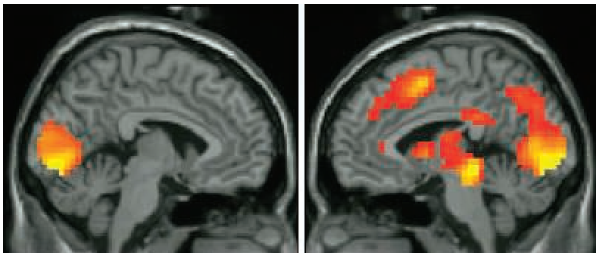
NEUROSCIENCE

Economic Game Shows How the Brain Builds Trust

As any economist will tell you, people don't always behave rationally when it comes to money. For instance, we sometimes trust complete strangers with our hard-earned dough. This suggests to many that a tendency to trust is hard-wired into the human brain.

Until now, little was known about the neural circuitry underlying the capacity to trust. But on page 78, neuroscientists and economists from Texas and California report an intriguing insight: Activity in a brain region called the caudate nucleus reflects one person's intention to trust another with a sum of money. Their results also suggest that trust isn't purely noble—it may stem from a cold calculation of expected rewards.



Tête-à-tête. Brain scans of the investor (*left*) and trustee in an economic exchange game shed light on the neural basis of trust.

"I think it's a very important paper. It's going to change the way we think of social interactions," says Paul Zak, who directs the Center for Neuroeconomic Studies at Claremont Graduate University in California. "It's an exceedingly well done and rigorous study," agrees Paul Glimcher, a neuroscientist at New York University.

The research exemplifies the fledgling field of neuroeconomics, which combines the brain imaging tools of neuroscience with the exchange games economists have invented to probe how people behave during financial transactions. It's also one of the first studies in which the brains of two people were scanned simultaneously during a social interaction. Two volunteers played a trust game from inside functional magnetic resonance imaging scanners, one at the California Institute of Technology in Pasadena and the other at Baylor College of Medicine in Houston, Texas.

In each of 10 rounds, one player, the designated "investor," received $20. The investor then had the option of sending some, all, or none of the $20 to the other player, the "trustee." According to the rules of the game, which were known to both sides, any money the trustee received tripled. The trustee then had the option of returning a portion of the new sum to the investor. The players' only knowledge of each other came from numbers flashed on a monitor that indicated the amount of money changing hands in each round, as well as each player's total for the game.

The extent to which a player trusted another with his or her money depended on the recent history of the exchange. If an investor increased the contribution to a trustee immediately following a round in which the trustee had reduced payback, the trustee generally rewarded this benevolent reciprocity with a greater return in the next round. But if an investor demonstrated malevolent reciprocity by repaying generosity with stinginess, the trustee usually returned less the next time around.

Examining the trustees' brain scans, the researchers found that activity in the caudate nucleus was greatest when the investor showed benevolent reciprocity and most subdued when the investor showed malevolent reciprocity. Moreover, caudate activity rose and fell with changes in the amount of money trustees returned to their investors on the subsequent round. The team concludes that activity in a trustee's caudate nucleus reflects both the fairness of the investor's decisions and the trustee's intention to repay those decisions with trust (or not).

The caudate nucleus's "intention to trust" signal appeared about 14 seconds sooner in later rounds of the game, an indicator that the trustee is building an opinion of the investor's trustworthiness, says Read Montague, who led the Baylor team.

The caudate nucleus is well connected to the brain's reward pathways, and previous work has shown that it revs up when subjects expect a reward such as juice or money. Montague and colleagues speculate that trust, admirable trait that it is, boils down to predicting rewards—in this case, the "social juice" of the investor's reciprocity. Trust has been an element of human social interactions for many thousands of years, says Ernst Fehr, a neuroeconomist at the University of Zurich in Switzerland, so it makes sense that it would tap into ancient neural systems like the reward pathways.

