BRIAN HAYES

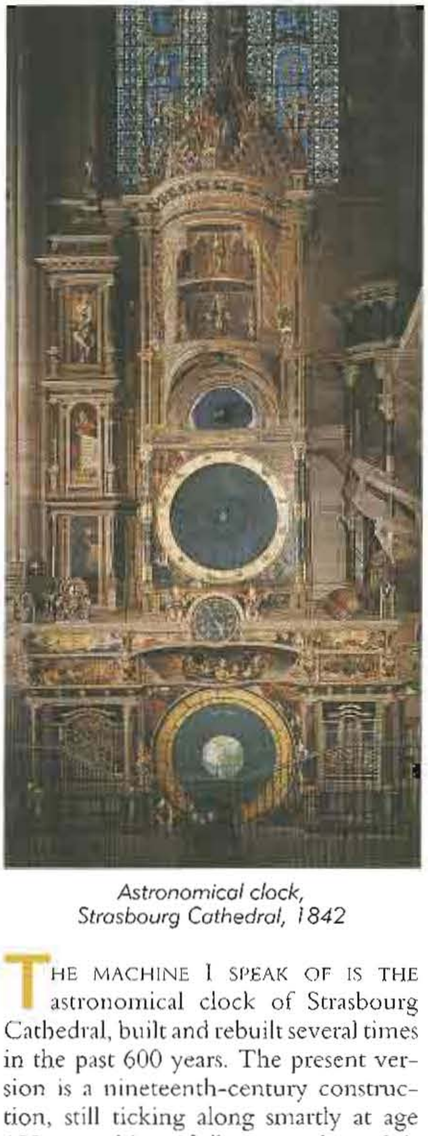
Clock of Ages

When one millennium's bright ideas become inscrutable legacies for the next

AS THE WORLD SPIRALS ON toward 01-01-00, survivalists are hoarding cash, canned goods and shotgun shells. It's not the Rapture or the Revolution they await, but a technological apocalypse. Y2K! The lights are going out, they warn. Banks may fail. Airplanes may crash. Your VCR will go on the blink. Who could have foreseen such turmoil? Decades back, one might have predicted anxiety and unrest at the end of the millennium, but no one could have guessed that the cause would be an obscure shortcut written into computer software by unknown programmers in the 1960s and 1970s.

Whether or not civilization collapses on January 1, those programmers do seem, in hindsight, to have been pretty short on foresight. How could they have failed to look beyond year 99? But I give them the benefit of the doubt. All the evidence suggests they were neither stupid nor malicious. What led to the Y2K bug was not arrogant indifference to the future ("I'll be retired by then. Let the next shift fix it"). On the contrary, it was an excess of modesty ("No way *my* code will still be running thirty years out"). The programmers could not envision that their hurried hacks and kludges would become the next generation's "legacy systems."

Against this background of throwaway products that someone forgot to throw away, it may be instructive to reflect on a computational device built in a much different spirit. This machine was carefully crafted for Y2K compliance, even though it was manufactured when the millennium was still a couple of lifetimes away. As a matter of fact, the computer is equipped to run until the year 9999—and perhaps even beyond, with a simple Y10K patch. This achievement might serve as an object lesson to the software engineers of the present era. But I am not quite sure just what the lesson is.



Astronomical clock, Strasbourg Cathedral, 1842

THE MACHINE I SPEAK OF IS THE astronomical clock of Strasbourg Cathedral, built and rebuilt several times in the past 600 years. The present version is a nineteenth-century construction, still ticking along smartly at age 150-something. If all goes as planned, it will navigate the various calendrical cataracts of the coming months without incident, unfazed by January 1, 2000, or the subsequent February 29, or the revels of the latter-day millenarians on New Year's Day, 2001.

The Strasbourg Cathedral clock is not a tower clock, like Big Ben in London, meant to broadcast the hours to the city. It stands inside the cathedral in a case of carved stone and wood fifty feet high and twenty-four feet wide, with three ornamented spires and a gigantic instrument panel of dials and globes, plus a large cast of performing automata. Inside the clock is a glory of gears.

