How many mathematicians does it take to be a professor, research director, journal editor, and world-class juggler? Just one–

Ronald Graham

BY BILLY ALLSTETTER

You never know when Ronald Graham will start juggling. During a commencement speech at the University of Alaska, he reached under his formal gown, pulled out four balls, and began an impromptu demonstration. On a recent trip to Paris, he carried five bean bags with him so he could hone his skills in his hotel room. Any day at work, he may sneak out of his office to practice new routines with a colleague.

Graham's profession, however, is not juggling; he is a mathematician, and one of the most distinguished in the world. Still, he sees no incongruity between his passion for the abstract realm of numbers and the delight he takes in the concrete art of keeping six balls in the air at one time.

For Graham, the fascination of juggling comes at least partly from what he sees in the airborne juggling clubs, plates, or balls. Instead of a chaotic conglomeration of objects propelled by a frantic pair of hands, the mathematician sees order. To help others see that order, Graham—a past president of the International Jugglers Association—recently directed professional jugglers, The Flying Karamozov Brothers, for a segment of the children's educational television program "Square One TV."

"The idea was to start with a complex pattern, break it down into its elements, and build it back so people could see the patterns—what has to come together to make the whole thing work," says the softspoken Rutgers professor. "It's very controlled. If it were chaotic it would collapse. You can't just juggle randomly for very long."

Graham has spent much of his life breaking complex phenomena into their elemental parts and finding the order hidden within. His current project is golf. He practices in front of a machine that senses his swing, then delivers measurements of several components, including club head speed, angle of the clubface, and the distance the imaginary ball will travel. By mastering the components, he plans to master the game. He has already used that approach to master the boomerang, Ping-Pong, tennis, the trampoline, and Chinese. This method, however, extends beyond his hobbies. It arises out of mathematics.

"To me, the universe runs on mathematical principles," he says. "Mathematics is a search for structure and pattern. It's more than a subject; it's almost a way of approaching life.

"It's an open-ended challenge. That's one reason so many mathematicians are interested in juggling—it's controlled instability, right on the edge of doing a little more than you should. There's always one more variable, one more ball."

Graham's zest for challenge and his astonishing energy are among the attributes that have brought him to the top of his difficult field. A member of the National Academy of Sciences and chairman of its mathematics section, he holds the post of adjunct director of the Research, Information Sciences Division at AT&T Bell Laboratories in addition to his part-time Rutgers professorship. At the same time, he is a member of the editorial boards of some 30-plus mathematics and computer science journals.

Harvard math professor Persi Diaconis—with whom Graham is writing a book on the uses of math in performing magic tricks—effuses respect:

"He's an incredibly accomplished mathematician," says Diaconis. "He's really amazing. If I'm ever stuck, he just seems to find the time to get me unstuck. He hears that panic in my voice and he

Peter L. Vidor

takes the time out to help me. He's just this dynamo of good."

Graham has also taken on the responsibility of looking after the world-famous monk of mathematics, Paul Erdös. At 76, the eccentric genius travels the globe, lecturing and visiting other mathematicians, living largely out of a shabby suitcase; Graham built an addition onto his Watchung, New Jersey, house to accommodate the visitor. Graham stores Erdös's papers, takes care of his extensive incoming correspondence, manages his money, and gently does what he can to persuade the elder mathematician to protect his health. The two friends share mathematical conundrums and insights that delight them both.

Meanwhile, Graham finds time to write about a dozen journal articles each year, often in collaboration with his wife, Fan Chung. He met Chung, a respected mathematician herself, at the University of Pennsylvania when he served on the committee reviewing her thesis. After her graduation they worked together at Bell Laboratories. They have been married six years and have four children from previous marriages.

"There's always one more variable, one more ball."

Graham has focused much of his mathematical effort in a particularly difficult area called Ramsey Theory.

"The philosophy of Ramsey Theory is that complete disorder is impossible," says Graham, whose license plate reads "RAMSEY." "There's always a certain amount of order that's inevitable."

