tain Gabba "just laughed and pushed him away." Gabba floated calmly downstream, and if he was anything like the Rangers I'd known, he must have felt that he was in no real danger because of all the training he'd had under much worse conditions. He must have felt good, too, masterful, confident. He'd eaten, he'd slept—hell, he could do this until the wheels came off. Then he arrived at a place where a big rock blocked the middle of the current. Gabba was sucked under, pinned, and drowned. The official report said, "The guest clearly did not take the situation seriously." But that's not true. He took it very seriously.

It's easy to see hubris in Gabba's behavior, but it's more subtle than that. Everyone carries around a necessary measure of his environment and of the self. From conception onward, the organism defines what is self and what is not. The immune system examines materials from the environment to assess whether they are a threat or harmless. Cells within that system hold up proteins in an almost ritualistic way so that T-cells can read them and see if they are self or foreign. If a T-cell recognizes the protein as self, it commits suicide. If the protein is unfamiliar, the T-cell gives the B-cell permission to create an antibody, which helps mobilize an attack to destroy the invading protein.

In that and other ways, the immune system continuously rearranges the organism's relationship to its environment. That's called adaptation. A lifetime of experience builds the system, but a subtle change in the environment can mean that the system no longer has the correct response. It's suddenly out of adjustment. For example, when Europeans brought unfamiliar diseases west with them in the 1500s, the previously healthy and thriving Native Americans were rapidly wiped out. But some creatures are amazingly adaptable. At the beginning of summer, I used to have hundreds of crows circling my house at dawn, barking noisily. Then one morning they were all gone. They'd been threatened by the West Nile virus. They went away for months. Now they're back. Crows are survivors.

models of the words. You don't read each letter to decode the word, as a child who is learning to read must. But if you come across words that are too similar, such as psychology and physiology, you may have to pause.

The fact that new information, especially emotionally charged information, forces things out of working memory means that we can't pay active attention to too many things at once. Unless something is successfully transferred from working memory into long-term memory, it is lost to conscious awareness. We all have this experience when we try to memorize something that has no emotional content, such as an address or driving directions. In most people, the executive function can do one task at a time, and attempting to perform simultaneous tasks that involve a conflict begins to break it down. For example, if you flash the word "blue" printed in green ink on a screen for a second and then ask someone to say the word or the color, he'll have to stop and think before he answers.

The limited nature of working memory (attention) and the executive function, along with the shorthand work of mental models, can cause surprising lapses in the way we process the world and make conscious or unconscious decisions. That is why even experts can miss things that are right under their noses. In May 1989 Lynn Hill, one of the most famous rock climbers in the world, was in Buoux in southern France preparing to climb a one-pitch bolted route. Bolted routes are where beginners start, because they are the safest of climbing environments. Hill and her husband were simply climbing it as a warm-up. She became distracted as she was tying the rope to her harness and didn't finish her knot. The task of tying the knot had been in working memory when a conversation with a Japanese woman nearby and the act of putting on (and tying) her shoes bumped it out. (With conflicting demands on working memory, she may have unconsciously substituted tying her shoes for tying the climbing rope.)

As Hill walked back to begin her climb, there was a slight residue of the memory left, but it had not been completely formed. "The thought occurred to me that there was something I needed to do before climbing," she wrote in *Climbing Free*. The fragments of a half-formed memory had left a gut feeling, an emotional bookmark, and she considered taking off her jacket, which would have revealed the half-tied knot, but "I dismissed this thought."

She climbed to the top unaware of the trap she'd set for herself. She had created a mental model that had worked in the past. She was now depending on it to match reality. She asked to be lowered, put her weight on the rope, and the half-tied knot came loose. She fell 72 feet. A tree barely saved her.

CHARLES PERROW is a sociologist known for studying industrial accidents, such as those that occur with nuclear power plants, airlines, and shipping. In *Normal Accidents*, he wrote that "We construct an expected world because we can't handle the complexity of the present one, and then process the information that fits the expected world, and find reasons to exclude the information that might contradict it. Unexpected or unlikely interactions are ignored when we make our construction." The snowmelt in the Siskiyou Mountains, the unseasonal rains, were unexpected and unlikely interactions in a system involving water, air, gravity, and terrain faced by boaters on the Illinois River. The possibility that the river could rise 15 feet to reach a flow rate of 20,000 cubic feet per second was outside the normal experience of the river's guides, contradicting their model. It may seem difficult to believe that they could have missed the trees zooming down the river and the noise it was making, but it might be easier than it seems. In fact, the two people in the shredder were caught for a time in a violent eddy, along with a floating tree.