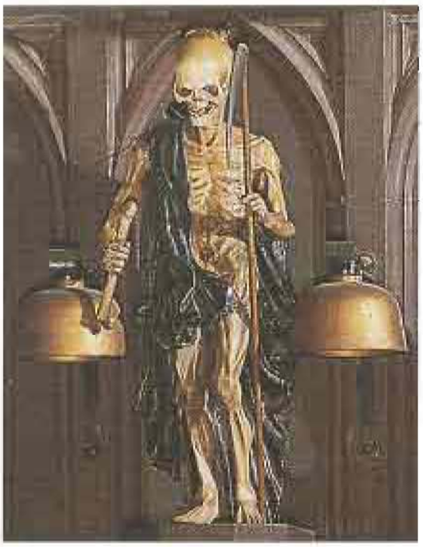
"Clock" is hardly an adequate description. More than a timepiece, it is an astronomical and calendrical computer. A celestial globe in front of the main cabinet tracks the positions of 5,000 stars, while a device much like an orrery models the motions of the six innermost planets. The current phase of the moon is indicated by a rotating globe, half gilt and half black.

If you want to know what time it is, the clock offers a choice of answers. A dial mounted on the celestial globe shows sidereal time, as measured by the earth's rotation with respect to the fixed stars. A larger dial on the front of the clock indicates local solar time, which is essentially what a sundial provides; the prick of noon by that measure always comes when the sun is highest overhead. The pointer for local lunar time is similarly synchronized to the height of the moon. Still another dial, with familiar-looking hour and minute hands, shows mean solar time, which averages out the seasonal variations in the earth's orbital velocity to make all days equal in length, exactly twenty-four hours. A second pair of hands on the same dial show civil time, which in Strasbourg runs thirty minutes ahead of mean solar time.

There's more. A golden wheel nine feet in diameter, marked off into 365 divisions, turns once a year, while Apollo stands at one side to point out today's date [*see photograph on page 12*]. What about leap years? Presto: an extra day magically appears when needed. Each daily slot on the calendar wheel is marked with the name of a saint or some church occasion. Of particular importance is the inclusion of Easter and the other "movable feasts" of the ecclesiastical calendar. Calculating the dates of those holidays requires feats of mechanical trickery.

For the Y2K police, the crucial component of the clock is, of course, the counter of years. It is an inconspicuous four-digit register that anyone from our age of automobiles will instantly recognize as an odometer. On December 31, at midnight mean solar time—and thus half an hour late by French official time—the digits will roll over from one-triple-nine to two-triple-zero.

Wait! There's even more! The clock is inhabited by enough animated figures to open a small theme park. The day of



Death and his chimes

the week is marked by a slow procession of seven Greco-Roman gods in chariots. Each day at noon (that's mean solar noon) the twelve apostles appear, saluting a figure of Christ, who blesses each in turn. Every hour a putto overturns a sandglass. At various other times figures representing the four ages of man and a skeletal Death emerge to strike their chimes [*see photograph above*].

All of that apparatus is housed in a structure of unembarrassed eclecticism, both stylistic and intellectual. The central tower of the clock is topped with a froth of German-baroque frosting, whereas the smaller turret on the left (which houses the weights that drive the clockwork) has been given a more Frenchified treatment. The third tower, on the right, is a stone spiral staircase that might have been salvaged from an Italian Renaissance belvedere. In the base of the cabinet, two glass panels allowing a view of brass gear trains are a distinctively nineteenth-century element; they look like the store windows of an apothecary's shop. The paintings and statues are mainly on religious themes—death and resurrection, fall and salvation—but they also include portraits of Urania (the muse of astronomy) and Copernicus. Another painting portrays Jean-Baptiste Schwilgué, whose part in this story I shall return to presently.

IT'S ALL DONE WITH GEARS. ALSO PINions, worms, snails, arbors; pawls and ratchets; cams and cam followers; cables, levers, bell cranks and pivots.

The actual timekeeping mechanism—a pendulum and escapement much like the ones present in other clocks—drives the gear train for mean solar time. All the other astronomical and calendrical functions are derived from that basic, steady motion. For example, local solar time is calculated by applying two corrections to mean solar time. The first correction compensates for seasonal changes in the length of the day, the second for variations in the earth's orbital velocity as it

PARTS OF THE STRASBOURG CLOCK *look deep into the*

follows its slightly elliptical path around the sun. The corrections are computed by a pair of "profile wheels" whose rims are machined to trace out a graph of the appropriate mathematical function. A roller, following the profile as the wheel turns, adjusts the speed of the local-solar-time pointer accordingly. The computation of lunar motion requires five correction terms and five profile wheels. They all have names: anomaly, evection, variation, annual equation, reduction.

