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NOVEMBER 2005

Time Machine

Will a clock that works flawlessly for 10,000 years become the greatest wonder of the world?

BY BRAD LEMLEY PHOTOGRAPHY BY DAN WINTERS

SOMETIMES, WHEN THINGS GET SUFFICIENTLY WEIRD, SUBTLETY NO LONGER works, so I'll be blunt: The gleaming device I am staring at in the corner of a machine shop in San Rafael, California, is the most audacious machine ever built. It is a clock, but it is designed to do something no clock has ever been conceived to do—run with perfect accuracy for 10,000 years.

Everything about this clock is deeply unusual. For example, while nearly every mechanical clock made in the last millennium consists of a series of propelled gears, this one uses a stack of mechanical binary computers capable of singling out one moment in 3.65 million days. Like

LONG CLOCK

Opposite: Prototype number two of the Clock of the Long Now is, at nine feet tall, a diminutive model of the final version, which is expected to be at least 60 feet tall and will have multiple displays. This prototype records the changes in the relative positions of Earth and the five other planets that humans can eyeball without a telescope. "If you came up to the clock thousands of years from now, you could still read the time, even if you did not have the same time system we use now," says designer Danny Hillis.

other clocks, this one can track seconds, hours, days, and years. Unlike any other clock, this one is being constructed to keep track of leap centuries, the orbits of the six innermost planets in our solar system, even the ultraslow wobbles of Earth's axis.

Made of stone and steel, it is more sculpture than machine. And, like all fine timepieces, it is outrageously expensive. No one will reveal even an approximate price tag, but a multibillionaire financed its construction, and it seems likely that shallower pockets would not have sufficed.

Still, any description of the clock must begin and end with that ridiculous projected working life, that insane, heroic, incomprehensible span of time during which it is expected to serenely tick.

Ten thousand years.

The span of time from the invention of agriculture to the present. Twice as long as the Great Pyramid of Giza has stood. Four hundred human generations.

How?

Or more to the point, why?

MOST HUMANS ARE PREOCCUPIED WITH THE HERE AND now. Albert Einstein, echoing the sentiments of other deep thinkers of the modern era, argued that one of the biggest challenges facing humanity is to "widen our circle of compassion" across both space and time. Everything from ethnic discrimination to wars, such reasoning goes, would become impossible if our compassionate circles were wide enough.

That is exactly why W. Daniel Hillis, the man whose insights underlie the world's most powerful supercomputers, has spent two decades designing and building prototypes of what he has dubbed the Clock of the Long Now. The clock in the corner of the machine shop, you should understand, is a prototype, the second prototype. Nonetheless, even the prototype can tick away for 10,000 years. Hillis and his team just finished it a few weeks ago. There will be more prototypes over the next few decades before the final, much larger version is embedded in a mountain in Nevada.