Mental models can be surprisingly strong and the abilities of working memory surprisingly fragile. A psychologist who studies how people behave when they're lost told me, "I saw a man I was hiking with smash his compass with a rock because he thought it was broken. He didn't believe we were heading in the right direction."

PSYCHOLOGISTS WHO study survival say that people who are rule followers don't do as well as those who are of independent mind and spirit. When a patient is told that he has six months to live, he has two choices: to accept the news and die, or to rebel and live. People who survive cancer in the face of such a diagnosis are notorious. The medical staff observes that they are "bad patients," unruly, troublesome. They don't follow directions. They question everything. They're annoying. They're survivors. The *Tao Te Ching* says:

The rigid person is a disciple of death;
The soft, supple, and delicate are lovers of life.

SIX

THE SAND PILE EFFECT

AT ABOUT TEN minutes to nine on Thursday morning, May 30, 2002, Bill Ward sat at the top of Hogsback Ridge on a natural shelf just below the summit of Mount Hood in Oregon. His team of four climbers had begun its descent. Chris Kern was a forty-year-old investigator for the New York appellate court. Harry Slutter was his old friend from Long Island. Slutter had met Ward, an experienced climber, through his job with a large commercial nursery that had offices in New York and Oregon. Ward, in turn, had brought along his friend Richard (Rick) Read, a local Oregonian who'd never climbed a mountain before.

Read, who would be dead within the hour, had been led to believe that Mount Hood was a beginner's mountain, suitable for his first climb. Unfortunately, there's no such thing as a "beginner's mountain." It's a concept that doesn't work, like beginner sex. One difficulty is that the standard route up (and down) Mount Hood is not technical. It's more of a hike on a steep snow field. On a good day, you can walk it without crampons, snap some pictures on the summit, and be back at the Timberline Lodge ski resort for

New Zealand fire-broiled spicy lamb loin chops. It's a dangerous illusion, because success depends on doing everything perfectly. Any fall is apt to be a very long one into inhospitable terrain. Mount Hood is an active volcano, with glaciers, ice fields, sudden 140-mile-an-hour winds, and rime ice. The fumarole, a volcanic vent, sucks in those who fall and suffocates them with hydrogen sulfide gas. People slip and accelerate across the ice, slam into the Steel Wall, and die on the rocks. Sudden whiteout blizzards leave people wandering for days in the Zig-zag Wilderness Area or the crevasse field on the Eliot Glacier. Mount Hood claims at least one life each year. Some years, as in 2002, it claims a lot more.

Starting at about eight-thirty in the morning, Bill Ward and his crew had descended from the summit and gathered on the shelf above the steep Hogsback Ridge, a graceful catenary arc of ice that descends 1,000 feet from the summit. Kern put his ax into the snow as an anchor and belayed Slutter. He made sure that there was no slack as he fed the rope out to Slutter for his descent. If Slutter fell, the taut rope would stop him before he got going too fast. Recent rains—freezing at night, partly thawing by day—had turned the snow into a mixture of hard ice and soft slush, making it easy to fall but difficult to stop.

They had practiced self-arrest techniques in the days leading up to the climb. Everyone, including Rick Read, the novice, had been able to stop. When one person on a team falls, he's supposed to shout, "Falling!" and all the others are supposed to throw themselves down and bury their ice axes in the snow. The rope tying them together should arrest the fall. With experience and practice, it becomes second nature, a secondary emotion, such as Remarque's soldiers had developed in response to the whistling of high-explosive shells. But although it had worked in practice, belaying from a fixed anchor is more reliable.

Once Slutter had descended 35 feet, Ward put his ice ax in, wrapped the rope around it, and belayed Kern. Kern pulled his ice ax out of the snow and started down. As he moved, so did Slutter, in order to keep the rope taut.

The plan, the idea, was that everyone would move down on belay one at a time until there was no slack in the rope. Anyone who fell would fall only a few inches. Then, lined up like beads on a string on the 1,000-foot ridge, they'd pull the last ice ax and walk carefully down the mountain.

Ward and Read watched from the ledge until the rope was taut. Then Ward belayed Read, who descended his 35 feet, taking up the slack between himself and Ward. Slutter and Kern moved, too, to keep the rope taut.