The overall accuracy of the clock can be no better than the adjustment of the pendulum, which requires continual intervention, but for the subsidiary timekeeping functions there is another kind of error to be considered as well. Even if the mean solar time is exact, will all the solar, lunar and planetary indicators keep pace correctly? The answer depends on how well celestial motions can be approximated by rational arithmetic—specifically, by gear ratios. The Strasbourg clock comes impressively close. For example, the true sidereal day is twenty-three hours, fifty-six minutes, 4.0905324 seconds, whereas the mean solar day is, by definition, exactly twenty-four hours. The ratio of the two intervals is 78,892,313 to 79,108,313, but grinding gears with nearly 80 million teeth is out of the question. The clock approximates the ratio as the reciprocal of $1 + (450/611 \times 1/269)$, which works out to a sidereal day of twenty-three hours, fifty-six minutes, 4.0905533 seconds. The error is less than a second a century.

The most intricate calculations are the ones for leap years and the movable feasts of the church. The rule for leap years states that a year N has an extra day if N is divisible by 4, unless N is also divisible by 100, in which case the year is a common year, with only the usual 365 days—but if N happens also to be divisible by 400, the year becomes a leap year again. Thus 1700, 1800 and 1900 were all common years, but 2000 will have a February 29. How can you encode such a nest of if-then-else rules in a gear train?

The clock has a wheel with twenty-four teeth and space for an omitted twenty-fifth. That wheel is driven at a rate of one turn per century, and so every four years a tooth comes into position to actuate the leap-year mechanism. The gap where the twenty-fifth tooth would be takes care of the divisible-by-100 exception. For the divisible-by-400 exception, a second wheel turns once every 400 years. It carries the missing twenty-fifth tooth and slides it into place on every fourth revolution of the century wheel, just in time to trigger the quadricentennial leap year.

The display of leap years calls for as much ingenuity as their calculation. On the large calendar ring, an open space between December 31 and January 1 bears the legend *Commencement de l'année commune* ("start of common year") [*see photograph on page 12*]. Shortly before midnight on the December 31 before a leap year, a sliding flange that carries the first sixty days of the year ratchets backward by the space of one day, covering up the word *commune* at one end of the flange and at the same time exposing February 29 at the other end. The flange remains in that position throughout the year, then shifts forward again to cover up the twenty-ninth and reveal *commune* just as the following year begins.

THE RULES FOR FINDING THE DATE of Easter are even more intricate than the leap-year rule. Donald E. Knuth, in his *Art of Computer Programming*, remarks: "There are many indications that the sole important application of arithmetic in Europe during the Middle Ages was the calculation of [the] Easter date." Knuth's version of a sixteenth-century algorithm for the calculation has eight major steps, and some of the steps are fairly complicated. Here (to paraphrase the mathematics slightly) is step five:

Calculate the sum $11G + 20 + Z - X$, where the numbers G, Z and X come from earlier steps in the algorithm. Now reduce that sum modulo 30—that is, divide by 30 and keep only the remainder. Label the result E, for the so-called epact, the "age" of the moon at the start of the year. Finally, if E is equal to 25 and G is greater than 11, or if E is 24, then increase E by 1.

Programming a modern computer to perform the Easter calculation requires some care; programming a box of brass gears to do the arithmetic is truly a tour de force. I have stared at diagrams of the gears and linkages, and tried to trace out their action, but I still don't fully understand how it all fits together.

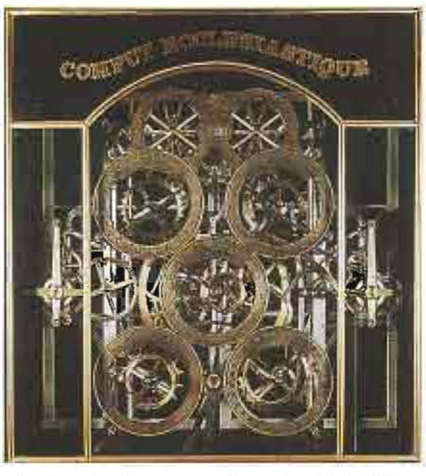
In the abstract, it's not hard to see how a mechanical linkage could carry out the basic steps of the epact calculation. A wheel with thirty teeth or cogs would ratchet $11G$ notches clockwise, then add twenty steps more in the same direction, then another Z steps; finally, it would turn X steps counterclockwise. The "modulo 30" part of the program would be taken care of automatically if the arithmetic were done on a circle with thirty divisions. So far, so good. The thirty-tooth wheel does exist in the Strasbourg clock, and it is even helpfully labeled *"Epacte."* Where I get lost is in trying to understand the various lever arms and rack-and-pinion assemblies that drive the epact wheel, and the cam followers that communicate its state to the rest of the system. There appear to be a number of optimizations in the works, which doubtless save a little brass but make the operation more obscure. Perhaps if I had a model of the clock that I could take apart and put back together. . . .

