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REINVENTING TIME

What do planet Earth, a swinging pendulum, a quartz crystal, and a Cesium atom have in common? They have all been used by humans to measure time. They represent humanity's progress through time in measuring time itself. But what is it, really, that humans set out to measure? Let's step outside our modern lives for a minute and go back to a time before "time."

There is no such thing as a clock, or even a sundial. You live in a cave with your extended family. When it gets dark, somebody strikes two stones together to light a fire. You learn about animals and the Sun and the stars, and when the fire dies down, you wrap up in your animal furs and go to sleep. When the Sun comes up again, you awaken and go about the business of earning your living as self-respecting cave-dweller—until the Sun goes down again. You know nothing of alarm clocks and noon whistles, or bus schedules and tardy bells. Nothing! All your people care about time is whether the Sun is in the sky, and, of course, the season.

In other words, nature is your timekeeper. You might care how many days have passed since the last leaves fell off the trees, so you know about how many days must pass before your favorite wild turkeys come back for roast . . . er, roosting. So you learn to count days by carving notches on a stick or making scratches on a stone.

Eventually, people invented farming. Rather than always moving, going wherever the food was, they stayed put most of the time. Then things started to get complicated. People had different jobs to do. Social structure developed, with leaders, governing councils, and structures built for different purposes. People would gather to socialize, worship, or make decisions. Along with this complexity grew the need to keep everyone "in sync." In other words, they desperately needed standard clocks, all set to the same time.

WHAT A DIFFERENCE A DAY MAKES

Before they could measure it, somebody had to decide what they were actually measuring. It started with the most obvious natural cycle they knew—one day. They didn't know what "caused" a day-night cycle—Earth's rotation—but it didn't really matter. So a day became the primary unit of timekeeping.

Well, a day is pretty long, so eventually they decided to break it up into 24 parts (called hours), and break each hour into 60 parts (called minutes), and each minute into 60 parts (called seconds). Why 24 hours? Someone might have thrown a handful of rice into the air and counted the grains that landed inside a circle drawn in the dirt, for all we know. They could have chosen to divide the day into 50 parts, or 100 parts, or 539 parts. As a matter of fact, one of the earliest time-keeping systems, invented 5,000 years ago by the Sumerians (who lived in what is now Iraq), divided the day into 12 periods, each of which was divided into 30 parts.

When the need arose to measure time in smaller units than a day, people began to measure the passage of time based on the duration of other "standard" events that happen faster than Earth making one revolution on its axis—for example, the time for 500 drops of water to fall from a leaky container, or the time for a cup of sand to fall through a hole in the cup, or the time for a pendulum of a certain length to swing 100 times.

Over thousands of years, mechanical timekeeping became more and more reliable and precise. Now, instead of counting the swings of a pendulum, we can count the vibrations of an atomic nucleus. Using modern technology, one second, or even a billionth or a trillionth of a second, can be timed with exquisite precision.

But wait a second! Earth itself doesn't even keep time with that degree of regularity. A day isn't even really 24 of our hours long. The *average* or *mean* time of one rotation of Earth is 23 hours 56 minutes 4.091 seconds*, but it varies a little.

What is the "it" we are measuring if nature isn't even as regular as our ability to measure "it"? What is the relationship of our minutes and seconds to nature? Well, actually, none! The "time" to which we are often such slaves is our own invention.

ZONING OUT

Once technology began making our world smaller by giving us such inventions as trains and the telegraph, it became important for people over large distances to agree to a common time standard. With *Local Mean Time,* people in towns east or west of each other, setting their clocks by the sun, operated on somewhat different clock times. That wasn't a problem—at least until things like

* *This is the time it takes for Earth to rotate once with respect to the distant stars. Relative to the Sun, Earth has to make an additional 1/365 of a rotation to compensate for the distance Earth has moved in one day in its orbit around the Sun. This period of Earth's rotation is called a solar day and takes an average of 24.0 hours.*

trains connected places. A train conductor in town A would schedule arrival in town B at 12:00 noon and departure at 12:05 PM. His watch would show 12:00 noon as the train pulled into the town B station—unfortunately, the clocks in town B might all show 11:43 AM. as the local mean time. Successful train riding required outstanding math skills.

