batch of blastocysts proved normal, the researchers prepared a second batch of oocytes with transferred nuclei and cultured the developing embryo on mouse fibroblast cells for 8 or 9 days. They then selected 10 of the blastocysts and implanted two in each of five hosts. All five became pregnant and were cared for at the Ishikawa Prefectural Livestock Research Center, on the Japan Sea coast 300 kilometers west of Tokyo.

Two other groups started cloning efforts at about the same time, and more joined the chase once news of Tsunoda's pregnant cows spread. But Tsunoda's group won the race when one of the surrogate mothers delivered healthy twin calves after 243 days, only 37 days earlier than a normal gestation. The average weight at birth of the eight calves, all born naturally, was about 32 kilograms; the average for natural pregnancies is about 27 kilograms.

Despite Tsunoda's success, other groups have had problems with large calves, including one cloned from fetal cells that weighed in at a whopping 52 kilograms after a cesarean section. And although it won't be clear until their reports are published, few of the other groups seem to be matching Tsunoda's success rate. Kubota says only about 10% of his team's implanted embryos have been carried to term, and the Roslin Institute group produced only one live sheep from 13 transferred blastocysts.

Tsunoda believes that the most important factor in his high success rate may be his use of cumulus and oviductal cells, because of their role in reproduction. Other groups have used a variety of cells, including muscle and skin cells. Tsunoda is hoping to begin to clarify such issues through a systematic screening of cells. A second batch of cloned calves still in utero has been produced using cells from 20 different tissues, including the liver, kidney, and heart. Tsunoda anticipates results by spring.

Most research efforts outside Japan are likely to focus on cloning cattle from fetal rather than adult cells, says Will Eyestone, a reproductive physiologist working on transgenic animals at PPL Therapeutics Inc. in Blacksburg, Virginia. Embryonic cells containing fetal or embryonic DNA are believed to grow faster, and the resulting animals appear to live longer than if they had been cloned from adult cells, he notes. "It's a better way to go," adds Robl, if the goal is to modify the genetic makeup of the animals so that their milk contains drugs for use in humans. Using adult cells might offer an advantage in getting exact copies of cows or bulls that are particularly valuable for breeding purposes or for meat, however. But producing calves for agricultural purposes through cloning is not likely to prove economical in the United States. "We don't have a market for very high premium beef," Robl says.

But Japan does. "The cost of agricultural products in Japan is high, but they still sell," says Tokyo University's Tomohiro Kono. Superpremium Matsuzaka beef roasts, for example, cost $100 a pound, and those prices would support the expense of cloning prize beef cattle. But just how commercially important cloning might be is an open question. A genetically ideal calf is just the starting point for Matsuzaka beef. The animals are also fed beer and given daily massages as part of a regimen that results in fine flecks of fat uniformly scattered throughout the meat. "We have a long way to go to make [premium] beef inexpensive," says Hiroto Takahashi, an official in the Agriculture ministry's animal production division. "In other countries, there would be no meaning in producing [cattle] this way," he adds.

Given those limitations, some scientists feel that the research efforts should be focused on understanding the cloning mechanism itself. Kono, who uses rabbits to study that mechanism, says that while it was important to confirm the Roslin results in cattle, there is no need to have the efforts duplicated by so many groups. "It is a Japanese trait, [in which] everyone heads in the same direction," he says. "There isn't much originality in the research."

Tsunoda agrees that a lot of the work is redundant. But using different cells may help researchers clarify the mechanism through which cells are reprogrammed to start the development process anew. "Right now, what happens in cell reprogramming is a black box," he says. "We are at the starting point to study the reprogramming [of cells]."

–DENNIS NORMILE

COMPUTER SCIENCE

From Army of Hackers, an Upstart Operating System

The open-source software movement has developed a free computer operating system that is poised to compete with Microsoft's Windows

In the titanic struggle between Microsoft and the Justice Department, one of the software giant's chief defenses against the charge of monopoly-building is to argue that its lead in the operating-system market is vulnerable. New competitors, say the company, could challenge it at any time. That argument may seem laughable on the surface, given that neither Apple nor IBM was able to best Microsoft in the operating system wars. But there is a competitor on the horizon—and if internal Microsoft documents are to be believed, the software Goliath may be showing some nervousness.

