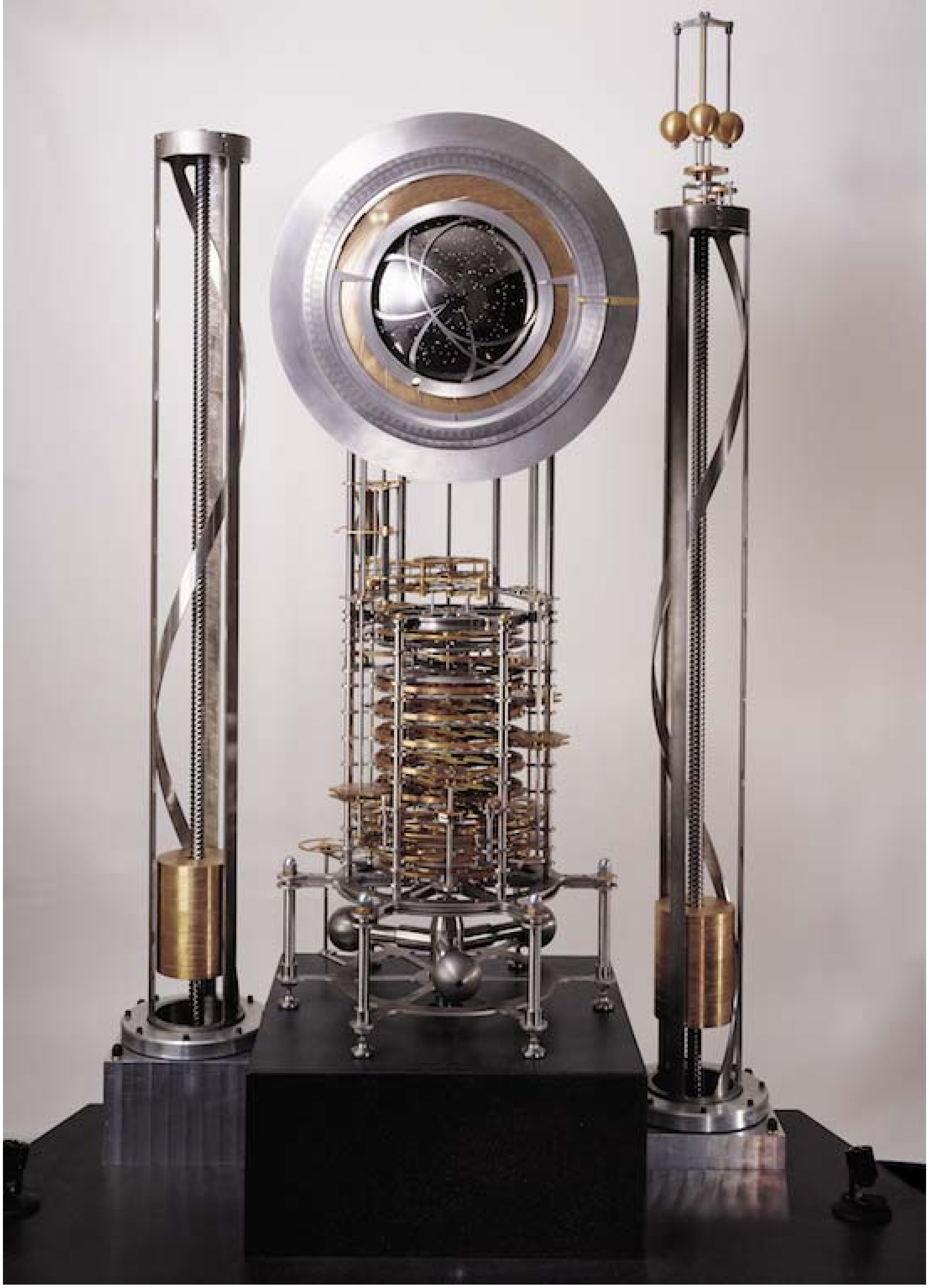
NOVA LENS

Good morning!

