The Sizesaurus. Stephen Strauss. New York: Avon Books (1995)

Every time there is an earthquake in California, I stare at my fingernails. It is about the only time I have anything like a deep communion with those hardened hunks of clear, dead tissue. As the television shows pictures of bridges collapsed and cars crushed into slabs, I regard those keratin-filled first cousins of hair and silently intone to myself a science writer's mantra:

SanFranciscoismovingnorthwardatthespeedfingernailsgrowinayear.
SanFranciscoismovingnorthwardatthespeedfingernailsgrowinayear.

To tell you the truth, I don't know who must be credited with first coming up with this highly evocative way of describing the slow but inexorable movement upward of a part of the Pacific plate on which California sits. However, every geophysicist in North America now seems to be aware of the measure and gives it in response to that inescapable question from reporters: "How fast does that plate move and can you compare that to anything, like, human?"

In and of itself, the fingernail imagery is quite wonderful. It has a certain Zen, beach-bum quality. Say:

SanFranciscoismovingnorthwardatthespeedofafingernailgrowinginayear

eight times quickly and you can almost hear the existential surf crashing inside your head. A drifting continent has all the unstoppability of a fingernail.

A wonderful image, but one which quite early in my reverie I also realized that nobody else watching California rock and roil is truly interested in. We are not a metaphorical and Zen culture. We are a scientific culture, and we expect to have earth movement conveyed precisely; we want to have the fingernail measure turned into a number, something which fastidiously describes the mayhem that occurs each time a plate moves. And when I look up from the Zen of my fingernails, I realize that the television reporter will soon tell me just such a figure. I mean, of course, the seemingly simple scale of Mr. Charles Francis Richter and his portentous 7.6s and awesome 8.2s and god-forbid 10s. The reporter will use the number and assume that I will understand the Richter scale as easily as I did the fingernail image.

But I won't. Not intrinsically. Not historically. Not truly comparatively. I won't, because I never know what the Richter numbers mean in terms that touch me.

Nonetheless, I will listen, nod my head, purse my lips, and disguise my confusion, because Charles Richter's rating of earthquakes is one measure every modern person is expected to comprehend instinctively. Indeed, in sixty years, Richter's numbers have so completely entered popular consciousness that they have themselves been turned into a scalar metaphor. The economic fallout of a megamerger is not just big, but "off the Richter scale." Excitement about Toronto winning its second World Series is rated a "10 on the sports Richter scale." And because for the longest time I assumed that everyone else was completely comfortable with Richter's measure, I thought that I was doomed to fake understanding forever. It was the sort of thing cynical friends could have engraved on my tombstone: "Here lies Stephen Strauss. He was the sort of person who knew 7 was a lot larger than 6 on the Richter scale, but was afraid to admit he didn't know why, or how much bigger." Then a kind of salvation occurred while I was browsing through the pages of *Nature* magazine. There on page 512, at the bottom of an article about the likelihood of Seattle being riven in two by a huge earthquake, I came upon the startling words of U.S. geologist Thomas Heaton. "The many different existing magnitude scales are generally all included together in the maddeningly vague term 'Richter scale.' This is popular with the press, but meaningless to a seismologist," he wrote.[1]

Hooray, I thought, I have a right to be confused about degrees Richter — even the scientists are. And with that, I vowed to one day try to make sense of Richter's scale. Simply put, I wanted to know: Why is something which looks as simple as 1-2-3-4-5-6-7-8-9 so bloody confusing?

What I have learned is that part of the answer, as with many measures, emerges from the history of the scale and the awkward interaction of science and technology which underlies it. Or, to put it in a homelier fashion, earthquake measurement follows the old adage of "He who has a yardstick measures the universe in yards." The Chinese were the first to calibrate earthquakes, using the person-sized, wine-jar-shaped "seismoscope" built in 132 by Chinese astronomer royal Zhang Heng. However, it was a very limited measuring device. The direction of a quake was indicated when a ball dropped out of the mouth of a bronze-cast dragon into the mouth of one of eight metallic frogs beneath it. And, as with many Chinese technological breakthroughs, what developed out of the seismoscope was not science, but mechanical awe. The Chinese didn't ask if there was a pattern to where the earthquakes occurred that could be quantified, or whether it was possible to measure the strength of the quake. No, it was the seemingly magical relationship of the earth movements and the ball drops which transfixed Chinese observers. When the seismoscope was able to record an unfelt earthquake which occurred 650 km (400 mi) away, the court historian recorded "everyone admitted the mysterious power of the instrument."[2]