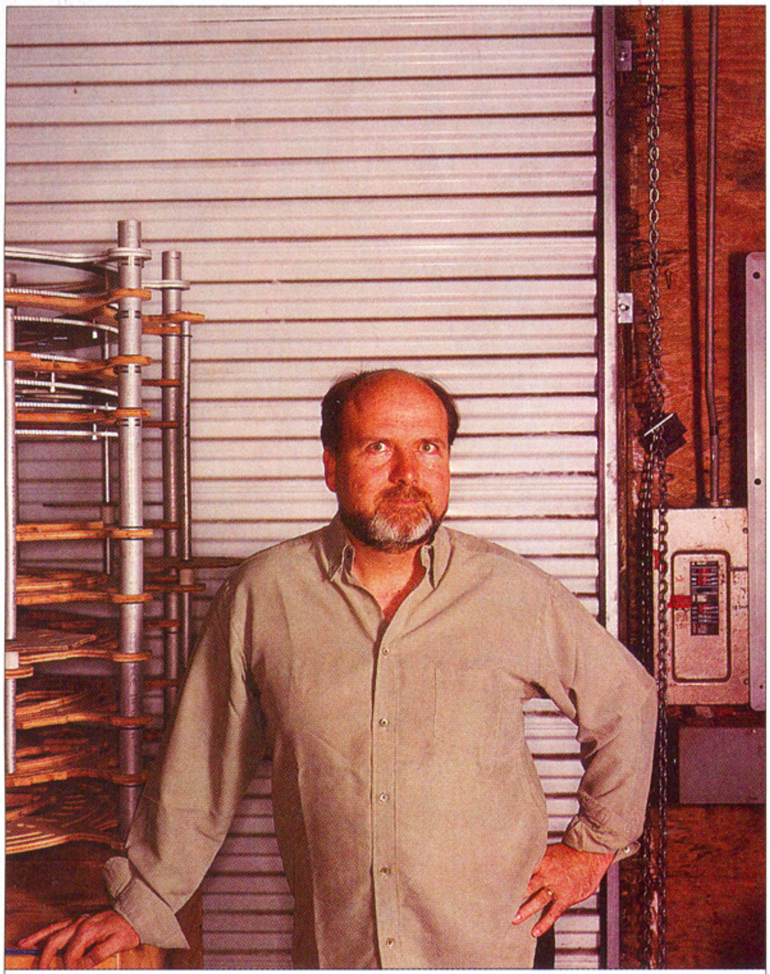
The clock idea originally sprang from Hillis's observation that in the 1980s, all long-range planning seemed to smack into a wall called the year 2000—the nice, round number seemed to be the omega point for everyone from software programmers to international policymakers: "Nobody could even think about the year 2030. It bugged me." Because technology began 10,000 years ago—there are pot fragments at least that old—Hillis decided to build a clock that would tick that long into the future, conceptually fixing humanity in the center of 20 millennia. Musician Brian Eno, Hillis's friend and a clock project collaborator, dubbed that vast span "the long now." The clock of his dreams, said Hillis in 1993, "ticks once a year, bongs once a century, and the cuckoo comes out every millennium."

The final version, which will be at least 60 feet tall, frankly strikes more than a few people as pointless. "Many people are completely uninterested. They think it's nonsense, a waste of time," Hillis says. And he concedes that "in the world of ideas, it's an odd one."

Still, project insiders have found that the idea, like the clock itself, ticks away patiently, incrementally engaging skeptical minds. "People will make some flippant comment, then come back months later with an idea about how to make it work," says Alexander Rose, a codesigner and executive director of the Long Now Foundation, which finances the clock.

Hillis, at first motivated by a vague desire to promote long-term thinking, has been transformed by his idea: "Now I think about people who will live 10,000 years from now as real people." His eyes take on a distant focus as he says this, as if he sees them massed on the horizon. "I had never thought that way before."

But Hillis, who has been known to drive a fire engine to work, also cautions against regarding the Clock of the Long Now too gravely: "This project has a lovely kind of lightness to it."

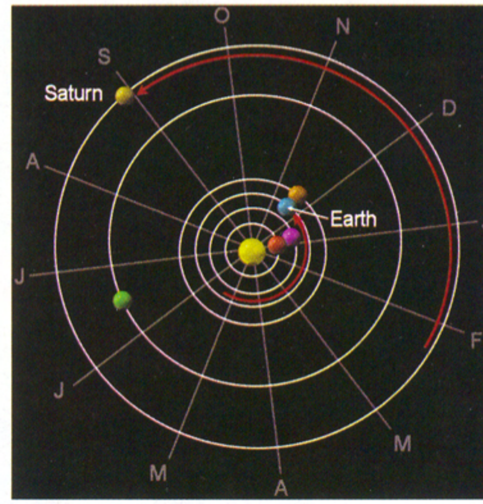


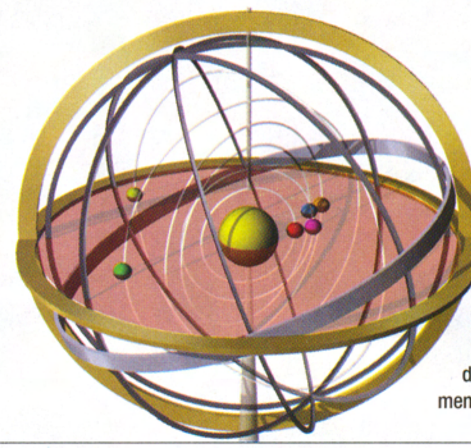
LONG VIEW

Clock designer Danny Hillis, standing next to an early plywood and aluminum prototype, knows that looters and vandals pose a significant threat to his engineering marvel, no matter how well it works. "The most dangerous period will be the couple of hundred years after I'm dead, before the clock is really old and assumes historical importance," he says. "So there will have to be a caretaker. That's part of the plan."

