MIDDAY ROUND-TABLE DISCUSSION OF OCTOBER 6, 2011

The draft of the proposal to be voted upon at the ITU-R Radiocommunication Assembly in January 2012 offers only two options: maintain the *status quo* with leap seconds, or abandon the insertion of leap seconds altogether. This discussion contemplated the viability of other possible options. Variations on the handling of time have already been tried. In most cases there have been quirks which limit the applicability of various options or which cause confusion among users needing precise time.

Neil deGrasse Tyson wondered if the main problem with UTC was not with leap seconds *per se* but rather with their lack of predictability within software. He wondered if a low (second) order model of Earth rotation rate might be a viable option, acknowledging that such would be less accurate yet usefully predictable. He suggested that a model could be used to plan leap adjustments centuries in advance, effectively becoming part of the calendar, and would therefore be useful for protecting software systems over their service lifetime.

David Terrett noted that this would be a change from the current convention, and that any change would bring about issues. Daniel Gambis noted that decadal variations can be significantly larger than the long term trend, making estimation and prediction of a trend difficult in the long-term. Steve Allen noted that this option or a variation of it was an early consideration but it did not seem acceptable to anyone at the time, and that there are more fundamental problems that such a solution does not address. Ken Seidelmann noted that the length of year is now known rather accurately and this is what makes predicted leap days in the Gregorian calendar workable. Terrett also noted that programmers still get the rules of the Gregorian calendar wrong, so having a predictable leaping rule for time of day for software does not necessarily solve the software issue. Tyson questioned whether the dismissal of a predictable rule should be based on the anticipated incompetence of some programmers, but then it was appreciated by most in the room that the proposed redefinition of UTC was already being motivated by the very same argument.[1]

Frank Reed noted that the second-order model was perhaps accurate to only two significant figures at best, and therefore was far too inaccurate to be useful as a prediction model. Dennis McCarthy said that any such approach would require loosening of the current ±0.9-second tolerance for UT1-UTC, but that in principle the proposal should meet a concern of programmers regarding the predictability of leap adjustments. McCarthy also shared that some programmers do not appreciate that accurate leap-second insertions are not predictable, and Allen noted that "future leap seconds" is a very common internet search phrase. Rob Seaman suggested that extending the predictions from six months to a few years may be helpful in some cases. Daniel Gambis said that the IERS could confidently predict leap seconds in advance of "two or three years." McCarthy said that prediction years in advance could be a good option for almanacs and other publications that are printed well in advance. At this point Steven Malys reminded the attendees that the proposal for consideration in January was that UTC should diverge from Universal Time indefinitely and without further adjustments, which McCarthy and others affirmed.

Ken Seidelmann asked Gambis to affirm whether leap seconds might really be predictable out to three years; however, Allen suggested that three years' prediction still would not be enough to satisfy software people. Seidelmann wondered if extended prediction might help some software, but Terrett said that he thought the primary software issues were really caused by programmer ignorance about the existence of leap seconds, rather than a need for extended forecasts. Allen suggested that it was more than ignorance, and his upcoming presentation would discuss the fundamental problems, and that satisfaction would not be had by any scheduling scheme. Reed said that leap seconds are just generally confusing for software people.

Mark Storz said he had mistakenly thought that the IERS might continue to announce leap seconds as a service to systems that expect them, but they would simply be ignored in future UTC broadcasts. John Seago asked if there was any risk of an independent party attempting to coordinate and publish future leap seconds announcements should this service no longer exist. Rob Seaman replied that there are commercial entities who try to make money in the time-service business through unconventional ways. Allen noted that the authority of such an announcement would be the issue, citing Gregorian calendar reform as an example where universal agreement could not be had even by papal decree. Wolfgang Dick noted that almanacs that need to predict or publish UT1-UTC in advance will effectively have this information. Storz noted that while people could calculate potential adjustments from that information, their insertion into timekeeping systems would not be coordinated. Allen noted that such a situation would result in the "proliferation of independent time systems" that the ITU-R was reportedly attempting to avoid via the cessation of leap seconds.[2] Dennis McCarthy suggested that truncation of the leading digit could lead to a simple rule as to when to insert such a correction. John Seago and Mark Storz also wondered if rounding might also lead to a suggested rule.

Kaplan said that when the Very Large Array (VLA) became operational in the 1980's, he had hoped that astronomical systems would take up its example of running on TAI as a standard. He noted that a significant complication with UTC is that the computation of precise time intervals was not algorithmic and required archived leap-second tables. Allen noted that people will always be faced with the application of tabulated corrections, because our ancestors have always taken actions that seemed stupid to later generations yet cannot be undone.

