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# LEAP SECONDS IN LITERATURE

John H. Seago*

The advent of electronic textbooks and the digitization of less-recent scholarly documents has resulted in significantly increasing amounts of archived information searchable via computer networks. Internet search-engine technology can therefore be used to casually discover hundreds of archival references that reference *status-quo* UTC with leap seconds. While searchable electronic documents represent only a fraction of literature actually published, such reviews suggest a range of technical fields that may rely on UTC, the literature of which would be need to be revised should UTC be redefined.

## INTRODUCTION

UTC is a broadcast standard for coordinating the distribution of standard frequencies and timing signals per ITU-R Recommendation 460.[1] By international agreement, UTC represents a sequence of SI seconds progressing at the same rate as International Atomic Time (TAI) maintained by the International Bureau of Weights and Measures (BIPM), except that the epochs of UTC are infrequently adjusted relative to TAI by inserting or neglecting so-called leap seconds to assure its concordance with Universal Time (or, mean solar time at Greenwich) to within ±0.9 seconds. These adjustments are announced in advance by the International Earth Rotation and Reference Systems Service (IERS). The adjustments have been necessary because Universal Time is the astronomical basis of civil timekeeping and ensembles of atomic clocks forming TAI run at a different rate than Universal Time.[2]

The cessation of leap seconds has been discoursed without consensus for more than a decade.[3] The functional definition of UTC has remained largely unchanged since the early 1970's, so changes to the UTC standard now are expected to impact many technical operations of unknown scope. One issue contributing to this debate is the degree of expense. The absence of accurate information regarding cost is understandable because highly reliable, official cost-estimation is typically expensive to generate and approve; thus, organizations and businesses are not motivated to start financial impact assessments until they absolutely must.

Technical cost assessments must consider the labor needed to initially identify and report compulsory modifications—that is, the cost of estimating the cost. For many systems that are thought to be unaffected by UTC redefinition, methodical investigations will still be needed to conclusively prove that no modifications are in fact necessary. Once initial investigations are funded and accomplished, the next level of necessary expenditures for affected systems might involve the development of requirements or specifications (planning meetings, regulatory paperwork, *etc*.), software and hardware development, testing and benchmark development, implemen-

* Astrodynamics Engineer, Analytical Graphics, Inc., 220 Valley Creek Blvd, Exton, PA, 19341-2380.

tation and installation. Accurate cost estimation is also complicated by the uncertain value to be placed on lost productivity or data missed during outages caused by system upgrades and testing. Government programs may experience additional managerial and regulatory expenses to oversee and approve changes to government systems.

Personnel will also need to be re-trained or re-educated at uncertain expense, where personnel training and education are directly related to quality documentation. Much existing documentation would be invalidated by a change in the definition of UTC. Without dedicated outlays to remedy this across all technology fields reliant on UTC, technical confusion could ensue, which has its own financial repercussions.

The absence of accurate cost information is exacerbated by the ubiquitous use of UTC. Fortunately, surveys of digitized documentation might provide insight into affected technology domains. This paper experiments with an internet search engine to categorize potential areas of technical specialization that might warrant careful examination if UTC is redefined. As a check on the results, this approach is also applied to a set of documentation collected by the study groups responsible for studying and recommending a redefinition of UTC.