HOW STARS TELL US THE TIME

One universal way to visualize the passage of time is to make a dynamic model of the heavens. The changing relationship of Earth and the five other innermost planets can be calculated based on how long it takes each planet to revolve around the sun, which ranges from 87.97 Earth days for Mercury to 10,759.5 Earth days for Saturn. The diagram at right shows the position of the planets on November 15, 2005.





HOW THE CLOCK CAN BE READ

The Clock of the Long Now prototype features an orrery, a simplified planetary display. The spherical cage of the orrery, called the firmament, is tilted at 23.45 degrees, the approximate angle of the Earth's axis in relation to the flat plane of the planets as they radiate out from the sun. The frame includes a celestial equator with degree markings for measuring the alignment of the planets at any given time.

GENIUS IS A SHABBY, ABUSED, AND DEgraded noun, but Hillis reminds one of what it should mean. He is cochairman and chief technology officer of Applied Minds in Glendale, California, a 21st-century analogue of Thomas Edison's Menlo Park laboratories. There, an elite engineer corps patents a river of inventions ranging from voice encryptors to cancer detectors. Universally called Danny, Hillis is affable and witty but tends to veer abruptly into subjects like lattice theory, which "describes a piece of graph paper in *n* dimensions," and from there the conversation becomes a labyrinth impossible to negotiate.

"Danny's intelligence is the rarest of kinds," says Rose. "The sheer practicality of his knowledge makes him a true genius."

As an MIT undergrad in 1975, Hillis and his friends built a binary computer out of 10,000 Tinkertoy pieces. It could beat all comers at tic-tactoe. About a decade later he invented an electronic mainframe computer called the Connection Machine that worked somewhat like a human brain; instead of one processor, it had 65,536, all firing at once like buzzing neurons, a model that supercomputers have used ever since. The irony is inescapable: The architect of the world's fastest machine now designs the world's slowest.

The trip to Hillis's office is a cross between a Disney ride and the multidoor opening sequence of the 1960s television show *Get Smart.* I enter a low-slung industrial building, meet Hillis in the lobby, follow him into a red, British-style phone booth, pick up the receiver, wait for him to say the password, and follow him through the false back when it opens into a cavernous workroom. I then pass under a 13-foot-tall, five-ton, four-legged robot he designed, marvel at his new invention that instantly makes three-dimensional maps of any place in the world, then settle into his gadget-strewn office complete with a *New Yorker* cartoon of a gypsy behind a crystal ball who says: "Why ask me about the future? Ask Danny Hillis."

So that's what I do: "How do you build a clock that will keep perfect time for 10,000 years?"

Hillis, who loves gadgets and was once Walt Disney Imagineering's vice president for research and development, smiles and begins to explain the challenges involved. The clock must remain accurate for 100 centuries while sitting on an atmospherically, geologically, and worst of all, culturally violent planet. To forestall looting (the bane of many built-for-the-ages projects, such as the Egyptian pyramids), it cannot contain parts made of jewels and expensive metals. In case of societal collapse, it must be maintainable with Bronze Age technology. It must be understandable while intact, so that no one will want to take it apart. It must be easily improved over time, and it must be scalable so that the design can be shown via smaller prototypes.