CREDIT: LOS ALAMOS NATIONAL LAB

Supercomputing on the cheap. The Linux operating system melds 140 desktop machines into the Avalon supercomputer, developed by Michael Warren and colleagues.

David in this case is called Linux (www.linux.org), a simpler-to-use variant of the old standby UNIX. Already, Linux is the operating system of choice for Internet servers, the computers that route Internet traffic and host sites on the World Wide Web, and its use is growing rapidly for small-sized servers on local area networks. It also serves as the operating system on a cut-rate supercomputer at Los Alamos National Laboratory, called Avalon. And now, thanks to a massive effort by programmers around the world, all but a handful working for free, Linux is poised to make significant inroads in the workstation and desktop personal computer world, which is largely the domain of Microsoft and, to a lesser degree, of UNIX.

Linux, by all accounts, is stable, powerful, and fast—and it's free. Yes, free: Linux is the fruit of a kind of online commune, an intellectual descendant of the counterculture of the 1960s. And although free software is

nothing new—UNIX itself was initially distributed free by its developer, Bell Labs—Linux represents one of the most visible successes of what is called the open-source software (OSS) movement, an approach to software development first championed in 1983 by computer scientist Richard Stallman at the Massachusetts Institute of Technology. Proponents of this model, which now include the Web giant Netscape, believe that all software should not only be free, but should also be accompanied by its native code, the instructions written by programmers. "By making the code open and providing it free with the binary software, it means that you are now allowing users to start tinkering with a program," says Miguel de Icaza, a programmer and system administrator for Universidad Nacional Autónoma de Mexico in Mexico City. "Essentially, you harness the power of millions of users to find problems, whether they be bugs or just deficiencies, and thousands of programmers to fix them quickly."

"The end result," he says, "is that you get software that's smaller, less buggy, and more stable"—which many computer scientists say is the case for Linux. The Avalon supercomputer has been running for many months now without crashing, reliability that is almost unheard of in the supercomputer world. Some common applications for personal computers and workstations also run faster under Linux. According to an internal Microsoft memo, leaked to the public via the Internet by an internal source and confirmed as authentic by Microsoft, Netscape's Navigator Web browser rendered graphics and text "at least 30-40% faster" when it ran in Linux than it did in Microsoft's own operating system, Windows NT. Finally, Linux's small size and speed mean that it runs just fine on less expensive computers, including those with Intel's older 80486 processor and its clones. "For low-budget operations, you can take used 486s, install Linux, and you have a really cheap but powerful Internet server," explains Todd Lewis, a Linux volunteer whose paying job is at MindSpring, an Internet service provider.

Linux's source code has been open since it was first created in 1991 as a simpler-to-use version of UNIX by Linus Torvalds, then a 21-year-old undergraduate at the University of Helsinki. He posted the approximately 10,000 lines of code on the Internet, and in short order other programmers began sending him fixes and improvements, which Torvalds incorporated into the system. As news of Linux spread through the programming community, more programmers joined the effort, and in March 1994, with 100,000 users, version 1.0 was released along with supporting software. This was followed in June 1996 by version 2.0.

By then, the Linux kernel—the core operating system—had grown to 400,000 lines of code, all of it written by volunteers and incorporated into the kernel by Torvalds. Under the terms of the "CopyLeft" license developed by Stallman's Free Software Foundation, a virtual organization that is promoting the concept of open-source software, anyone can use the code and modify it, but they must then send the change to the community for review. "Then, the ultimate decision on whether or not to incorporate a change rests with one of the 'benevolent dictators' that 'rule' a particular part of the Linux project," explains Lewis. Several thousand volunteers now contribute, but the buck still stops with Torvalds, who works for a small Silicon Valley chip designer called Transmeta Corp. in Santa Clara, California.

Face of GNOME. This Linux "front end" for desktop computers will debut next year.