Time zones were invented to solve that problem. Instead of time changing around the globe at the Sun's even rate, it was decided to make time change in regular steps, every 15 degrees of longitude. Now everyone in each 15 degree zone would have the same time on their clocks—*Standard Mean Time*. All zone clocks could now be set to when the Sun (with a correction we will discuss later) passed over the central meridian of the zone. (There are some odd exceptions to this "decision." See the website www.timeanddate.com/worldclock for some exotic examples.)

The time zone borders vary here and there for the convenience of the human inhabitants. For example, in the U.S., they sometimes follow states' north-south borders, or skirt around cities so as not to divide them into two time zones.

Time Zones in Space?

But what time is it on Mars? Or anywhere out there beyond the turning of Earth and the marking of a day? We have taken our invention of time far, far beyond the natural rhythms that inspired it.

Timekeeping is a very important part of many technologies that we use every day. Timekeeping functions form an important part of our technology infrastructure. For example, we plug all our lights, computers, refrigerators, TVs, vacuum cleaners and toothbrushes into an electrical power grid that quite reliably delivers alternating current at 60 cycles per second. All the things we plug into it depends on the accuracy of the clocks that control the generation of this power. Computer processors run at a certain speed. For example, a speed of 1 gigaHertz (GHz) means that the central processing unit (chip) runs at 1 billion cycles per second. It requires a very precise clock to control this chip. Communications (TV and radio broadcasts, cell phones, two-way radio, satellite relay of phone calls, the Global Positioning System, etc.) require precise clocks to control frequencies of transmission signals and to tune receivers to detect incoming signals at specific frequencies.

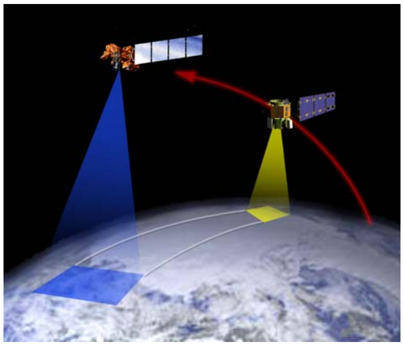
Spacecraft have clocks that control their computers and most of their other systems and instruments, including their communications with Earth. No matter what the spacecraft's mission or where it is going, timekeeping is as important to its functioning as is electrical power and propulsion to get it to its destination. (To learn all about spacecraft time conventions, see www.jpl.nasa.gov/basics/bsf2-3.html.)

To forge into the future of space exploration, NASA must develop new technologies never before dreamed of, much less flown in space. So NASA has set up The New Millennium Program (NMP) to make sure we have adequately developed and tested the other technologies needed to venture farther into the frontiers of understanding about Earth, our star system, and our universe.

Among the new technologies validated by NMP are the Small Deep-Space Transponder, validated on a spacecraft called Deep Space 1, and the Mini Transponder for Small Spacecraft, about to be validated on a mission called Space Technology 5. Transponders are essential elements of the spacecraft communications systems. They use internal clocks called oscillators to control the frequency of the radio waves they send and to measure the frequency of the radio waves they receive. Without these very precise and stable clocks, communications with spacecraft would not be possible.

No matter how new and sophisticated future technologies become, they will depend on the basic infrastructure of timekeeping. What began as a simple way to mark the natural rhythms of nature on Earth has become a human invention with little relationship to what it once described. Now that invention is a foundation for all our other ventures, including the ultimate one into space.

Propelling us ever further on our quest for knowledge and into the unknown, NASA's New Millennium Program (NMP) develops and tests new technologies never before dreamed of. All of them depend on the basic infrastructures of time measurement.



NMP's Earth Observing 1 (EO1) spacecraft is testing new imaging technologies. It flies in formation 1 minute behind Landsat 7 in the same ground track. Both spacecraft observe the same ground location (scene) through the same atmospheric region and their images are compared. This formation flying requires precise navigation. EO1 must know its velocity, position, and the exact time in order to maintain its position with respect to Landsat and to precisely point its imaging instruments.

