Is Time Broken (or, Will It Be Y2K All Over Again)?

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Abbreviations in this article:
AAS – American Astronomical Society
GPS – Global Positioning System
ITU – International Telecommunications Union
USNO – United States Naval Observatory
UT – Universal Time
UTC – Coordinated Universal Time
Y2K – Year 2000

1. Introduction

Scientist speak: "*It is not clear that official decision-making processes within governmental organizations have been sufficiently transparent or that the most affected communities have registered substantive input.*"[AAS 11-660]

Translation: It is clear that official decisions in government are opaque and, as a result, affected users have done little.

In October 2011 a group of scientists concerned with timekeeping methods met at a colloquium sponsored by American Astronomical Society (AAS) to discuss whether or not to eliminate the "leap second". The statement above was made by one of the presenters in reference to discussions to retain or eliminate the leap second. A few months later, in January 2012, the official global timekeepers, the International Telecommunications Union – Radiocommunication Sector (ITU-R), met to make a decision. The official question before ITU-R was "*Does the current leap second procedure satisfy user needs or should an alternative procedure be developed?*" [ITU-R236/7]

If ITU-R voted for change, leap seconds would be eliminated at the end of 2017. What does such an organization do when it has a tough question before it? Well, it does what any political group would do – defer the question and request more studies so someone else in the future has to deal with it. One of the problems was that, in spite of asking this question over a decade ago, the ITU-R working group felt it did not have enough user input at its January meeting to help make a decision. There is no public record of any analysis of the requirements for change and no cost estimates of the change or of any alternatives. Perhaps we are lucky that ITU-R did not vote for change, and perhaps a perceptive non-scientist would simply conclude that, if no usable input was obtained over a ten-year period, then present timekeeping methods are fine and not broken. The question then becomes "*If time is not broken, why fix it?*"

2. What is a leap second?

The leap second does for our clocks what the leap year does for our calendars. Both are used to keep our time synchronized with the position of Earth as it rotates and orbits the Sun. However, there is a difference in their implementation. Leap years are based on set rules and are regularly implemented at predetermined intervals. During leap years, an extra day is added in February to keep the calendar synchronized with the Earth's movement in its orbit around the Sun. The actual length of the year (one orbit) is 365.2636 days and not 365 as used in a normal calendar. According to the rules, every four years February has 29 days (rather than 28) to compensate for the extra partial day, and the calendar has 366 days in that year. This results in slight over-compensation, which is handled by making only every fourth century year, those evenly divisible by 400, a leap year. For example, 2000 was a leap year but 1900 was not. The next century leap year will be 2400.

Unlike leap years, leap seconds are used only when needed as determined by measurements. A leap second is added or subtracted every so often to keep Universal Time (UT, in particular, UT1) and Coordinated Universal Time (UTC) synchronized within less than ±0.9 second. The UT time scale is based on Earth's rotation rate, which determines much of our daily lives. Embedded in UT is the mean astronomical second, which is defined as 1/86 400 of the mean solar day as determined by precise measurements. On the other hand, UTC, which is the legal basis for timekeeping and the time reference used in most countries (see [ITU-R-TF460]), is an atomic time scale based on the emissions frequency of cesium atoms when certain electrons change state (see [BIPM-SI]). Embedded in UTC is the definition of the second, which is 9 192 631 770 periods (a frequency of about 9.193 GHz) of the radiation emitted from cesium 133 when it is under certain environmental conditions.

UTC satisfies the need for a very precise time scale and UT satisfies the need for a time scale tied to our daily lives determined by the Sun's position in the sky. There are several other time scales, each with its own specific purpose, but I will limit my discussion to UT and UTC. Interested readers may obtain a concise description of other time scales from the US Naval Observatory (USNO). [USNO-179]

The problem is Earth's rotation rate is slowing, mostly due to tidal deceleration but also due to the interaction of Earth's mantle with its core and even large-scale weather patterns. On the other hand, atomic emissions frequencies are constant over time. As a result, the two time scales drift apart. The drift is not very fast and is not constant – a leap second has been added 25 times since 1972 when UTC and leap seconds were first introduced (some sources show 24 leap seconds but 25 are listed on US Naval Observatory's website as officially announced from 1972 to the time of this writing in May 2012 [USNO-Dat]). The leap second mechanism couples our civil time with atomic time.

