science revolution, books were the main way of disseminating new ideas. The process was costly, haphazard and slow. An innovation, the scientific journal, made its debut in 1665. The Philosophical Transactions of the Royal Society of London was published monthly, and its success prompted a deluge of such periodicals over the years. Printed Journals Face Problems

Today at least 40,000 scientific journals roll off presses around the world, flooding libraries and laboratories with more than a million new articles each year. Some of the best-known journals are published weekly.

Publication can still entail delays of many months, and sometimes years. Moreover, the distribution of journals can be severely limited by geographical barriers and skyrocketing costs, which have risen for two decades at an average rate of 13.5 percent a year. Today an annual subscription can cost $1,000 or more. As a result, foreign scientists visiting the United States from major cities in the Southern Hemisphere often spend much of their time in libraries photocopying articles.

Ann Okerson, head of scientific publishing at the Association of Research Libraries, a trade group in Washington, said journal costs were so high that last year the top 100 university libraries of the association collectively cut 60,000 serial subscriptions.

At the same time, she added, these libraries were dramatically increasing their use of the

computer networks.

"They really do transform the way work is done," she said from a conference in Hawaii, where she periodically tapped the Internet from a portable computer hooked up to a hotel telephone.

The seeds of the network revolution were sown in the 1960's, when the Pentagon's Defense Advanced Research Projects Agency, or Darpa, pioneered a technique known as packet switching. This breaks computer data sent over phone lines into billions of tiny bits and directs them to their destination across a welter of different routes. If there is a pause or fluctuation at the electronic source, then the network fills the void with messages destined for someone else so as to save valuable time. Phone lines thus always work at nearly full capacity, sharply cutting costs. Heated Electronic Discussions

In the 1970's the main users of packet-switched networks were the military and its contractors. The 1980's saw an explosion of civilian spinoffs, often physically based on fiber-optic lines leased from phone companies. The linkup of these nets was possible if they adhered to a Federal standard for the Internet known as the Transmission Control Protocol, which insures that transmitted packets arrive in the order sent. Most nets adopted the standard.

Today electronic mail with an address in the regular Internet format -- user's name@machine's name -- can zip through an electronic labyrinth around the globe to reach its destination almost instantly. Remarkably, the labyrinth has no overlord. It is an alliance of technical republics.

The bulletin boards that have been dotting the networks in recent years have carried heated discussions on such hot scientific topics as cold fusion, high-temperature superconductivity, bucky balls and supernovas that have burst into view.

"The debates have been in the lead of most of the traditional scientific literature," said Alex A. McKenzie, vice president for data communication at Bolt Beranek & Newman Inc., a Cambridge, Mass., concern that helped the Federal Government found the networks.

On the horizon, experts say, is a burst of electronic publishing that could shake up or usurp the market for paper journals. A pioneer has been Los Alamos, which boasts not only Dr. Ginsparg's electronic preprint service but a vast apparatus to disseminate data on the international effort to unlock the genetic secrets of all organisms.

In the 1980's, the so-called GenBank at Los Alamos collected research from scientists around the world on the DNA sequences at the heart of all genetic codes and distributed

the data as printed books. The turnaround time was up to 13 months. Now it is all electronic, with data coming in over the networks and going out over them. Turnaround is less than 48 hours. Questions About Quality Control

"We've gone from being the Wells Fargo of data collection to the Federal Express," said Dr. Paul Gilna, who helps run GenBank.

Many scientific societies that now publish paper journals are either experimenting with or weighing the merits of electronic publishing over the networks, including the American Physical Society and the American Association for the Advancement of Science. Print journals pride themselves on a quality-control process known as peer review, in which anonymous reviewers judge whether submitted manuscripts are fit for publication. Although imperfect, this process is meant to bar research that is shoddy, repetitive, useless or fraudulent. Some experts have suggested that electronic networks need such winnowing and sifting, while others say one of their fundamental strengths is that they have so little filtering and potential for reviewer bias, which in some cases has kept revolutionary work from breaking into print.

The shift in science communication from ink and paper to the bits and bytes of computer networking will undoubtedly be bumpy, with some experts already expressing doubts about the integrity of the new wave.

"You don't know what information you can trust," said Dr. Marcel C. LaFollette, a science analyst at George Washington University.

But scientific users often wax ecstatic about the electronic onslaught, saying a new age is beginning.

"It's the one unifying technology that can help us rise above the epidemic of tribal animosities we're seeing worldwide," said Dr. Smarr of the University of Illinois. "One wants a unifying fabric for the human race. The Internet is pointing in that direction. It promotes a very egalitarian culture at a time the world is fragmenting at dizzying pace."

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