When they'd played out all their rope, Slutter was 105 feet below the shelf, Kern was 70 feet down, and Read was 35 feet below Ward, who still sat on the shelf with his ice ax in, protecting the team. Now Ward stood and pulled his ice ax from the snow and the only thing holding them to the mountain were the crampon points. The system was free to behave as it might.

It was a simple theory, and from my interviews of the survivors, it was clear that they'd given it a lot of thought. The difficulty with the theory was that the top man, Ward, must not fall. (The order from top to bottom was Ward, Read, Kern, and Slutter.) If you drop a brick 6 inches, you can probably catch it safely. If you drop a brick out a third-story window, it could hurt somebody. There were 35 feet of rope between Ward and the second man, Read. If Ward fell, he'd have to go 70 feet before the slack was gone. Think about catching someone who's fallen from a seven-story building. It's all about energy levels, and while they didn't put it this way, the climbers were attempting to manage the vast amounts of energy they had put into a system of rope and weights. Only at an instinctive level did they understand that it was critical to keep that energy from escaping all at once. Ward, being the most experienced, was at the top. Surely, he wasn't going to be the one to fall. Everyone was worried about Read. The word "experienced" often refers to someone who's gotten away with doing the wrong thing more frequently than you have.

By roping themselves together, they had created a deceptive system. A rope is simple, yet capable of surprisingly complex behavior. It can transmit all the force imparted to it from an infinite number of points along its length. It can double and double again. It can transmit force along its length and deliver it somewhere else. It can stretch, shrink, vibrate, and break. It is such an elegant equation. But powered by the infinite resource of gravity and coupled to four bodies, it turns out to be capable of a staggeringly complex array of outcomes.

Slutter, the lowest man on the rope, was looking down at some other climbers. The two nearest ones had celebrated with him and his team just half an hour earlier, snapping photos, laughing, sharing water and candy bars on the summit. Slutter could see them now: John Biggs and Tom Hillman, both from California. Hillman was a Methodist pastor, Biggs was his parishioner.

"I was making a mental note at the time of where Hillman and Biggs were," Slutter told me a few days later. They were off to one side, so he assumed that they were not in his fall line. It was one of the many illusions of Mount Hood. Slutter turned to look over his right shoulder at Kern, 35 feet above him. "I had a better view of where the spine [of the Hogsback] went." So he called up to Kern, "Back up a little and get yourself over the spine more."

Then, out of the corner of his eye, Slutter saw a blur and felt a tremendous surge of norepinephrine. He believed that whoever was falling could not be from his group, because the blur was going to one side of him and not straight down toward the Timberline Lodge. Two days after the accident, I made the same mistake of perception myself. I was climbing the mountain with Steve Kruse, the mountain manager for the ski resort. He asked me which way was down and I pointed at the lodge. But a ball rolled from the top does not go to the lodge. It goes east into the Zig-zag Wilderness or west into the Eliot Glacier.

Nevertheless, appreciating the precariousness of his position, Slutter reacted instinctively. "There was no hesitation," he said. He threw himself down and dug in with his ice ax.

Moments before, another group of four climbers had appeared above Ward from the summit just in time to see what happened. The criminologist for Clackamas County, Tim Bailey, investigated the accident. In his report, he said that the entire fall took only three to five seconds, covering hundreds of feet on the way to a crevasse that cuts the Hogsback Ridge about halfway down. A teenager named Luke Pennington was in the group of four that had appeared above the victims just as Ward pulled his protection. He saw Ward facing east, trying to turn and plant his left boot while descending. Then the one thing that must not happen did happen: The top man fell. "At that point he slipped and fell," Bailey said. "When he slipped and fell he landed on his back with his head facing down the mountain and he started sliding downhill."

Before his rope went taut against Read's harness, Ward was going as much as 30 miles an hour, the equivalent of the speed you'd attain by jumping from an eight-story building. Once he took Read (then Kern, then Slutter), the acceleration continued unabated. They had taken to the boundaries of their world for adventure. And as James Gleick writes in *Chaos*, "Strange things happened near the boundaries."