Tyson noted that Nobel-Prize winner Joe Taylor lamented the unexpected effort that was required to process pulsar measurements tagged to UTC due to leap-second insertions, citing this as an example affirming that many astronomers are likely unfamiliar with the definition of UTC. Arnold Rots gave an example from a recent IAU symposium where astronomers generically labeled data and graphs without any acknowledgement of the underlying time scale. Dennis McCarthy offered that there are IAU resolutions recommending proper time scale nomenclatures, such as endorsement of the use of Modified Julian Date (MJD). Terrett asked how the time scale should be stipulated and Allen clarified that guidance was noted in 1997 Resolution B1 of the IAU.[3] Allen also suggested that it is useful to provide users with a citation to educate and convince the reader that the presentation is the proper one.

Seago offered that the civil dating of events is traditionally done in terms of a "calendar day" and "time of day" within an astronomically based calendar, and that UTC's leap seconds are a consequence of maintaining an astronomically based calendar. Without such adjustments, the calendar becomes entirely algorithmic, and the complete detachment of a "metric" day from celestial motions potentially raises some issues mentioned by Paul Gabor. Seago suggested that an extrapolation of this line of thinking could also argue for the abolition of civil time zones and calendars, yet that level of change had yet to be advocated. Seaman noted that France attempted unconventional changes to measuring time after the French Revolution which proved unpopular. Seidel-

mann noted that conventional Julian Days already exist for those who might prefer that type of representation.

Kaplan noted that many proposed solutions are seemingly worse than the problems they are trying to solve, as they could cause unnecessary complications in the distant future. One idea of particular concern might be the introduction of an NTP service of variable frequency that attempts to track UT1 (as UTC did before 1972). Kaplan felt that such a service would inevitably be used by someone inadvertently thinking that it was UTC. The tagging of data by such a service would pose significant complications in the distance future as it could be difficult to relate the time supplied by the service back to uniform atomic time. Steve Malys wondered if we might be creating unknown problems for the future with the current proposal to decouple civil timekeeping from Earth rotation, as it seems that motivations for the decoupling are not adequately justified. The major argument favoring changes now seems to be the inconvenience to software-programmers, which appears to be a weak reason for denying our progeny civil time linked to the astronomical day. Tyson agreed that this reasoning would be embarrassing to admit a century from now.

Seaman reminded the group that the colloquium topic is about the decoupling of civil timekeeping and Earth rotation, and that UTC is simply the current solution. There are vast possibilities for civil timekeeping that could be explored beyond leap seconds that could stimulate interesting discussion; however, Seaman expressed skepticism as to whether such discussion could readily turn into a simple solution, noting in particular that TAI-like time is not going to be the solution to every civil-timekeeping problem. Seaman also wondered if the status of TAI might change if UTC were redefined; if so, would it be wiser to start labeling epochs according to TT's system of dating events which is offset from TAI by 32.184 seconds. Terrett said that TAI exists by definition indefinitely as a sequence of *SI* seconds. Allen suggested that the existence of TAI presupposes that the BIPM maintains TAI. McCarthy clarified that really there is no clock maintaining TAI, but Seidelmann countered that TAI could be made available by trivially subtracting leap seconds from UTC.

Tyson wondered if there is anything that could be learned by imagining ourselves placed a century into the past to understand the challenges that were important then, and then exploring if our priorities today will seem like folly to our progeny. Terrett suggested that trying to predict requirements a century forward would likely be impossible for our generation, but Tyson noted that is part of the value of the exercise; it might reveal the kinds of issues that were made obsolete or otherwise solved over time. Seidelmann noted that such an exercise would likely reveal that we simply cannot anticipate what technological changes will occur that will have an effect on the definition of civil time scales; therefore, there is limited value in making seemingly arbitrary changes now when future technology will eventually force changes regardless. He cited variable Earth rotation and general relativity as examples of physical issues that were not well known a century ago and have resulted in great complications in our modern timekeeping. Seaman added plate tectonics to list of physical causes that were unknown a century ago.

Allen offered that changes occur not because people have a clear idea of what will be needed in the future, but they happen whenever the state of the art becomes so impractical that making *any* change outweighs the perceived risk of making the wrong decision for the future. Simpson noted that, because there seemed to be no compelling reason to abolish leap seconds right now, the current situation did not seem to meet the condition for an immediate change that Allen described. Allen replied that perceptions may differ depending on the situations of different communities.

Gambis wondered if there might be some value in thinking much longer term, such as 1000 years in advance. As an example of how technology can change with time, Seidelmann offered that the second itself may be redefined according to a more-precise optical standard in the not too distant future. Tyson asked what applications might be driving the need for this extra precision. Allen responded that a new standard would simply measure what cannot be measured now. Seidelmann agreed by noting that metrological improvements feed technological advancement.

McCarthy said that the key in trying to decide in what's going to happen in the future is to make things flexible enough right now so that we can accommodate things down the road and to not hardwire in things like leap seconds. Tyson replied that he did not get a sense from these conversations that flexibility was a primary consideration. Terrett said that a point in his talk was that openness and willingness seems to be needed already, particularly as it relates to software inertia, and that software needs to be designed with a certain level of flexibility that it has not enjoyed yet. McCarthy noted that people needed to realize that Earth rotation rate will continue to vary in ways that cannot be accurately predicted. For everyone's amusement, Tyson speculated that geo-engineering might somehow allow the Earth's rotation to be controlled far into the future.

