Magazine Feature Story

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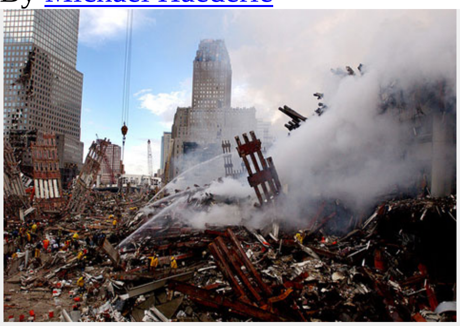
The Physics of Terror

After studying four decades of terrorism, Aaron Clauset thinks he's found mathematical patterns that can help governments prevent and prepare for major terror attacks. The U.S. government seems to agree.

By Michael Haederle



Aaron Clauset is one of a handful of U.S. and European scientists searching for universal patterns hidden in human conflicts — patterns that might one day allow them to predict long-term threats. (slagheap/Flickr.com)

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Last summer, physicist Aaron Clauset was telling a group of undergraduates who were touring the Santa Fe Institute about the unexpected mathematical symmetries he had found while studying global terrorist attacks over the past four decades. Their professor made a comment that brought Clauset up short. "He was surprised that I could think about such a morbid topic in such a dry, scientific way," Clauset recalls. "And I hadn't even thought about that. It was just … I think in some ways, in order to do this, you have to separate yourself from the emotional aspects of it."

If the professor's remark gave Clauset pause, it was the briefest instant of hesitation in a still-unfolding scientific career marked by a string of self-assured, virtuoso performances. At 31, he has published in fields as diverse as paleobiology, physics, computer science, artificial intelligence and statistics, spent four busy years as a research fellow at the Santa Fe Institute and secured a spot at a University of Colorado think tank.

He also has the unusual distinction (at least for a scientist) of having once been a cast member on a reality television show.

But it is his terrorism research that seems to be getting Clauset the most attention these days. He is one of a handful of U.S. and European scientists searching for universal patterns hidden in human conflicts — patterns that might one day allow them to predict long-term threats. Rather than study historical grievances, violent ideologies and social networks the way most counterterrorism researchers do, Clauset and his colleagues disregard the unique traits of terrorist groups and focus entirely on outcomes — the violence they commit.

Call it the physics of terrorism.

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“When you start averaging over the differences, you see there are patterns in the way terrorists’ campaigns progress and the frequency and severity of the attacks,” he says. “This gives you hope that terrorism is understandable from a scientific perspective.” The research is no mere academic exercise. Clauset hopes, for example, that his work will enable predictions of when terrorists might get their hands on a nuclear, biological or chemical weapon — and when they might use it.

It is a bird’s-eye view, a strategic vision — a bit blurry in its details — rather than a tactical one. As legions of counterinsurgency analysts and operatives are trying, *24*-style, to avert the next strike by al-Qaeda or the Taliban, Clauset’s method is unlikely to predict exactly where or when an attack might occur. Instead, he deals in probabilities that unfold over months, years and decades — probability calculations that nevertheless could help government agencies make crucial decisions about how to allocate resources to prevent big attacks or deal with their fallout.

“I would really like to be able to get some broad sketch of what the next 50 years of conflict is going to look like, because that’s what the long-term planners need to know,” he says.

This comprehensive approach explains why Clauset — more of a friendly, super-smart hipster than a Dr. Strangelove — has been invited to consult with the Department of Defense, the Department of Homeland Security and other government agencies. “His is some of the most important research in the statistics of complex adaptive systems being done today,” says Ken Comer, a deputy director of the Joint Improvised Explosive Device Defeat Organization, or JIEDDO, which is leading the defense department’s all-out effort to combat IEDs. Because Clauset has shown that terrorism obeys the arcane laws that seem to govern complex systems, it follows that ordinary predictive tools are useless for guessing when and where terrorists might strike. That knowledge saves the government critical time and resources, Comer says: “He keeps me from going down some blind alleys.”

We’re sitting on a shaded porch at the hilltop campus of the Santa Fe Institute, the fabled theory shop set up in 1984 by a band of researchers from nearby Los Alamos National Laboratory. On this warm, clear summer afternoon, it seems like we can see half of northern New Mexico, with rugged mountain ranges 50 or 60 miles away standing out in stark relief against blue sky. In such a serene setting, it seems surreal to be comparing the lethal tactics and timing of the Tamil Tigers with those of the Taliban, Hamas and the Irish Republican Army, but that is how Clauset has spent much of his time over the past seven years.

