Researchers Feel Lure of the I-WAY

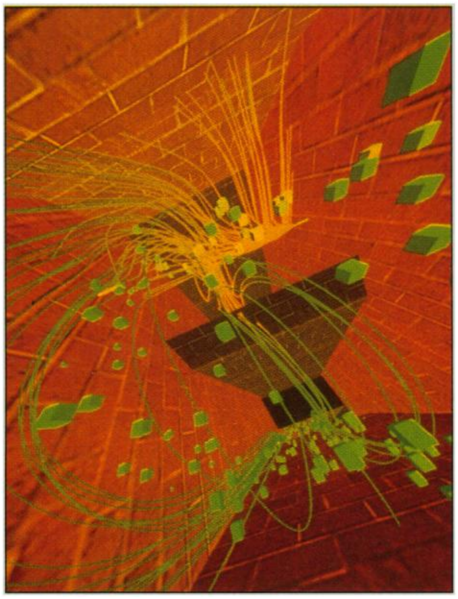
A group of computer scientists has organized a demonstration of a new kind of network that could offer faster transmissions with fewer glitches than the existing Internet

SAN DIEGO—"You're about to be combusted," says computer scientist Lori Freitag of Argonne National Laboratory, as she guides a hesitant group into a dungeonlike inferno at the Supercomputing '95 conference held here last month. "Does anybody feel kind of warm?" The heat is easy to imagine. Flashing around them on all four sides of a 3-meter cube, the group sees computer-generated images of the innards of a large tire incinerator: Orange and yellow flames flicker while jets of pollution-reducing chemicals squirt in through pipes in the walls and swirl about in the maelstrom before rushing upward with the incinerator's flue gases. But the realism of the display isn't the only remarkable thing about this virtual-reality tour.

On the far side of the incinerator, the crowd also sees a stick figure in sunglasses, waving and flitting about on its own. The figure shows the virtual "position" of Argonne's Daniel Heath, who is really 3000 kilometers away at the Advanced Research Projects Agency (ARPA) in Washington, D.C., moving through a twin of this virtual reality environment, where he can move the pipes and change the circulation of chemicals in the incinerator. Meanwhile, a supercomputer at Argonne, in Illinois, is performing the fluid-dynamics calculations that sustain the whole demonstration, determining how the circulation pattern changes in response to Heath's actions. The real star of the show is an unprecedented communications network that makes possible this three-way, continent-wide exchange of data: a system called the I-WAY, for Information Wide Area Year.

Put in place on a nationwide scale for the supercomputing conference and scheduled to run on and off over the next year, the I-WAY may pave the way to the future of networking, say some specialists. The demonstration I-WAY has roughly 2000 nodes at companies and academic and governmental sites and is both a physical network of switches and a new set of protocols for sending data over existing fiber-optic lines. Its goal is to combine the best features of the existing Internet and of digital telephone systems while eliminating their disadvantages. Like the Internet, it makes efficient use of the information-carrying capacity of the lines, but like a digital telephone system, it opens up uninterrupted pipelines for data, thereby allowing the seamless integration of voice, video, and data transmissions and avoiding random delays due to rerouting and slow-footed switching.

"We're not talking [just] about sending e-mail back and forth," says Gary Kerbel, a physicist at Lawrence Livermore National Laboratory whose group used the system to present a virtual fusion device called the numerical tokamak by its developers, who work at sites scattered across the country. The goal here, says Kerbel, is "a [collaborative] lab space in the ethereal sense."



Road show. A virtual reality simulation of a tire incinerator, driven by a distant supercomputer.

That's not all its proponents envision. The demonstration I-WAY, organized by computer scientists from Argonne and their colleagues elsewhere, created high-speed links among all 17 of the nation's supercomputer centers—allowing them, in theory at least, to act as a single megamachine. It also carried a video conference featuring fast, interactive communications between New York and San Diego, organized by IBM, which hopes to offer the service commercially. The massive investment in existing Internet technology may prevent the service from spreading beyond special-purpose commercial networks, say some analysts. But others think I-WAY technology could dovetail with the existing Internet or even replace it altogether. Says Thomas DeFanti of the University of Illinois, Chicago (UIC), one of the project's organizers: "In some sense, this is the next-generation Internet."