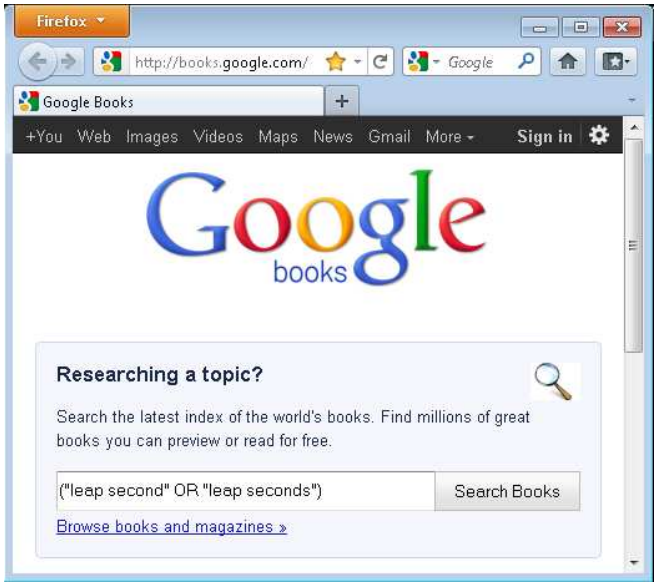



**Figure 1. Title Search Using the Google Books Internet Search Engine.**

## THE EXPERIMENT

The advent of electronic publications and the digitization of older scholarly work has significantly increased the amount of archived information searchable via computer networks. Straightforward internet search-engine technology can be used to casually discover hundreds of archived references that refer to *status-quo* UTC with leap seconds. While searchable electronic documents represent only a fraction of literature actually published, queries of searchable documentation might suggest the varying range of technical fields that may care about the definition of UTC, or at the very least, identify literature that would need to be revised should UTC be redefined.

## Approach

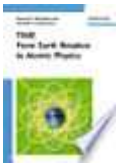
The approach of this limited study was to simply execute the following query using the Google Books internet search engine using a web browser (Figure 1):*

(UTC OR GMT OR "universal time") ("leap second" OR "leap seconds")

This particular query can find documents categorized as "books" that at least includes "UTC" *or* "GMT" *or* the phrase "universal time", and also includes the phrase "leap second" or its plural. The query on *universal time* will also discover *Coordinated Universal Time*.

The query for this analysis was performed in mid-September 2011 and declared about 2,400 matches and returned approximately 370 viewable outcomes. The search was intentionally limited to books because books are a relatively expensive method of archiving and disseminating information; therefore, it might be presumed that the identification of *status-quo* UTC in a book implies that the definition of UTC is not irrelevant to the book's subject or audience. Another practical reason to limit searches to books is that a general internet search query† results in over 200,000 reported discoveries, which was unmanageable for this exercise. Finally, a search using the Google Scholar search engine‡ provided up to 1000 viewable results out of a reported 1,730 available returns (neglecting patents and legal papers), but many of these results were topical papers about the leap-second controversy, which were less useful for the immediate purpose of discovering potentially unknown or overlooked stakeholders in the definition of UTC.

Computer Network Time Synchronization: The Network Time Protocol



Time: From Earth Rotation to Atomic Physics

Satellite Orbits: Models, Methods, and Applications

Global Positioning Systems, Inertial Navigation, and Integration

Reference Data for Engineers: Radio, Electronics, Computer, and Communications

**Figure 2. Top Five Results Searching for**
**(*UTC* or *GMT* or *universal-time*) & (*leap-second* or *leap-seconds*)**

The five book results ranked most relevant by Google's search technology at the time of the query included books about computer network-time synchronization,[4] horology,[5] satellite orbit determination,[6] navigation (including GPS),[7] and a reference book for electrical and communications engineers[8] (Figure 2). The top results of such a search are not definitive or terribly significant, as the search rankings can vary somewhat from day by day; nevertheless these outcomes present a nice cross section of some of the various technology fields recognized by the search process.

As a point of reference, a more general search criterion was also tried without requiring the presence of "UTC" *or* "GMT" *or* the phrase "universal time", namely

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* URL http://books.google.com/
† URL http://www.google.com/
‡ URL http://scholar.google.com/

"leap second" OR "leap seconds"

The more general query declared more than twice as many matches (5,700) but only about one-dozen more viewable returns. The more general query also ranked less-technical books higher in the search outcomes. This is evidenced by looking at the top five search results for this more general search criterion, which included a history book and a general interest science book in the third and fourth positions. The general-interest science book contains non-technical treatments of recent science news—in this case, the controversy over abolishing leap seconds.[9] The astronomical history book includes a page-length discussion explaining the need for leap seconds to the layman.[10] This latter book does not appear to mention UTC, GMT, or Universal Time at all, as therefore it did not appear in the more-limited search requiring the presence of "UTC" *or* "GMT" *or* the phrase "universal time".

Time: From Earth Rotation to Atomic Physics

Computer Network Time Synchronization: The Network Time Protocol


Eclipse: The Celestial Phenomenon That Changed the Course of History


The Why? Files: The Science Behind The News

Reference Data for Engineers: Radio, Electronics, Computer, and Communications

**Figure 3. Top Five Results Searching for *leap-second* or *leap-seconds***

## Caveats

Unfortunately this experiment is fraught with limitations that affect the completeness and conclusiveness of the results. Several shortcomings are now mentioned, which should be considered when trying to interpret these data.