But never mind my failures of spatiotemporal reasoning. The mechanism does work. Each New Year's Eve a metal tag that marks the date of Easter slides along the circumference of the calendar ring and takes up a position over the correct Sunday for the coming year. All the other movable feasts of the church are determined by the date of Easter, so the indicators of their dates are linked to the Easter tag and move along with it.

THE PRESENT STRASBOURG CLOCK IS the third in a series. The first was built in the middle of the fourteenth century, just as the cathedral itself was being completed. The original clock had three mechanical Magi that bowed down before the Virgin and child every hour on the hour.

By the middle of the sixteenth century, the Clock of the Three Kings was no longer running and no longer at the leading edge of horological technology. To supervise an upgrade, the Strasbourgeois hired Conrad Dasypodius, the professor of mathematics at Strasbourg, as well as the clock maker Isaac Habrecht and the artist Tobias Stimmer. Those three laid out the basic plan of the instrument still seen today, including the three-turreted case and most of the paintings and sculptures. A curiosity surviving from that era is the portrait of Copernicus—a curiosity because the planetary display on the Dasypodius clock was Ptolemaic. The second clock lasted another 200 years or so.

The story of the third clock starts with an anecdote so charming that I can't bear to look too closely into its authenticity. Early in the 1800s, the story goes, a beadle was giving a tour of the cathedral, and mentioned that the clock had been stopped for twenty years. No one knew how to fix it. A small voice piped up: "*I* will make it go!" The boy who



Mechanism for computing church holidays

made the declaration was Jean-Baptiste Schwilgué, and forty years later he made good on his promise.

There was mild conflict over the terms of Schwilgué's commission. He wanted to build an entirely new clock; the cathedral administration wanted to repair the old one. They compromised: he gutted the works but kept the case, and built his new indicators and automata to fit the old design. The new mechanism began ticking on October 2, 1842.

Schwilgué was clearly thinking long-term when he undertook the project. As I noted earlier, the leap-year mechanism includes parts that engage only once every 400 years—parts that will soon be tested for the first time, and then lie dormant again until 2400. Such very rare events might have been left for manual correction: it would have been only a small imposition on the clock's maintainers to ask that the hands be reset every four centuries. But Schwilgué evidently took pride and pleasure in getting the details right. He couldn't know whether the clock would still be running in 2000 or 2400, but he could build it in such a way that if it *did* survive, it would not perpetrate error.

THE CONTRAST WITH RECENT PRACtice in computer hardware and software could hardly be more stark. Some computer programs, even if they survive the Y2K scare, are explicitly limited to dates between 1901 and 2099. The reason for choosing that particular span is that it makes the leap-year rule so simple: it's just a test of divisibility by 4. Under the circumstances, that design choice seems pretty wimpy. If Schwilgué could take the trouble to fabricate wheels that make one revolution every 100 years and every 400 years, surely a programmer could write the extra line of code needed to check for the century exceptions. The line might never be needed, but there's the satisfaction of knowing it's there.

Other parts of Schwilgué's clock look even further into the future. There is a gear deep in the works of the ecclesiastical computer that turns once every 2,500 years. And the celestial sphere out in front of the clock has a still-slower motion. In addition to the sphere's daily rotation, it pirouettes slowly on another axis to reflect the precession of the equinoxes of the earth's orbit through the constellations of the zodiac. In the real solar system, that stately motion is what has lately brought us to the dawning of the age of Aquarius. In the clock, the once-per-sidereal-day spinning of the globe is geared down at a ratio of 9,451,512 to 1, so that the equinoxes will complete one full precessional cycle after the passage of a bit more than 25,806 years. (The actual period is now thought to be 25,784 years.) At that point we'll be back to the cusp of Aquar-

...future: one wheel turns once a century, another turns only once every 2,500 years.

ius again, and no doubt paisley bell-bottoms will be back in fashion.