With all that energy balanced on ice on a crampon point, it took only a slight tug, the pinprick that popped the balloon. "It played out in slow motion," Slutter said. The speeding up of reflexes, the fast-processing mode into which the brain and body go in an emergency, makes the world seem to run in slow motion. "I know that Chris went into the arrest position, but I don't remember seeing him move. It's amazing because I didn't hear a word." Perhaps it was a result of perceptual narrowing. Perhaps no one said anything. "I saw nothing else. I was facing up the hill. I remember looking at my ax dug in, and my chest was on top of it. My head was cocked and my hand was over it." Slutter focused on the one thing that seemed most important: his anchor point. "Then I remember watching it ripping through the ice. I'm thinking: We're going pretty fast here. I was ripped from the mountain."

Kern was ripped from the mountain, too, and remembers flying through the air. He couldn't tell how far, but it seemed like a very long way. When he hit the snow again, it was a stunning blow that broke his pelvis. Then, as the ropes began playing out and going taut, he was snapped free again, flung into the air, and sent rocketing down the mountain.

Perhaps only a second had passed. Perhaps two. All four were now in chaotic motion, accelerating toward Biggs and Hillman, who were carefully descending. They were less than 100 feet below. They had no chance.

Bailey reported: "Mr. Pennington said when they reached the next group . . . they clotheslined Mr. Biggs. The four falling were falling in such a manner that the taut rope was stretched out and it hit Mr. Biggs, it actually knocked Mr. Biggs into the air."

"I heard someone shout 'falling!'" Hillman recounted. "They hit Biggs like a billiard ball. He was airborne for three or four feet and was knocked upside down. I saw the one Oregon guy hook his red rope on our blue rope as he passed. I knew that I would have to arrest five people, and I stopped watching and got down. I prayed because I knew that I would have 50 feet until they reached me," which was the length of rope between him and Biggs, "and then 50 feet more until I was engaged. I was ready." But with 100 feet of slack, at least a couple of the five bodies, maybe more, would fall ten stories before they pulled Hillman's rope taut. By that time, the force was so great—thousands of pounds—that it ripped his shoulder from its socket. Still, he held on. "I remember the ax ripping the ice all the way down until the crevasse."

But it wasn't over yet. Just above the crevasse, perhaps 400 feet below, two teams of climbers were heading up the mountain. They were led by Jeff Pierce, a paramedic with the Fire and Rescue Department in nearby Tualatin Valley. He'd brought four other paramedics up for their first experience of climbing a mountain. In addition, the department's physical fitness trainer, Chad Hashburger, and Cole Joiner, the fourteen-year-old son of one of the paramedics, had come along. After their 3:00 A.M. Snow-Cat ride to the top of Palmer, the highest ski lift, Pierce had divided them into two groups. He led Cole Joiner and Jeremiah Moffitt, a paramedic, on the lead rope. The other four formed the second team, led by Dennis Butler, also a paramedic, and the only other experienced climber among them. His team of four was still below the crevasse when the accident happened.

Pierce had already led Joiner and Moffitt around the left side of the crevasse as they ascended. "I was coming around the crevasse," he remembered, "looking up at some other climbers high on the route above, and planning my moves." Pierce wanted to stay out of the way in case someone fell, but because of a seemingly insignificant decision he'd made earlier (to go to the left instead of the right), his team first had to cross beneath the higher climbers. He and Joiner then started moving to their right. But Moffitt was still in the fall line.

Pierce looked up and saw the teams falling. He'd seen people fall before; therefore, as he told me, "I expected them to drop, self-arrest, and start descending again." But as the first rough images began to resolve in his brain, a tremendous jolt of chemicals flooded his system and set him in motion. "I dropped and buried my ice ax. I really dug in, and everyone else did, too." Six human projectiles, tangled in a mess of ropes and bristling with the points of crampons and ice axes, were plummeting toward him.

Bailey reported: "Now we have six climbers coming down. The other witnesses . . . said by this time they were all bouncing off each other, they were spinning around in circles."

Moffitt was hit so hard he was knocked unconscious. His rope jerked Pierce and Joiner into the crevasse, where all nine climbers hit the lower wall and settled into heaps of bodies. Biggs was already dead. Ward was buried head-down in the snow, suffocating under a pile of bodies. Read, on his first and last climb, was alive, conscious, and dying.

At that moment, the manager, Steve Kruse, was opening the mountain for the day's skiing. He was at the top of the Palmer chair lift talking to a ski patroller when the boy in the lift house said there was a call for him. Kruse heard a sheriff's sergeant tell him there'd been a 911 call reporting a climbing accident 2,000 feet above him at the bergschrund, which is what the locals call the crevasse. It was a little garbled, a little wild, but it sounded as if a bunch of climbers had gone into the 'schrund.