At the beginning of the age of science, the Europeans were also creatures of awe, but their reverence was increasingly reserved for quantification. They were (and we still are) entranced by Descartes's observation that nature is "a universal mathematics." A true understanding of nature came not through wisdom, but through systematic counting. And, in that line, Italian physician Domenico Pignataro began some of the demon numeration which separates a scientific culture from all cultures which existed before it. In 1786, he classified 1,186 quakes which occurred in the

Calabria area of Italy between the years 1783 and 1786. These he divided into categories of slight, moderate, strong, very strong, and violent. In the same report, the chief physician in the court of Naples, Giovanni Vivenzio, translated these categories into a more humanly meaningful number. He outlined the damage and death which occurred in villages affected by these quakes, and therein illustrated the dualism intrinsic to quake quantification. The ground moves, and that movement smashes things up. It was not clear then, and in many ways is not clear now, which is the cataclysm's most important feature. Today's seismologists are interested in what the tremors tell us about the nature of the Earth; today's engineers want to know what kind of buildings to build to avoid the earthquake damage; ordinary folk want to understand the extent of their danger and a quantification of that havoc. But, in the beginning, there was no simple way of separating the shifting ground from the damage it caused. Thus, earthquake measures unselfconsciously annotated the quake's effects on people and their belongings. Accordingly, in 1828, P.N.C. Egen, from his study of a Dutch quake during that year, suggested a six-point intensity scale. Number 1 was a quake that you could miss if you didn't concentrate. Number 2 saw a few people feeling the shock, a few small potted plants vibrating, a few glasses that were close together jingling. With number 3, the windows rattled, bells in houses rang, and most people realized there was actually an earthquake going on. Number 4 saw the furniture shift a bit and left no doubt in anyone's mind that the earth had moved. In number 5, the furniture was strongly shaken and walls were cracking, but "only a few chimneys [were] thrown down." And finally, in category 6, furniture was strongly shaken, mirrors and glass broke, chimneys tumbled down, and walls cracked.

Simply put, Egen's scale measured how quakes interacted with nineteenth-century northern European housing technology and communal organizations. Egen's measure also looks decidedly

Dutch. The worst consequences were moderate and middle ground, as suits a country where villages weren't regularly being razed by the earth's movement. By the end of the century, several varieties of intensity measures came into being which stretched the scale to include more horrific consequences. The Italian Michele Stefano De Rossi and the Swiss François Alphonse Forel combined to produce a ten-point scale which related quakes to such things as clocks stopping, chandeliers shaking, general panic, and "a general ringing of bells." Number 10 consisted of "great disasters, ruins, disturbances of strata, fissures in the earth's crusts and rock-falls from mountains."

By the early part of the twentieth century, intensity became, as best there was, the world measure of an earthquake. Modified into a twelve-point scale by priest-geologist Giuseppe Mercalli, it has served as the basis of a variety of locally tailored scales. Two Americans in 1931 included Southern California–type references to "steering of cars affected" and "concrete irrigation ditches damaged." New Zealand threw in mentions of damaged domestic water tanks, which were found on many of its farms. To accommodate individual differences in 1958, two Russians calculated there were forty-four different intensity scales at work. However, despite all efforts to customize it, the Mercalli was a scale that everyone understood was seriously flawed. How accurately was anyone measuring a quake's intensity? Confusion often existed between what the media said had happened and how an intensity rating was "scientifically" calibrated. "Newspaper reports are useful," wrote Charles Richter himself, "if one becomes accustomed to reporters inserting details which 'ought to' be there whether they correspond to fact or not. 'Buildings here were shaken' means only that persons felt an earthquake and does not imply any structure vibrated visibly."[3] And what about quakes which happened under the sea or in unpopulated areas? Were they somehow unauthentic because no human was there to measure and observe the damage in accordance with the

Mercalli scale? How were alternative building technologies to be compared? The Chinese, who had been recording quakes for three thousand years, regularly made mention of catastrophic fires in describing the effect of their huge tremors. And what about the fact that locally sharp quakes were given a higher profile than quakes that affected a larger area?

