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RECOMMENDATIONS ON UTC DEFINITION FROM IAG WORKING GROUP 1.1.1

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This paper presents the points of view on UTC from the Working Group on precise orbit estimation of the International Association of Geodesy (IAG) that existed over the period 2004-2011. The IAG organization of commissions, subcommissions and working groups is regularly restructured, and in the most recent reorganization this Working Group has been superseded by various new entities. However, the reply from the Working Group 1.1.1 to the questionnaire on the possible discontinuation of leap seconds will be of interest to the current study, and is presented here.

INTRODUCTION

At the risk of restating the obvious, the core problem will be formulated first for sake of completeness. Any time standard is characterized by its rate of progression (scale) and its definition of epochs (date). The key characteristic of UTC is that it *coordinates* two conflicting requirements on scale and date, namely, it uses the highly stable atomic time standard for its scale while at the same time it defines its dates in close agreement with solar time, which reflects the decelerating rotational rate of the Earth. The desire to keep the date stamps within one second of solar time leads to the need for occasional adjustments of the coordinated UTC scales, which are the leap seconds. In practice these lead to various problems, mainly in the area of correct handling of leap seconds in analysis software. It is therefore investigated whether the further application of leap seconds should perhaps be discontinued, so that the offset between UTC dates and UT1 dates will grow beyond a one-second band.

RELEVANCE OF VARIOUS TIME STANDARDS TO SATELLITE TRACKING AND ORBIT DETERMINATION

In space geodesy, various time standards are of interest and their relative offsets must be accurately known. The main time definitions of interest are:

- TAI International Atomic Time
- UT1 Universal Time: mean solar time as implied by actual Earth rotation
- UTC Coordinated Universal Time
- GPS TAI realization by the GPS ground segment, at constant 19 s offset to TAI

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- GLO UTC realization by the GLONASS ground segment at three hour offset to UTC

At the basis of time modeling in any computer program is usually a purely mathematical integer count, *e.g*. a progression of seconds or minutes. This mathematical count can be interpreted as a representation of TAI, because its rate is strictly regular over any interval of interest. It forms the basis for various time-dependent computations in the software, such as numerical integration of satellite orbits in inertial space as a function of a strictly continuous time.

For accurate modeling of the tracking geometry between ground stations and objects in space, the software needs to model the instantaneous rotation angle of the Earth as a function of its mathematical TAI count. The Technical Notes of the International Earth Rotation Service (IERS) define a highly sophisticated transformation model between the celestial reference frame and the terrestrial reference frame.[1] This Earth-rotation model also includes empirical corrections for daily *dUT1* parameters (or equivalently, length-of-day variations). These *dUT1* numbers, along with polar motion offsets dX_p and dY_p are regularly published by the IERS. In practice they are obtained from routine analysis by the services of the International Association of Geodesy (IAG), in particular the International GNSS Service (IGS), as GPS has become the dominant tracking technique in satellite geodesy.[2]

In other words, for the modeling of precise satellite orbits, the key time standards in the analysis software are TAI and UT1. All further time definitions, such as UTC, GPS time or GLONASS time, are only relevant because various input data sets may use time stamps in these other standards, or output data files may require time tags in, *e.g.*, UTC or GPS time. The discussion on leap seconds in satellite analysis is therefore mainly a discussion on interface problems: input UTC time tags must be converted to the correct internal TAI seconds, or internal TAI-like time stamps of the software may need to be converted to an output UTC epoch.

Almost every software tool used in satellite data analysis is therefore confronted with time conversions to or from UTC input and output time stamps. Two problems were reported most frequently:

- *Ambiguous treatment of leap seconds within the software*. Analysis techniques tend to be iterative, for instance, the same input observation may have to be processed multiple times in a single orbit estimation run, or a numerical integrator may perform prediction/correction logic that revisits the same epoch multiple times. As soon as UTC time tags are involved anywhere in the input or output data streams, the software needs fairly complex housekeeping logic to unambiguously know whether leap seconds have already been applied to this data element, or not. There is no standard solution, and brute force methods (such as rewriting all data with TAI time tags instead of UTC) are often prohibitive in terms of processing time or storage space.

- *Outdated leap second information in the system*. Every (future) new leap second requires an update of some internal leap second data base file or source-code file at the processing center. This is not always possible, for instance, operational satellite ground segment software is usually frozen for the duration of the mission for security reasons, and cannot be updated to add a new leap second (or, this minor change would require a very costly repeat of all system tests). It also happens that analysts are simply unaware of the occurrence of a new leap second, or do not realize that their local leap second database is obsolete.

ARGUMENTS IN FAVOR OF ABANDONING LEAP SECONDS

Considering the above, the arguments in favor of abandoning leap seconds would seem to follow directly from the reported problems, namely, without leap seconds there are no more software issues related to the leap seconds and no more operational issues related to updating databases.

However, the software argument only applies to the analysis of future data, because many historic datasets still have UTC time stamps. Satellite geodesy does not just process the latest data arriving in near real-time: for many investigations it is necessary to reprocess historic data sets, often covering many years. As an example, the increasingly important reprocessing activities of the IAG services can be mentioned, which usually form the basis of significant improvements in satellite models or geophysical models.[2] Any analysis software that is used for the processing of historic data will *forever* have to cope with past leap seconds, unless all associated data is transformed to, *e.g.*, TAI-like time stamps. However, such a conversion may require other software modifications, or duplication of all storage, and would certainly lead to many new discussions among the analysis centers. There is no easy way around these problems, so that ultimately, most software will have to be capable of dealing with leap seconds, even if no further leap seconds are applied in the future.

