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The Mathematics of Terrorism

Seemingly random attacks contain an unexpected regularity: the same numerical pattern seen in Wall Street booms and busts.

By Andrew Curry | Wednesday, December 01, 2010

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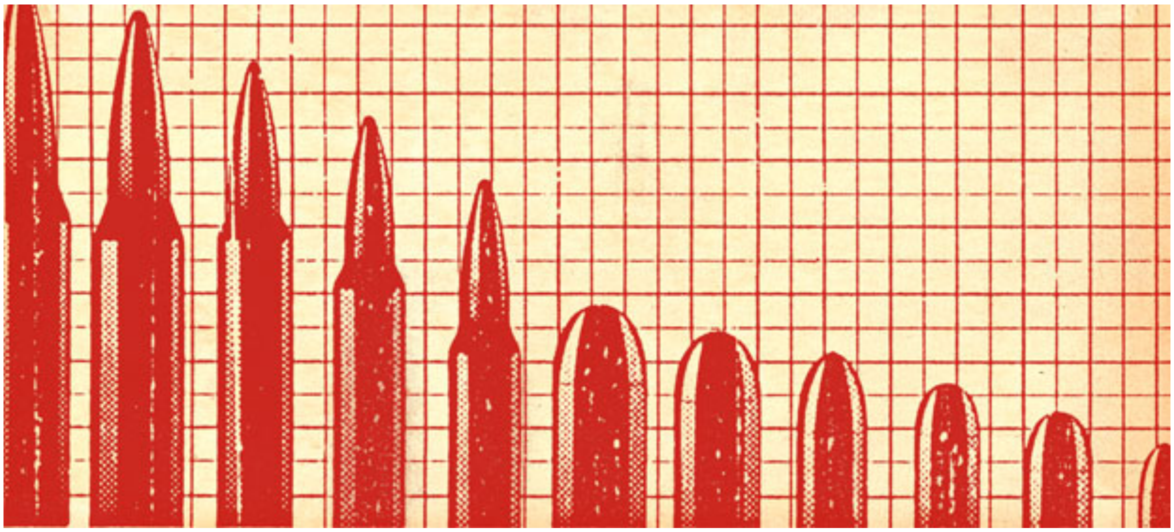

Illustrations by Tavis Coburn

Since the 1960s, the mountains of southern Colombia have been home to a war between the government and a leftist guerrilla movement known as the Revolutionary Armed Forces of Colombia, or FARC. The conflict has simmered for decades. Sometimes it flares up in battles with government forces, a terror bombing, or a particularly high-profile kidnapping. Sometimes it fades into the background as cease-fires or negotiations quiet the hostilities. FARC has been fighting for so long that the war has become almost like background noise, says Neil Johnson, a University of Miami physicist who travels to Colombia every year to visit his wife's family. Even locals have become numb to the conflict. "There's this war going on, but I didn't think too much of it. You hear numbers of dead every day, like football results," Johnson says. "It took me 10 years to realize that maybe there was important information hidden in those numbers."

Johnson, who specializes in the study of complexity, is one of a new breed of physicists turning their analytical acumen away from subatomic particles and toward a bewildering array of more immediate human problems, from traffic management to urban planning. It turns out that subatomic particles and people are not that different, he explains. "The properties of individual electrons have been known for many years, but when they get together as a group they do bizarre things"—much like stock traders, who have more in common with quarks and gluons than you might think. So profound is the connection that quants (quantitative analysts, often with backgrounds in physics or engineering) have flocked to Wall Street, creating elaborate models based on the way markets have moved in the past. ArXiv, a clearinghouse for physics research papers, includes an entire section on "quantitative finance."

Still, it was not until a chance 2001 meeting in Bogotá with Mike Spagat, an economist at Royal Holloway College, University of London, that Johnson considered modeling something as human as warfare. Spagat had a Colombian Ph.D. student named Jorge Restrepo who was gathering data on attacks and death tolls, provided by the nonprofit Center for Investigation and Popular Education, so he could look for patterns in the conflict. Johnson hoped the numbers could tell them something about how the individual particles—in this case, insurgents rather than electrons—functioned when put together in large groups.