In this turmoil, Charles Richter, a compulsive seismologist who taught at the California Institute of Technology, began to put a scientific face on earthquakes. How compulsive was he? He was a man so obsessed with earth movements that he had a seismograph installed in his house and regularly commandeered the one telephone in the Caltech laboratories so he would be the voice of authority to the press. But in the early 1930s, he was beginning a career and facing a very much smaller problem than how to construct a true scale to compare all the world's earthquakes. What he was trying to do was prorate the two hundred to three hundred quakes that took place in Southern California every year. The reason for this was that Caltech had begun issuing monthly earthquake reports from the seven seismometers it had distributed around Southern California. The feeling at Caltech, particularly after the panic which had been associated with the 1925 Long Beach quake, was that these reports had to be quantified in some easily understood manner for the general public. "We felt a certain responsibility to keep the public informed, particularly as misinformation was often seized upon and twisted in a way which was contrary to the public interest," Richter later recalled.[4] It is important to dwell for a second on this original motivation. The scale was a blatant public-relations effort. It was for us, and not for seismological science, that Richter was initially working.[5]

All Richter had originally hoped for in a public-measured science was a very rough approximation. An earthquake scale of "small, medium, or large" was his original goal. To achieve it, ways of comparing seismographic readings that were being taken from seven locations at various distances from the quake's center had to be devised. To appreciate the difficulty, you have to know a little about earthquake waves and seismographs. An earthquake is a harmonic; that is, what we feel and see is in some sense the various ways in which the energy from a sudden shift in the Earth's crust vibrates the instrument we call planet Earth. When the ground suddenly shifts, it generates a series of very different waves. The first to appear are P (for primary) waves. They alternately compress or expand rock, lava, or any other substance in their path. The roaring sound which often signals the onset of a big quake is the result of P waves that have reached the surface and are agitating the air.

P waves are followed by slower S (for shearing) waves, which jiggle rock particles from side to side and up and down in a contorted movement we might liken to a dirty carpet being simultaneously shaken and stretched. Collectively, P and S waves are called "body waves," because they move through the body of the Earth. But there also exist surface waves of ground motion, Rayleigh (R) waves, which move across the surface like rolling ocean waves, and Love waves, which have a side-to-side slithering quality. As a general principle, a seismograph uses weighted pendulums to make measures of all these different waves. The pendulums are suspended from a frame that is itself anchored to the ground. During a quake, the movement of the weighted pendulum lags behind that of the frame. The pendulum's relative motion is then recorded — at its simplest, by a needle scratching a line on sooty paper.

The problem for Richter was trying to figure out how the various wiggle patterns could be fitted together. He made a breakthrough when he came upon a paper by Japanese seismologist Kiyoo Wadati. Wadati described a rule by which a seismic wave diminished in height the farther it traveled from the quake center. This would allow readings from a variety of seismograms to be compared if the epicenter of the quake was known. Richter was able to verify Wadati's demonstration of wave diminishment, but

the "corrected" values didn't lend themselves to an easy scaling. Collectively, when the smaller quakes were put at the bottom and the bigger ones at the top, a kind of chevron pattern (something like a sergeant's stripes) was produced. To give you a sense of the scaling variation, the smallest amplitude reading was about 1 millimeter — half the thickness of a dime — and the largest was about 12 cm — about the width of my hand.

Richter was stumped about how to make something meaningful out of these differences; then Beno Gutenberg, who directed the Caltech seismic laboratory, suggested he arrange the quake readings logarithmically; that is, set them in a scale in which the differences between quakes would increase by ten times for each number on the scale. Logarithmic organization had already been done for a variety of scientific measures, ranging from the brightness of stars to the pH levels that depict how acidic or basic a substance is. Not only did logarithmic progression allow the quakes to be compared, but it gave the immensity of the differences between them a clear face. As Richter would later comment, "If there was anything you could call an actual discovery that came out of the scale, it was that the biggest earthquakes were enormously bigger than the little ones."[6]

Richter announced his computations of what he called "the magnitude scale" in a 1935 paper. The magnitude scale was initially very localized, being tied to readings from Caltech's special type of seismograph. It worked only with relatively shallow — no more than 16 km (10 mi) deep — earthquakes, and it was applicable only to quakes occurring within 600 km (400 mi) of a seismographic station. The standard magnitude for a given quake was one which a Woods-Anderson seismograph might have recorded if it was located about 100 km (60 mi) from the quake epicenter. This became known as the "local magnitude" of a quake, or M_L in the shorthand of seismology.

