quick study

The pros and cons of leap seconds

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Time as determined by Earth's rotation and time as determined by atomic clocks slowly but steadily diverge. Should they be forced to agree?

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Children learn that a day is 24 hours long and the Sun is at its highest point at noon. Unfortunately, that lesson is not strictly true. The desire to make it true, at least on average, is at the heart of the leap second.

The leap second concerns two different ways to measure time. Earth rotation time (UT1) is, as it sounds, based on the variable rotation of Earth on its axis. The second time, coordinated universal time (UTC), is based on steady atomic clocks. A recommendation proposed by the International Telecommunication Union (ITU) Radiocommunication Sector in 1970 and subsequently incorporated into radio regulations states that a leap second be added to or subtracted from UTC so that the absolute difference between UTC and UT1 is never more than 0.9 seconds (see the figure).

A new proposal before the ITU would keep UT1 and UTC synchronized only to within an hour. Users of UT1 and UTC are currently debating whether the proposal should be accepted. Where people stand on the issue has a lot to do with how they use their time.

Background

Earth was the first clock humans used. By watching the locations and motions of the Sun, Moon, and stars, our ancestors could tell time. Eventually artisans built devices that allowed people to measure time without needing to look to the heavens. As scientific and engineering skills advanced, the ability to make clocks improved; by the 1930s, high-precision clocks were more stable than Earth's rotation.

Earth's nonconstant rotation period can differ from its average by as much as a few milliseconds. The causes of those fluctuations include tidal variations, large-scale weather phenomena such as El Niño, geophysical phenomena, and tidal deceleration modified by deglaciation. The effect of tidal deceleration is predictable, but the others are not, which makes synchronizing Earth rotation time and atomic clock time more challenging.

The details of Earth's rotation were less fully understood in the 1950s, when the second was defined in terms of atomic frequency. The atomic second was set equal to a second of ephemeris time—that is, to a fraction of a day in the 1820s, the epoch of the observations used to define ephemeris time. It didn't take long for scientists to realize that keeping rotation-based and clock-based times close was going to take significant effort. Even into the 1960s, the length of the standard second was allowed to vary, and occasional "jumps" in UTC were used to keep standard time in accord with Earth's rotation. Eventually, the scientific community adopted the ITU leap-second recommendation; the first leap second occurred in 1972.

Dilemmas

Leap seconds have been applied once every year and a half on average since 1972. As Earth's rotation continues to slow down, they will occur, in general, with greater frequency. For many people, the insertion of a leap second is, at worst, a minor inconvenience. But for those who design and work with computer and satellite systems, it causes problems.

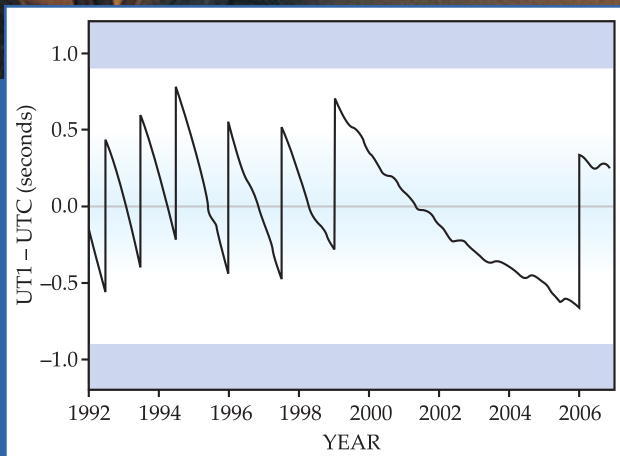
Continuing the use of leap seconds is not a zero-cost option. Before each leap second is applied, software and technical equipment undergo testing to ensure that systems will behave as expected before, during, and after the leap second. The cost of that testing is often hidden, but it cannot be ignored.

In many cases, leap seconds are so problematic that designers use independent time scales that have no leap seconds. The global positioning system, for example, uses its own internal time and presumably so will the European Union's *Galileo* global navigation satellite system. As the time scales developed to address particular problems are appropriated by other applications, new time scales are born.

The proliferation of nonstandard time scales can make system interoperability a challenge. To ensure that information is handled properly, system operators must know the relationships among time scales. A single standard time scale without leap seconds would be much more convenient. Neglecting the difficulties created by leap seconds now will only make the implementation of future changes more difficult.

Why bother to keep atomic clock time and Earth rotation time in sync? The desire for synchrony is not just about history. Celestial navigation and the pointing of antennas at satellites or other distant sources, for example, require the routine observation of UT1. For applications requiring an accuracy of no better than 1 second, one can approximate UT1 with UTC. This approximation is convenient because it is considerably easier to read time from a clock than to read time from Earth. Indeed, that assumption that UTC and UT1 are nearly the same has been built into so many systems for so long that any change to that assumption would be a significant undertaking. Even determining the magnitude of the problem is difficult.

Legal issues may also come into play. In some countries mean solar time is the legal time. As a practical matter, UTC, as currently defined, is often used as the basis for legal time in those countries. Legal ramifications may ensue, however,



Precision clocks, such as the black hydrogen maser atomic clock on the right in current use and the older display companion shown here, measure a time independent from that defined by Earth's rotation. The graph shows the steady drift between one atomic clock time scale, coordinated universal time, and the Earth-rotation-based scale UT1. The seven spikes show the leap-second adjustments made to UTC since 1992 to ensure that the two standards don't drift too far apart. The international agreement that established those adjustments is currently being reconsidered; the leap second may soon be a thing of the past. (Courtesy of Richard Schmidt, US Naval Observatory.)

if the leap second is abandoned and UTC is no longer closely tied to mean solar time.

One argument in favor of keeping the leap second is misleading: If the leap second is abolished, the Sun will not cross the local meridian at noon. Because of the considerable size of time zones, the sporadic application of daylight savings time, and the variation in Earth's orbital velocity vector during the year, the Sun can cross the meridian hours before or after noon. The effects of the proposed leap-second change would be well within that variation for centuries to come.

The debate surrounding the proposal to change the definition of UTC by removing the leap second has narrowed down to two options, and both sides have supportable positions. No matter what is decided, complications will arise, and no compromise will make everyone happy. The real questions are who is impacted more and who can more easily accommodate those impacts.

If any good has come of the leap-second debate, it is that more people are aware of the complexity of time. Hopefully, the increased awareness can be put to use as new systems are developed. A few ideas should probably be considered no matter how the leap-second issue is resolved. Computer- and satellite-system designers should avoid creating new, independent time scales. People who write or rewrite software should make an effort to be as flexible as possible when dealing with time so that as timing interface and development standards are created, implementation of necessary changes to applications is as easy as possible.

The ITU is currently accumulating information to help it make an informed decision, including input from professional organizations that are evaluating how the maintenance or elimination of leap seconds would affect their members. If you have information that you would like to share with the ITU, I suggest you contact the appropriate professional organization or Ronald Beard (ronald.beard@nrl.navy.mil), who is the chairman of the ITU working party addressing the leap-second issue. Comments bolstered with detailed descriptions and documentable facts would help the ITU to decide on the best course of action.

Additional resource

▶ R. A. Nelson et al., *Metrologia* **38**, 509 (2001). ■

The online version of this Quick Study provides additional material on the history and definition of time standards.