



## Do you want a 20-second warning?

If we adopted UC Berkeley seismologist Richard Allen's breakthrough earthquake alarm system, your cell phone and laptop could alert you to the Big One before the shaking begins. Tell that to the powers that be.

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One evening last fall—at 8:04 p.m. on October 30, 2007, to be precise—Richard Allen was watching TV in his Oakland Hills home when the room around him started to rumble. Every California schoolkid knows what to do in this situation: dive under a desk. But as Allen's possessions skittered across tabletops and bookshelves, the 36-year-old UC Berkeley seismologist just sat there, bemused.

Allen, a slight, quiet man with a British accent and the refined air of a 19th-century gentleman scientist, has an undergraduate degree in geophysics, a PhD in seismology, and a tenured position in one of the top earth-sciences departments in the world. By his own admission, he has no real interests or hobbies beyond earthquakes. Yet until this moment,

he had barely felt one.

“It was very exciting,” he recalls. “I would love to know if any seismologist does not get excited when he feels an earthquake.”

Seismologists sometimes betray their excitement by dropping to their knees and caressing the ground—a low-tech way of figuring out which way the waves are traveling and how far away the epicenter might be. By the time Allen thought to fall to the floor, though, the shaking had stopped, so he hurried upstairs and checked his email. In his inbox was an alert from ElarmS, a computer program he had spent seven years developing and had launched just three weeks before. It said a 5.6 temblor—the biggest in the Bay Area since the catastrophic Loma Prieta quake in 1989, magnitude 6.9—had originated near the San Jose suburb of Alum Rock. What’s more, ElarmS had mapped the quake’s path two or three seconds *before* San Francisco and parts of the East Bay had begun to shake. Technically, the computer knew the quake was coming before Allen did.

As earthquakes go, Alum Rock was no big deal. But as breakthroughs go, it was a doozy. For the first time, a computer program had pinpointed the magnitude and epicenter of a quake in California before surrounding areas could feel it, proving that a statewide earthquake early-warning system is not just the fantasy of a few obsessive scientists, but a viable concept that can be realized quickly (and surprisingly cheaply) for the benefit of millions of people. “It was a vindication,” Allen says with typical understatement—one that, in a just world, would bring accolades, awards, and grants. But instead of breaking out the bubbly, Allen typed up a memo and went to bed. Creating ElarmS was the easy part; the real challenge, he knew, would be getting anyone to care.

When it comes to earthquake research, what scientists and lawmakers care about most is prediction—a dependable way of determining when and where a fault will rupture, weeks or days or hours in advance. Despite enormous advances in modern seismology, they’re still dreaming. Allen has set his sights lower, hoping to give people in the path of a major quake just a little warning—depending on where you are in relation to the epicenter, maybe 10 seconds, possibly a full minute—before the most destructive seismic waves break around them. A few moments might not seem like much, but it’s plenty of time to get a classroom of kindergartners out of harm’s way before plate-glass windows shatter and walls collapse, or to slow down a speeding train so it doesn’t derail. Had Allen’s system been up and running when the Loma Prieta quake struck, San Franciscans might have had 20 seconds’ warning—and eight people killed in SoMa and the Marina district might have survived, a 13 percent drop in the fatality rate. (It’s unclear whether ElarmS would have helped the 55 others who died as a result of the quake.)



*Allen's computer projection shows how seismic waves from a 7.9 quake along the northern San Andreas Fault would travel south through the Bay Area—a scenario in which ElarmS could provide up to a one-minute warning, he claims.*

Now think of the 2.5 million people living along the Hayward Fault, where huge quakes (magnitude 7.0-ish and above) happen every 140 years or so, the last one in October 1868—you do the math. Or the 3.5 million people in the counties traversed by the 186-mile northern San Andreas Fault, which is capable of generating a magnitude 8.0 quake (the 1906 quake was 7.7). With 20 seconds' notice, you might be able to crawl under the pool table in the den, or turn off the gas so your house doesn't burn down, or maneuver your van full of soccer-bound third-graders so you aren't under a freeway overpass as the quake hits. Firefighters and paramedics could open their garage doors before the power goes out or the building shifts, thereby averting the types of problems that happened after Loma Prieta, when some first responders were forced to break through doors, wasting 10 to 20 precious minutes.