In his original paper, Richter went so far as to suggest how his new scale might have applied to some previous large quakes, and estimated that the 1906 San Francisco quake was probably between 7 and 7.5 on the magnitude scale. "How far above this the magnitudes of actual earthquakes may extend is a difficult, and in one sense an unanswerable, question. Judging by the relative amplitudes of distant records shocks, there must be cases of at least magnitude 9, and very probably 10," he wrote.[7]

This reference was the origin of the notion of the infamous "10 on the Richter scale." In truth, as Richter emphasized, the scale is open-ended and arbitrary. It goes as high — or as low — as nature permits and as machines can measure. As well, Richter took great pains to point out in the original paper that the zero which started the scale was not an indication of "no quake," but rather a baseline. It was only the smallest earth tremor that the seismographs of the day could detect. And indeed, since Richter's era, instruments with more refined sensibilities have been developed, and seismologists now report recordings which baffle the public by registering as –2 on the Richter scale.

Gutenberg immediately realized that the magnitude scale had possibilities as a worldwide standard if it could be detached from its Southern California biases. With Richter's help, he proceeded to universalize the measure, and almost as quickly made it more complicated. Richter's initial scale had been rigorously minimalist. It computed a number based on the maximum line height recorded on a seismograph of a given type. However, everyone knew that this was a wildly artificial thing to do. In the original Richter calculation, absolutely no distinction was made as to which wave was being measured, and even Richter admitted that, depending on where you were in relationship to the epicenter, almost any wave could be the highest. While wave discrimination didn't matter if all that was being measured, using the same machines, was shallow Southern California quakes; deeper and farther was another question. This was soon addressed by turning the Richter scale into the Richter scales.

Theoretically, one could make a scale out of the seismic fingerprint produced by each wave type. In 1936, Gutenberg and Richter published a paper in which a standard measure using horizontal surface waves which occurred over a 20-second interval was used. This spread the distance at which the scale was applicable to 1,000 km (600 mi) and allowed varying types of seismographs to be used. It too got a scientific nickname — M_S for magnitude of teleseismic (distant) earthquake.

Ideally, the two measures should have collapsed into each other; that is, the same magnitude should have appeared no matter which wave was chosen to be the yardstick. Alas, earthquake measurement is not a domain in which the natural phenomenon respects the measuring implement. When measuring quakes below 5 on Richter's original scale the M_S was often as much as half a magnitude off. Half a magnitude is about three times smaller, a magnitude paycheck of 33 cents on the dollar.

Besides, Richter scale two did not permit a computation of the magnitude of deep quakes either, because these shocks did not generate surface waves and because, when they did reach the surface, the surface waves' amplitude was seriously dampened by complicated changes in the Earth's crust. Therefore, Gutenberg came to believe that the most accurate way of assigning magnitude to deep and extremely powerful quakes was to calculate the magnitude of body waves. What emerged out of this was yet another Richter-type measure that lumped together P and S waves and was called M_B. By the 1960s, when an earthquake occurred all of the dreaded M measures — M_L, M_S, M_B, and scales that combined M_S and M_B averaged in some way — were being gathered and reported, often without explaining which was being used. And major disputes were breaking out between the founders. Gutenberg came to believe that M_B was the most accurate way of assigning magnitudes and, in his publications, reported all magnitudes in that dimension. Richter thought Gutenberg was wrong and was sowing confusion. He reported his findings as either M_L or M_S, arguing "in many instances it has been shown that initial waves are those of a small foreshock, to which alone the magnitude supposed determined for the following shock will apply."[8] By way of example, the huge 1964 Alaskan quake registered 8.6 on the surface-wave Richter scale and only 6.5 on the body-wave scale.