Within the context of Tyson's suggestion of placing ourselves in the past and thinking forward to the present, Seago noted that Simon Newcomb seemed very concerned regarding the accuracy of his *Tables of the Sun*, perhaps believing that they would be in use for a long time, and it appeared that his goal was to do the best he could with the methods and data available to him at the time to minimize adverse impact on future generations.[4] Seago then noted that there are really only two proposals under consideration at the moment: atomic time without any allowable adjustments, and *status quo* UTC which allows for adjustment. With regard to McCarthy's issue of maintaining software flexibility for the future, Seago said of these two options, the decoupling of civil timekeeping from Earth rotation appeared to provide the *least* flexibility for the future, and software support of small calendrical adjustments promoted the greatest flexibility. Malys agreed with this assessment, believing that it would be very difficult to resynchronize civil time with Earth rotation if they were allowed to separate, and that the level of difficulty would grow with size of the difference.

Tyson said that much of the conversation had focused on engineering and technology, but if the issue is really about "civil time", *e.g.*, if civil time can be defined as someone wanting to catch a train, then the discussion had not approached that issue very far. Allen pointed out that a cellular telephone with a stock Android® operating system will display Global Positioning System time by default, which is presently fifteen seconds ahead of UTC, and the telephone must be hacked to display civil time. Seago repeated that, with regard to issue of the meaning of "civil time", Newcomb recognized two fundamental representations governing the dating of events: calendar day and time of calendar day, both of which are astronomically based.[5] Seago offered that astronomical concepts like *day* and *time of day* may be fundamental to what the populace expects from civil time, for without an astronomical basis, the long-term meaning of "day" becomes an added issue in the debate. If *time of day* means something that tracks the Earth, then engineering and technology would place requirements on the desired level of synchronization. Some technologies may desire closer synchronization than others, while some technologies, such as telecommunications, may not demand close synchronization to the astronomical day at all.

Malys noted that GPS serves to differentiate itself by representing system time in terms of week number, and seconds of week. Seago agreed and noted that there may be confusion as to the meaning of the very term "time scale". He thought that, to most people, a "time scale" was little more than a dating system for labeling events, and that this description is consistent with past metrological publications that he had seen.[6] Therefore, when people refer to, say, "TAI", they are

not intending to refer to the paper clock via BIPM *Circular T*, but they are suggesting a method of labeling real-time atomic UTC seconds uniformly, *i.e.*, UTC + DTAI. Seago wondered if different ideas about the meaning of "time scale" might be inhibiting broader discussions about available options for uniform dating schemes.

Gabor noted that the European Galileo navigation system would create yet another timing system. Allen noted that much effort was expended to ensure that Galileo signals would not interfere with GPS signals and that the GPS and Galileo system times would be highly compatible. Reed pointed out that GLONASS provides yet another GNSS system time. Malys commented that GPS provides a realization of UTC time and Galileo should be able to provide yet another realization that would be slightly different than UTC(GPS). Allen noted that the differences of realization would likely be at the nanosecond level. McCarthy clarified that the differences between internal GPS system and internal Galileo system time would be broadcast by both systems so that future GNSS system can interoperate with both sets of signals, and that the level of offset would likely be at or below 10 ns. McCarthy also noted that the reference epoch for both GPS and Galileo time scales would be the same. Allen noted that the epoch of the Chinese Beidou navigation system was offset from the GPS and Galileo epoch by 14 seconds.

Kaplan noted that many people think of "GPS time" as UTC provided via a GPS receiver, so it is often unclear whether people are referring to the internal time scale of the GPS system or UTC as available through corrected GPS signals. McCarthy also added that some GPS receivers can toggle between UTC and GPS system time and consequently some users do not know which time is being used.

REFERENCES

[1] Kamp, P.-H. (2011), "The one-second war." *Communications of the ACM*. Vol. 54, No. 5, pp. 44-48.

[2] Beard R. (2005), "Future of the UTC time scale." 45th Civil GPS Service Interface Committee Meeting (Long Beach, CA, 13 September 2005).

[3] Resolution B1 of the IAU XXIIIrd General Assembly - Transactions of the IAU Vol. XXIII B Proceedings of the 23rd General Assembly Kyoto, Japan, August 18 - 30, 1997 Ed. J. Andersen Kluwer Academic Publishers.

[4] Newcomb, S. (1895), *The Elements of the Four Inner Planets and the Fundamental Constants of Astronomy*. Supplement to the American Ephemeris and Nautical Almanac for 1897. Government Printing Office, Washington. p. 188.

[5] Newcomb, S. (1906), *A compendium of spherical astronomy*. Macmillan Company, p. 114-7.

[6] Blair, E.B., (ed.), *Time and Frequency Fundamentals*, NBS Monograph 140, p. 4.