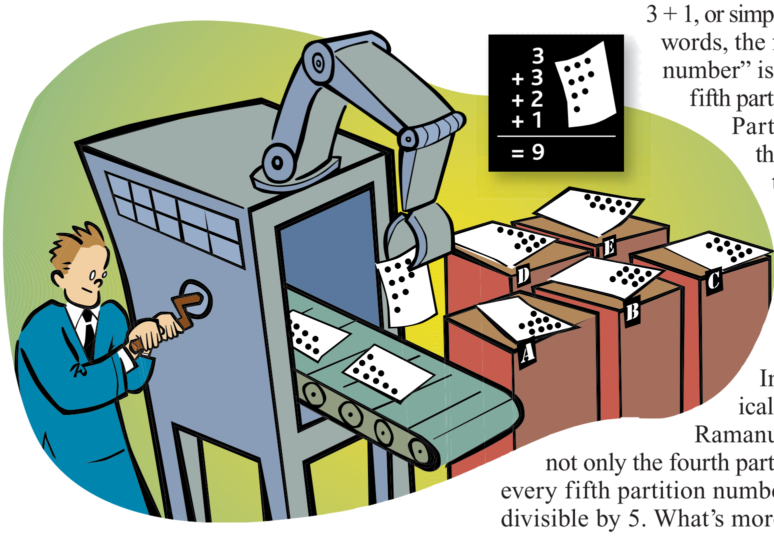
–GREG MILLER

MATHEMATICS

'Cranky' Proof Reveals Hidden Regularities

Mathematicians crave patterns, and nowhere do they find richer pickings than in the theory of numbers. Five years ago, a breakthrough in a long-standing problem connected with one of the simplest functions of number theory yielded an unexpected bonanza of new patterns. Now, a new proof suggests that that was just the beginning. "It's almost certain that there will be more where this came from," says number theorist George Andrews of Pennsylvania State University, University Park, whose work helped pave the way for the new result.

The proof involves the partition function, which counts the number of ways you can reach any integer by adding other positive integers. For instance, the number 4 can be partitioned in five different ways: 1 + 1 + 1 + 1, 2 + 1 + 1, 2 + 2, 3 + 1, or simply 4 itself. In other words, the fourth "partition number" is 5. Similarly, the fifth partition number is 7.



Sorting it out. "Rank" and "crank" functions divide partitions (above, of 9) into classes.

Partitions crop up throughout number theory and have proved handy for balancing energy budgets in particle physics.

In 1910 or so, Indian mathematical genius Srinivasa Ramanujan noticed that not only the fourth partition number but every fifth partition number after it is also divisible by 5. What's more, every seventh partition number (beginning with 7) is divisible by 7, and every eleventh partition ▸

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number (beginning with 11) is divisible by 11. There, mysteriously, the pattern stops.

Freeman Dyson, now a professor emeritus at the Institute for Advanced Study in Princeton, New Jersey, read about the pattern as a schoolboy in the 1940s and discovered an explanation for Ramanujan's first two observations. "It was my first real piece of research," he says.

Dyson defined what he called the "rank" of a partition: the largest number in a partition minus the number of terms in the partition. By noting that the partitions of 4, 9, 14, and so on could be sorted into five equal-sized bins according to rank, Dyson explained why the number of partitions in each case is divisible by five. Similar reasoning showed why the number of partitions of 5, 12, 19, and so on must be divisible by 7. Unfortunately, Dyson's rank formula didn't work for Ramanujan's third pattern, the one dealing with divisibility by 11. He conjectured that some other binning procedure, which he called a "crank," would explain that pattern, but he never found it. Andrews and another number theorist, Frank Garvan of the University of Florida, Gainesville, finally discovered the elusive crank in 1988.

Meanwhile, mathematicians had started turning up a few other patterns like Ramanujan's. In 2000, Scott Ahlgren of the University of Illinois, Urbana-Champaign, and Ken Ono of the University of Wisconsin, Madison, hit the jackpot. Using methods similar to those that Andrew Wiles of Princeton University had used in 1994 to prove Fermat's Last Theorem, they showed that divisibility patterns in the partition function exist not just for 5, 7, and 11, but for *every* prime number greater than 3. For example, every 157,525,693rd partition number, beginning with the 111,247th, is divisible by 13. "Instead of two or three galaxies, they showed that there is a sky full of galaxies," Andrews says.