*Extremely Limited Discovery*. The methods of discovery only identified titles written in English; also, searchable electronic documents represent only a fraction of published material. Searchable titles are sometimes scanned imperfectly, inhibiting recognition of the search keyword(s). Therefore, the results presented here must represent an extremely limited sample. Because the discover methods are limited, one cannot make firm conclusions about the full size and scope of fields interested in UTC redefinition.

*Degree of Consequence*. The context of most search outcomes is lacking. Often only a few lines of text surrounding the search words are exposed. The relevance of the definition of UTC is not always apparent, so it is hard to draw conclusions about the implications of consequences of a possible redefinition. The mention of UTC and leap seconds within a publication does not guarantee that there will be consequences within the author's profession, excepting the matter of obvious documentation revisions.

*Subjectivity of Categorizations*. The identification of potential stakeholder groups requires classification of references according to topical domains. This process is somewhat subjective and likely imperfect. Many titles are multi-discipline, so a determination was made as to which category the title best fits. More than one copy or edition of the same title can occasionally appear within the outcome of searches, the duplication which may result in a slight increase in the size of

some categories. Because of these reasons, one cannot make firm conclusions about relative sizes of fields identified.

Despite these qualifications, there appears to be some merit to the search method as a means for exploring potential areas that could be investigated more deeply as to their reliance upon and usage of UTC. The process is also useful for illustrating that documentation revisions may not be a trivial or inexpensive issue if UTC is redefined. Search results are nonetheless informative, but not conclusive.

**Outcomes**

Each viewable title was assigning to one of 23 topical categories. These categories were developed based on what was discovered. The categories and their contents are now generally described, with the number assigned outcomes specified by a parenthetical number.

*Technical Reference (43)*. This category included the largest numbers of entries and includes encyclopedias, dictionaries, handbooks, and reference data related to computer science, engineering (general), audio engineering, environmental engineering, geophysics, astrophysics, astronomy, radio standards, electronics, telecommunications, broadcasting, scientific units, government and military terminology, mapping, charting and geodetic terminology, physics, fiber optics, scientific guides, economists desk reference, tables and formulae, science and technology.

*General Reference (3)*. This category included general encyclopedias and dictionaries like Britannica.

*Astronomy – professional and student (31)*. This category included titles aimed at professional astronomers, with topics related to fundamental astronomy, observational astronomy, spherical astronomy, radio astronomy and interferometry, astrometry, cosmology, high-energy astrophysics and astrophysical quantities, asteroseismology, relativity, and astronomy of ancient cultures. It also included titles related to astronomical methods, such as data analysis and reduction, including analysis software and information handling. The references mentioning *status-quo* UTC were predominately textbooks, but also included a few meeting proceedings, doctoral dissertations, and professional notices. This category included published proceedings related to International Astronomical Society (IAU) assemblies, meetings and colloquia.

*Astronomy – amateur (15)*. This category included titles aimed at amateur or advanced amateur astronomers, including telescope usage, astronomical computing, observing methods and observing technology (notably eclipse and comet observation), and star atlases.

*Computing (25)*. This category included titles related to computing technology, multimedia computing, program and system information protocols, (distributed) operating systems and OS timekeeping, system administration, embedded and ubiquitous computing, and fault-tolerant computing. This category attempted to collect titles on computer science not obviously dedicated to programming.

*Database Technology (9)*. This category included titles related to databases and database architectures, database management, query languages and programming, and metadata tools.

*Information Technology (5)*. This category included titles related to information technology / information services and its systems, applied informatics, local networking, web-based energy information and control systems.

*Software (13)*. This category included titles related to commercial software, libraries, software languages and programming, web application design, and spatial and geographic visualization (KML), Unix programming, object-oriented programming. Programming or scripting languages

specifically notably cited included C, C++, R, Ada, awk, gnu, Haskel, ActionScript, Matlab, Standard ML (SML), and Java.

*Metrology (28)*. This category included titles related to metrology, including units and fundamental constants, measurement and control instrumentation, standards and guides, data processing, the metric system, historical surveys, government-issued publications, proceedings, transverse disciplines, both scientific and of general interest.