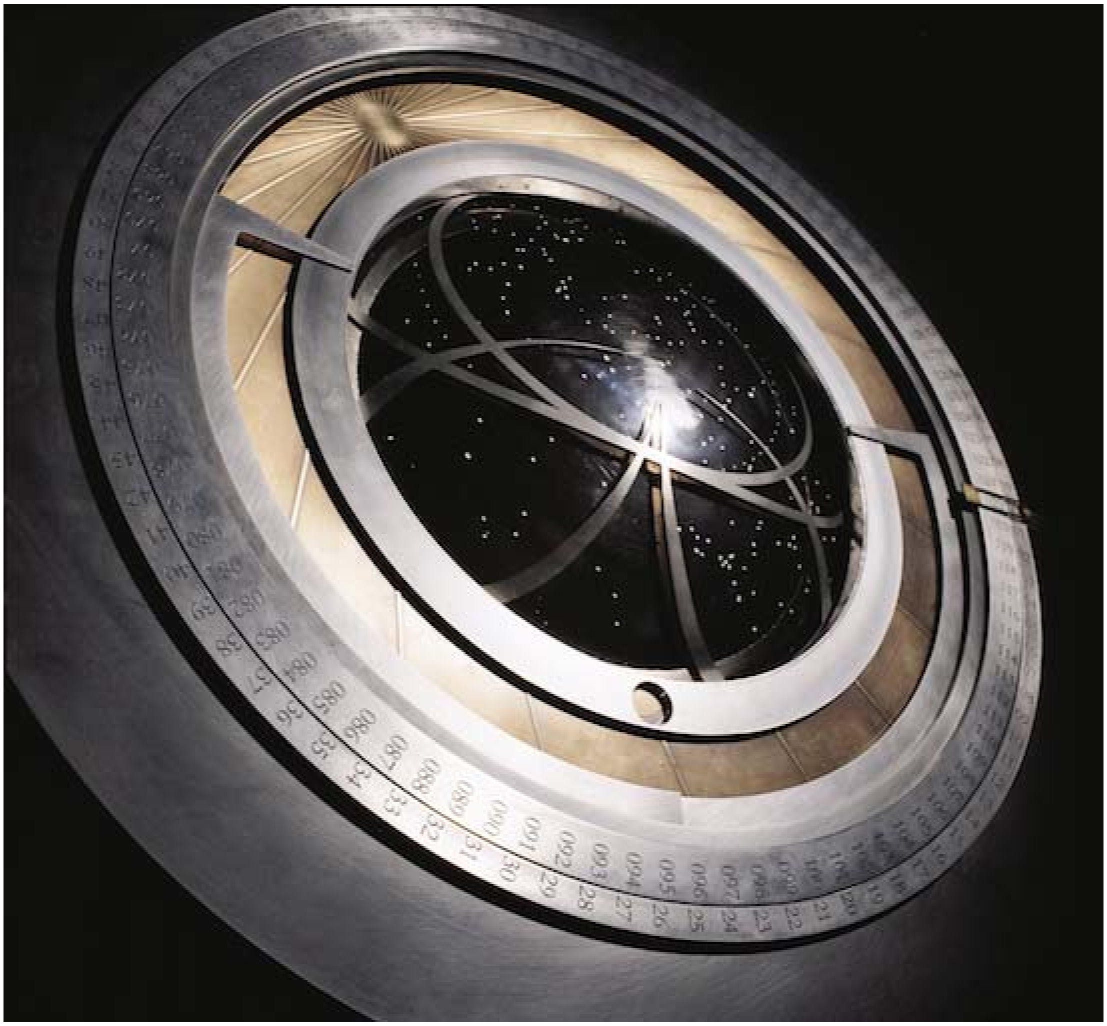
Mindfulness gurus tell us to focus on the present, but what if we chose to be much more forward-thinking? How would society function if we saw a year as not 12 months, but a sliver of a century?