The operational issue of having to update internal leap second data can usually be avoided by adequate design, for instance by converting input data time stamps outside the frozen system, or by tagging the data immediately with, *e.g.*, GPS time stamps at the instrument level.

In other words:

- Abandoning the further application of leap seconds would *not* solve the software problems caused by the leap seconds. We are forever stuck with the leap seconds that were applied over the period 1972 - 2012, and satellite-tracking datasets from this period will remain relevant to science for decades to come.
- Abandoning the further application of leap seconds would only be one of several possible solutions to the operational (database) problems caused by leap seconds, and probably not the best solution. Good alternatives exist, such as using TAI or GPS time stamps, in operationally critical data-flows.

ARGUMENTS IN FAVOR OF MAINTAINING LEAP SECONDS

The key feature of UTC, as summarized before, is its marriage between the homogeneous TAI time scale and the inhomogeneous UT1 time scale, leading to occasional adjustments in the form of leap seconds. Many people understand the "C" of UTC as a reference to this coordination between scale and epochs, although another explanation is the coordination of time standards from different countries or agencies. If leap seconds cease to be applied it could become confusing or even misleading to keep using the name "UTC". We should probably call the new time standard something else, like TAS (*Shifted* Atomic Time). This new time standard would have the following characteristics:

- Its rate is that of TAI (…just like TAI itself, or GPS time, or any UTC realization).
- Its offset to TAI would be frozen forever, *e.g.*, at current value TAI – UTC = 35 seconds.

What could be the reasons for using a shifted atomic time scale instead of TAI itself? Other than to be different, there are none. In fact, we already have a shifted TAI-like scale in the form of GPS time, with an arbitrary offset of TAI − GPS = 19 seconds. Other than to be different, this offset serves no practical purpose and merely leads to occasional bugs in software. Having yet another shifted TAI-like scale, with another arbitrary offset, would be redundant:

- People / software that really cannot live with leap seconds may already use a TAI-like scale or GPS time today; there would be no benefit whatsoever in using "TAS" over GPS time.
- People / software that need reasonable synchronization with solar time would be forced to use UT1 directly, which is not accessible through any known method other than by full evaluation of the IERS models, involving daily updates of the empirical dUT1 parameters from the Bulletin B publications. This is much more troublesome than dealing with occasional leap seconds in the UTC standard.

LEAP HOURS, LEAP DAYS OR OTHER INTERVALS

A seemingly clever way of solving the problems caused by leap seconds, while still maintaining the "coordinated" character of UTC, would be to insert fewer, larger adjustments of UTC, *e.g.*, leap minutes or leap hours instead of leap seconds. After all, the jump of one second is also a fairly arbitrary choice, and is already far too large to satisfy precise timing users who operate at nanosecond or picosecond level. If UTC had been defined to stay within one minute of UT1, the entire period 1972 – 2012 would be free of adjustments. The first "leap minute" would probably not occur before the year 2030. The first "leap hour" might not occur for the next 1000 years or so, and by that time any current time standard will most likely have become meaningless.

However, these considerations come too late. In the year 1972, the leap second was created, not the leap minute or the leap hour. The leap seconds of the past cannot be undone, so that the suggestion of using larger leap intervals than an integer second is really not different from the notion of abandoning Universal Time altogether.

SUMMARY AND RECOMMENDATION

At first sight, leap seconds merely cause various practical problems in analysis software and satellite operations, and abandoning them may seem like an attractive idea. However, avoiding future leap seconds does *not* solve the software problems with past leap seconds, while operational problems can already be solved today in various ways. The arguments in favor of abandoning leap seconds are therefore rather weak.

The arguments in favor of continuing the UTC definition as it is today are stronger, whether we like it or not. First of all, the UTC standard is only *coordinated* with UT1 thanks to the leap seconds. Without leap seconds coordination would no longer exist. The new "uncoordinated" universal time would be a non-entity, nothing more than a shifted version of TAI just like GPS time is today. This time standard has no obvious advantage over a TAI-like scale and mainly illustrates a lack of resolve among timing community scientists.

The conclusion is therefore that by abandoning leap seconds the world loses something relevant (namely, its only solar-coordinated time standard) without getting anything in return; the problems with past leap seconds will not disappear. *There is nothing to be gained from a change in the current UTC definition*. The recommendation is therefore to continue UTC just like it has been over the period 1972 - 2012, namely, with occasional leap seconds to stay within one second of mean solar time.

REFERENCES

[1] Petit, G., Luzum, B. (eds) *IERS Conventions 2010* (Technical Note 36). Frankfurt am Main: Verlag des Bundesamts für Kartographie und Geodäsie, 2010. URL http://www.iers.org/IERS/EN/Publications/TechnicalNotes/tn36.html

[2] Dow, J.M., Neilan, R.E., Rizos, C. "The International GNSS Service (IGS) in a Changing Landscape of Global Navigation Satellite Systems", *Journal of Geodesy*, Vol. 83, No. 3-4 March 2009, pp. 191-198.