After mapping tens of thousands of global terrorism incidents, he and his collaborators have discovered that terrorism can be described by what mathematicians call a power law. Unlike the familiar bell curve — where most events tend to cluster around the average, with only a small number at the margins — a power law distribution produces a wide range of highly dissimilar events.

Physicist Aaron Clauset

A graph comparing the severity of terrorist attacks — how many die — and their frequency produces an L-shaped relationship that mathematicians often describe as having a “long” or “heavy” tail. One would expect to see thousands of small attacks that kill no one or at most a handful of people, a few hundred events that kill a dozen people, a few dozen events that kill a hundred, and a handful of 9/11-scale attacks.

Using this power law relationship — called “scale invariance” — the risk of a large attack can be estimated by studying the frequency of small attacks. It’s a calculation that turns the usual thinking about terrorism on its head. “The conventional viewpoint has been there is ‘little terrorism’ and ‘big terrorism,’ and little terrorism doesn’t tell you anything about big terrorism,” Clauset explains. “The power law says that’s not true.”

Massive acts of violence, like 9/11 or the devastating 1995 bombing of the U.S. embassy in Nairobi, obey the same statistical rules as a small-scale IED attack that kills no one, Clauset’s work suggests. “The power law form gives you a very simple extrapolation rule for statistically connecting the two,” he says.

Although the U.S. and European nations have remained for years in a semipermanent state of high alert, the majority of terrorist attacks actually occur in the developing world, the data show — yet they are not the most severe. “Terrorist attacks happen less often in the developed world, but when they do happen, they’re often bigger than in the developing world,” Clauset says. “That was striking. We have no explanation for why that was the case.”

The size of terrorist groups is also an important variable. “The bigger they are, the faster they attack,” he says. “Most groups probably start small. They attack, they gain notoriety, they get some recruits and they get bigger. Once they reach a certain size, they can last longer.”

Yet gaining experience in committing violence doesn’t necessarily make terrorists more lethally efficient. “The severity of attacks for groups that have done a hundred attacks, versus the severity of attacks in groups that have done 10 attacks is no different,” he says. “They don’t actually get any better at killing people. They just try more often.”

When terror attacks are broken down by weapon types, explosives are responsible for 44 percent of the deaths, while firearms account for 36 percent, their study shows. The remaining 20 percent include unconventional weapons, chemical or biological weapons, fire and knives.

Why, I ask, should there be these regular patterns in terrorist attacks among unrelated groups, irrespective of geography or ideology? It is a question Clauset gets asked frequently.

“It may be that there is something fundamental at play, that a notion like self-organized criticality is somewhere lurking underneath,” he responds. “I’m skeptical of that hypothesis for terrorism, in particular, but it may be the answer in the end. I don’t know.” If terrorist attacks really are power-law distributed, he says, a more likely possibility is that “there might be some kind of fundamental social or political process underneath that creates this very special kind of pattern.”

“My childhood wasn’t one of these stereotypical scientist childhoods where I was taking things apart,” says Clauset, who grew up in Winston-Salem, N.C., the child of two scientifically minded educators. He did embrace computers at a young age, learning to program on an Apple IIc. Later, he discovered physics, astrophysics and cosmology with an early CD-ROM.

At Haverford College, he hoped to double major in physics and sociology, but he grew disenchanted with the latter after taking only two courses. “Even Newtonian mechanics is more advanced than the best social theory we have, and Newtonian mechanics is 300 years old,” he says.

Clauset’s love affair with computer modeling began when he tried simulating evolution with algorithms. “I was fascinated by the idea that I could have an ecosystem inside my computer,” he says. “I could leave in the evening and come back the next morning, and something weird would have happened overnight.” He moved on to the University of New Mexico for his doctorate, drawn in part by its proximity to the Santa Fe Institute, a place where he could hone his skills in evolutionary computation.

On a trip to New York in 2004, he happened to visit an actress friend who worked for an agency that was casting *Average Joe*, an NBC reality series. “She got tickled with the idea of me going on it, and after a couple of days, convinced me to try,” he says. After an audition, he was invited to join the cast.