Kruse's head snapped around. Far above, he could see the crevasse with a few small figures around it. He felt his heart tick into a canter. He knew this was going to be a big one. He grabbed his radio, called down to Jeff (Floodo) Flood, "my ace Cat driver," and told him to get up to the top of Palmer as fast as he could. He could see the yellow Sno-Cat snort black diesel smoke as it began churning uphill from the Timberline Lodge.

ABOVE HIM, deep in the crevasse, Bill Ward, buried in the snow, had already suffocated. Chris Kern was folded in half, jammed beneath a rock, with a broken pelvis. He was screaming in agony. Harry Slutter, who'd been leading the highest team down, had been knocked unconscious when he hit the crevasse wall. He awoke jammed upside down, his ice ax still in his hand. The scene, lit by ice-blue sunlight, was surreal. Debris and snow were still pouring in from above. "I felt like I was drowning, breathing in all that fine snow," Slutter remembered.

He righted himself and took stock of his injuries. He was almost certain that he'd broken both his jaw and an ankle, but he was more concerned about Biggs. "I think my body was on his or his on mine; there was no separation," Slutter said. He rolled over and checked: Biggs wasn't breathing. Slutter began trying to resuscitate him. Then Pierce, leader of the Tualatin group, came over and "he confirmed what I suspected," Slutter said. "John was dead."

Kern was still screaming. Slutter shouted at him: "Put away the pain and hold on!" He and Kern ran races together, and that's what they told each other when the going got tough. Kern quieted down and tried telling Rick Read the same thing. Read was talking as he died. Moffitt was moaning, babbling incoherently.

Tom Hillman, the Methodist pastor, had been knocked unconscious, but his Camelback water bag had burst against the wall, absorbing some of the impact. Despite that, he'd cracked a thoracic vertebra. Hillman, who was trained as an EMT, began assessing himself as soon as he awoke. "I went back to my EMT training and before I moved, I did a mental evaluation. I thought at least I would have a tib/fib fracture, an ankle, or a femur. I was mentally ready. But when I woke up, I was amazed that I had not broken anything. I had torn muscle and ligaments in my arms, shoulders, and back from holding onto the ice ax in arrest. I wanted to be able to respond and go into rescue mode, but with my concussion I was like molasses." It is typical of the best survivors that, despite his injuries, Hillman was surrounded, as the *Tao Te Ching* puts it, "with a bulwark of compassion." His thoughts were not for himself but for others. It is not insignificant that he had chosen to devote his life to the ministry. "The hardest moment," Hillman said, "was not being able to respond with the equipment and training I had."

Every time Hillman moved, he brushed ice onto Kern, who would cry out in pain. Hillman crawled out of the way and lay down. Only Jeff Pierce and the fourteen-year-old Cole Joiner were nearly uninjured. They immediately set about helping the others. Dennis Butler, leader of the other team, which was still outside below the crevasse, began setting up a rope system to haul out the dead and injured.

. . .

THE TYPE of accident that happened on Mount Hood on May 30, 2002, was going to happen, as it always does, to someone somewhere. All the available theory tells us that it is an inevitable part of the larger system that puts climbers on steep snowy slopes in large numbers.

Climbers travel in roped teams without fixed protection all the time. They get away with it, too. They use ice axes like walking canes on descent. All the elements of the system in the Mount Hood accident were normal and can be explained by normal accident theory. It was Charles Perrow who coined the term "system accidents" in the 1980s, and it's a fascinating (if academic) exercise to see how his work and both chaos theory and the theory of self-organized criticality dovetail. The Mount Hood accident involved two broad categories of effects: the mechanical system that the climbers were using, and the psychology and physiology that contributed to the accident.

In recent years, those who study accidents in outdoor recreation have begun to recognize that all accidents are alike in fundamental ways. If you find yourself in enough trouble to be staring death in the face, you've gotten there by a well-worn path. Your first reaction might be: *How could this have happened? What rotten luck!* But if you are alive afterward and bother to examine what happened, it will all seem as orderly as the Cajun Two-Step.