So far, all the leap seconds have been positive – extra seconds were inserted into the UTC time scale, indicating that Earth's rotation rate has slowed slightly and UTC needed to be retarded. A chart best shows how this rate has changed over the last several hundred years (figure 1). It is possible that a leap second may have to be subtracted from time to time. When the leap second was introduced in 1972, a correction of 10 seconds was required. Two seconds were initially inserted, one at the end of June and another at the end of December in 1972, and then one second yearly for the next eight years. The last leap second prior to this writing was inserted 31 December, 2008. The effort to maintain synchronization between UT1 and UTC results in a stair-step pattern (figure 2).

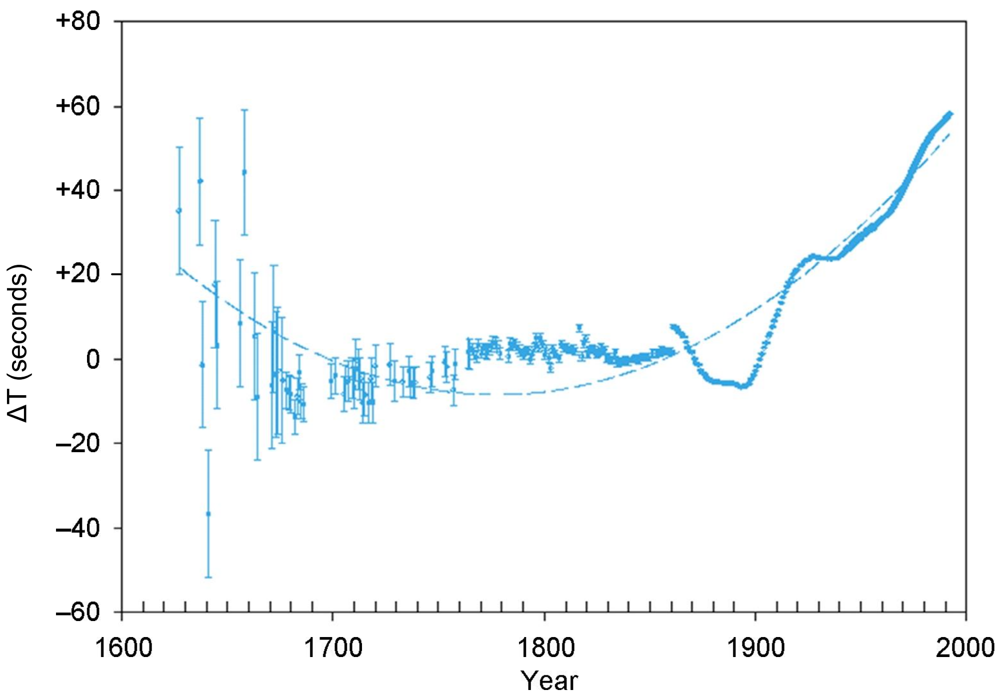

Fig. 1 ~ Observed difference between time determined from Earth's rotation rate and time based on a uniform scale. The dashed line is a quadratic (parabolic) curve fit. Chart from [GPSW-Nov99]

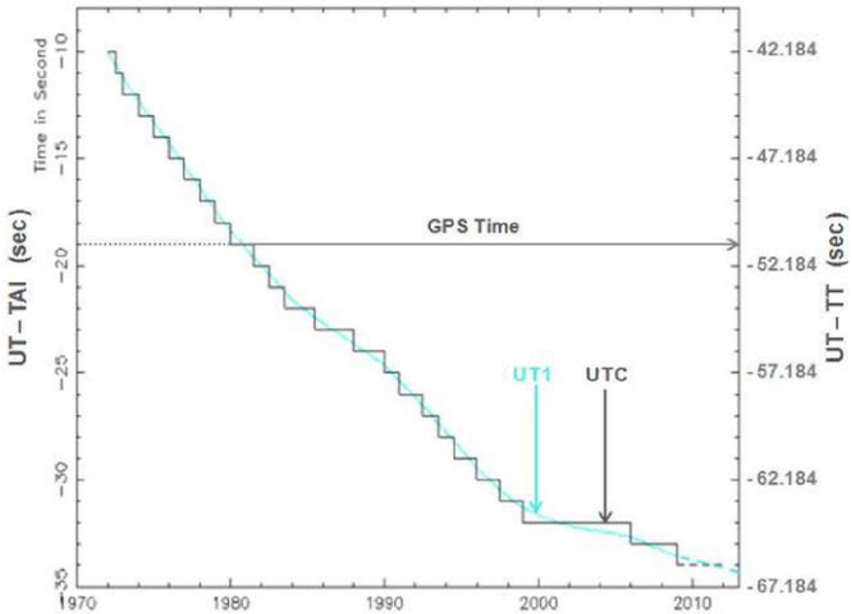

Fig. 2 ~ Adjustments by inserting leap seconds in UTC to keep it within ±0.9 seconds of UT result in a stair-step pattern. Chart from fig. 4 of [AAS 11-674]