The odometer of years, as I mentioned earlier, runs to 9999. According to some accounts, Schwilgué suggested that if the clock is still going in 10000, a numeral *1* could be painted to the left of the thousands digit. The simplicity of that proposed solution suggests that the Y10K crisis may turn out to be less severe than the Y2K one. Unfortunately, though, it appears that Schwilgué's clever little patch doesn't actually work for his own clock, at least not without some further tinkering. The pattern of leap years would continue correctly (assuming there is no change to the Gregorian calendar), but the date of Easter does not repeat on a 10,000-year cycle. If the Strasbourg clock treats 11999 as if it were identical to 1999, Easter will fall on April 4. In reality, that holiday 10,000 years from now should be celebrated on April 11.

BUT IF LOOKING AHEAD two or three generations is good, does that mean looking ahead

IN REALITY? WHOSE REALITY? From another point of view, worrying about the date of Easter in the 120th century is a sure sign we have left reality far behind. I hear another small child's voice piping up in the crowd gathered around the cathedral clock. The voice calls out: "Get a life!" Surely there must be *something* that needs doing more urgently than planning an Easter egg hunt for the spring of 11999.

Is there any chance the Strasbourg clock will actually run for 10,000 years? No products of human artifice have yet lasted so long, with the exception of cave paintings and some sharpened flints. Stonehenge and the pyramids of Egypt are half that age. The two earlier Strasbourg clocks, built with similar technology, both failed after roughly two centuries. Very few complex machines with moving parts have lasted more than a few hundred years.

Even if the clock keeps ticking, will anyone in 11999 want to know the date of Easter? Will people still be counting the years of the Common Era? No system of timekeeping has lasted anywhere near 10,000 years. The Roman calendar was abandoned after 1,500 years; the Mayan one may have lasted as long as 2,000 years, the Egyptian, possibly 3,000. The Chinese have been recording dates by cycles and reigns for something like 3,500 years. The Hebrew calendar is at the year 5760—but that's not to say the scheme has been in use that long (there was no one around, after all, to turn the page on 1 Tishri 1). The Julian day system was invented only 400 years ago. Meanwhile, other calendars have come and gone. If Schwilgué had rebuilt the Strasbourg clock just a few decades earlier, it would have listed dates in Brumaire, Thermidor, Fructidor and the other months decreed by the French Revolution in September 1792, and the clock's register of years would now be reading just 208.

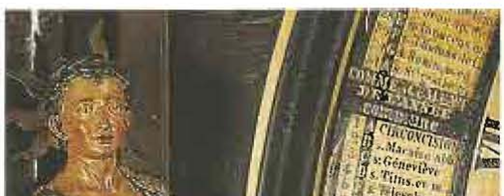


Figure of Apollo, the indicator for the current date on the calendar wheel

I WANT TO ADDRESS ANOTHER QUESTION. Even if a clock can be kept ticking, and even if the calendar it keeps retains some meaning, is the building of such multimillennial machines a good idea? I have my doubts, and they have been redoubled by a recent proposal to build another 10,000-year clock.

The new plan comes from Danny Hillis, the architect of the Connection Machine, an innovative and widely admired supercomputer of the 1980s (Hillis is now at the Walt Disney Corporation in Glendale, California). Together with several friends and colleagues he has proposed building a clock described as "the world's slowest computer." The project is outlined in *The Clock of the Long Now,* a book by Stewart Brand, the instigator of the *Whole Earth Catalog.*

Technical details of the Long Now clock remain to be worked out, but the provisional design that Brand describes has a torsion pendulum (one that twists rather than swings) and a digital counter of pendulum oscillations instead of an analog gear train. Although the counter is digital, it is emphatically not electronic; Hillis's design uses mechanical wheels, pegs and levers to count in binary notation.

The plan is to build several clocks of increasing grandeur. A prototype now under construction will be eight feet high. A twenty-foot model will be placed in a large city for ease of access, then a sixty-footer will be installed somewhere out in the desert for safekeeping. Here is one of Hillis's visions of how the big clock might be experienced:

> Imagine the clock is a series of rooms. In the first chamber is a large, slow pendulum. This is your heart beating, but slower. In the next chamber is a simple twenty-four-hour clock that goes around once a day. In the next chamber, just a Moon globe, showing the phase of the lunar month. In the next chamber is an armillary sphere tracking the equinoxes, the solstices, and the inclination of the Sun. . . .
>
> The final chamber is much larger than the rest. This is the calendar room. It contains a ring that rotates once a century and the 10,000-year segment of a much larger ring that rotates once every precession of the equinoxes. These two rings intersect to show the current calendrical date.