The events that we call "accidents" do not just happen. There is not some vector of pain that causes them. People have to assemble the systems that make them happen. Even then, nothing may happen for a long time. That is how mountains such as Hood, McKinley, Longs Peak, and others get a reputation as milk runs. Many of the people who get into the worst trouble on such nontechnical peaks are those who have climbed more difficult mountains elsewhere. Often they have climbed in the Himalaya or South America and come to Denali or Hood with an attitude that they're slumming. Perhaps they're doing a favor for a friend who wants to have the experience. Perhaps they're trying to climb the highest peak in every state. They are hijacked by their own experience combined with ignorance of the true nature of what they're attempting to do.

Perrow's *Normal Accidents*, first published in 1984, is a work of seminal importance because of its unusual thesis: That in certain kinds of systems, large accidents, though rare, are both inevitable and normal. The accidents are a characteristic of the system itself, he says. His book was even more controversial because he found that efforts to make those systems safer, especially by technological means, made the systems more complex and therefore more prone to accidents.

In system accidents, unexpected interactions of forces and components arise naturally out of the complexity of the system. Such accidents are made up of conditions, judgments, and acts or events that would be inconsequential by themselves. Unless they are coupled in just the right way and with just the right timing, they pass unnoticed. Bill Ward had slipped and caught himself before or was in a position where slipping didn't matter. He'd pulled his protection, too, but not just before a serious fall. Perrow's point is that, most of the time, nothing serious happens, which makes it more difficult for the operators of the system (climbers, in this case). They begin to believe that the orderly behavior they see is the only possible state of the system. Then, at the critical boundaries in time and space, the components and forces interact in unexpected ways, with catastrophic results.

The space shuttle had flown many times without incident. It had gone up on cold Florida mornings and nothing bad had happened. The people responsible for it began to regard this outcome as the only possible behavior of the system. Then, one morning, the cold caused a rubber seal to crack. The engineers who understood the system better than those in charge had warned about the possibility. Under the pressure of schedule and politics, *Challenger* was launched anyway, and those in charge, along with the entire world, saw a graphic demonstration of another possible, if rare, behavior of the system known as the space shuttle.

Perrow used technical terms to describe those systems. He called them "tightly coupled." He said that they must be capable of producing unintended complex interactions among components and forces. In his view, unless the system is both tightly coupled and able to produce such interactions, no system accident can happen (though other failures happen all the time).

The parts and forces and their potential interactions might be hidden and are difficult to imagine beforehand. The climbers could not see all the energy they had stored. Because they had watched self-arrest techniques work before, they couldn't imagine them not working again. The coffeemaker or the toilet on an airliner is not supposed to be able to destroy the plane, but both have done so.

An airliner is a perfect example of a complex, tightly coupled system: a large mass containing explosive fuel, flying at high speeds, and operating along a fine boundary between stability and instability. Small forces can upset it, causing the destructive release of the large amount of energy stored in the system. In that way it is like the system set up by the climbers: The energy in their system had come from their own muscles, electrochemical energy produced as they climbed. As they moved up, they stored more and more as potential energy in the system, which was tightly coupled because of the rope. It was like blowing up a balloon. The tiniest pinprick, an almost imperceptible force, can release the air all at once. The climbers would have been better off if they had tried to descend the slope with no safety system at all.

When a system is tightly coupled, the effects spread. In a loosely coupled system, effects do not spread to other parts of the system. Falling dominoes are a familiar illustration of how tight coupling works. Move the dominoes farther apart and knock one over: only one will fall. If the climbers had not been roped together, Ward wouldn't have taken everyone else with him. (For that matter, if they had not misperceived which way was down, they might not have positioned themselves over Hillman and Biggs.) But the accident was still no one's fault. There is no cause for such system accidents in the traditional sense, no blame, as the *I Ching* says. The cause is in the nature of the system. It's self-organizing.

WHEN *NORMAL ACCIDENTS* was published, neither chaos theory nor the theory of self-organizing systems was widely known or accepted. But it is possible to see hints of both in Perrow's work. Chaos theory arose out of a huge vacuum in the physical sciences: disorder. We see it everywhere we look, from the functioning of a living organism to the behavior of flowing water: turbulence; erratic behavior; nonperiodic natural cycles from weather to animal populations. Classical physics ignored all that and used idealized systems to explain the world. But that left most of the real world unexplained. The errors in Newton's calculations of planetary motion were ignored until Einstein came along to explain them. Traditional economics assumed perfectly rational agents. So does traditional survival training. Neither assumption reflects the messy real world.