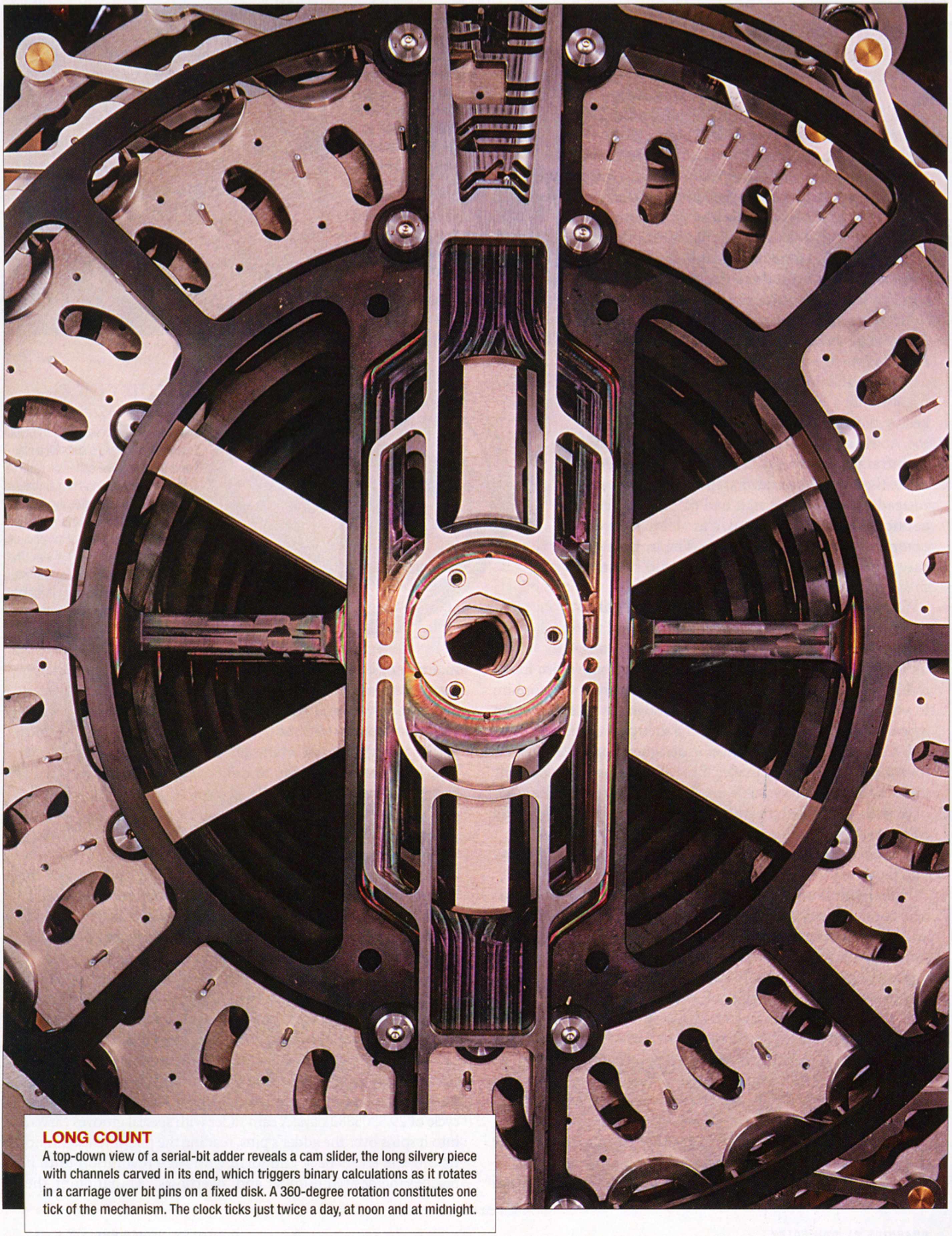
"The ultimate design criterion is that people have to care about it," says Hillis. "If they don't, it won't last."

All straightforward, but ludicrously daunting. Time can mean many things, but Hillis's machine needs to track a particularly messy version: Earth-surface clock/calendar time, which is based on a byzantine agglomeration of astronomical rotations, orbits, and perturbations of hugely varying lengths, overlaid with arbitrary cultural whims about how to divide it up. What kind of machine can, for 10 millennia, accurately reconcile hours, days, weeks, months, leap years, leap centuries, the precession (wobbling around an axis) of planetary orbits, and, grandest cycle of all, the 25,784-year precession of the equinox?

Answer: a digital one. A calculation that extends to 28 bits is accurate to one in 3.65 million—or in clock terms, one day in 10,000 years. Bits and bytes are typically rendered electronically, but Hillis says he "rejected electronics from the start. It would not be technologically transparent and probably not durable. I could quickly see that the clock had to be mechanical."