Soon the new team had a database that included more than 20,000 separate incidents from two and a half decades of FARC attacks. Johnson and Spagat expected that the success of the attacks, measured in the number of people killed, would cluster around a certain figure: There would be a few small attacks and a few large ones as outliers on either end, but most attacks would pile up in the middle. Visually, that distribution forms a bell curve, a shape that represents everything from height (some very short people, some very tall, most American men about 5'10") to rolls of the dice (the occasional 2 or 12, but a lot of 6s, 7s, and 8s). Bell curves are called normal distribution curves because this is how we expect the world to work much of the time. But the Colombia graph looked completely different. When the researchers plotted the number of attacks along the y (vertical) axis and people killed along the x (horizontal) axis, the result was a line that plunged down and then levelled off. At the top were lots of tiny attacks; at the bottom were a handful of huge ones.

That pattern, known as a power law curve, is an extremely common one in math. It describes a progression in which the value of a variable (in this case, the number of casualties) is always ramped up or down by the same exponent, or power, as in: two to the power of two (2 x 2) equals four, three to the power of two (3 x 3) equals nine, four to the power of two (4 x 4) equals 16, and so on. If the height of Americans were distributed according to a power law curve rather than a bell curve, there would be 180 million people 7 inches tall, 60,000 people towering at 8'11", and a solitary giant as tall as the Empire State Building. Although power laws clearly do not apply to human height, they show up often in everyday situations, from income distribution (billions of people living on a few dollars a day, a handful of multibillionaires) to the weather (lots of small storms, just a few hurricane Katrinas).

In Colombia's case, decades of news reports confirmed that the number of attacks formed a line that sloped down from left to right. In general, an attack that causes 10 deaths is 316 times as likely as one that kills 100. The larger the event, the rarer it is.

At first the pattern seemed too clear and simple to be true. "Immediately I thought, 'We need to look at another war,'" Johnson says. With the U.S. invasion of Iraq in full swing, he and his collaborators had an obvious second test. In 2005, using data gleaned from sources like the Iraq Body Count project and iCasualties, a Web site that tracks U.S. military deaths, they crunched the numbers on the size and frequency of attacks by Iraqi insurgents. Not only did the data fit a power curve, but the shape of that curve was nearly identical to the one describing the Colombian conflict.

Around that time, a Santa Fe Institute computer scientist named Aaron Clauset was applying the same approach to what seemed like a distinctly different problem. Rather than looking at specific guerrilla movements, Clauset was examining total deaths caused by global terrorist attacks since 1968. When he plotted nearly 30,000 incidents on a graph, they formed a curve to the power of –2.38. (The power number is negative because it reflects a decrease rather than an increase in the number of events as death tolls rise.) With its characteristic downward slope, the curve was eerily similar to those generated by Johnson and Spagat for Colombia and Iraq.

To rule out coincidence, Johnson, Spagat, and University of Oxford physicist Sean Gourley gathered data on nine other insurgencies. One after another, the curves clicked into place: Peru's Shining Path guerrilla movement: a curve with a power of –2.4. The Indonesian campaign against rebels in East Timor from 1996 to 2001: –2.5. The Palestinian second intifada: –2.55. Fighting against Afghanistan's Taliban from 2001 to 2005: –2.44. By contrast, traditional conflicts in which two armies squared off against each other (such as the Spanish and American civil wars) yielded graphs that looked a lot more like bell curves than power curves. Although the politics, religion, funding, motives, and strategies of the insurgencies varied, the power trends did not.

In an age of biological weapons and dirty nukes, the implications are chilling. Although truly massive power-law events—like the Great Depression or killer storms—are drastically less common than smaller disruptions, they still occur. In the normal distribution of a bell curve, you never get such extremes, but the pattern underlying the power curve enables a few rare events of extraordinary magnitude. One might use the math to argue that the 9/11 attack that killed more than 2,700 people in New York City was bound to happen. And there is ample reason to believe that an even bigger one is on the way, sooner or later.

For Johnson, a Cambridge- and Harvard-educated physicist who has studied stock markets and other apparently unpredictable systems, the power law was familiar territory. Whether in New York, Tokyo, or London, markets tend to follow the same boom-bust cycles, with little daily upticks and downticks punctuated every few decades by a big crash or boom. "Markets move every day, but some days they move a lot," Johnson says. "There are different people, different stocks, but that just seems to be the way people get together and trade."