The 10,000-year clock, shown here, was first conceived by Danny Hillis in 1986. | Photo courtesy the Long Now Foundation

That's the philosophy behind the Long Now Foundation, which has entered the spotlight for its support of a Franklin-esque invention: a futuristic timekeeping device that can last for 10 millennia. This "10,000-year clock" looks like it's straight out of a Star Trek episode—or the set of *Interstellar*. The team behind this impressive feat of engineering hopes that the clock will inspire people to think long-term.

Danny Hillis began fantasizing about what he then called a "millennium clock" in 1995, when the American scientist, entrepreneur, and writer penned [this column] for Wired magazine. Hillis's family and friends thought he was crazy—but Alexander Rose didn't. He had heard about Hillis's idea through his friend, Stewart Brand, one of the founders of the Long Now Foundation and editor of the Whole Earth Catalog. As a child, Rose played near the old World War II shipwrecks in the San Francisco Bay—"I grew up literally in a junkyard," he says—so he has a penchant for building things.



The clock's first prototype | Photo courtesy the Long Now Foundation

“I went to a [Long Now Foundation] board meeting and met Danny Hillis and started working with him immediately on the first prototype,” Rose said. They completed an initial prototype in 1999, which is now on display at the Science Museum in London. In 2010, they broke ground on the project in western Texas.

Now, they’re beginning the underground installation of the 500-foot mechanical marvel—yes, underground, carved into the side of a mountain where the clock will be protected from the elements. Visitors will be able to hike to the clock and then descend a secret staircase to see it for themselves. As an extra precaution against wear-and-tear over many millennia, the scientists made the clock out of mostly stainless steel and titanium. Dry-running ceramic bearings (which don’t need lubrication to run) separate the dissimilar metals so that they don’t react to each other. “Those used to cost about $15,000 each,” Rose said. “Now they’re in rollerblades and fidget spinners.”

Here’s how the clock works. Its energy is stored in a large weight, similar to how a grandfather clock operates. The weight moves as a result of changes in temperature throughout the day. One air tank near the surface of the mountain (above the device) heats up while it’s exposed to the Sun, while another tank is kept cool inside the mountain. The difference in temperature throughout the day (a few tens of degrees) causes the air to move from the hot tank to the cool one. When the surface tank cools down at night, the airflow reverses. The potential energy stored in the lifted weight then drives a series of gears, which regulate the speed of a six-foot balanced pendulum.

While the clock’s partitions of time come from the pendulum, which completes one back-and-forth about every seven seconds, it also recalibrates to the Sun at solar noon. Because of that idiosyncrasy, the clock is more like a calendar, according to Steve Allen, a member of the software team at the University of California's Lick Observatory. The clock will actually "tick" once a year for 10,000 years, its century hand will move every 100 years, and a cuckoo will emerge every 1,000 years. The musician Brian Eno composed a different chime sequence for each day (listen to some sample tracks here).

But there are a few major differences between the 10,000-year clock and the antique grandfather clock at your, uh, grandfather's house.

For one, the clock also derives some of its energy from manual labor. When people come to visit it, they will have to wind the clock to make visible—on a set of dials—what the clock already "knows" internally about how much time has passed.

"It doesn't show you the time that it is when you arrive," Rose said. "It shows you the time of the last people who visited it, and then you wind up the dials until it stops at the 'now' point to see the difference. So if it was 100 years since the last people were there, you would wind it for quite a while."

In this way, the 10,000-year clock is symbolic of not just long-term thinking, but it also illustrates a fundamental tension in how humans have recorded the passage of time—and how today's advanced methods of timekeeping still struggle with vestiges of past practices.

For most of our existence as *Homo sapiens*, time was set by watching the sky (and was aided with a transit circle telescope in later years). The Sun was, quite literally, the ultimate arbiter of time.