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GETTING IN SYNC WITH NATURE

THE ANALEMMA: CALIBRATING TO NATURE

Our time "measuring system" has taken on a life of its own, bearing only an approximate resemblance to the natural occurrences it set out to measure. The "analemma equation of time" was created to precisely set our clocks by converting irregular Sun time to the even, regular tempo of *mean* time.

This is how it works.. Suppose you want to set your clock to local *mean* time when the Sun is highest overhead today? In theory, local time will be 12:00 noon (assuming you are not on daylight savings, time). But the "theory" assumes two conditions:

1) Earth's orbit around the Sun is a perfect circle.
2) Earth's axis of rotation is perpendicular to its orbital plane around the Sun.

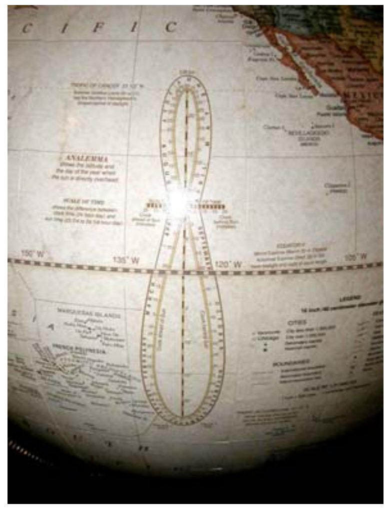
Neither of these assumptions is true!

First, Earth's orbit around the Sun is somewhat elongated, or elliptical. Thus, for the part of the year when Earth is closest to the Sun, Earth is actually moving faster in its orbit than when it is farthest from the Sun. This variation (which follows Kepler's Second Law) causes the Sun's apparent east-west position in the sky at the same time each day to drift slightly.

Second, Earth is tilted on its axis of rotation 23.5 degrees from the plane of its orbit. As Earth makes its annual trip around the Sun, this tilt causes the Sun's apparent north-south position in the sky to vary quite a lot. If you live in the northern hemisphere, for example, you know that in January the Sun traverses the sky farther to the south than it does in July.

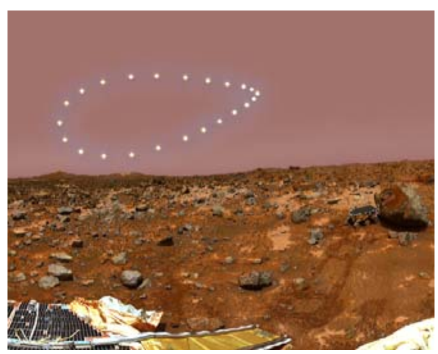
Analemma with the Temple of Apollo at Ancient Corinth. This image was made by astro-photographer Anthony Ayiomamitis. He took 47 separate photos of the Sun using the same piece of film at exactly 9:00 AM local time between January 7 and December 20, 2003, plus 1 fore-ground exposure. See his other beautiful analemmas at perseus.gr .

The result of these two motions together can be shown graphically as a figure 8! If you snapped a picture with the Sun in it at the same place and same exact local time each week, and then put all those pictures together, you would see the Sun tracing out a figure 8 in the sky. In the northern hemisphere, the top loop of the 8 is quite a bit smaller than the bottom loop. In the southern hemisphere, it is the opposite.



Many globes have this figure 8, called an "analemma curve," drawn on them some-where out in the Pacific Ocean (really has nothing to do with any particular place on Earth).

Fairly simple mathematical equations can be used to calculate exactly how far off in minutes, plus or minus, the clock time will be from the actual Sun time based on the date. The website www.analemma.com has a great explanation, along with the math. This site also shows the very different analemma curves for Mars and other planets of the solar system!



This image simulates the analemma pattern on Mars for one Mars year (683 Earth days). The image was made from one taken by NASA's Mars Pathfinder rover in 1997.

