DISCUSSION CONCLUDING AAS 13-507

ANDREW MAIN thoroughly approved of RUSSELL REDMAN's idea of maintaining a technical glossary but took issue with some elements of the definitions presented. Generally, MAIN found REDMAN's definition list too short. There is a large hierarchy of concepts on which the practical issues of broadcast timescales are founded, and some levels seemed to be absent. REDMAN noted that the full set of definitions in the contribution to Working Party 7A was too long to completely include in the presentation.

Regarding REDMAN's proposed definition for *Reference Coordinate Time* (RCT), MAIN thought the mention of the rotating geoid made it appear that only Terrestrial Time (TT) satisfied the definition, whereas the name 'Reference Coordinate Time' sounded like it ought to cover Barycentric Coordinate Time (TCB) and Geocentric Coordinate Time (TCG). TCB and TCG are basic relativistic standards upon which Terrestrial Time is an additional layer, TT being a linear transformation of TCG. MAIN asked if RCT intended to represent an ideal like TT, or if RCT intended to represent a physical realization using atomic clocks. REDMAN replied that RCT is intended to be a conceptual ideal related to Terrestrial Time (TT), except that TT is usually used in a different context. REDMAN's goal was to focus on a physical concept rather than any particular realization or representation.

MAIN suggested that there may be some conflation of the physical ideal with a realization in terms of atomic time, because there was a column labeled 'RCT' in the illustration of leap-second processing alongside the labels of seconds with minutes. Presently, leaps occur explicitly in an atomic timescale which is a realization of a physical ideal; leaps are not applied onto the physical ideal. REDMAN accepted the criticism, but clarified that the label 'RCT' was for illustrative purposes and was not intended to be something that anyone "would actually want to see." Main cautioned that that Internet URLs were never meant to be visible to humans either; attempts to hide defined labels will not likely succeed.

MAIN also understood 'uniformity' and 'predictability' to be different concepts, yet REDMAN's presentation seemed to portray them as equivalent. REDMAN clarified that his use of 'uniformity' was to convey a notion that larger units of duration, such as minutes, have equal duration relative to the more fundamental unit of seconds. Fixed duration at all levels of scale thus allowed the timescale to be predictable. MAIN disagreed with this interpretation conceptually, because it was entirely possible to imagine a timescale that inserted leaps at mathematically regular intervals which remained entirely predictable. A direct parallel exists with calendars; the Gregorian calendar is non-uniform in the sense that the lengths of calendar months vary, yet it is perfectly predictable by definition. Thus, there seemed to be a need to separate the concepts of 'uniformity' and 'predictability' within a glossary.

REDMAN thought the particular problem with MAIN's calendar example is that, over very long time intervals, the duration of the year is not perfectly predictable. If science improved to the point where the duration of the year becomes more usefully predictable, then the Gregorian algorithm would be revisited to reflect that knowledge. MAIN said that argument exposes the concern of whether a purely algorithmic version of leap-second insertion into UTC would fulfill the cur-

rent needs, because it would not approximate UT1. For example, one might want a scale that can diverge from UT1 but is usefully predictable, just as the Gregorian calendar.

MAIN also took small issue with REDMAN's use of the word 'binary' to describe a simple number that increments uniformly to represent a time code, because there is no requirement for those simple numbers to be represented as binary numbers. MAIN suggested the word 'linear' to describe that concept; a binary (base 2) system is simply one way in which a linear time code could be represented. ROB SEAMAN offered the term 'scalar', which MAIN found agreeable. However, REDMAN noted that the Network Time Protocol (NTP) divides up time representation into two integers, and thus the representation is "not quite linear" owning to the data structure. MAIN agreed that a different radix for different parts of the data structure was an interesting aspect, but he thought that NTP was rather good by maintaining a binary-fraction part, unlike the structures one experiences under POSIX which are decimal based. REDMAN added that, given the breadth of vision that apparently went into the development of NTP, it was astonishing that NTP managed to miss the existence of leap seconds.

MAIN also found the term 'starting point' being used ambiguously to describe two separate concepts: a defining point for synchronization, and the beginning of the applicability of a time scale. REDMAN replied that the word 'epoch' might be a better term, although it was more open ended as to whether 'epoch' should describe a real starting point or a just a dimensional one. For instance, because of the way the definition of International Atomic Time (TAI) has mutated over the years, one might still want to use 1972 as the 'epoch' of the current definition of TAI, recognizing that atomic time extends further back to at least 1956. REDMAN had thought about the proper way to phrase that; given the three properties (starting time/epoch, starting value, ending time), it might be more sensible to group together (starting time/epoch, starting value) and keep separate the optional ending time, but how to exactly break up that definition was an interesting question. MAIN thought the range of applicability should be addressed separately from the synchronization in the definition. REDMAN agreed it might be better to have the epoch separated.

STEVE ALLEN perceived the Internet community as seeing the ITU-R coming out of a meeting saying "Here is a standard—now you guys go implement it." ALLEN therefore appreciated REDMAN's willingness to consider all suggestions, and asked if there was a way to extend REDMAN's suggestions outside the audience of the colloquium and to a broader user community, and also whether public feedback could be incorporated into the ITU-R study process (by means of say, the Internet). REDMAN was not sure it would be a good idea to generally distribute proposals under ITU-R study, although he had no personal objection to such. Although REDMAN would not characterize the ITU-R process as secretive, it is a small community, such that the people who care most tend to be already involved. REDMAN noted that the publication of his particular talk as part of the colloquium proceedings already facilitated its dissemination.