So Hillis invented—and patented—a serial-bit adder, or a mechanical binary computer. Instead of using "voltage on" or "voltage off" to define zeros and ones like a typical electronic computer, the disk-shaped adder uses levers that can rest in either the "0" or "1" position. An individual adder can be programmed with 28 pins—what a programmer would call 28 bits—to represent in binary code any number displayed by the clock, such as the lunar cycle of 29.5305882 days. A cam slider with special grooves carved into it spins over the adder's pins, reading the pins and levers and ticking the levers back and forth with each revolution until it reaches the desired number and "overflows." At that point, the

GRAPHICS BY DON FOLEY



LONG COUNT
A top-down view of a serial-bit adder reveals a cam slider, the long silvery piece with channels carved in its end, which triggers binary calculations as it rotates in a carriage over bit pins on a fixed disk. A 360-degree rotation constitutes one tick of the mechanism. The clock ticks just twice a day, at noon and at midnight.

slider pops out of the clock's side—rather like a cuckoo popping out on the hour—and engages a small wheel, which in turn moves some part of the clock's display. The clock's guts are a stack of serial-bit adders, each controlling a different part of the display.

As if that were not complicated enough, the final clock will require a helical column called the "equation of time" cam. Its purpose will be to make the conversion from absolute time to local solar time. Using a stylus that traces the cam's rather feminine shape, the clock will be able to compensate for elliptical eccentricities in Earth's orbit around the sun and the tilt of Earth's axis. These two celestial phenomena "beating against each other," as Hillis puts it, produce variations in the the sun's apparent rate of travel through the sky that would add up to about 15 minutes per year over the clock's lifetime. (That a short section of the cam vaguely resembles a nude female's hips and thighs isn't accidental: Hillis twiddled and tweaked to make the cam look like that. "Other configurations could have worked, but it would not have looked nearly as wonderful," he says.)

Still, no mechanical clock, however cleverly crafted, can keep perfect time for 10,000 years. So Hillis added solar synchronization: A sunbeam striking a precisely angled lens at noon triggers a reset by heating, expanding, and buckling a captive band of metal.

And what about power? By harnessing natural processes like temperature or pressure changes, "there are lots of ways to make it totally self-winding," says Hillis. "But I want people to engage the clock, not forget it." So the perfect power system could handle neglect but would respond to love. The final clock, untended, will wind itself enough to keep its pendulum swinging and track time, but human visitors—perhaps by merely stepping on a platform—could also wind the display. "So when you visit the clock, it shows the last time someone was there," says Hillis. "When you wind it, it catches up to now and stops, set for the next person. It rewards attention."

The last question, what to display, gives Hillis the most pause. All cultures recognize days, months, and years because they spring from simple "once around" astronomical cycles, but hours, weeks, centuries, and other divisions are arbitrary, varying wildly across times and places. Hillis is still mulling how to handle that, but he knows for sure that the final clock will somehow mirror the positions of the planets relative to the stars and to one another. "That will be one of many displays it has," he says.

Hillis is in the process of rolling out these and more ideas in a series of increasingly complex prototypes. The first one, now on permanent display at the Science Museum in London, was financed by an anonymous donor who lent it to the museum. "The deal we offer is, if you fund the next stage of the development of the clock, we will give you a prototype," says Hillis. "We have spent millions of dollars so far—I don't know the exact number."

The nine-foot-tall London clock uses a slowly rotating torsional pendulum, ticks once every 30 seconds, and tracks hours, sidereal and solar years, centuries, phases of the moon, and the zodiac—and happens to be hauntingly beautiful. Incredibly,