Authorities in China, where a 7.9 quake in May killed at least 70,000 people—many of whom were trapped in small buildings that could have been evacuated in half a minute or less—are said to be looking into an early-warning system. In Japan, where the 1995 Kobe quake caused 6,400 deaths, 37,000 injuries, and \$120 billion in economic losses, making it one of the most costly natural disasters in history, the government has spent hundreds of millions of dollars on an integrated seismic network that can send out instantaneous alerts by cell phone, TV, radio, and household gizmos. Other quake-prone countries—Turkey, Italy, Greece, Mexico, Taiwan, even Romania—are developing their own versions.

In Northern California, where the worst-case scenario for a 7.9 quake involves tens of thousands of injuries and deaths, we have ElarmS—basically, a promising science project with just enough federal funding to support Allen, a grad student, and a part-time technician. That minuscule budget has already been targeted by the Bush administration. Now, with the economic temblors convulsing Washington, D.C., it seems less and less likely that ElarmS will make it out of the lab in time to do the Bay Area any good.

**The idea behind earthquake early warning** is based on simple physics. Like a rock landing in calm water, an earthquake starts at an epicenter and spreads powerful seismic waves in every direction. These travel at around 10 times the speed of sound—fast by most standards, but practically crawling compared with the electromagnetic waves in telephone wires, which zoom along at nearly the speed of light. This discrepancy makes it possible to send an SOS that reaches its destination well before the seismic waves do.

Not all seismic waves are the same, though, and the difference between them is at the core of Allen's work. The primary waves, or P-waves, are the faster-moving, relatively harmless ones that occur first. In a major quake, they register as jolts; in a minor quake, you barely feel them. Secondary waves, or S-waves (as well as the lesser-known R- and L-waves), are larger, longer, more rhythmic, and far more destructive. In the Loma Prieta quake, the P-waves traveled at about 3.4 miles a second and took 10 seconds to arrive in San Francisco, about 60 miles away, scaring the bejesus out of people but causing little damage. The S-waves started rolling in approximately 12 seconds later and continued for 15 seconds, rocking the ground so wildly that buildings slid from their foundations, a section of the Bay Bridge plunged onto the lower deck, and the Cypress Freeway collapsed.

Despite their differences, P- and S-waves are believed to be proportional, and a few years ago, a team of researchers, including Allen, discovered that by measuring P-waves, it's possible to predict the size of S-waves. The ElarmS program is based on this finding. It instantaneously analyzes data on P-waves from a statewide network of seismic detectors, calculates the size of the S-waves to come, and uses geological data to extrapolate how these waves will reverberate through California's varied terrain—that is, which areas will rattle like crazy and which will barely twitch.

Allen's mentor is no less an authority than Hiroo Kanamori, professor emeritus of geophysics at the California Institute of Technology and a man so influential in his field that scientists often divide seismology into two eras: pre- and post-Kanamori. (His moment-magnitude scale has supplanted the Richter scale as the preferred method for measuring earthquakes, while his research into the physics of faults has revolutionized our understanding of how quakes occur.) "There are lots of good seismologists who are working on more basic seismological problems: determining the structure of the earth, determining earthquake mechanisms, and so on," Kanamori says. "There are also people who are working on essentially mitigation problems"—for example, how to retrofit a building. Allen, he adds, "is one of the rare people who can work on both."

Allen, in turn, credits Kanamori for making earthquake early warning a respectable field of scientific study. Before Kanamori turned his attention to the concept, which originated in his native Japan, American seismologists tended to sneer at warning systems as pedestrian—"It's not science, it's *engineering*," says Allen, repeating the widespread prejudice. "To have somebody of Hiroo's standing disregard those kinds of criticisms, I think that is the real contribution he has made."