The development effort has spread to the commercial world. Today, at least four companies, including RedHat Software in Research Triangle Park, North Carolina, and Caldera Systems in Orem, Utah, develop and sell Linux-compatible ancillary software such as graphical user interfaces and suites of common business applications, which the companies package with Linux. They, too, send proposed Linux modifications to the appropriate individual and adhere to the same CopyLeft license as everyone else. According to industry newsletters, the operating system now runs on an estimated 10 million computers, mostly workstations and Internet servers, displacing other UNIX systems and Microsoft's Windows NT.

Linux is also making inroads in the research community. Recently, Michael Warren's group at Los Alamos used Linux as the operating system for Avalon, a collection of 140 Digital Equipment Corp. Alpha desktop computers wired in parallel. The result is a genuine supercomputer, capable of 47.7 billion calculations per second, at a total cost of $300,000—parts, labor, and software included. Several research groups at Los Alamos have used Avalon to solve problems in areas as diverse as astrophysics and molecular dynamics (cnls.lanl.gov/avalon).

Linux will soon make its most direct challenge to commercial software in the form of a set of programs called GNOME (the g is pronounced), a so-called front end that would turn Linux into the equivalent of the Windows 98 operating system for PCs, complete with supporting functions such as a file management system, text editor, mail protocol interpreter, and disk formatter. GNOME can't run software configured for Windows 98, but with filters it can work with files prepared in various Microsoft applications, such as Word and Excel. Recently, de Icaza, who heads GNOME development, "froze" further additions to the software in anticipation of releasing the first complete version in March 1999. "Now, the GNOME community—several hundred strong—will complete testing and debugging," says de Icaza.

That enormous people resource gives the Linux development effort and open-source software in general a key advantage, explains Ransome Love, president of Caldera Systems. "We and everyone who uses Linux, as well as the other companies that distribute it, benefit from the 24-hour-a-day efforts of thousands of people around the world who just pounce on problems and get them fixed." It's an advantage that Microsoft has noted. In a confidential memo posted to various bulletin boards by someone inside the company, Microsoft product manager Vinod Valloppillil wrote, "The ability of the OSS process to collect and harness the collective IQ of thousands of individuals across the Internet is simply amazing."

In Linux, Valloppillil said in a second leaked memo, the process has resulted in "a best-of-breed UNIX that is trusted in mission critical applications and due to its open source code has long-term credibility which exceeds many other competitive [operating systems]. Long term, [our] simple experiments indicate

CREDIT: WWW.GNOME.ORG

that Linux has a chance at the desktop market." A Microsoft spokesperson has confirmed publicly that these memos are legitimate, saying they describe "business models that would be valuable in order to stimulate additional internal dialog within Microsoft."

Linux is not the only success of the open software movement. Many add-on programs, so-called utilities such as the file compression program Zip, and file readers such as Ghostview were born of this movement. Apache, an Internet server program that runs under Linux and was developed by about 20 programmers from around the world, is now found on more than half the computers that host Web sites, according to the November 1998 Netcraft Web Server Survey (www.netcraft.com/Survey). BIND, developed by hackers at the University of California, Berkeley, in the 1980s, is used by virtually every Internet router system to convert Web aliases into true numeric addresses, and the open-source program Sendmail routes about 80% of all e-mail sent today.

Netscape embraced the open-source software credo last March when it released the source code for the latest version of its Communicator software. Within hours after its release, a group of Australian hackers wrote a small piece of cryptographic code that greatly increased the security of Communicator, which can be downloaded free from Netscape's Web site. Netscape got the fix for free, every user of Communicator benefited, the Australians, who call themselves the Mozilla Crypto group, got kudos from the programming community for their great hack, and their consulting group, Cryptosoft in Brisbane, probably got some more business.

Is the open software movement likely to have further successes? Microsoft evidently thinks so. These programs have proven to be "at least as robust—if not more—than commercial alternatives," wrote Valloppillil. And for participants in the movement, the rewards remain strong. "It's a very positive ego thing, knowing that you've contributed to a great piece of software," says Lewis.