"Years ago, if you looked at [fire] insurance policies, they would all expire at noon," Allen said. "The insurance company could be reasonably sure that someone who witnessed a fire would have noticed whether the sun was on the east side or the west side of the building when the fire happened, and they would know whether [the policy] expired."

Though the Sun was still supreme, our notion of time began to change gradually in 1656, when Dutch scientist Christiaan Huygens invented the first pendulum clock that measured what we now know of as a second. Electric-motorized clocks (late 19th century) and quartz clocks (1927) made time measurement even more precise.

Then in the 1950s, the atomic clock changed everything. "It became immediately clear that they were better than any other timekeeping device that had ever existed," Allen said. Atomic clocks apportion time based on the vibrations of cesium atoms, and they're critical to the functioning of GPS, satellites, and more.

But far from being the foremost authority on time, atomic clocks sent our timekeeping systems into conflict. Neither the calendar nor the clock quite line up with each other. The Earth's rotation is not always consistent (it fluctuates in response to events like earthquakes, dramatic changes in climate, etc.), yet many technologies require unchanging atomic time, so the world was forced to reconcile the two. The compromise, which throws what's called a "leap second" into the mix, is now known as Coordinated Universal Time (UTC).

"The leap second was the answer, because that allowed you to say, 'We're going to keep the calendar day defined by watching the sky. Each second will be defined by cesium. Whenever they disagree, we'll throw in another second,'" Allen said.

As early as 1999, the leap-second has been in danger of being scrapped by the International Telecommunications Union, an arm of the UN that helps coordinate global communication standards, which depend on accurate timekeeping. Some people felt (and still feel) that the leap second is an imperfect hack to resolve the difference between calendar time and atomic time.

That is, should we adjust our clocks to the Earth's slowing rotation, or should we drop leap seconds and let atomic clocks be fully responsible for measuring time? So far, the scientific community has failed to reach an agreement on this question (case in point: this 2016 NPR story).

Allen says the 10,000-year clock highlights this very issue (he and others wrote a paper about it in advance of a colloquium held in 2011).

Rose points out that "the 10,000-year clock is one of few devices that tracks natural and absolute time simultaneously." Because of that, it is representative to many of this debate—this tension—over whether humans should decouple timekeeping from natural cycles.

Jon Giorgini, an engineer at NASA's Jet Propulsion Laboratory who was a co-author on the aforementioned 10,000-year clock paper, says he's impressed by the scale of the project. "Most engineers designing software or hardware build and keep a mental model of the system in their head," he said. "They observe it in their mind's eye, take it apart, and 'watch' it work. Doing this for a system running over 10,000 years is really mind-expanding."

Rose says the team picked the number 10,000 because that's roughly how long it's been since agrarian civilizations began. "How do we place ourselves not at the end of a 10,000-year story, but in the middle of a 20,000-year one?" he asked. "And if you did that, how would you act differently?"

Climate change and world hunger, for example, are things that we can't solve in a quarterly report or over the course of a four-year election cycle. But in 200 years, society could make a difference. "It's a multi-generational effort," Rose said. "We want to put that kind of thinking back on the table."

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WHAT'S ON YOUR MIND

To wrap up Black History Month, we produced this video about black scientists whose innovations we can celebrate at any time.

In response to the video, Michael Supino wrote:

> **Michael Supino** Fantastic! Had my mathematics students watch it for extra credit!
> Like · Reply · Message · 7h

Thanks for letting us know, Michael! We LOVE hearing about teachers using our videos in the classroom.