With regard to proposed language within the definition of 'Reference Coordinate Time', JIM KIESSLING asked if was appropriate to say "time generated by clocks" as opposed to time recorded or monitored by clocks. REDMAN agreed that language needed to be altered; a clock that actually "generated time" would come in handy!

In the proposed definition of 'Reference Coordinate Time', KEN SEIDELMANN noted the specifications "from a specifiable origin" as well as "the SI second on the rotating geoid." SEIDELMANN said that the specification of the geoid restricts the specification of the origin because the origin cannot be either the geocenter or the barycenter of the solar system. REDMAN clarified that 'specifiable origin' in the context of the RCT definition intended to refer to some "zero-point" within the coordinate scale.

By way of example, REDMAN said that a usable timescale could be generated using the voltage across a capacitor in an electrical timing circuit. When such a circuit is triggered, the voltage increases to some threshold value, after which the circuit stops. The origin or starting time for this timescale is the moment when the circuit is triggered, with the ending time defined implicitly by the condition that the voltage crosses the threshold voltage. The passage of time is indicated by the changing voltage across the capacitor, so the starting value of the time-scale is just the initial voltage. Depending on the application, there need not be an explicit mechanism to convert the voltage into seconds of elapsed time, although such a mechanism is possible in principle.

SEIDELMANN observed that the proposed definition of RCT starts with "a general-relativistic coordinate system". This language implied a relativistic coordinate system that can exist under differing potentials, but that was not the case with this definition. REDMAN said that RCT defines a very specific frame of reference, KIESSLING adding that it is specific to the space-time curvature associated with Earth's gravitation at the rotating geoid. SEIDELMANN thought that level of specificity suggests that is not "general"; REDMAN replied that it is meant to be "general" in the sense of conforming to the theory of general relativity.

SEIDELMANN also cautioned that the word 'epoch' has different meanings in different languages, so it is not suitable for international terminology. REDMAN acknowledged that might be a good reason not to use it, yet he thought 'epoch' was a term already maintained within the ITU-R. SEIDELMANN encouraged REDMAN to go back and look at that very carefully.

The proposed definition of 'coordinate time' included reference to "simultaneous events." GEORGE KAPLAN asked if "simultaneous events" needed to be defined. REDMAN said that the phrase "simultaneous events" was something he added to help overcome objections of people unaccustomed to seeing "general relativistic time" and "absolute Newtonian time" in the same sentence. REDMAN said he did not include a precise definition of 'Newtonian time' but thought that 'Newtonian time'" was a scale where "simultaneous events happen at the same time."

KAPLAN thought that the (lack of a) definition of 'simultaneous' presented a conundrum. REDMAN agreed that that the phrasing is probably not adequate for the purpose. Although the introduction of 'Newtonian time' did not originate with REDMAN, it was believed necessary because relativity provided too much flexibility in coordinate systems. For this purpose, a very specific frame of reference is sought—one that approximates Newtonian time as people understood it a hundred years ago. To do any better, one would need to define 'Newtonian time', but REDMAN was not sure how to approach that. KAPLAN clarified that there still seems to be a need to define what is meant by 'simultaneous'. REDMAN said he would probably seek to change the phrasing because he was not sure how to address the definition of 'simultaneous' in this context. MAIN thought that an objective definition of 'simultaneous' was not needed, because any useful timescale will inherently define its own concept of simultaneity.

SEIDELMANN noted that REDMAN's proposed definition of 'coordinate time' also suggested "…an actual clock will approximate this [mathematical real number] with a specific time coding." SEIDELMANN said a potential problem with that phrasing is that an actual clock cannot physically exist at the origin of some coordinate timescales (*e.g.*, the geocenter). MAIN said that part of the definition related to the concept of realization of a timescale. The realization of timescales and how they relate to each other should be brought out and discussed more explicitly in the glossary.

Given a change of mandate requesting that Working Party 7A consider *all* options for potentially achieving "a continuous timescale", STEVE MALYS asked if there was any agreement as to how a list of candidate options would be considered; for example, would a vote be taken on every

option? MALYS thought the decision process ought to involve more than an up-or-down vote on each option on a list. REDMAN said that aspect was outside his purview; regardless, REDMAN did not expect very many different options to come out of the study process. REDMAN thought that priority at this stage should be given to generating a sensible list of useful options. REDMAN said that the options need to be sufficiently clear and distinguishable from one another to discuss the benefits and costs of each one. That level of effort would discourage the generation of a long list of options. ALLEN asked if that logic extends to exploring the degree to which different options affect the definition of "date" throughout the ITU-R *Radio Regulations*. REDMAN felt that nobody had thought that far.

In closing, REDMAN said the delegates attending WP7A in September 2012 spent two days attempting to trace various changes to definitions of timekeeping terminology, a task which illustrated to him why it is important to avoid polysemic terminology. This task would have been "a lot cleaner" if each of these ideas carried its own term from the start.