The premise: A group of regular-looking guys would compete for the heart of a beautiful, unattached woman (a redheaded car-show model, in this case). Clauset — tall, on the skinny side, with gold-rim glasses framing his wide-set blue eyes — fit the bill as the wonky computer scientist wading into the deep end of the dating pool. He made it through two episodes of competition before being eliminated.

He still gets teased about it, yielding a scientific insight of a different order: “I learned a very valuable lesson, which is that a little bit of embarrassment on your part leads to a lot of enjoyment on your friends’ part.” Romance won out in the real world, though. Last year, he married Lisa Mullings, a nutrition educator who, until recently, worked for the state of New Mexico. “I often joke that Lisa’s having a more important impact on the world than I am,” he says.

In December 2006, Clauset took a postdoctoral fellowship at the Santa Fe Institute, an incubator for big ideas that brings together scholars with vastly different backgrounds — from computer scientists and physicists to linguists, economists and anthropologists. “You’re encouraged to think outside the box and interact with people from other disciplines — to find new ways of attacking old questions and to come up with new questions that no one had thought of before,” he says.

That may be as good a description as any of what goes on inside the notoriously hard-to-define institute, which is housed in a 1950s Santa Fe Territorial-style mansion with a new wing grafted on to provide quarters for nearly 100 faculty, fellows, visitors and staff. Visitors commonly encounter major-league science talent, like Murray Gell-Mann, the Nobel Prize-winning physicist who helped found the institute, but on this afternoon I notice novelist-in-residence Cormac McCarthy shyly mingling at the 3 p.m. tea, a daily ritual meant to draw people out of their offices. Valerie Plame Wilson, whose career as a covert CIA officer was torpedoed by I. Lewis "Scooter" Libby's indiscretion, works in the development office.

One of Clauset's first projects at the institute was an effort to tease out simple evolutionary rules governing mammalian body size. He saw a tradeoff between the survival advantages of animal species that grow larger — and thus better able to regulate body temperature, control food sources and avoid predation — and the disadvantages, which include smaller population, lower birth rate and increased sensitivity to environmental changes. "You have a few really big things, like elephants and whales, and many, many small things, like mice and other kinds of rodents," Clauset says. "This tradeoff is what generates this asymmetric pattern."

Over the past two years, Clauset has published a series of papers calculating the effects of macro-evolutionary forces with a simple model that intentionally omits many of the classic processes recognized in evolution, such as competition among species, geography, predation and population dynamics. "It all comes back to this idea that you don't have to know all the details of processes in order to understand how the interactions lead to patterns," he says.

His computer model generates a curve that nicely matches the real-world size distributions for some 4,000 recent mammalian species. "You don't often see models do that," he says. "They usually require more tinkering." Clauset, who claims he hasn't taken a biology course since the 10th grade, expects to deepen his understanding of biology in his new role as an assistant professor at the Colorado Initiative in Molecular Biotechnology, an interdisciplinary research center at the University of Colorado in Boulder.

He and some collaborators there are trying to see if genetic algorithms can be used to shape bacterial evolution, with the admittedly ambitious hope that their metabolism could be coaxed into reversing the combustion cycle, turning carbon dioxide back into fuel. It's classic Clauset, careering between abstract theoretical questions and real-world threats as imminent as terrorism and global climate change. "I like to have one foot in both worlds," he says. "I like to do things that increase understanding, but I want to do things that have an impact as well."

Ever since the retired Athenian general Thucydides sat down to ponder the catastrophic, nearly 30-year-long war that enveloped the Hellenic world 2,400 years ago, people have sought to comprehend human conflict. Why do wars arise, and why do they persist? What determines who wins and who loses?

For the most part, these questions have been addressed by social scientists — historians, political scientists, sociologists, economists and the like. But 60 years ago, Lewis Fry Richardson, a British physicist, mathematician and pacifist who had served as an ambulance driver in World War I, published *Statistics of Deadly Quarrels*, in which he compiled data on most of the wars from 1820 to 1950, classifying them by their magnitude. Among other things, Richardson found there were many more small conflicts than large ones.