© Dennis Mammana (www.skyscapes.com),
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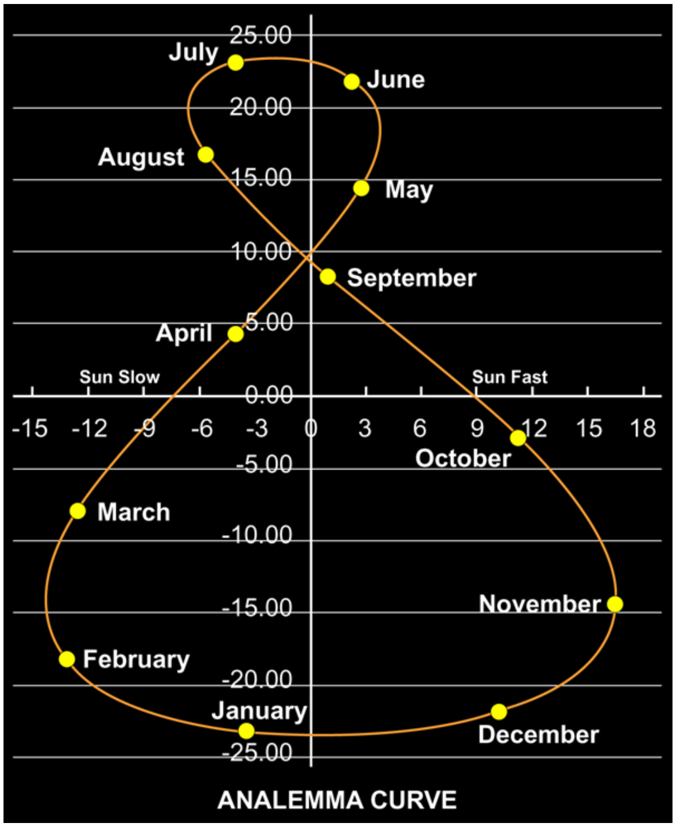
The analemma equations give us the dates to put on the figure 8 curve, as well as the numbers to put on a grid to represent Sun angle and clock time. The vertical scale of the grid represents the declination (how high or low in the sky) of the Sun. Or, the vertical scale also stands for the latitude (+ for degrees north of the equator, - for degrees south of the equator) at which the Sun is highest in the sky at exactly 12:00 noon, and, of course, it corresponds to the date. The horizontal scale shows how many minutes to add or subtract from the true Sun time to show the current clock time (and vice versa).



The Time Zone Factor

But before you can know the exact difference between your clock and true "high noon" Sun time, you have to also take your time zone into account. On the east side of a normal time zone, if the Sun rises at 6:00 AM, it will not be seen on the west side until 7:00 AM.

So, obviously, your east-west position in your time zone is going to have a large bearing on how far off your clock is from Sun time at high noon.

For purposes of this neat trick we are about to show you, we are going to assume that all the time zones are 15º across, and ignore the irregularities imposed for convenience. The longitude "count" begins at the Prime Meridian in Greenwich, England. This is longitude 0º. The related time zone extends 7-1/2º on either side of it. Los Angeles is at about 118º W, or about 1/3 of the way around the world west from Greenwich. Manila, the Phillipines, is at about 120º E, or about 1/3 of the way around the world from Greenwich in the other direction.

The *center of each time zone* is the meridian, divisible by 15, when "high noon" occurs at 12:00 noon by the clock.

If you don't know it, you can look up the latitude and longitude for your city (or the closest one listed) at www.bcca.org/misc/qiblih/latlong_us.html .

Find out how many degrees longitude you are from the center of your time zone. Remember, time zone meridians are longitudes divisible by 15. So, for example, if you are at 86ºW, you will be within seven and one-half degrees of the 90ºW meridian, which extends from 82.5ºW to 97.5ºW. At 86ºW, you will be about half the distance from the center of the time zone to its western border. So, when the Sun is at high-noon at your location, your Standard Time clock will say about 12:15 (not counting the analemma adjustment).

Analemma Adjustment Plus Time Zone Adjustment = Sun Time!

Put these two adjustment factors together and find out how far off your clock is from Sun time. In other words, you will be able to calibrate your technological measuring device to more accurately represent nature. Again, the question is, **what time is high-noon (Sun time) today?**

So, reading for today's (approximate) date on the analemma curve, how many minutes (slow or fast) is the Sun compared to your watch?

Now, how many minutes should you add or subtract based on your longitude within your time zone (approximately)?

Add these two together. What time is high-noon today?

Try the same trick again with the date exactly six months from now.

On the analemma curve, what are the dates when clock time exactly agrees with Sun time? Is there anything familiar about those dates?

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