If physics-based models can predict the behavior of stock markets, Johnson reasoned, why couldn't they foresee the behavior of insurgents so that attacks could be prevented? "Prediction is the holy grail everyone is in pursuit of," says Brian Tivnan, a modeling expert at a U.S. Department of Defense–funded think tank called the Mitre Corp. Tivnan brought Johnson's work to the attention of Pentagon officials. "We were very encouraged to see physicists and mathematicians looking at the data from an apolitical, analytic perspective," he says.

But if they were going to develop a predictive model, Johnson and his team would have to figure out what it was about the behavior of insurgents and terrorists that made their bloody fingerprints so similar all around the world. They started by tossing the traditional take on insurgencies out the window.

Conventional counterinsurgency thinking tries to get into the heads of rebels by understanding their motivations and methods. Political scientists and sociologists studying the conflicts in Iraq and Afghanistan have emphasized tribal affiliations, nationalism, religion, social networks, and other cultural concerns. Using lessons learned (or perhaps mislearned?) in Vietnam, meanwhile, Pentagon planners approached these conflicts as if they were facing smaller armies with worse equipment, hoping that if they could knock out the enemy's leadership they would decapitate and demoralize the insurgency.

But these assumptions were off. Guerrilla fighters in Vietnam, like U.S. troops, answered to a central command; insurgents in Iraq did not. And from a physics point of view, getting inside an insurgent's head was irrelevant. "In political science literature, human rationality is primary. They assume groups are rational actors, have access to all the information, and make the right decisions," Clauset says. "A physicist's natural approach is to assume people are like particles, and their behavior the result of constraints beyond their control."

Basing their computer models on programs written to predict all sorts of fluctuating phenomena, from traffic flow to stock prices, Johnson's team tried to create equations that reflected the behavior of the individual insurgents seen in the data. The equations that came closest "involved a soup of conflict groups of varying strengths, in a constant process of coalescing and dissolving," Spagat says.

Johnson likens the insurgent groups in his computer model to a pane of glass that shatters into smaller and smaller splinters with each hit. The bigger shards are capable of delivering the deepest, nastiest cuts, but they are also the easiest to target. The smallest slivers of glass, on the other hand, might deliver the casualty equivalent of a pinprick, but there are so many of them, and they are so hard to spot, that the total amount of damage they cause stays high.

If the model is correct, then insurgents conduct "asymmetrical warfare," battling a larger and better-equipped enemy with a loose network of fighters lacking central command. However obvious this seems today, it was a concept that escaped American military planners when the fighting in Iraq and Afghanistan began nearly a decade ago. "The insurgents kept the most powerful military the world has ever seen at bay for four years," says John Robb, a former Special Operations pilot and author of Brave New War: The Next Stage of Terrorism and the End of Globalization. "You're not going to defeat them by killing groups or killing people. You have to change the entire dynamic. It's a tough lesson for a lot of military folks to absorb."

Indeed, the harder the U.S. forces hit, the more the insurgency shattered into near-invisible shards. By the time Johnson's paper was published in Nature last year, the military had learned, through bitter experience, the futility of fighting insurgents with traditional tactics. (The military has never published on the issue, but Johnson says that strategists have recently heard about his ideas.)

The splintered, disorganized nature of insurgencies became still clearer when Johnson and his colleagues looked at the timing of attacks. The numbers in Iraq, Colombia, Peru, and Afghanistan followed similar patterns, with "sudden bursts of activity, then quiet periods," Spagat says. "If it were random, you would have far fewer busy days and far fewer quiet days than are captured in the data." Without a centralized command to issue orders, there must be something else behind the clustered timing of attacks.

Spagat and Johnson argue that the missing element is the role played by media and other sources of information. For an insurgent group, a successful strike is not one that does the most damage, but one that draws the most attention. "Media and publicity are the oxygen of terrorism," says anthropologist Scott Atran, an expert on terrorism at the National Center for Scientific Research in Paris. "Without them, it would die."

Spagat likens the relationship between the dozens of groups in Iraq and the media to drivers at rush hour. Much as drivers try to outguess other drivers to pick the least-traveled route home, the data suggest that terrorists and insurgents aim to stage their attacks when they will have the media's undivided attention. "Instead of competition for road space, there's competition for media space," he says. "You want to be the only person making an attack on a given day. If there are more than a few attacks on a given day, your story tends to get lost in the system."