Clauset had never heard of this research when he and a computer scientist friend named Maxwell Young started talking about modeling terrorism in 2003, about the time the U.S. invaded Iraq. Clauset realized he could apply the same simplified, data-averaging technique to terrorism as he had to mammalian body sizes. “It all comes back to this idea that you don’t have to know all the details of processes in order to understand how the interactions lead to patterns,” Clauset says. “It turns out no one had really thought about taking this approach to thinking about terrorism — looking at the big patterns.”

Standard counterterrorism research approaches its subject in essentially human terms: Why do people resort to violence or join terrorist groups? Are they poor, disenfranchised or uneducated? “They’re really interested in the ‘why’ questions,” Clauset says. “I said to myself, ‘I don’t care why people do it. I want to know how. Given that they’re going to do it, what do they do? When do they do it? How big do they do it?’”

Clauset and Young (later joined by University of Essex political scientist Kristian Gleditsch) found a database of worldwide terrorist attacks that had been maintained by the Oklahoma City-based Memorial Institute for the Prevention of Terrorism. A U.S. Department of Homeland Security training partner, MIPT recorded 36,018 terrorist events in 187 countries from 1968 to 2008, of which 13,407 attacks had killed at least one person.

Plotting the frequency of the 13,000 lethal attacks against their severity yielded an unexpected pattern: The more frequent attacks resulted in relatively fewer deaths, while the infrequent big attacks killed the most people, Clauset found. Such scale-invariant patterns can be detected in many phenomena that follow power laws: the variety of global languages, urban populations, financial markets and earthquakes, for example.

The researchers tried slicing the data in different ways, cataloguing attacks in industrialized versus nonindustrialized countries, as well as by the kind of weapon used, and were surprised to find that the most severe attacks were clustered in the developed world. Clauset has a theory about why that might be. “On the one hand, you have the physics of population density fluctuation — where people go, when they’re there and how many people are there at that time,” he says. “Then you have targeting, which is strategic. The terrorists can choose where they put the bomb and when it goes off.”

Because terrorists aim for high-density (hence high-visibility) targets, “the bombs are attracted to where the people are” — trains and airplanes, for example.

Clauset finds this model intellectually satisfying. “It’s bridging this world between the physics side of things and the social-science, motivation-behavioral side of things,” he says, “and it’s the combination of those two effects that gives you what we see.”

Where the identity of the perpetrators could be determined, he has also found that contemporary “fourth wave” terrorism fueled by religious extremism differs in a critical respect from earlier waves — 19th-century anarchism, the anti-colonialist insurgencies of the early 20th century and Cold War-era revolutionary movements. “Religious groups accelerate their attacks faster than secular groups,” Clauset explains. “We come back to this growth dynamic: Religious groups grow faster than secular groups, and this may be because of that pool of people that are sympathetic to the rationale.”

Clauset soon came to realize that his findings about terrorist groups were an extension of Richardson's broader research into human conflicts. "He really started all this," he says. "I draw a line from what I'm doing right back to him. He was an inspiration in many ways."

This is all fascinating, I tell Clauset, but I have to ask: Just how significant are these findings? After all, most counterterrorism researchers are grappling in real time with the most urgent of problems — how to avert mass carnage in the next terror attack. "I can't tell you whether next Tuesday there's going to be an attack somewhere, or who's going do it, or why they're going do it," he concedes. "I can tell you about the overall patterns, which allows me to do some interesting things, like ask, 'What's the risk of events the size of 9/11? How often do they happen? Are there patterns in the past that let us paint a broad picture about what might happen in the future?'"

With information on frequency and patterns, decision-makers can better allocate resources to deal with serious long-term threats, he says. There is, for example, a "very real" danger of an attack even more devastating than the 9/11 plane hijackings, in which nearly 3,000 died. "The danger comes from nuclear, primarily," he says. "It's well within the realm of possibility within the next 50 years that a low-yield nuclear bomb is detonated as a terrorist attack somewhere in the world." Such a bomb could kills tens of thousands of people, depending on when and where it goes off.

Clearly, that is an eventuality society might want to be prepared for.

On the other hand, Clauset's findings might also take some of the terror out of terrorism, which draws its power from its shadowy, unpredictable nature. For example, knowing a group's size should enable governments and law enforcement to gauge the true threat it poses (because the power law proves that size determines the frequency with which it can attack).

