Health Services. Much of the concern stems from the health risks of the vaccine itself, which caused one to two deaths and 14 to 52 life-threatening complications for every million doses when it was last used in the 1960s. The vaccine's fatality risk, however, is one hundredth the average death rate from motor vehicle accidents in the U.S. and one 200,000th the mortality rate from smallpox, which would be likely to kill 30 percent of the people infected.

U.S. intelligence officials suspect that both Iraq and North Korea possess stocks of smallpox. The big uncertainty is whether terrorists could spread the disease effectively—spraying the live virus over a wide area is technically difficult, and a smallpox martyr could not infect others until he or she was quite ill. Smallpox experts note, though, that the public would demand mass vaccinations even if only one case appeared in the U.S. and that health care workers might be unwilling to perform that task if they had not been previously vaccinated themselves. Says William J. Bicknell of the Boston University School of Public Health: "To vaccinate the whole country in 10 days, we'd need two to three million workers."

Only a few states have come close to that level of preparedness. Nebraska, which had one of the highest per-capita smallpox vaccination rates as of mid-March, benefited from the zeal of Richard A. Raymond, the state's chief medical officer, who personally lobbied administrators at dozens of hospitals. "Government is all about priorities, and this was a priority for us," Raymond says. "An attack may start in a big city, but because Americans are so mobile, the entire country is at risk."

Joseph M. Henderson, associate director for terrorism preparedness at the Centers for Disease Control and Prevention, notes that vaccinations are not the only defense against smallpox. New York City, for instance, has an excellent disease surveillance program, increasing the chances that epidemiologists would be able to identify and contain a smallpox outbreak. "Overall, New York gets a passing grade," Henderson says. "But they should have a lot more people vaccinated. They're doing it, but not as fast as we'd like."

BEYOND SMALLPOX

Smallpox is not the only bioterror agent that Iraq is believed to possess. Under pressure from the United Nations, Iraqi officials admitted in 1995 that their laboratories had churned out these bioweapons:

- **Botulinum toxin: nerve agent produced by the bacteria that cause botulism**
- **Anthrax: bacteria that lie dormant in spores; if inhaled, the bacteria multiply rapidly in the body, causing internal bleeding and respiratory failure**
- **Aflatoxin: chemical produced by fungi that grow on peanuts and corn; causes liver cancer**
- **Perfringens toxin: compound released by the bacteria that cause gas gangrene**

MATH

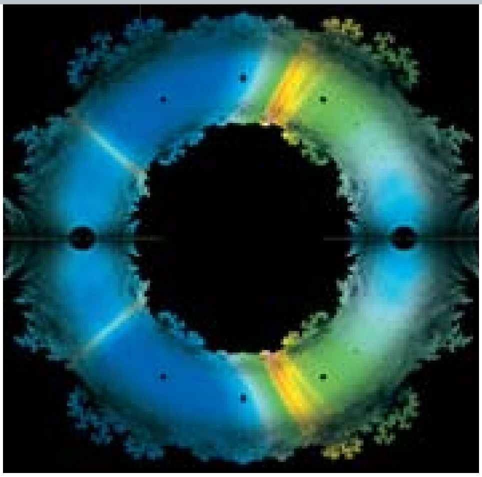
A Digital Slice of Pi

THE NEW WAY TO DO PURE MATH: EXPERIMENTALLY **BY W. WAYT GIBBS**

"**One of the greatest ironies** of the information technology revolution is that while the computer was conceived and born in the field of pure mathematics, through the genius of giants such as John von Neumann and Alan Turing, until recently this marvelous technology had only a minor impact within the field that gave it birth." So begins *Experimentation in Mathematics,* a book by Jonathan M. Borwein and David H. Bailey due out in September that documents how all that has begun to change. Computers, once looked on by mathematical researchers with disdain as mere calculators, have gained enough power to enable an entirely new way to make fundamental discoveries: by running experiments and observing what happens.

The first clear evidence of this shift emerged in 1996. Bailey, who is chief technologist at the National Energy Research Scientific Computing Center in Berkeley, Calif., and several colleagues developed a computer program that could uncover integer relations among long chains of real numbers. It was a problem that had long vexed mathematicians. Euclid discovered the first integer relation scheme—a way to work out the greatest common divisor of any two integers—around 300 B.C. But it wasn't until 1977 that Helaman Ferguson and Rodney W. Forcade at last found a method to detect relations among an arbitrarily large set of numbers. Building on that work, in 1995 Bailey's group turned its computers loose on some of the fundamental constants of math, such as log 2 and pi.