But since there is no one to coordinate attacks, the resulting patterns are "bursty," a term used to describe many real-world events that unfold in short, intense fits. Think of the traffic jams that seem to come out of nowhere and disappear just as quickly. They are the product of thousands of drivers with incomplete information trying to outguess thousands of other drivers trying to pick the best route home. Sometimes enough people will guess wrong and spend two hours sitting on the freeway.

As fascinating as their mathematical patterns are, Johnson and Spagat remain far from their goal: anticipating attacks and being able to stop them. Atran says the researchers' findings bear out what he has seen during his fieldwork on the psychology of suicide bombers and the importance of media attention. But that level of understanding is not good enough. In the end, the math may not explain it all, he contends. "Insurgencies are sui generis; each takes place within its own social, cultural, and political milieu. Trying to create a unified model is a fool's errand. I don't think there is enough cultural awareness of what moves people to do what they do."

Cultural context is not something Johnson pays much attention to. Accustomed to analyzing particles, which are not known for their reasoning capabilities or complex inner lives, physicists tend to ignore the why and go straight to the how. “All those questions of ‘why’ show a lack of understanding,” Johnson insists. “Whatever the reasons are, this is how they operate.” He has explained this to British and American military officers, Iraqi officials, and even security officials at the London Olympics. “Insurgents may be doing it for all sorts of reasons, but the mechanics are what matters.”

That kind of talk makes many counterinsurgency analysts bristle. Andrew Exum, a fellow at the Center for a New American Security who led a platoon of Army Rangers in Iraq and Afghanistan, says that quantitative analysis is a useful tool, but only when it is sensitive to the complexities of real-life situations and is coupled with the expertise of someone well versed in the specific political and religious contexts at hand, as well as in military strategy. “I'm turned off by the confidence with which these scholars presented their model,” he says. “A little more humility might have been in order.”

The complaint has definite resonance in the wake of the recent financial crisis, which saw Wall Street quants creating ostensibly rational models that drove the financial markets to the brink of disaster. While academic physicists like Johnson try to account for the behavior of the traders in their models, the standard quant approach is based on markets moving at random. It is an approach that Johnson is eager to distance himself from. “If you account for human collective behavior, you get results that are different from the standard quant models,” he says. “We started looking at financial models precisely because we thought crashes were not properly taken into account.” From a distance the difference can seem academic; to most people, a computer model is a computer model. Johnson admits he has had as little luck selling his power law approach to firms on Wall Street as to traditionalists in the military.

Former Special Operations pilot Robb, an advocate of the mathematical approach, says the cool reaction to the quantitative analysis of terrorism is par for the course. During the Vietnam War, soldiers blamed the number crunchers—those informing decisions in the Pentagon based on body counts and kill ratios—for the war's bad turn. As a result, “a lot of people think counterinsurgency is very qualitative, very mushy, and should stay that way. It's almost a mystical thing,” Robb says.

“Nothing we've done suggests we can predict there will be an attack in, say, the next two weeks,” Spagat freely concedes. “Rather, a physics-inspired insurgency model can help guide more general decisions. If the data show that attacks happen in a bursty pattern, it makes sense to have emergency medical teams able to react to several attacks at once. And the data offer a rough guide to how big those attacks might be, based on how they've looked in the past.” Moreover, he says, if the model is right about modern insurgencies' being a constantly shifting collection of small, unconnected groups, it would be a useful tool for military planners trying to find the most effective tactics. Notable military research groups such as Mitre and the Pentagon's IED Defeat Organization have met with Johnson and Spagat to talk about their work. During the course of such meetings, Johnson must counter the ingrained notion that human behavior is uniquely complex and unpredictable.

Never before have researchers had ready access to decades' worth of social data that could be analyzed, and never before has it been so easy to find patterns amid the complex streams of numbers. As the world learned after the Wall Street crash, finding patterns is not the same as understanding which ones are meaningful and acting on them in a responsible way. But given the rush of numbers, the analytical approach of physicists and economists—on Wall Street and now in war—will inevitably keep spreading, Clauset says, "We are entering an era in which social sciences have access to a wealth of data beyond their wildest dreams."