"It tells you that while a lot of things are flexible — different terrorist organizations are very different — there are a couple of things that they can't change," Clauset says. "That means that even if they know that we know this, they can't do anything about it."

Yet he has learned the hard way to be wary of claiming too much. In a 2005 draft of their paper, Clauset and his collaborators projected that another 9/11-magnitude attack would occur within seven years, a finding that sparked newspaper headlines ("Physicists Predict Next 9/11 In Seven Years"). Clauset now says there were too many uncertainties in the data to make such a specific prediction. "What we had said was, if the future is exactly like the past and the assumptions of the model are correct, this is what you would expect," he says. "But that number I don't trust."

Comer, deputy director of the government's anti-IED effort, says Clauset's new approach to modeling terrorism arrived at the right time. "The interesting part of it all is we didn't commission Aaron to start working that topic," Comer says. "We were looking for researchers doing an advanced statistical reconstruction of our kinds of data and came upon his research." But, Comer says, Clauset clearly grasped the import of his own work: "When we did finally show up at Santa Fe Institute to chat with him, he said, 'I was wondering how long it would take the Department of Defense to look me up.'"

The war in Afghanistan, where NATO troops have suffered hundreds of casualties in IED attacks, represents a model of asymmetrical warfare in which the "enemy" might be farmers by day — or even government policemen — and Taliban fighters by night. Leadership structures are less important to the overall movement because individuals or small cells are making their own tactical decisions, so analysis based on the model of opposing armies tackling one another head-on is nearly useless, Comer says. "This is so far beyond the typical quantitative analysis that the DOD has done for decades," he says, "[that] we'd better be talking to the Aaron Clausets of the world."

Gary LaFree, who directs the National Consortium for the Study of Terrorism and Responses to Terrorism at the University of Maryland, says his center is considering funding one of Clauset's projects. A criminologist by training, LaFree calls the discovery of power-law distributions in terrorism a "paradigm shift" that extends to other kinds of criminal behavior. "You don't get the 'aha' moments very often in the business," he says, "but this is one of them."

LaFree notes that ever since 9/11, policymakers have focused their planning on preventing another epic attack, spending billions of dollars, but that response is based on a distorted view of the threat. "The typical terrorist attack involves zero casualties, occurs in Latin America and involves groups in existence for less than a year," he says. "If you base public policy around 9/11, most of the time you're wasting your energy."

LaFree predicts Clauset's work will change the way social scientists look at crime and terrorism — eventually. "I think it's going to take some time," he says, "because it's a pretty big departure from the way people think about these things."

Some people in the counterterrorism establishment are politely skeptical about Clauset's work. Walter L. Perry, a senior information scientist at RAND Corporation who has worked with battlefield commanders in Iraq to make next-day predictions of when and where insurgents might mount IED attacks, says the predictive power of mathematics-based forecasts improves when more is known. "We talk about getting inside the enemy's decision-making loop," he says. With the Iraq project, "we looked at more recent historical data. What happened six months ago was of no use to us. We looked at what took place within the last month."

Their model achieved 35 percent accuracy, Perry says, information for which the commanders were grateful. It's a classic example of applied operations research, a field that RAND in its earliest incarnation helped develop during World War II.

The level of abstraction used by Clauset and other researchers makes Perry uncomfortable. "If they could do it, it would be useful," he says of their long-range forecasting. "I'm a little bit skeptical that something like that can actually be done. The groups that do these terrorist attacks are loose cannons: There's no two alike, and it's all very localized and depends on local grievances." Inevitably, he says, such long-term modeling implicitly assumes that the past is prologue to the future — and that's a big assumption.

Clauset finds such objections familiar; after all, reviewers for some academic journals have rejected his papers, and analysts trained in the social sciences often deny that there might be impersonal patterns to human behavior. He finds the reliance on social-dynamic analysis in much of the counterterrorism establishment “discouraging.”

“There’s a sort of belief that if we can map the friendship network of Afghanistan, we’ll know who to kill,” he says. “I think that’s misguided.”

Clauset has his own theories about why common patterns emerge among global terrorist groups, one of which involves organizational dynamics. “There are fundamental constraints on the behavior of terrorist organizations that look very similar to the kinds of constraints that startup companies face — that all social groups in some ways face,” he says. “This limit is manpower.”