SLOWER THINKING

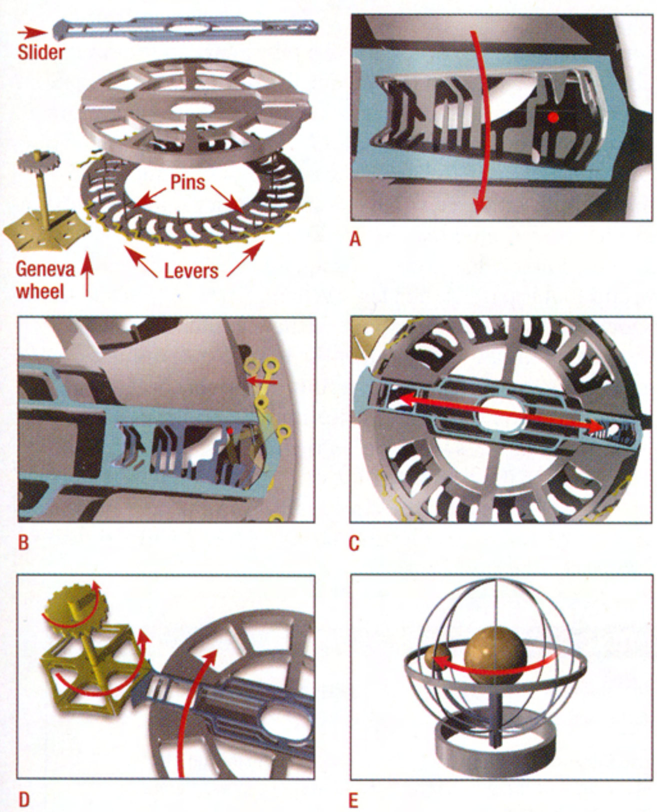
Aside from its eponymous clock, the Long Now Foundation, formed in 1996, pursues projects aimed at promoting "slower, better" thinking:

- **THE ROSETTA PROJECT** attempts to preserve all human languages. The project concentrates on languages that are likely to go extinct by 2100, including hundreds whose native speakers number in the thousands or fewer. Its document database, representing some 2,300 languages as of June 2005, is online (www.rosettaproject.org) and will be periodically published in a book and on a micro-etched disk for widespread distribution.
- **SEMINARS ABOUT LONG-TERM THINKING,** a series of monthly lectures in various locations around San Francisco, have included such speakers as geographer Jared Diamond, astronaut Rusty Schweikart, and musician Brian Eno.
- **THE LONG BETS WEB SITE** (www.longbets.org) lets all comers wager on long-range predictions (a minimum of two years; there is no maximum), with proceeds going to a charity named by the victor. For example, $2,000 is riding on the prediction "By 2030, commercial passengers will routinely fly in pilotless planes."

HOW THE CLOCK COMPUTES

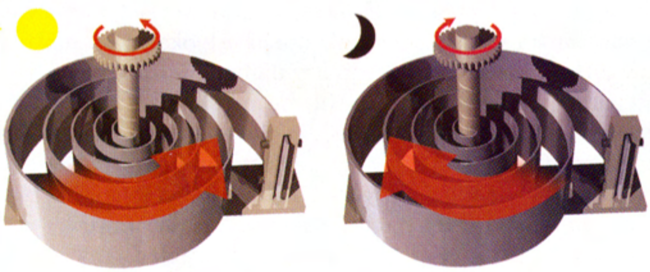
The clock is driven by binary mechanical computers called serial-bit adders with one adder per planet. An adder consists of a disk with an outer set of bit-pin levers, each of which can take on a value of "1" or "0," as well as an inner ring of fixed bit pins programmed with a mathematical constant that represents the duration of the planet's orbit. (A) The levers and pins are read by a series of channels in a cam slider that rotates in a carriage. (B) The slider also adds sums by tripping levers as it goes. (C) During each rotation, the slider jitters back and forth as it accumulates sums. (D) When the accumulated sums reach an overflow value, the slider pops out of the carriage and catches a Geneva wheel. (E) The movement of the Geneva wheel updates the planetary display.

SERIAL-BIT ADDER



HOW THE CLOCK IS POWERED

The clock may be energized by a bimetallic spring—a coil of two alloys bonded together and fixed at one end. The heat-sensitive alloy on one side of the spring expands or contracts as temperatures change, turning a shaft at the other end of the spring. That ratchets up a weight, which can be released to drive the clock's mechanisms.



its three-year-long construction was completed in a mad rush scarcely one hour before midnight on December 31, 1999. That meant there was no time to test it before the switch to the year 2000, the most complex date change in the Gregorian system since the year 1600 because it involved a once-in-400-years leap year exemption.

Yet at midnight, "it bonged twice. It was perfect. That was a great moment," says Hillis softly. "Some people say their millennium experience was anticlimactic. Mine wasn't."

IN HIS BIODIESEL-POWERED TOYOTA LAND CRUISER, ALEXANDER Rose drives me from the Long Now Foundation's office in the historic Presidio district in San Francisco across the Golden Gate Bridge to Rand Machine Works, a metal shop in San Rafael that's about the size of a three-car garage. In a dark back corner the second prototype is rising, adder ring by adder ring. It is funded by billionaire Nathan Myhrvold, former chief technology officer of Microsoft and a longtime Hillis pal. The clock's builder is Chris Rand, a nonpareil build-anything machinist who has helped craft everything from the *Star Wars* land cruisers to America's Cup yachts. This project, he says, is working on him.