*Almanacs, Atlases, and Yearbooks (25)*. This category included titles related to almanacs, explanatory supplements, or similar reference information, aimed at either professionals (such as astronomers or navigators) or at the general public, including some calendars and national yearbooks. Because some general-interest almanacs are annual publications, some slight duplication was noticed, but no attempt was made to track and remove any suspected duplications from the sample.

*Navigation and Surveying (22)*. This category included titles related to general navigation technology, perhaps including but not specific to GNSS, such as inertial navigation and integration, avionics, celestial navigation, radio navigation, surveying, transport geography and spatial systems, emergency navigation, piloting, sailing, and seamanship, This category included mostly books but also a few journal articles and published proceedings.

*GNSS Technology, Applications, and Practice (19)*. This category included titles predominately devoted to the theory, technology and practice of global navigation satellite systems (GNSS), including GPS, GLONASS, Beidou / Compass, and Galileo, GNSS-based geodesy and surveying techniques, software and data processing, receiving equipment, and some geographic information systems (GIS) reliant on GNSS.

*Earth science (18)*. This category included titles related to hydrography, oceanography, seismology, (geometrical and satellite) geodesy, geodynamics, geophysics, geological site surveys, polar motion monitoring and nutation studies. This category also included one IUGG proceedings.

*Spacecraft (18)*. This category included titles related to the technology of space-based systems, including spacecraft operations and communications, deep-space networks, spacecraft technology, space vehicle design, spacecraft guidance, remote sensing, and interplanetary missions. It also included titles related to the theory and application of celestial mechanics, dynamical astronomy, astrodynamics, and related areas, including planetary or satellite motion, satellite orbit determination, geostationary orbits, and satellite navigation. It included some published government reports and journals.

*Science – general interest (16)*. This category included titles related to scientific presentations aimed mostly at the general public, including space science, timekeeping issues, history of scientific technology, nature of light, critical thinking, published magazine volumes (American Scientist, Nature, Science, Popular Science), and books on current events.

*Telecommunications (17)*. This category included titles related to telecommunication technology, including digital radio and audio broadcasts, fiber optic communication, real-time systems, telemetering, wireless internet, cellular networks, signals, network synchronization, radio relay, future of UTC, television, and amateur radio. It included mostly books but some published government reports and documents. This category also included one proceedings related to PTTI.

*Network time transfer (7)*. This category included titles related to network time protocol (NTP), signal communication architectures and protocols, network clock synchronization, and government services related to network time distribution.

*Horology (16)*. This category included titles related to timekeeping technology aimed at either technologists or the general public, including historical surveys of timekeeping technology, calendrical computations, clock hardware, astronomically-based time, time-scale determination, clock instrumentation and control, and video time encoding. It included three wikipedia-based print-on-demand e-books discussing leap seconds, UTC, and TAI.

*Physics, Science, and Math (12)*. This category included a variety of titles related to physics and science (and to a much lesser extent mathematics), including student textbooks, instructional materials for teachers, physical science, scientific computation, quantum mechanics, gravitation and relativity, and Royal Society proceedings.

*Applied engineering (8)*. This category included titles related to miscellaneous engineering applications, such as mechatronics, cryptography, industrial research, estimation theory, manufacturing, quality control and applied statistics, and machine design.

*Electronics (4)*. This category included titles related to information about electronics, general textbooks, instrumentation, power system management, and popular electronics.

*Economics (4)*. This category included titles catering to economic applications, such as global trade issues, research and development, and the technology of high finance.

*General Interest (11)*. This category included titles related to information to popular culture, trivia, pseudoscience, science fiction, human philosophy, metaphysics, psychology, science words, history, literature, (some of which may only reference UTC and leap seconds in their glossaries).

**Table 1. Title Count by Topical Category**

| Topical Category | # | Topical Category | # |
|---|---|---|---|
| References (Technical + General) | 46 | Spacecraft | 18 |
| Astronomy | 46 | Telecommunications | 17 |
| Computing | 25 | Time Transfer | 7 |
| Databases (+ IT/IS) | 14 | Horology | 16 |
| Software | 13 | Science (general interest) | 16 |
| Metrology | 28 | Physics, Science, Math | 12 |
| Almanacs, Atlases, and Yearbooks | 25 | Applied engineering | 8 |
| Navigation and Surveying | 22 | Economics | 4 |
| GNSS | 19 | Electronics | 4 |
| Earth science | 18 | General Interest | 11 |
| | | *Total* | *369* |

A larger number of smaller categories is most useful for pinpointing potential domains that might be affected by UTC redefinition; however, for a concise tabular presentation, it was useful

to combine a few related categories (Table 1). Databases and IT/IS are arguably related, as is professional and amateur astronomy, and general and technical references.