To the researchers' great surprise, after months of calculations the machines came up with novel formulas for these and other nat-



COMPUTER RENDERINGS of mathematical constructs can reveal hidden structure. The bands of color that appear in this plot of all solutions to a certain class of polynomials (specifically, those of the form $\pm 1 \pm x \pm x^2 \pm x^3 \pm \ldots \pm x^n = 0$, up to $n = 18$) have yet to be explained by conventional analysis.

COURTESY OF JONATHAN M. BORWEIN AND PETER BORWEIN *Simon Fraser University*

CRUNCHING NUMBERS

Mathematical experiments require software that can manipulate numbers thousands of digits long. David H. Bailey has written a program that can do math with arbitrary precision. That and the PSLQ algorithm that uncovered a new formula for pi are available at www.nersc.gov/~dhbailey/mpdist/

A volunteer effort is under way to verify the famous Riemann Hypothesis by using distributed computer software to search for the zeros of the Riemann zeta function. (German mathematician Bernhard Riemann hypothesized in 1859 that all the nontrivial zeros of the function fall on a particular line. See "Math's Most Wanted," Reviews, on page 94.) To date, more than 5,000 participating computers have found more than 300 billion zeros. For more information, visit www.zetagrid.net

ural constants. And the new formulas made it possible to calculate any digit of pi or log 2 without having to know any of the preceding digits, a feat assumed for millennia to be impossible.

There are hardly any practical uses for such an algorithm. A Japanese team used it to check very rapidly a much slower supercomputer calculation of the first 1.2 trillion digits of pi, completed last December. A pickup group of amateurs incorporated it into a widely distributed program that let them tease out the quadrillionth digit of pi. But mathematicians, stunned by the discovery, began looking hard at what else experimentation could do for them.

Recently, for example, the mathematical empiricists have advanced on a deeper question about pi: whether or not it is normal. The constant is clearly normal in the conventional sense of belonging to a common class. Pi is a transcendental number—its digits run on forever, and it cannot be expressed as a fraction of integers (such as $355/113$) or as the solution to an algebraic equation (such as $x^2 - 2 = 0$). In the universe of all known numbers, transcendental numbers are in the majority.

But to mathematicians, the "normality" of pi means that the infinite stream of digits that follow 3.14159... must be truly random, in the sense that the digit 1 is there exactly one tenth of the time, 22 appears one hundredth of the time, and so on. No particular string of digits should be overrepresented, whether pi is expressed in decimal, binary or any other base.

Empirically that seems true, not only for pi but for almost all transcendental numbers. "Yet we have had no ability to prove that even a single natural constant is normal," laments Borwein, who directs the Center for Experimental and Constructive Mathematics at Simon Fraser University in British Columbia.

"It now appears that this formula for pi found by the computer program may be the key that unlocks that door," Bailey says. He and Richard E. Crandall of Reed College have shown that the algorithm links the normality problem to other, more tractable areas of mathematics, such as chaos theory and pseudorandom number theory. Solve these related (and easier) problems, and you prove that pi is normal. "That would open the floodgates to a variety of results in number theory that have eluded researchers for centuries," Borwein predicts.

INTERNET

A Man, a Plan, Spam

A STANFORD LAWYER PITS HIS JOB AGAINST JUNK E-MAIL **BY WENDY M. GROSSMAN**

Like most Internet users, Stanford University law professor Lawrence Lessig hates junk e-mail—or, as it is formally known, unsolicited commercial e-mail (UCE). In fact, he hates it so much, he's put his job on the line. "I think it will work," he says of his scheme for defeating the megabyte loads of penis extenders, Viagra offers, invitations to work at home, discount inkjet cartridges, and requests for "urgent assistance" to get yet another $20 million out of Nigeria.

Lessig, who wrote two influential books about the Internet and recently argued before the U.S. Supreme Court against the extension of copyright protection, has developed a two-part plan. The first part is legislative: pass federal laws mandating consistent labeling so that it would be trivial for users and Internet service providers (ISPs) to prefilter junk. Federal antispam legislation hasn't been tried yet, and unlike state laws—which have been enacted in 26 states since 1997, to little effect—it would have a chance at deterring American spammers operating outside the nation's borders. Second: offer a bounty to the world's computer users for every proven violator they turn in. Just try it, he says, and if it doesn't work, he'll quit his job. He gets to decide on the particular schemes; longtime sparring partner and CNET reporter Declan McCullagh will decide whether it has worked.

"Spam only pays now because [spammers] get to send 10 million e-mails and [they] know five million will be delivered and 0.1 percent will be considered and responded to," Lessig explains. "If all of a sudden you make