"I think about everything more long term now," he says.

Someday this clock may become a holy object, but for now it's a half-finished project in a gritty shop that infidels can touch and tinker with. I scoot the adder arm around with my index finger. A complex series of channels cut into its end makes it jitter back and forth as it slides over pins. The whole thing is so brilliant it makes me laugh. Gears constitute the heart of the calculation engines of most other mechanical clocks, but as friction grinds them down, they get smaller, which means they move faster, which means they lose accuracy. But an adder's pin—even a worn one—is either there or not there, at either "1" or "0" until the thing shears clean through, which in a big clock with massive pins should take more than 10,000 years. Genius.

Still, materials remain a tricky question. The prototypes so far have been made largely of stainless steel, but the metals that will compose the final clock remain in doubt. "Just about nobody is doing research on materials that will last for thousands of years," says Rose.

Hillis, Rose, and Rand will make at least one more prototype after this one, but before Hillis dies, they will build the big one. The Long Now Foundation made a serious commitment to the final clock when, in 1999—or, as foundation literature renders this and all other years, "01999"—it bought 180 acres of desert mountain land adjoining Great Basin National Park in eastern Nevada. Dry, remote, and geologically stable, the site has one other serendipitous attribute—it is studded with bristlecone pines, the world's oldest living things. At the Long Now Foundation's office, Rose hands me a core section of a bristlecone on the property. "This is just the outer trunk, just 1,000 years, from 944 to 2003," he says. Some bristlecones in the area are nearly 5,000 years old. The clock site may be the only spot on Earth where commencing a 10,000-year process seems like a halfway sensible thing to do.

Hillis's plan for the final clock, which he reserves the right to change, has it built inside a series of rooms carved into white limestone cliffs, 10,000 feet up the Snake Range's west side. A full day's walk from anything resembling a road will be required to reach what looks like a natural opening in the rock. Continuing inside, the cavern will become more and more obviously human made. Closest to vast natural time cycles, the clock's slowest parts, such as the zodiacal precession wheel that turns once every 260 centuries, will come into view first. Such parts will appear stock-still, and it will require a heroic mental exertion to imagine their movement. Each succeeding room will reveal a faster moving and more intricate part of the mechanism and/or display, until, at the end, the visitor comprehends, or is nudged a bit closer to comprehending, the whole vast, complex, slow/fast, cosmic/human, inexorable, mysterious, terrible, joyous sweep of time and feels kinship with all who live, or will live, in its embrace.

Or so Hillis hopes.

Some people will no doubt make a pilgrimage to the cavern, but for the next century at least, that will probably require some commitment, as the site is "as far as you can get from civilization within the continental United States," Hillis says. "That will help people forget about it and avoid the contempt of familiarity."

Most people, however, will never visit the clock, just as most people never visit the Eiffel Tower. They will only know that it exists. That knowledge alone will acquaint them with the Long Now, and that is part of the plan. "When Danny first proposed the clock and I told people about it, they would say, 'What?'" says Stewart Brand, cochairman of the Long Now Foundation's board of directors. "Now as I go around, people come up and say, 'Hey, Stewart, how's the clock coming?' People are already engaged by it, and it is working on them. It exists before it exists." Even after it exists, the idea of the clock will no doubt change more minds than the clock itself.

How much power resides in that deceptively simple idea? Ask yourself in a month. ⊠

DISCOVER MORE [also see Resources, page 82]

For information on the Long Now Foundation and its various projects, visit www.longnow.org.

The Clock of the Long Now: Time and Responsibility: The Ideas Behind the World's Slowest Computer. Stewart Brand. Basic Books, 2000.

GRAPHICS BY DON FOLEY

LONG STACK
The Long Now prototype's calculation engine consists of six serial-bit adders, stacked like pancakes. The long shaft, topped with small gears, is part of a Geneva wheel mechanism. The clock features six of these devices. Each one links an individual serial-bit adder to a large gear that moves a planet in the display.