Although we can draw no strong conclusions regarding the relevance of UTC to certain fields based on the numbers of counts per category, it may not be surprising to see that most references citing leap seconds occur in what is described here as "technical reference" literature (encyclopedia, dictionaries, handbooks, atlases, almanacs, *etc*.), astronomy, and computing.


**Figure 4. Word Cloud of Assigned Book Categories.**

To get a visual sense of the categories and their relative sample sizes, we employ the use of a "word cloud".[*] A *word cloud* is a semi-random arrangement of the words whereby the height of the word correlates to word's usage frequency. For this application, we express a consolidated category as a single word or word pair, with its height being in proportion to the number of samples assigned to that category. Figure 4 presents a word cloud for the book data consolidated in Table 1. With the word cloud, it is visually apparent that *astronomy*, *references*, *metrology*, *almanacs*, and *computing* are the top five domains in terms of frequency of mentioning UTC and leap seconds.

## EXPLORING INCORRECT NOMENCLATURE

This activity can be extended to discover other interesting results. For example, the transposed phrasing "Universal Coordinated Time" is sometimes observed in literature; it is conjectured that people mistakenly use this rearrangement because the acronym "UTC" suggests that the adjective "Universal" should be first. One might speculate that such usage reflects a lack of familiarity with UTC as a realization of Universal Time, which could be useful in prioritizing outcomes to be investigated.

A search on the term "Universal Coordinated Time" used in combination with "UTC" displayed approximately 450 books, the largest percentage appearing in texts related to computer science and programming, general interest science and technology, navigation, and communica-

[*] http://www.wordle.net/create

tions. Of these, approximately 90 books actually used the erroneous term "Universal Coordinated Time" while also mentioning leap seconds. Other incorrect usages and their frequency of occurrence are noted in Table 2.

**Table 2. Transposed Nomenclature Used with "UTC" Appearing in Books**

| Searched Criterion | Declared Matches | Displayed Results |
|---|---|---|
| ***Coordinated Universal Time*** | ***9,160*** | ***426*** |
| Universal Coordinated Time | 2,440 | 446 |
| Universal *Coordinate* Time | 65 | 65 |
| *Coordinate* Universal Time | 24 | 24 |
| Coordinated Time Universal | 5 | 5 |

## CATEGORIZATION OF STUDY DOCUMENTS

For the purposes of comparison, categorizations were also applied to a list of 43 documents collected by the ITU-R for supporting a redefinition of UTC. In April 2008, a drafting group chaired by Dr. Elisa Felicitas Arias of the BIPM was formed to document and summarize the data and materials considered by the ITU-R Working Party 7A and its Special Rapporteur Group during its ten (10) year study period 1999-2008.[11] The drafting group developed a "final" report (not publicly released) that included an overall summary and a number of derived conclusions. The drafting group believed that the collection of documents "offered a full and comprehensive perspective of the overall [study] effort" with the caveat that the available material was still "not necessarily a complete compilation."

### Outcomes

The drafting group reportedly processed 26 contributed documents collected over a ten-year study interval, in addition to 17 reports and statements generated within the ITU-R. Most of these were received following the 2005 leap second, and several were received in 2008 especially for the "final" report. Because the details of the original documents are not publicly available, the classifications are loosely assigned according the area of expertise of their originators.

*Network time transfer (6)*. Three letters from NIST personnel, one report from Time Dissemination Working Group, PTB, one report from the USNO, one report from the Internet Engineering Task Force.

*Metrology (2)*. One letter from Bundesamt für Eich- und Vermessungswesen (BEV, Austria), one letter from Time Section of the *Real Observatorio de la Armada* (ROA, Spain).

*Astronomy (5)*. Two reports from the American Astronomical Society, two reports from the IAU, and one communication from the Royal Astronomical Society.