Earth's rotation rate is predicted to continue slowing such that more than one leap second will be needed each year in the foreseeable future. It is estimated that by 2050 about 1.5 leap seconds per year will be needed. [GPSW Nov99] One of the problems with the leap second is that it cannot be predicted with any accuracy beyond about one or two years. This can be problematic for software writers who use time in their code and prefer to work with algorithmic processes.

The preferred time and date for leap second insertion or deletion is midnight 30 June or 31 December but 31 March and 30 September also may be used if necessary to stay within the 0.9 second difference requirement. The next leap second will be inserted 30 June 2012 using a predetermined sequence (figure 3).

Fig. 3 ~ A leap second will be inserted to retard UTC at the end of June 2012. The clock shown here is conceptual and based on the UTC time scale, so it will occur at different local times depending on the user's time zone. It is unlikely that any real clock will show the digits "60" in the seconds field as shown here.

As I pointed out in my article "Maintain Your Time" in the May-June, 2012 issue of ***Radio Astronomy*** [Reeve], most of us live our daily lives based on the local time. Local time consists of two elements, a time reference and a time zone, where Local time = Time Reference ± Time Zone. UTC is the Time Reference, so Local Time = UTC ± Time Zone. Time zones are based on Earth's longitude with respect to Greenwich, a district in south London, England. The Greenwich longitudinal reference has historical roots and continues to be used today. Greenwich also was the reference point for a time scale called Greenwich Mean Time (GMT), but the use of GMT is obsolete in modern technical discussions.

Ideally, there would be 24 time zones, one for each hour in Earth's 24 hour rotation time and covering 15 degrees of longitude, but time zone boundaries are heavily modified according to political and national considerations (figure 4). With time zones the Sun theoretically has the same position in the sky at, say, 9:00 AM local time no matter where we are on Earth but, as seen in the time zone map, this cannot be true in practice. The main thing is we can go to work, eat our lunch and catch our flight at the proper local time, and we will know when the Sun will rise and set at our location.