WHAT'S ON OUR MIND

"Welcome back," Iceland whispers through wind and wet snow as I touch down in the night. "You've decided to get to know me in the winter? Allow me to conjure a blizzard and cancel your domestic flight to Ísafjörður." "That's ok, I'll drive the five-ish hours with colleagues and friends," I say, "through your frost, your fjords, your flurries." Iceland raises her icy eyebrow. A whiteout conceals her face. A tow truck pulls us from a snowbank. Night falls, and we arrive in Hólmavík, a town halfway to our destination. The journey continues tomorrow

Join me over the next week as I report from Iceland—on a frigid ocean current crucial to the circulation of seawater and heat on our planet, and on a team transforming air into rock.

—Ari Daniel, NOVA digital producer (follow his serialized Instagram reporting here)

Ari is pretty familiar with Arctic climes. A few years ago, he travelled to Greenland to report on glacial melting. Check out his videos (which feature pristine footage of the Danish territory's icy landscape) here and here.

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It’s the early 1900s in England, and several scientists are gathered for teatime. However, when offered a teacup, one member of the party fervently refuses. Raising eyebrows, Muriel Bristol justifies her offense with a curious claim: she tastes distinct differences between tea poured into milk, and milk poured into tea—and she only likes her tea poured into milk. Anything else simply won’t do.

She may have sounded absurd in the context of this story, but Muriel was no fool—she held a PhD and professed in algae research. However, her host Ronald A. Fisher was no fool either. Fisher was an influential math wiz of the time, and speculated his friend Muriel was full of drivel. After all, the tea composition is virtually identical between both preparations. Could she really detect a difference?

The type of math Fisher employed to answer this question was a powerful form, called statistics. At an early age, Fisher had recognized math’s predictive power, and saw statistics as the only viable smell-test to disprove (or prove) Bristol, later dubbed “the Tea Lady," and her ridiculous claim.

Rather than test if the teas were substantially different, Fisher sought to statistically examine Bristol’s purported accuracy, and began drafting possible experiments to challenge her claim.

Say you give Bristol a cup prepared either way, and ask her to identify whether it's tea or milk first. Simple enough, right? However, upon closer inspection, Fisher recognized that if we stopped the experiment there, there's a 50% chance Bristol could answer correctly using pure luck. How many cups would it take to remove the possibility of random chance, and really trust the Tea Lady's claim?

The sum of these questions—how many teacups, should cups be presented one at a time or all at once, how can we remove human tendencies out of the tea presentation to minimize lucky guesses, and how much leeway exists for said lucky guesses—became the framework for something much more important than proving a dear colleague wrong about tea.

It was Fisher's publication, "Mathematics of a Lady Tasting Tea," that laid the groundwork for modern experimentation. Notably, it specified a threshold for how much "random chance" scientists could permit in their measurements before rejecting the statistical strength of a claim. Fisher decided on a 5% threshold for random chance, or phrased scientifically, a "p-value less than 0.05."

Fisher's arbitrary threshold was hastily instituted as a gold standard—a passing grade for statistical tests like T-tests (invented prior to Fisher's tea test). Numerically, 0.05 represents a 1/20 chance for randomness to explain differences in data sets—and so anything under that value, be it 0.045, or 0.0000003, was sufficient statistical stringency in Fisher's eyes.

It's served as a default filter for scientific discovery—filtering out medicines that don't work before they are prescribed, and vetting observed trends like climate change. However, with nearly a century of unquestioned usage, scientists are now reconsidering how to utilize Fisher's p-value effectively.

Regardless of its fate, it's widely accepted that Fisher's experimental designs for a Lady Drinking Tea (among many other proposed experiment designs) have penetrated decades of scientific innovation.

So what ever happened with the tea test?

Dr. Bristol is presented with a tray holding eight cups of tea: half milk-first, and half tea-first. After being instructed to categorize the cups by taste, Bristol faces a strong trial of accuracy: there's only a 1.4% chance that she'd sort every cup correctly by pure luck, and to prove her prowess, she needs to pass Fisher's tea test with a p-value under 0.05. With only eight cups of tea, she fails Fisher's test if she guesses a single cup wrong (for clarity, Fisher interprets her failure to categorize a single cup as a 25% chance of being lucky for identifying the remaining teacups correctly—far above the 5% threshold).