To illustrate the concept, he mentions an episode from the "Cosmos" television series in which narrator Carl Sagan said people often look into the night sky and see, say, four stars almost in a straight line. The temptation is to think that their alignment couldn't be an accident but must be the result of a deliberate action by intelligent beings, perhaps arranging a navigational aid. Sagan pointed out, however, that if you look at a large enough collection of stars, you can find almost any pattern you want—a line, a bear, a dipper. Ramsey theorists seek to prove the inevitability of those patterns. They formulate mathematical theorems to calculate such things as the smallest possible number of stars whose arrangement is bound to contain four that deviate by no more than, say, one degree from a straight line. Graham estimates that number at somewhere between 2,000 and 3,000—but no one yet knows for sure. Ramsey theorists spend much of their time refining estimates, making increasingly precise descriptions of the universal patterns they are convinced lie waiting to be revealed.

Ramsey-type problems are among those known to mathematicians as "hard" problems. Often easy to state, they rapidly become tremendously complex as the number of variables increases. They include routing problems—a major practical issue for communications networks at Bell Labs. Graham, who has earned a citation in *The Guiness Book of World Records* for devising the largest number ever used in a mathematical proof, takes special delight in solving such difficulties. Asked why, he recites a nursery rhyme:

"Problems worthy of attack
prove their worth by fighting back."

Graham adds, "If it were too easy, aaaaaaahhh . . . it's not so interesting."

One of Graham's major contributions to this field has been the development of a method, known as worst-case analysis, that helps computer scientists get a handle on hard problems. In the real world, people must and do tackle hard problems, even if the solutions they come up with are not optimum ones. Worst-case analysis allows problem solvers to see how far off they could be, at the worst, if they use simple procedures. During the Apollo space missions, NASA engineers wanted to schedule the astronauts' time to make sure that, along with sleeping, eating, and guiding the ship, they also performed as many ex-

Boggling the Mind

The classic Ramsey problem is often stated in terms of guests at a party: What is the smallest number of people—collected at random—that would have to be invited to guarantee that at least three would either all know one another or would all be strangers to each other?

OK, you don't plan your parties that way. But just for fun—think about it a minute. It's not so easy.

Give up?

Mathematicians can prove that six must be invited. They look at it this way:

Call one of the party guests Joe. He must either know, or not know, at least three of the other five, right? Assume, for the moment, that he's acquainted with three. (It works out the same way for the opposite assumption.) The next step is to think about the relationship among those three. If two of them know each other—as well as Joe—they form the required group of three acquaintances; on the other hand, if none of Joe's three acquaintances knows each other, they constitute a group of three strangers. (A party of five is not enough, because it may turn out that Joe knows exactly two, and his two acquaintances may each know a different one of the two who are strangers to Joe.)

Mathematicians have also worked out that 35 must be invited to guarantee a group of four friends or four strangers. But if you want a fivesome—well, mathematicians can only tell you that the smallest party must have somewhere between 43 and 55 guests. Ramsey problems can quickly explode into complexities that strain the imagination.

periments as possible. The number of ways to allocate the tasks was astronomical—so great that even NASA computers couldn't try them all out. NASA mathematicians developed what they hoped would be the most efficient schedule possible; Graham used worst-case analysis to assure them that, although he couldn't identify the very best schedules, the ones they had worked out never varied markedly from the most efficient ones possible.

At Rutgers, which he joined in January 1987, Graham is University Professor of Mathematics and Computer Science and on the executive committee for the new Center for Discrete Mathematics and Theoretical Computer Science (DIMACS), which he calls "a jewel in the crown" at Rutgers. The multimillion-dollar center, on Busch campus, was established by the National Science Foundation and is a joint effort of Rutgers and Princeton universities, Bell Laboratories, and Bellcore.

Discrete mathematics, generally known among mathematicians as combinatorics, is the kind of math used most frequently in computer science. Combinatorial mathematicians are coming from around the world to New Jersey to focus on this developing branch of the field, Graham says.

"Combinatorics is one of mathematics' emerging areas and Rutgers is certainly one of the world leaders," he says.

Convincing some mathematicians to learn about this new area is not always easy, but Graham welcomes the challenge. Many, he believes, are too committed to the more traditional areas of mathematics. But Graham's philosophy, as evidenced by his repeated forays into new activities, is to keep moving ahead.

"It's good to keep your brain thinking in new patterns, to be flexible, to force it out of its ruts," says Graham. "If something is too easy, especially if you're successful at one particular thing, you may be tempted to keep doing that thing. You stop thinking."

It's not a fate likely to befall Ronald Graham. □

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