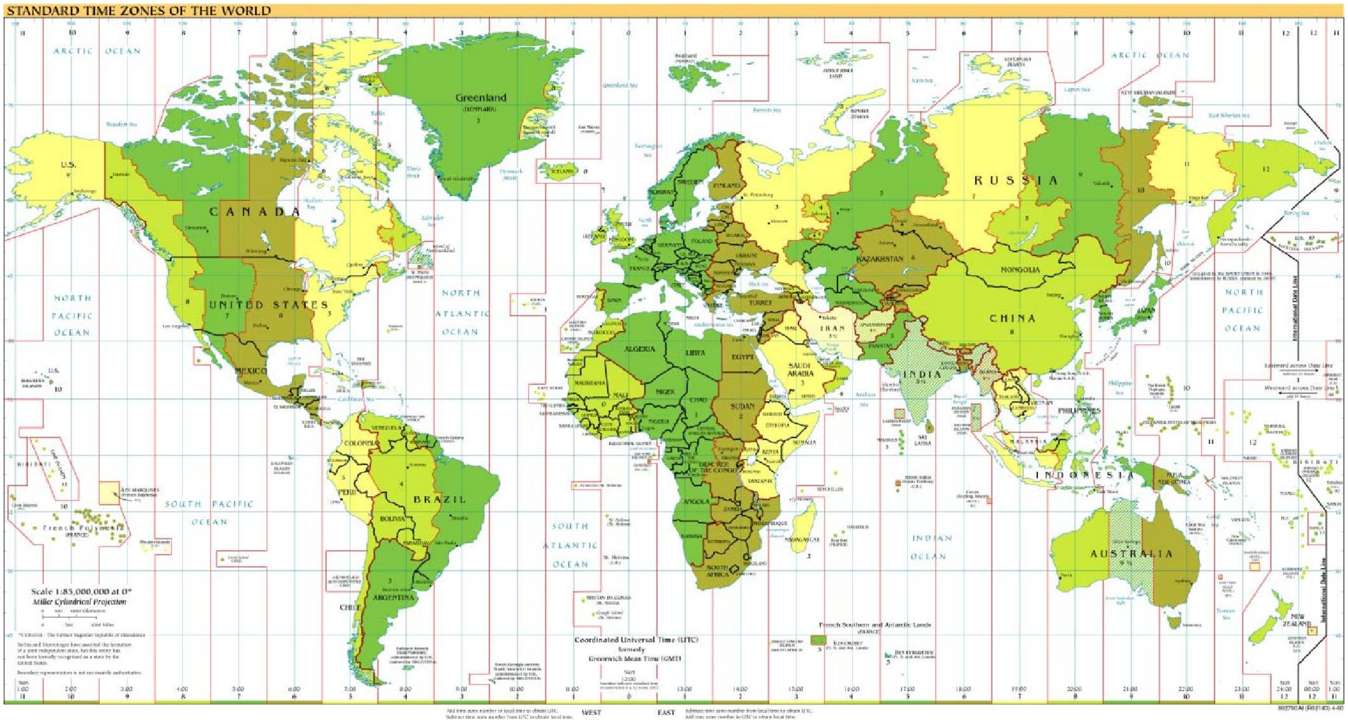

Fig. 4 ~ Time zones are loosely related to longitude with respect to Greenwich, England. Illustration from http://www.convertit.com/Go/ConvertIt/World_Time/Time_Zones_Map_Large.asp, ©2000-2002 ConvertIt.com, Inc.

3. How did this become a problem?

The controversy came about because of an expressed need by certain “user communities” to decouple civil time from Earth’s rotation rate. One such “community” is the telecommunications industry. The telecommunications industry relies on very precise frequencies to keep their networks operating in lock-step (a process of *syntonization* but most often called *synchronization*). The frequencies of the clocks used in these networks are traceable to atomic clocks, most often the Global Positioning System, GPS, but also terrestrial cesium beam clocks. The GPS itself does not use leap seconds and is not directly coupled to civil time. Interestingly, GPS administrators are not in a “community” that favors elimination of leap seconds.

The present difference between GPS time and civil time is 15 seconds (that is, GPS time is 15 seconds ahead of civil time). When the next leap second is added at the end of June 2012, the difference will increase to 16 seconds. It is interesting that the very popular Android handsets generally use GPS time whereas the equally popular iPhones generally use UTC. As a result there is 15 seconds difference between the two (increasing to 16 seconds in July 2012). Of course, how well cellphones and handsets keep time depends on the handset itself and how it is setup to keep time as well as the service provider and how their network is setup. Most cellphone handsets probably keep time within about one second of the time provided by the service provider’s network. However, if the network time is “wrong” then the handset will be wrong. The irony here is not surprising – elimination of the leap second supposedly benefits the telecommunications industry but it cannot keep civil time to within 15 seconds anyway. Of course, one might ask: How many handsets are used for precise timekeeping purposes? My own quick canvas of users resulted in the following very common and concise response: “What ... are you talking about?”

It is easy to understand that telecommunications, navigation and related fields have a need for a single continuous time scale but, so far, they apparently have coexisted with the discontinuities caused by the leap second in UTC.

Publicly reported problems have been minor and transient and only anecdotes are available concerning more serious problems. However, it is not clear that this coexistence can continue for the long term – it is not clear because no public and transparent studies have emerged one way or another. Indeed, the several informal surveys that have been made overwhelmingly indicated that no changes to UTC are necessary. [AAS 11-668, AAS 11-672]

4. What could be broken if we fix time?

Eliminating the leap second could cause the computer year 2000 software problem (Y2K), or "millennium bug," all over again. Many readers will remember Y2K. Prior to 2000 a great many software and firmware systems were poorly designed, leading to an unknown state when the time and date rolled over from 31 December, 1999 to 1 January, 2000. In most software at the time, the year was represented by two decimal digits, and the 19 was implicit – all years were assumed to start with 19 (as in 1999), leading to a potential ambiguity between the years 19xx and 20xx. This was not necessarily the fault of the software engineers and program coders, at least for the many so-called "legacy" systems that were designed prior to about 1990 and still in-use in 1999 – the coders probably did not have access to the needed information. However, we cannot be so generous about any software or firmware written after about 1990 – much of it had embedded problems with the date roll-over.