According to witnesses, Bristol sorts all eight cups flawlessly. It's still a mystery how.

Want to learn more about tea tests, p-values, and the predictive power of stats? Don't miss NOVA's "Prediction By The Numbers," now available for streaming online. And join us today (Friday) at noon Eastern for a Reddit AMA with Jordan Ellenberg, mathematician and author of "How Not to Be Wrong: The Power of Mathematical Thinking" on the subreddit r/science.

—Tiffany Dill, NOVA Next contributor

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Have a question for NOVA? Want to see us cover something in the news? Let us know—tweet at @novapbs, use the hashtag #NOVALens, send us a direct message, or email us at nova_lens@wgbh.org. We might give you a shout-out in next week's newsletter.

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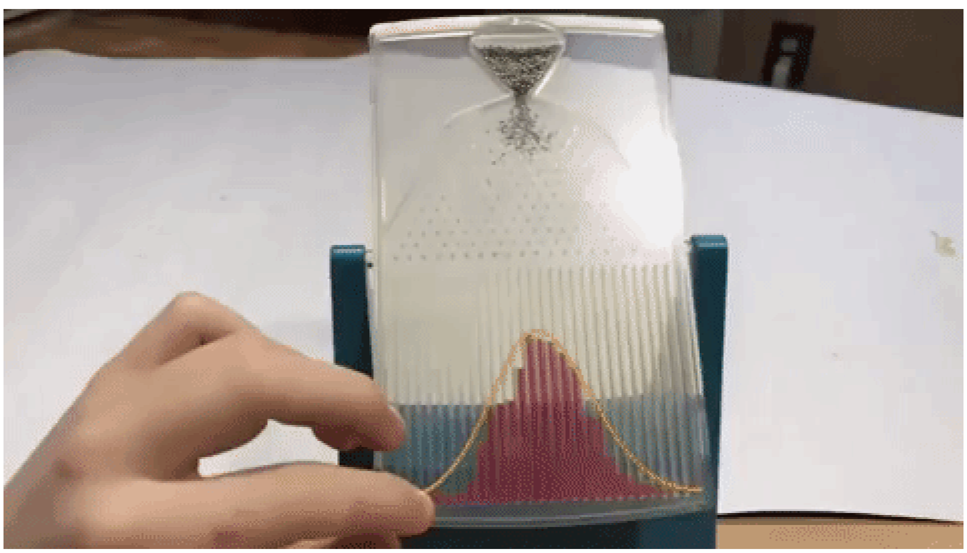
POSTSCRIPT

We noticed this great GIF from Twitter user (and applied mathematician) Chris Danforth:



Statistics in slo-mo

Chris mentioned something in a follow-up tweet about how this video models financial market predictions, so in the spirit of this week's "Prediction by the Numbers" premiere, we asked him about it.

Here's what he had to say about it:

Chris Danforth @ChrisDanforth · Feb 23

.@peterdodds suggests a financial market prediction version where the pegs are spring loaded & coupled to each other

4 2 66

Allison Eck @allisonceck · 10m

Hi @ChrisDanforth! I'm a digital reporter for @novapbs, & I'm including this tweet in a section of our weekly email newsletter (b/c we have a show airing this week on prediction). Wondering if you could DM me to explain what you mean by your second tweet (re: market prediction)?

1

Chris Danforth
@ChrisDanforth

Follow

Replying to @allisonceck @peterdodds @novapbs

nice! I’ve been looking forward to the episode tomorrow. Market price movements are often modeled as small random ups and downs, like the lefts and right turns made by beads in the toy.

5:21 PM - 27 Feb 2018

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By the way, if you got the link to this newsletter elsewhere, [subscribe here] (select "NOVA Newsletters") and check out [last week's edition].

See you next week,

Allison and the NOVA team

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