Styles of networking

The Internet's quirky history helps explain both the strengths and weaknesses of the current system. The Internet grew out of a military communications network developed at ARPA in the 1960s. The system was designed to allow the "host" computers in the network to keep communicating with each other even if part of the system was knocked out by, say, enemy attack. The idea was to break up each transmission into chunks, or packets, which would travel independently to their destination.

The source computer attaches source and destination addresses to each packet, then forwards the packet to a "router" computer at some intermediate point, explains Jonathan Smith, a computer scientist at the University of Pennsylvania. The router then decides how best to send the packet the next step of the way, to another router, and so on until it arrives at its final destination. These routing decisions mean that packets can be shunted around any gaps in the network—or, what is more relevant today, any parts that have gotten congested.

The strategy makes extremely efficient use of the available "bandwidth," or capacity, of an optical fiber or copper wire, because the software routines that guide the process, known as Internet protocols, shunt packets from many different transmissions through the network end-to-end, like traffic on a crowded roadway. But the need for many separate routing decisions can slow a transmission, and the standard Internet also has some more serious shortcomings. For one thing, separate packets in the same transmission may take different routes to their destination. A shifting route, like a warped vinyl record, can cause "wow" in voice transmissions. Worse, says Smith, one packet "can get caught behind a tractor trailer at a toll booth"—held indefinitely in a buffer while a long message ahead is transmitted.

To get around these problems, the I-WAY uses a protocol called ATM, for asynchronous transfer mode, which has been developed by industrial and academic researchers over the past 5 years. ATM adopts some features of digital telephones, which simply open a channel—guaranteed bandwidth along a fixed path—and send packets of data along it at precisely timed intervals. The digital-telephone packets carry no addresses, but switches along the way identify them by

D. DIACHIN *ET AL*/ARGONNE NATIONAL LABORATORY AND W. MICHELS/NALCO FUEL TECH their arrival times and send them along the proper route with little delay and no time-consuming calculations. Unfortunately, this method must reserve the time slot whether or not it is carrying information—even when, say, a caller isn't speaking—meaning that it is an inefficient user of the network.

ATM, too, opens a single channel from source to destination. But instead of using timing to identify the packets of information flowing along a particular channel, ATM tags each data "cell" with a few bytes of information that identify it as part of the same stream. As a result, there's no requirement to keep the cells coming, and the lines tied up, when no data is being sent. What's more, in contrast to the software-based Internet routers, the switches are controlled mostly by hardware and don't have to make complicated routing decisions, "so you don't introduce any additional delay," says Smith.

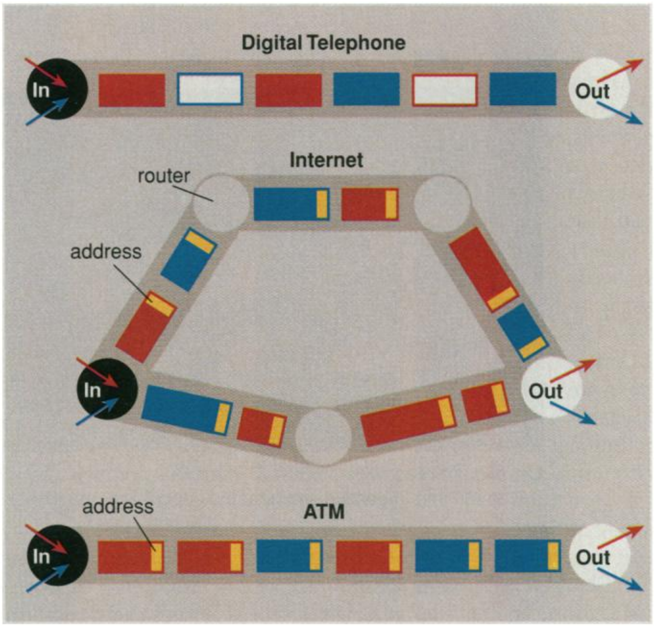
There are trade-offs, however: Unlike the current Internet protocols, which are designed to ensure that all data packets arrive at their destination no matter how long it takes, ATM drops cells that get delayed beyond some specified time and refuses to open new channels when traffic becomes too heavy. On balance, though, ATM's speed and carrying capacity "blow the socks off anything else I've seen on a network," says Argonne's Tim Kuhfuss, an I-WAY participant.