Like small companies, Clauset says, terrorist groups are made up of highly motivated people looking to make a product — terror attacks. “Both of these face the problem that they need to grow, or they’re going to die,” he says. With small groups, if a key member leaves, it’s a major blow; with a larger work force, one person’s departure doesn’t matter as much.

That’s why the U.S. decapitation strategy has failed to subdue insurgent groups, he believes. “Someone was joking a few years back about how we’ve killed the No. 3 al-Qaeda guy in Iraq 20 times,” he says. “They keep replacing him with somebody else. We need to understand the phenomenon, not the network. The network is the manifestation of the phenomenon.”

These ideas were given powerful expression in a high-profile paper published by Army Maj. Gen. Michael T. Flynn and several collaborators in January 2010. Called “Fixing Intel: A Blueprint for Making Intelligence Relevant in Afghanistan,” the paper argued that military intelligence units are fixated on identifying the individuals responsible for IED attacks without probing the larger social context within which those people operate.

“Analysts painstakingly diagram insurgent networks and recommend individuals who should be killed or captured,” they wrote. While aerial drones scan the countryside 24/7 in the hope of spotting insurgents burying bombs, “relying on them exclusively baits intelligence shops into reacting to enemy tactics at the expense of finding ways to strike at the very heart of the insurgency.

“These labor-intensive efforts, employed in isolation, fail to advance the war strategy and, as a result, expose more troops to danger over the long run.”

One measure of the seriousness with which the defense establishment regards Clauset’s research is the number of entities for whom he has consulted. In addition to the anti-explosive device group JIEDDO and START, the University of Maryland’s terrorism study consortium, they include the Defense Advanced Research Projects Agency, the U.S. Naval War College’s Strategic Studies Group and the science and technology office of the Department of Homeland Security.

He has also collaborated with The MITRE Corporation, a McLean, Va., nonprofit that oversees highly classified research contracts for the Defense Department and other national security agencies. Brian F. Tivnan, chief engineer in MITRE’s modeling and simulation department, says he followed the work of Clauset and Neil Johnson, a University of Miami physicist who has published his own mathematical model of terrorism, for some time before convening a meeting of top researchers and defense officials at the Santa Fe Institute in August 2009. Along with Clauset, Johnson and Comer, the participants included Peter Dodds and Chris Danforth, University of Vermont computational social scientists who have developed tools for measuring the collective mood of a population based on Internet data, Tivnan says.

There's one not necessarily obvious benefit to this type of data-driven terrorism research: It is less prone to the ideological distortion that accompanies more subjective analyses, says Tivnan, who emphasizes he can speak for himself and MITRE, but not for government agencies. "When we start thinking about the implications for national security, it first broadens the perspective beyond Sept. 11, 2001, in the United States," he says. "Analytically, we've looked at other kinds of conflict and terrorism itself for several decades. Aaron did a magnificent job in characterizing the dynamics of terrorism over the better part of four decades. From a scientific standpoint, it forces the conversation to remain analytical and apolitical, which is very important."

Working as he does almost within sight of the Los Alamos lab where the first atomic weapon was designed, Clauset is aware of the real-world implications of his research, and he says that scientists working in and around national security need to be careful. Johnson, for example, has speculated that his own model might indicate whether small teams of peacekeeping troops should be deployed to fight individual terrorist cells, Clauset says. "Many of the things he suggests are not things the model predicts at all," he says. While such a suggestion might be reasonable and echo established counter-insurgency doctrine, it's also advice that, if acted upon, could get troops killed.

"That's where I would exercise caution," Clauset says. "Some people make strong claims about what their models show. I don't know if policymakers are sensitive to these issues. Like many people, they trust scientists to be conservative and cautious. Scientists trust the policymakers to be conservative and cautious.

"The end result is that probably, over the last eight years, a lot of people have been killed that didn't need to be killed — whether on our side or on everybody else's side."

In regard to his own research, he says, any timeline of prediction is so long that no one would be directly targeted for elimination as a result of his advice. Still, there are times when he sets aside the abstractions with which he is most comfortable.

"It is weird when you step back and say, 'There are thinking, social beings in these organizations, they have families and causes and ideals and so on.' And I'm thinking about them as being a little bit like particles. "But," he says, "the patterns speak for themselves."