As the son of an engineer in the sprawling industrial city of Birmingham, England, Allen never shared his colleagues' snootiness toward applied science. Though he loved pure math and physics as much as the next nerd, he grew up believing that science should actively serve humanity. At Cambridge University, this impulse led him to geophysics, a field many theoretical physicists place just above digging ditches. He went on to earn his PhD at

Princeton, doing some impressive modeling of the earth's structure under Iceland, including a plume of super-hot rock half the size of the island. He could have happily studied that stuff forever, but a lingering notion that his work should benefit society led him to a postdoc at Caltech, where Kanamori took notice.

Among other things, Kanamori is famous for having one of the messiest offices in all academe. "We're talking about stacks of paper two feet high," Allen laughs. "And he can pull out sheets of paper from the middle of that stack, and it's exactly what he's looking for." One day, during a meeting about potential research projects, Kanamori reached deep into a pile and retrieved an obscure 1988 paper about the frequency content of P-waves. Kanamori and a team that included Allen picked up where the earlier research had left off. Seven years later, Allen is trying to convince policymakers from California to the nation's capital that the software spawned by that research is worth rescuing.



*Most of the 285 sensors that make up the California Integrated Seismic Network are buried underground, like this one in an old water tank in Ohlone Park, in Hercules.*

**It's a warm evening, right around sunset,** when Allen leads me down a small, unmarked drive near the University of California Botanical Garden, behind the Berkeley campus. At the end of the road are a clearing and a vault in the side of a hill. Inside is a series of corridors leading straight back into the hillside.

It is arguably one of the stillest places on the planet. If it weren't for our clattering, you could almost hear a pin drop...in Abkhazia. The musty smell brings to mind either a church or a bomb shelter. It turns out that's not far off.

"It was built in 1962 as part of a military project to detect Soviet nuclear tests," Allen says, adding, "Watch your head." To the sensitive equipment inside this bunker, my softest footsteps seem like hurricanes. I can only imagine what cracking my skull would sound like.

It's true: The first seismic networks in the world were built not to understand earthquakes, but to keep an eye on the Russians. Long before satellite imaging, the best way to tell if a

country was testing an H-bomb was to listen to the earth. Apparently, nuclear explosions and quakes have a lot in common—both send tremors that cross the globe as if it were a spherical Jell-O mold. With the right equipment, the tiniest shudders are perceptible on the opposite side of the world.

In this bunker, the equipment consists of two types of devices. Accelerometers are the sensor equivalent of Cadillac Escalades—oblivious to all but the largest earthquake “bumps” (in other words, S-waves). Seismometers, meanwhile, are akin to Lamborghinis—handmade in Europe, more expensive, and extremely sensitive to the slightest pothole (or P-wave). As far as I can tell, they pick up everything from shivers on the Nazca Plate in the South Pacific to goat farts in eastern Turkey.

To develop and run ElarmS, Allen gets \$120,000 a year from the U.S. Geological Survey (USGS)—about as much as a top-of-the-line kitchen remodel—so he has to make do with whatever existing facilities and equipment he can find. “It’s absolute peanuts. I mean, it’s really insane,” he says. Luckily, he’s been able to tap into a grid of about 285 sensors—some contained in bunkers like this one, most buried in metal capsules a few feet underground—overseen by the California Integrated Seismic Network (CISN). By comparison, Japan has invested around \$35 million a year on its alert system, installing nearly 1,000 sensors to cover an area slightly smaller than the Golden State.

The CISN grid, however, is far from ideal. Most of the sensors are clustered around the Bay Area and Southern California, leaving much of the state unmonitored. In addition, most were put in place in the mid- to late 1990s after the Northridge quake, which means that, though functional, they are long outdated: Think floppy disk-era electronics in the digital age. “Imagine if you were still using the computer that you were using 15 years ago,” Allen says, shaking his head.

Given all these handicaps, ElarmS’ proof of concept last fall seems that much more impressive. True, a two- or three-second warning might not save a single life. But Allen is certain he can improve the Alum Rock results by another few seconds, just by tinkering with the software—and he could do a lot better than that, he says, without anywhere close to a Japanese-size investment. For a measly \$1 million—the cost of upgrading existing devices and adding about 50 new sensors to unmonitored areas along the Central Coast and the San Andreas Fault north of Sonoma—the state could have a system Allen calls “adequate.” Another \$3 million (the cost of 300 or so new sensors, installed) would buy California a grid that, despite its relative sparseness, would still rival Japan’s. (This doesn’t, however, include the cost of sending out alerts on cell phones, TV, computers, and other devices, which private businesses and the public would presumably share.)