The idea of chaos theory is that what appears to be a very complex, turbulent system (the weather, for example) can begin with simple components (water, air, earth), operating under a few simple rules (heat and gravity). One of the characteristics of such a system is that a small change in the initial conditions, often too small to measure, can lead to radically different behavior. Run the equations two, four, eight times, and they may seem to be giving similar results. But the harder you drive the system, the more iterations result and the more unpredictable it becomes.

Edward Lorenz, a meteorologist at MIT, was modeling weather systems on a computer in the early 1960s when he accidentally discovered that a tiny change in the initial state (1 part in 1,000) was enough to produce totally different weather patterns. That became known as the Butterfly Effect, "the notion that a butterfly stirring the air today in Peking can transform storm systems next month in New York," as Gleick wrote in *Chaos*.

Classical science aimed at predicting an outcome, then conducting an experiment to confirm it. But natural systems don't behave so neatly. The specific details can be described, yet no one can predict the outcome. You can describe how the weather works with high school math and physics, but you can't tell very far in advance when or even if it will rain. You can predict that lightning will strike under certain conditions, but you can't predict when or where. When I was a teenager, I teased my father by saying that from living with scientists all my life I had observed that they knew so much that they often seemed to know nothing at all. Classical science can't predict the behavior of a cloud, which is nothing but a bunch of water droplets moved around in the air by heat and gravity. Training and safety systems are also a form of prediction since they aim to control the future.

Chaos theory views such systems, which seem chaotic, as actually arising out of a simple, orderly set of mathematical functions. They may also produce effects that are the same at all scales. A cloud looks the same whether viewed up close or far away. So does a coastline. And much of what we call art appeals to the senses because of its so-called fractal nature. Nôtre Dame cathedral is beautiful at any scale. From far away, you can see the buttresses and the pleasing shape. The closer you get, the more interesting detail you see, until at last you are looking at the tiniest of figures sculpted on its surface. Matter itself appears to be like that. Just when you think you've found the smallest piece, you find another even smaller one.

The theory of self-organized criticality, sometimes called Complexity theory, was developed hard on the heels of chaos theory by some of the same people. It asked and suggested answers to questions as fundamental as: Where does order come from? How do you reconcile it with the second law of thermodynamics, which says that everything is heading toward more disorder? In a sense, complexity was an extension of the thinking that gave rise to chaos theory; indeed, it was often referred to as existing at "the edge of chaos." (There has also been strong objection to linking complexity and chaos and to using the term "complexity.") Like chaos theory, complexity theory postulated "upheaval and change and enormous consequences flowing from trivial-seeming events—and yet with a deep law hidden beneath." Complexity theory is a bold attempt to explain everything all at once, and so far it's done a better job in some ways than either Einstein's relativity theory or Niels Bohr's quantum mechanics did.

The climbers on Mount Hood discovered the enormous consequences of the trivial-seeming event of pulling their protection. Such upheavals are part of nature's mysterious tendency to create self-organizing systems at critical boundaries. The climbers did not recognize that they were part of a system that had reached that critical state where it would probably remain most of the time and where a seemingly insignificant force could set it going at any time.

PER BAK, a Danish physicist, set up an experiment in the 1980s that graphically demonstrates how accidents happen in wilderness recreation, though this was not his intention. He was demonstrating how a self-organizing system works. He created a pile of sand (or a computer model of one) and let more sand dribble on it from above as if from an hourglass. As the pile grew, it reached a certain height and then began to collapse. The pile didn't get any shorter, but it didn't get any higher, either. It simply continued in that steady state of continuous collapse. In his book *Complexity*, M. Mitchell Waldrop describes "the resulting sand pile as self-organized, in the sense that it reaches the steady state all by itself without anyone explicitly shaping it." No one had to design those collapses into the system. They were a characteristic of the simple system. It reached a state that some scientists call criticality (though, again, there is much argument about how to use this term, which has become jargon). "In fact," Waldrop adds, "the critical sand pile is very much like a critical mass of plutonium, in which the chain reaction is just barely on the verge of running away into a nuclear explosion—but doesn't." As more and more sand falls, there are many small slides. Now and then there is a great avalanche in which the mountain comes apart, but often nothing happens for a long time.