*Navigation and Surveying (2)*. One letter from Ephemeris Section of the *Real Observatorio de la Armada* (ROA, Spain), one communication from the Royal Institute of Navigation.

*GNSS (3)*. One letter from the Galileo Project Office, European Space Agency (ESA), one general service bulletin from SAAB, one general service bulletin from ACR Electronics.

*Earth Science (1)*. One letter from the International VLBI Service for Geodesy and Astronomy.

*Spacecraft (5)*. One survey report from the French Space Agency (CNES) and Paris Observatory, one (1) letter from EUMETSAT, one letter from JSAT Corp., two conference papers from this author.[12, 13]

*Applied Engineering (1)*. Report of the International Union of Radio Science (URSI) Commission J Working Group on the Leap Second (2000).[14]

*Horology (1)*. One journal article.[15]

*Telecom (17)*. ITU-R reports and statements submitted by member administrations and organizations.

**Table 3 Study Documents Count by Topical Category**

| Topical Category | # | Topical Category | # |
|---|---|---|---|
| Astronomy | 5 | Spacecraft | 5 |
| Metrology | 2 | Time Transfer | 6 |
| Navigation and Surveying | 2 | Horology | 1 |
| GNSS | 3 | Applied engineering | 1 |
| Earth science (+ IUGG) | 1 | **Telecom** (ITU-R) | **17** |
| | | *Total* | *43* |

As with the book-query data, some categorizations could overlap; the general service announcements could be classified as either GNSS or electronics, for example. The URSI survey result is hard to categorize because of its broad scope; applied engineering was chosen. Table 3 represents the final summary, which includes fewer than half as many categories compared to the book study, and the internally generated ITU-R documents assigned to the *Telecommunication* category makes up almost 40% of the documentation considered by the study.


**Figure 5. Word Cloud of Assigned Study-Document Categories (Including ITU-R Documents)**

In the interest of comparing the book results with the drafting group documents, a word cloud visualization was also attempted (Figure 5). However, the dominance of internally generated ITU-R documents assigned to the *Telecommunication* category greatly skews the word cloud. To compare to the book study, the word cloud was regenerated and limited to only the external documents contributed to the study group, excluding the *Telecommunication* category (Figure 6).


**Figure 6. Word Cloud of Assigned Study-Document Categories (Excluding ITU-R Documents)**

The word-cloud views of the study-document categories provide an interesting visual contrast to that of the internet book survey. That the number of study-document categories is much less may suggest that many of the categories derived from the survey of book literature are not really stakeholders in the definition of UTC. This is likely true for some categories such as general-interest literature; however, major technical categories appeared absent from the study-group documentation categories, such as computing, software, databases, and technical reference materials (including almanacs). It must be presumed that computing technology and reference materials will be affected by UTC redefinition in some way, but for this analysis it was unclear how these domains were represented and assessed by the ITU-R study group.

## CONCLUSION

Information technology has allowed technical documentation to become easier to store and access, such that it has become much more cost effective to manage and develop documentation over time. However, inaccurate or outdated information can also be easily circulated, widely exposed, and persist inside and outside of cyberspace for a very long time. Because the creation of good technical documentation is labor intensive, the expense is often neglected or deferred. Thus, the risk of technical confusion resulting from a redefinition of UTC is not negligible. At the very least, documentation changes will affect technology domains that are otherwise unaffected by a redefinition of UTC; therefore, this aspect is presumed to be very far reaching.

If UTC is redefined, the identification of affected technical areas will be tricky. This paper proposes that internet search-engine technology could be used to help identify various technical domains that dependent on the definition of UTC. Such investigations could be readily expanded to potentially explore sensitivities to proposed changes within these domains. Although the scale of this study is small and by no means conclusive, it reinforces a perception that technologies related to astronomy and computing might be significantly affected by UTC redefinition. There is also likely to be a significant amount of general reference materials in the form of encyclopedias, dictionaries, and general-purpose almanacs that would be need updating; often these types of resources are managed and edited by those not necessarily familiar with horology. Finally, based on declared study-group documents, it is unclear how thoroughly certain technology domains have been represented and assessed by groups studying the issue of UTC redefinition. Investigation of domains such as computing, software development, programming, databases, and perhaps applied engineering might be especially beneficial.

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