The motive for building such a monument to slow motion is not timekeeping per se; Hillis is not worried about losing count of the centuries. The aim is psychological. The clock is meant to encourage long-term thinking, to remind people of the needs and claims of future generations. The preamble to the project summary begins: "Civilization is revving itself into a pathologically short attention span. The trend might be coming from the acceleration of technology, the short-horizon perspective of market-driven economics, the next-election perspective of democracies, or the distractions of personal multitasking." The big, slow clock would offer a counterpoise to those frenetic tendencies; it would "embody deep time."

200 or 300 generations is better?

THE WISDOM OF PLANNING AHEAD, husbanding resources, saving something for those who will come after, leaving the world a better place—it's hard to quibble with all that. Concern for the welfare of one's children and grandchildren is surely a virtue—or at least a Darwinian imperative—and more general benevolence toward future inhabitants of the planet is also widely esteemed. But if looking ahead two or three generations is good, does that mean looking ahead twenty or thirty generations is better? What about 200 or 300 generations? Perhaps the answer depends on how far ahead you can actually see.

The Long Now group urges us to act in the best interests of posterity, but beyond a century or two I have no idea what those interests might be. To assume that the values of our own age embody eternal verities and virtues is foolish and arrogant. For all I know, some future generation will thank us for burning up all that noxious petroleum and curse us for exterminating the smallpox virus.

From a reading of Brand's book, I don't sense that the Long Now organizers can see any further ahead than the rest of us; as a matter of fact, they seem to be living in quite a short Now. All those afflictions listed in their preamble—the focus on quarterly earnings, quadrennial elections and so forth—are bugaboos of recent years and decades. They would have been incomprehensible a few centuries ago, and there's not much reason to suppose they will make anybody's list of pressing concerns a few centuries hence.

The emphasis on the superiority of binary digital computing is something else that puts a late-twentieth-century date stamp on the project. A time may come when Hillis's binary counters will look just as quaint as Schwilgué's brass gears.

Long-term thinking is really hard. Of course, that's the point of the Long Now project, but it's also a point of weakness. It's hard to keep in mind that what seems most steadfast over the human life span may be evanescent on a geological or astronomical timescale. Consider the plan to put one clock in a city (New York, say) and another in a desert (Nevada). This makes sense now, but will New York remain urban and Nevada sparsely populated for the next 10,000 years? Many a desolate spot in the desert today was once a city, and vice versa.

Needless to say, the difficulty of predicting the future is no warrant to ignore it. The current Y2K predicament is clear evidence that a time horizon of two digits is too short. But four digits is plenty. If we take up the habit of building machines meant to last past 10000, or if we write our computer programs with room for five-digit years, we are not doing the future a favor. We're merely nourishing our own delusions. In the 1500s, Dasypodius and his colleagues could have chosen to restore the 200-year-old Clock of the Three Kings in Strasbourg Cathedral, but instead they ripped out all traces of it and built a new and better clock. Two hundred years later, Schwilgué was asked to repair the Dasypodius clock, but instead he eviscerated it and installed his own mechanism in the hollowed-out carcass. Today, after another two centuries, the Long Now group is not threatening to destroy the Schwilgué clock, but neither are they working to ensure its longevity. They ignore it. They want to build a newer, better, different clock, good for 10,000 years.

I begin to detect a pattern. The fact is, winding and dusting and fixing somebody else's old clock is boring. Building a brand-new clock of your own is much more fun, particularly if you can pretend that it's going to inspire awe and wonder for ages to come. So why not have the fun now and let the next 300 generations do the boring parts?

IF I THOUGHT THAT HILLIS AND HIS associates might possibly succeed in this act of chronocolonialism, enslaving future generations to maintain our legacy systems, I would consider it my duty to posterity to oppose the project, even to sabotage it. But in fact I don't worry. I have faith in the future. Sometime in the 2100s a small child touring the ruins of the Clock of the Long Now will proclaim: "*I* will make it go!" And that child will surely scrap the whole mess and build a new and better clock, good for 10,000 years. •

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