To test that promise, Rick Stevens, head of mathematics and computer science at Argonne, began organizing the I-WAY 2 years ago, along with UIC's DeFanti and Larry Smarr of the National Center for Supercomputing Applications (NCSA) at the University of Illinois, Urbana-Champaign. About $1 million in grants from ARPA, the National Science Foundation, and the Department of Energy went into the effort, which entailed linking and extending small prototype ATM networks and enlisting the efforts of over 200 other researchers. For example, connecting the supercomputer centers—each of which has its own operating system, security protocols, passwords, and other idiosyncrasies—required a system of "gateway" workstations with mediating software to allow the big machines to operate in tandem.

Spectacle in a CAVE

For the I-WAY's debut, its architects organized some 60 demonstrations, most of them featuring surreal "Cave Automatic Virtual Environments," or CAVEs, driven by remote supercomputer calculations. These virtual-reality environments—the most elaborate to date—have been developed at UIC's Electronic Visualization Lab over the past decade. They call for the lockstep transmission of tremendous amounts of audio, video, and data to create a sense of total immersion in an imaginary 3D world. And they're a potentially valuable tool for exploring complex data sets, says Livermore's Kerbel: "You tap into your short-term visual memory, so that as a researcher you can relate to what's going on."

The "CAVE-to-CAVE" technique featured in the virtual tire incinerator could offer the same advantages to researchers collaborating at long distance, says Argonne collaborator Paul Plassmann. He notes that the company that builds the incinerators hopes the technology will eventually let engineers in the field solve problems in virtual collaboration with the home office. And in another long-distance collaboration, Ed Seidel of NCSA and eight co-workers used the I-WAY to find solutions to Einstein's equations of general relativity, which describe gravity as a curvature in the fabric of spacetime. General relativity predicts that cosmic events like colliding black holes can generate ripples in this fabric—gravity waves.



Alternate routes. ATM opens a single route from source to destination without the inefficiency of digital telephone links (empty boxes) or the shifting routes of the Internet.

Seidel and his colleagues used the I-WAY to yoke together two supercomputers at different sites on the Cornell University campus to calculate how gravity waves are generated and a CAVE in San Diego to display the results. "The environment of the I-WAY is essential for these kinds of calculations," says Seidel, because they call for a transmission bandwidth "that is simply not available on the existing Internet."

One parallel computer at the Cornell Theory Center found solutions to the equations, then shipped the data to a second machine at Cornell, which generated gravity-wave "surfaces," a process something like drawing lines along the peaks and troughs of water waves. A third computer in San Diego rendered the roiling surfaces in the CAVE, where viewers could alter the simulation and—thanks to the I-WAY—quickly see the effects as the Cornell computers redid the calculations. Said one awestruck observer after the presentation: "Now if we ever meet a black hole, we'll know it."

Scientists aren't the only ones feeling the lure of the I-WAY. The underlying technology, ATM, "is [one] that the telephone companies are very interested in" for future services that would combine voice, data, and video, says Stevens. "ATM very easily integrates voice traffic and data traffic," he explains, and "it's a platform that allows [the companies] to guarantee a certain level of service"—without, for example, unpredictable delays during a video conference. Indeed, much of the I-WAY consists of small-scale networks that MCI, Sprint, AT&T, and other carriers already had in place, in some cases for limited commercial services.

Not everyone predicts that ATM will one day usurp Internet protocols as a widespread standard on the networks. Popular Internet services like the World Wide Web and file transfer protocol would benefit from the faster transmission. But the ethernet systems used for local communications in many businesses can't support full ATM-like capabilities, notes Scott Bradner of the office for information technology at Harvard University and a member of a standards-review board at the Internet Society, which makes informal recommendations on such issues. "There's ump-dee-dum billion dollars worth of equipment" that couldn't make full use of ATM services once they are delivered, says Bradner. "I just don't see it [a widespread switch from Internet protocol] happening in anybody's lifetime."

Argonne's Stevens notes that the I-WAY organizers aren't advocating ATM over other possible choices, including possible revisions to the Internet such as the so-called resource-reservation protocol, which could allow users to reserve bandwidth on the Internet. The point, he says, is to keep looking for better ways to pave the information highway. "The same kind of research and innovation that led to the existence of the Internet is the mechanism for the future of the Internet," he says. "Just what the [future] Internet will look like—we haven't even invented that yet. But we've got to keep the whole innovation thing alive."

–James Glanz