–JOSEPH ALPER

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RUSSIAN SCIENCE

New Minister Sets Lofty Goals

As Russia unravels, Science Minister Mikhail Kirpichnikov struggles to find a balance between supporting basic research and forcing science to pay for itself

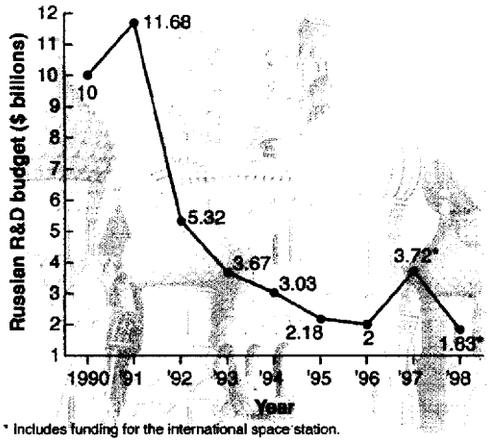
MOSCOW—If you find running a lab and stumping up grant support an oppressive burden, spare a thought for Mikhail Kirpichnikov, Russia's new science minister. Kirpichnikov, a protein chemist who still manages to keep one foot in the lab, is trying to patch together enough resources to keep the entire country's once-proud research enterprise from crumbling away. It's a daunting challenge. Russian researchers, sick of not receiving salary for months, are staging strikes. Unable to pay utility bills, institutes are plunged into a cold twilight during working hours. The few labs able to sustain world-class research rely on foreign colleagues for access to instruments or reagents. And in the latest blow to Russia's scientific community, the ruble has lost two-thirds of its value against the dollar in 3 months, vaporizing razor-thin budgets for Western research supplies.

Kirpichnikov, who moved into the research hot seat on 25 September, says his chief priority is to "do everything we can to protect basic research. It is our country's destiny." But just how to fend off further decay is a matter of vigorous debate among rank-and-file scientists—and is likely to dominate discussions at a meeting next week in Moscow, co-sponsored by the ministry and the Paris-based Organization for Economic Cooperation and Development, on the future of Russian science. Kirpichnikov "understands all the problems of science, I think," says Alexander Litvak, deputy director of the Institute of Applied Physics in Nizhny Novgorod. "But what depends on him? It all depends on money." Still, top officials place high hopes in him. "I am convinced that Kirpichnikov ... will do his best to preserve the best of Russian science," says Michael Alfimov, chair of the Russian Foundation for Basic Research, Russia's version of the U.S. National Science Foundation.

Kirpichnikov, who agreed to an interview with *Science* despite government restrictions on Cabinet members speaking with the press, says he is ready to try some new maneuvers to steer Russian science through its latest crises. These measures may include channeling money to some disciplines at the expense of others and "aggressively" claiming intellectual property rights for scientists. To Kirpichnikov, saving Russian science means exploiting it: stepping up efforts to patent inventions, license products, and contract out research. "Science is one of our strategic resources, a reusable resource," he says. "For years, science has been underutilized."

In the hot seat. Kirpichnikov.

Kirpichnikov acknowledges, however, that his ministry's options are limited by Russia's dwindling finances: This year, the government will spend less than $2 billion on science, the lowest sum in decades—and that's an official figure that, optimistically, includes payment of overdue salaries by month's end (see graph). August's financial crash made a bad situation far worse. The ruble lost half its value in a week, cutting pay for top scientists to $100 a month, says Vladimir Strakhov, director of the All-Union Institute of Earth Physics in Moscow. The result was double jeopardy for research: "On the one side, the ruble fell, and on the other, we get less rubles," says Strakhov, who went on a hunger strike in 1996 to protest shrinking research budgets. "Today's situation is the worst it's ever been for Russian science. And the most difficult times are in the future." Sources say that next year's budget, which is expected to go to the Duma, the lower house of parliament, on 12 December, includes a paltry 8 billion rubles ($444 million, at the present exchange rate) for science.



Sifting through the ruble. Science funding is in free fall.

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