There is nothing at all in the physics of silicon dioxide that could predict the behavior of the sand pile. You could use physics and chemistry to examine a grain of sand until your lights go out and never discover the Sand Pile Effect. But the Sand Pile Effect expresses a tremendous amount about the way all of nature works. And it explains as well why Perrow came to regard accidents as a normal characteristic of certain systems. The systems he called complex and tightly coupled are actually self-organizing systems. The accidents are the collapses, if you will, in big technological sand piles, such as nuclear reactors and jet airliners. They all operate continuously in failure mode. Most failures—collapses—are small ones, such as a broken switch, a burned-out light, a busted rubber gasket, the glitches that we dismiss as normal. And they are normal. But like the temblors in an earthquake zone, they are also the quiet harbingers of the larger collapses that must eventually happen.

Small collapses are common on the sand pile. Large-scale ones are rare. But collapses of all sizes do happen with an inevitability that can be described mathematically as inversely proportional to some power of the size (with earthquakes it's the 3/2 power, which curiously is the same power as the one used to determine the time that planets take to go around the sun: the square root of the cube of the size of the orbit). Similarly, fender benders are common, while sixty-car fatal pileups are rare. But they both happen. Murder is common; six-state murder sprees are rare. Mountaineering falls are common; nine people falling into a crevasse with three fatalities is rare. That so-called power law is found extensively in nature. It's a more precise way of saying what Perrow was saying: Large accidents, while rare, are normal. Efforts to prevent them always fail.

Both the Sand Pile Effect and normal accident theory predict that space shuttle accidents in which the entire craft and crew are lost will happen, albeit with long intervals between them. The space shuttle *Columbia* disintegrated on approach to landing almost exactly seventeen years after *Challenger* exploded. Such accidents are inherent characteristics of that system. NASA will investigate and explain all the details of how it happened, but knowing those details will not prevent the next accident. Indeed, the safety precautions they take may make it more likely.

In connection with the *Columbia* accident, most engineers I spoke to speculated that the tiles on the underside of the craft, designed to absorb the heat of reentry, probably caused the problem. Dan Canin of Lockheed wrote in an e-mail, "Every precaution and material science known to man has been applied to the problem of making the thermal protection system work. It's a known risk. The tiles are soft, and every astronaut knows that if the wrong ones are damaged, the shuttle burns up. But the odds against it are pretty good, especially when compared to the rewards of being an astronaut, so they're willing to take the chance. In fact, they FIGHT for it . . . as would a lot of us. But getting the public to buy this is a lot tougher, especially a public that expects every risk in their lives to be mitigatable to zero. It will be interesting to see if NASA tries to take on this challenge, explaining to the public that doing bold things isn't about engineering risk to zero. Shit happens, and if we just want to restrict ourselves to things where shit can't happen . . . we're not going to do anything very interesting."

So the accident on Mount Hood was predictable; but no one could know which climbers would fall, where or when, or with what injuries. As with the sand pile, the overall system involving gravity, mass, and simple materials obeys rules that can be known.

Like the sand pile, the system the climbers used was poised at the edge of chaos, in a state of criticality. The small points of contact between each person and the mountain (crampons, the tip of an ice ax handle used as a cane) were like the interlocking grains of sand on the pile, set to release at the slightest touch. Every step was another chance for a slip—a collapse—of any size. Most were small—1 inch, 5 inches—and died out. At a less frequent rate, bigger slips occurred. Hillman saw Biggs fall that morning. He quickly arrested himself with his ice ax. There are ten thousand climbers on Mount Hood each year and only one death on average. The power law applies: The bigger the accident, the less likely it is.

I like Perrow's description of such accidents, because while he was talking about a nuclear power plant, he could just as easily have been talking about Mount Hood: "processes happen very fast and can't be turned off . . . recovery from the initial disturbance is not possible; it will spread quickly and irretrievably for at least some time. . . . What distinguishes these interactions is that they were not designed into the system by anybody." He's describing the self-organizing behavior seen everywhere in nature, which complexity theorists, such as Stephan Wolfram, believe probably gave rise to life and to us in the first place.

The climbers were familiar with the system and had a good concept of how it behaved, but only with its more frequent smaller collapses. Hillman's comment that he was ready to arrest five people falling 100 feet indicates how little he understood the amount of energy in the system. The large-scale collapse, when it came, did "happen very fast" and couldn't "be turned off." It did "spread quickly and irretrievably," and allowed them no chance to recover.

Less than forty-eight hours later, as Steve Kruse and I climbed up Mount Hood, we sat and rested on a rock between the lift and the crevasse. "This thing went critical faster than anything I've ever seen," he told me. Without realizing it, he was using the jargon used to describe self-organizing systems.