As scientists began to realize the importance of the scale to their, and not the public's, understanding, they cheerfully spooned in complications to Richter's oh-so-simple initial "big wave means big quake" rating system. The Mercalli intensities were roughly correlated with various Richter measures. This regularly caused journalists and the public to confuse the one with the other and report that a quake was an 11 on the Richter scale when what they meant was an 8 on the Richter scale (which results in a 12 on the Mercalli scale).

But this is child's play when compared with Richter and Gutenberg's computation of the actual energy released during a quake, which appeared the year after the first paper. After a variety of computations, the two seismologists determined that, for each number on the Richter scale, the actual energy released in a quake went up not by a factor of 10 but by one of 31.6.

This means that the "Richter scale" — whatever that might mean to an ordinary person — has two separate and distinct logarithms embedded within it. The difference between a 6 quake and a 7 quake is *both* 10 in magnitude *and* 31.6 in energy release. Since energy release seems so much better a description of what happens during an earthquake, you might well wonder why it has not simply displaced the magnitude measure. Richter had an explanation.

"Frequently there have been suggestions that the scale should be defined in terms of energy, but to do that would have involved continuous revisions, both numerical and theoretical. I have always insisted that the magnitude scale represents what we observe, and this may or may not be interpretable in terms of energy," he said.[9]

And indeed his doubts have been borne out, as over the last fifteen years or so there has been a massive revision of the energy releases of quakes. Scientists realized that at the top end of the magnitude scale — above 7 or so — there was a blurring of differences between quakes. A quake which was the result of earth movement over hundreds of miles could get the same reading as one which was very localized. As a result of the revision, a 1960 Chilean quake was upgraded from what had been an 8.3 on the traditional Richter scale to a 9.5. Later calculations would suggest that this meant it had produced between 35 and 40 percent of all earthquake energy released between 1900 and 1989.[10]

While this is all fascinating for the professional, where are we in terms of Richter's original noble purpose — you remember: a public-relations effort to make earthquakes comprehensible to us common folk? Well, I'd have to say that Richter's chevroned seismograms ultimately have registered about a 6.5 on the Failure-to-Communicate scale. If they wanted to let us in on the picture, Richter and Gutenberg and the rest of the seismologists goofed. They got so interested in what their calculations told them about what they didn't understand about the intrinsic nature of quakes that they seem to have forgotten us altogether. They created a scale where 0 is not the bottom and 10 is not the top, and where any of a half-dozen measures may provide very different Richter-type numbers. They correlated a "magnitude" scale to an "intensity" scale without taking into consideration how ordinary folks wouldn't understand the technical redefinition underlying these terms. And not to mention those goddamned logarithms. Simply put, logarithms aren't a humanized measure. It goes against all our counting-on-our-fingers mathematics to have a scale where 0 equals 1 and 9 equals 1,000,000,000. The only sensible way of conveying this is to metricize measure. You make 0 equal to a Richter and 1 to a decaRichter and 2 to a hectoRichter and 3 to a kiloRichter, etc., etc. Using this measure, you might end up in the unfamiliar realm of mega- and gigaRichters, but at least it would be clear that your measures are playing leapfrog with one another and not simply getting one number larger. But I don't know how you metricize a scale which smashes together two logarithms and thereby creates a situation where, energy release–wise, a 9 is upward of 20 trillion times bigger than a 0.

What should have happened, and what would probably happen today, is that some PR person should have taken a look at what Richter was devising and shouted: Whoa, fella, your scales are all very interesting to you high foreheads, but the ordinary people whom the quakes buffet and shake have a right to understand what you mean. So no dueling logarithms. No M_S, M_W, M_L, M_B, and their competing numbers. And, if you can't talk to the public within the framework of your original Richter scale, devise another one which makes sense to the average ten-year-old.

But that probably won't happen, because all scales with the name Richter attached to them no longer belong to us. They are owned by the seismologists. And if there is any lesson that can be gathered from the history of the world we now inhabit, it is that while science may give us ordinary folks wondrous technology and startling discoveries, scientists will never let us redefine a basic measure. That, as I am sure Charles Francis Richter would tell us from whatever numerical heaven he finally rests in, would be so impossible it is off the Richter scale.