Those amounts represent barely a blip in the federal budget, but even before this fall’s economic meltdown, ElarmS’ funding was in danger. The White House’s proposed budget contains zero money for the program in 2009; Zoe Lofgren, the Democratic congresswoman from San Jose, complains that President Bush “seems to have targeted science—not just the USGS, but physics and other things.” Allen is likely to get a few months’ reprieve while the federal government tries to stave off a new worldwide depression, but the future for ElarmS looks decidedly bleak. (Meanwhile, Bush has asked for \$15.5 billion to grow the Army by 7,000 troops—or \$2.2 million per recruit.)



*This Cold War–era vault in the Berkeley Hills was built to listen for Soviet nuclear tests; now its sensitive equipment listens for earthquakes.*

**Of course, disaster preparedness is always** a tough sell to lawmakers—just ask the weary residents of New Orleans. With all the natural calamities vying for money across the U.S.—hurricanes, tornadoes, wildfires, drought, global warming—it can be hard for Congress to know where to start, much less for lawmakers from one region to put another region’s problems ahead of their own.

Nor can Allen count on public utilities and private agencies to help him come up with more money. Because its 100-mile system is highly vulnerable to derailment during a major quake, BART might be expected to be one of ElarmS’ boosters. But a spokesman says that 20 seconds’ notice wouldn’t be enough to initiate the transit system’s earthquake-response pro-ocols (it can take 45 seconds to stop a BART train). The spokesman adds that Allen’s “alleged system” is not yet proven and would need some sort of track record before BART would consider supporting it. (It doesn’t help Allen’s case that the closer you are to the epicenter, the more damage a quake would do—yet the less warning ElarmS could provide.)

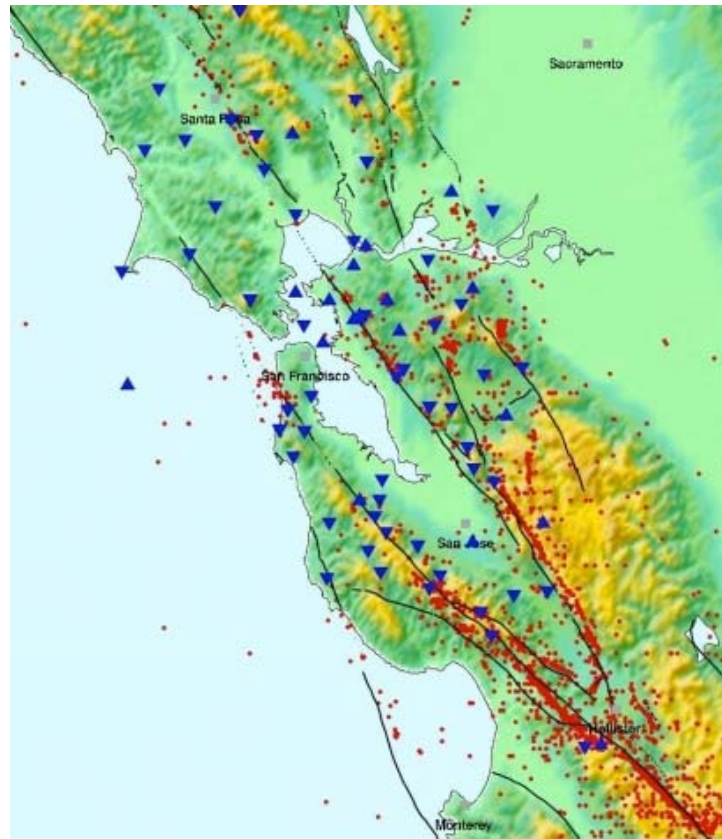
Similarly, PG&E’s Kristine Buchholz, who manages the electrical grids in most of Northern California, says it can take the utility 10 minutes or more just to determine that an outage was caused by a quake. ElarmS would give her a quicker heads-up, but when asked how much those few extra minutes would be worth to the company, Buchholz says probably not much.