We have a similar problem with the leap second and its possible elimination. What will break? As in the Y2K problem, we cannot know without extensive and expensive testing. Consultants and lawyers will once again fall over themselves while rushing to clients and conjuring doomsday scenarios, some of which may be actually true. People will once again stockpile canned chili, batteries and bottled water and build underground survival bunkers. Many people will blame their governments for not doing enough to save them from the alleged calamity.

Even the cost to estimate the costs associated with eliminating the leap second will be enormous. Much of the implementation costs will be in software modifications similar to Y2K, but on a much larger scale because now there are many more applications that assume there is a link between UT and UTC.

Aside from costs, there are other potential problems, some of which were reported in [AAS 11-672]:

- User preferences: Many users prefer that the time difference between UT and UTC be held within limited bounds as it is today;
- User reactions: Heretofore, every change to our system of timekeeping has been a contentious issue for the general public and much talked about. However, even with the discord caused by changes, the public often figures out a way to celebrate it and the media enjoys reporting it;
- Legal considerations: UTC is the legal basis for time in most countries. It is not known to what extent laws need to be modified to account for an "unbounded" UTC;
- Long-term effects on society: "Legal" time and solar time will drift apart if leap seconds are eliminated, and it is unknown how this affects society;
- Software and hardware modifications: There is no question that huge amounts of software, firmware and hardware presently are directly and indirectly based on coupled UT and UTC, but the extent is unknown;
- Non-technical and non-scientific applications: The general public has no knowledge of the extent to which their software applications, clocks or other devices handle time. How the elimination of the leap second would affect these applications is unknown;
- Re-education: A certain amount of re-education will be needed to explain why "legal" time and solar time are no longer synchronized;
- Celestial navigation and almanacs: Many such applications assume UT and UTC are coupled. It is not known what will be required to change them;
- Spacecraft flight software that depends on coupled UT and UTC: The software associated with timekeeping and data time-stamping on many spacecrafts cannot be changed.

5. Conclusions

ITU-R, the official global timekeeper, has been studying the elimination of leap seconds for over a decade yet no public studies or surveys have indicated that a change is necessary. ITU-R met in January 2012 to decide on the fate of the leap second but the only decision made was to study it further. Consequently, we will continue using leap seconds for the time being. The next leap second will be inserted at midnight, 30 June 2012 (UTC).

6. Epilogue

The leap second was added and apparently without problems on 30 June. Readers can view a short video of the SymmTime time-keeping application program updating a PC clock to include the extra second: http://www.reeve.com/current_projects.htm (scroll down to Time).

7. References and further reading

References:

[AAS 11-660] Seago, J.H., Seaman, R.L., Allen, S.L., The Colloquium On Decoupling Civil Timekeeping From Earth Rotation, Pre-print, American Astronomical Society, October 2011 (http://www.futureofutc.org/)

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[BIPM-SI] The International System of Units (SI), Bureau International des Poids et Mesures, 8th Edition, 2006 (http://www.bipm.org/en/si/si_brochure/chapter2/2-1/second.html)

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[ITU-R236/7] Question ITU-R 236/7, The Future of the UTC Time Scale, International Telecommunications Union – Radiocommunications Sector, 2001

[ITU-R-TF460] ITU-R Recommendation TF.460-6, Standard-frequency and time-signal emissions, International Telecommunications Union – Radiocommunications Sector, 2002 (http://www.itu.int/rec/R-REC-TF.460/en).

[Reeve] Reeve, W., Maintain Your Time, Radio Astronomy, March-April, 2012

[USNO-179] Kaplan, G., The IAU Resolutions on Astronomical Reference Systems, Time Scales, and Earth Rotation Models, Circular No. 179, United States Naval Observatory, October, 2005

[USNO-Dat] http://maia.usno.navy.mil/ser7/leapsec.dat

Further reading and study:
National Institute of Standards and Technology (NIST) Time Exhibits: http://www.time.gov/exhibits.html
Decoupling Civil Timekeeping from Earth Rotation: http://futureofutc.org/
United States Naval Observatory Precise Time: http://www.usno.navy.mil/USNO/time
International Telecommunications Union, Status of Coordinated Universal Time Study in ITU-R: http://www.itu.int/net/newsroom/wrc/2012/reports/atomic_time.aspx
Bureau International des Poids et Mesures, Time: http://www.bipm.org/en/scientific/tai/
Chi, A., Fosque, H., A Step in Time - Changes in standard frequency and time signal broadcasts, IEEE Spectrum, January 1972 (ieeexplore.ieee.org/iel5/6/5218452/05218478.pdf?arnumber=5218478)