One of Ono's graduate students, Karl Mahlburg, set out to find a "cranky" proof of the newly discovered patterns, although Ono tried to warn him away from what he considered a hopeless task. "I admit to a certain ignorance," Mahlburg says. "There were a lot of things that could have gone wrong." The effort paid off. In a paper submitted to *Annals of Mathematics*, Mahlburg shows that for prime numbers p bigger than 11, the crank does *not* divide the partitions into equal-sized bins—but it *does* group them in multiples of p. Thus, in a slightly different way, the crank accounts for Ono's congruences after all.

Next, Mahlburg says he plans to use a computer to find new divisibility patterns in the crank function itself. Andrews says he is eager to see what happens when Ono and his students try the Wiles-like technique out on other functions of interest in number theory.

–DANA MACKENZIE

Dana Mackenzie is a freelance writer in Santa Cruz, California.

ACADEMIC JOBS

Tenured UCLA Professor Under Fire

The University of California, Los Angeles, is taking steps that could lead to the firing of tenured biomathematics professor Sally Blower, accusing her of threatening students and harassing faculty, according to documents supplied to *Science* by Blower and her husband, UCLA geneticist Nelson Freimer. Blower, who left the University of California, San Francisco, 5 years ago with Freimer after accusing the university of gender discrimination (*Science*, 7 April 2000, p. 26), says the charges are false. UCLA administrators declined to comment, citing confidentiality rules.

According to the documents, UCLA Vice Chancellor Donna Vredevoe last week referred five charges against Blower to the school's Committee on Privilege and Tenure, which will help decide Blower's fate. The charges include "failure … to hold examinations as scheduled," "use of the position or powers of a faculty member to coerce the judgment or conscience of a student," and "verbal abuse, false statements, disparagement, and harassment of faculty."

Imminent departure? UCLA's Sally Blower and her husband Nelson Freimer say the school is trying to push her out.

CREDIT: JAKE FREIMER

The charges are only the latest storm surrounding Blower. On 12 November 2004, the dean of the UCLA School of Medicine, Gerald Levey, served Blower notice that she was barred from entering the biomathematics administrative offices pending resolution of charges filed in June. The November letter accused Blower of causing hives and increased blood pressure in two department administrators because she allegedly refused to leave their offices until security was summoned. Blower denies intimidating the administrators, noting that the incidents left her "almost in tears."

Several individuals familiar with the case say it appears to have spiraled out of control. "Honestly, I can't figure out why there's such a commotion," says gastroenterologist Peter Anton, who directs UCLA's Center for HIV and Digestive Diseases and has collaborated with Blower on HIV models for several years. "Certain personalities don't click well—but those usually seem to be resolvable without polarization, without … having to isolate and discredit a faculty member." Anton, who filed a letter in support of Blower, adds that he hasn't "seen any evidence of egregious behavior" on her part.

Blower is particularly incensed by the charge that she threatened students. In one case, she says, she is accused of threatening to withdraw as thesis adviser to Emily Kajita, then her only graduate student. Blower says she did e-mail Kajita saying the department was impeding her ability to advise students, but the two chose to proceed. Kajita praises Blower as "the best adviser you could ever have," adding that Blower paid nearly $4000 to cover her living expenses when Kajita was struggling to find graduate school funding.

Blower traces the charge of failing to hold exams to a September 2002 qualifying exam she postponed to attend the funeral of a close family friend in San Francisco.

Blower does admit to sending "rude e-mails" to members of her department but says she wouldn't have done so if they had responded to her inquiries for financial information and for room scheduling, so she could hold classes.

Blower joined the biomathematics department in 2000 after she and her husband struck a deal with UCLA. The university was aggressively recruiting Freimer, who said he would come only if his wife were also offered a tenured position. Blower says she was made to feel "invisible" by a department she had hoped to shake up, for example, by boosting the profile of its graduate program.

"There is a huge other side to this story; unfortunately, I can't divulge any of that," says David Meyer, senior associate dean for graduate studies at UCLA's medical school and one of those who filed a complaint against Blower.

Now, Freimer says that "without a doubt" he will leave UCLA if Blower is terminated. Even if she's found not guilty, he says, "my feelings about the place are so negative" that he might depart anyway.

–JENNIFER COUZIN