Other countries are more enthusiastic about earthquake early warning because dense populations and aging infrastructure make even midsize quakes like Alum Rock potentially devastating. Paolo Gasparini, a University of Naples geophysicist who is heading the Italian effort to develop a warning system, notes that many buildings in earthquake-prone parts of Europe are centuries old and would cost too much to retrofit. The 7.4 quake that struck Izmit, Turkey, in the middle of the night in August 1999 killed at least 17,000 people, mainly because poorly constructed houses could not withstand 37 seconds of violent shaking. A few seconds’ warning might have saved thousands of lives.

Since 1900, Turkey has had 17 catastrophic earthquakes (with 1,000 or more fatalities each), Japan has experienced eight such quakes, and Italy has had five. In California, by contrast, truly terrible quakes are few and far between. Of the 41 temblors above 6.0 to hit the state since 1900, only five were near enough to big cities to cause more than 50 deaths, and only one of those—the 1906 quake—killed more than 1,000 people.

As delicately as possible, Gasparini offers another reason why Americans are behind on earthquake early warning: “The distribution of responsibility in your country, as I understand, is not very clear.” Put another way, who would take responsibility for missing a big quake? Or suppose the system sent a false alarm and someone was injured or died as a result—who would be liable then?

Even the state-of-the-art Japanese system is far from infallible. In the past year, it has issued a handful of warnings, all of which either were false alarms or arrived too late to do much good. David Oppenheimer, a USGS seismologist who oversees part of the CISEN, sees the threat of litigation as something that needs to be addressed. “The first time we made a mistake—somebody rushed out of the building and had a heart attack—well, you know what would happen. There’d be a lawsuit.”



*In this map of the Bay Area, fault lines are shown in black, earthquakes in red, and seismic stations in blue.*

**Earthquake early warning, then, faces a major catch-22.** Few in this country want to put their faith in a warning system until the kinks are worked out, but the only way to work out the kinks is to create a functional system. Government and industry are often loath to adopt new disaster technologies, Allen says, since doing so involves admitting to inherent weaknesses and reminding consumers of a danger these institutions would just as soon like the public to forget. “Everybody wants to be first to be second,” he says.

Frustrated with the situation, a few academics and entrepreneurs have started looking for inexpensive and efficient ways to deliver alerts around California (see “Feeling the Earth

Move,” left). But Allen believes that lifesaving warnings shouldn’t be in the hands of for-profit companies. (In Japan, the government owns the alerts but works with the private sector to get the word out.) The benefits of an integrated warning system would not be limited to quakes, Allen maintains. Currently, the primary way to send out emergency announcements is by radio and TV. A statewide quake-alert system based on ElarmS that uses cell phones and home alarms might facilitate the delivery of other types of warnings—say, in the case of a terrorist attack.

But Allen’s biggest impediment may be simple human nature. Several times a year, it seems, the USGS or some other agency warns that a catastrophic quake could happen at any moment along the San Andreas or Hayward Fault. How many people turn away from those news reports because they’re just too scary? How many can’t bring themselves to put together an earthquake plan or stockpile food and water, much less bolt down the house? How would you feel knowing that in 10 or 20 seconds, your world might topple around you? Would you panic and do something stupid? Would you just stand there, too petrified to act?

These ideas irritate the normally mild-mannered Allen. “This is one of the biggest misconceptions about emergency situations—that people flip out and do silly things. It’s not true,” he says. “In an emergency, people take very rational actions when they know what to do.

“If I could tell you the ground is going to shake five seconds from now, are you really going to tell me you’d prefer not to know?” he demands. “If you explain, ‘You have a choice: You can have two seconds to get under a table, or not know,’ I find it very difficult to believe there are many people who would still say they don’t want to know.”

*Erik Vance has written for Nature, Mental Floss, and the Chronicle of Higher Education.*

*Main photo: UC Berkeley associate professor Richard Allen, at a seismic station in Richmond, thinks his ElarmS program could prevent thousands of injuries and deaths in a quake along the San Andreas or Hayward Fault—if it’s not killed first.*

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