Julian Day Numbers

by Peter J. Meyer

1. Introduction

Just as a *Gregorian date* is a date in the Gregorian Calendar, a *Julian date* is a date in the Julian Calendar. (For more on these calendars see The Julian and Gregorian Calendars.) Astronomers sometimes use the term "Julian date" in another sense, according to which it is related to what is called a "Julian day number". Such a use of the term "Julian date" makes it ambiguous, but the meaning is usually clear from the context. In this article the notion of the *Julian day number* will be explained, along with various meanings of the term *Julian date*.

According to the system of numbering days called *Julian day numbers*, used by astronomers and calendricists (those who study calendars, unfortunately not for a living), the temporal sequence of days is mapped onto the sequence of integers, -2, -1, 0, 1, 2, 3, etc. This makes it easy to determine the number of days between two dates (just subtract one Julian day number from the other).

For example, a solar eclipse was seen at Nineveh on June 15, 763 B.C. (Julian Calendar), according to the Assyrian chronicles in the British Museum, and a lunar eclipse occurred there on the night of April 14-15, 425 B.C. (Julian Calendar). These eclipses occurred at approximately 10:32 a.m. and 2:27 a.m. respectively. The Julian day numbers corresponding to these dates are 1,442,902 and 1,566,296 respectively. This makes it easy to calculate that the lunar eclipse occurred 123,394 days after the solar eclipse.

Generally speaking, an *integer date* is any system of assigning a one-to-one correspondence between the usual sequence of days (and nights) and the integers. Such systems differ only in the day chosen to correspond to day 0 or day 1. For example, in some applications NASA uses the *Truncated Julian Date*, which is the number of days since 1968-05-24 (at which time the Apollo missions to the Moon were underway). Other starting dates popular with computer programmers are, or have been, 1601-01-01 GC (Gregorian Calendar), 1900-01-01, 1901-01-01 and 1980-01-01 (when time began according to IBM PCs). The choice is usually a consequence of a trade-off concerning:

(i) the temporal precision required (days to microseconds),
(ii) the length of the period of interest (a decade, a century, a millennium, etc.),
(iii) the number of bytes available for storing the date and
(iv) the number of characters required to display the date.

2. The Julian Period

The Julian day number system is sometimes (erroneously) said to have been invented by Joseph Justus Scaliger (born 1540-08-05 JC in Agen, France, died 1609-01-21 JC in Leiden, Holland), who during his life immersed himself in Greek, Latin, Persian and Jewish literature, and who was one of the founders of the science of chronology. Scaliger's invention was *not* the system of Julian day numbers, but rather the so-called Julian period.

Scaliger combined three traditionally recognized temporal cycles of 28, 19 and 15 years to obtain a great cycle, the *Scaliger cycle*, or *Julian period*, of 7980 years (7980 is the least common multiple of 28, 19 and 15). According to the Encyclopedia Brittanica:

"The length of 7,980 years was chosen as the product of 28 times 19 times 15; these, respectively, are the numbers of years in the so-called solar cycle of the Julian calendar in which dates recur on the same days of the week; the lunar or Metonic cycle, after which the phases of the Moon recur on a particular day in the solar year, or year of the seasons; and the cycle of indiction, originally a schedule of periodic taxes or government requisitions in ancient Rome."

According to some accounts Scaliger named his Julian period after his father, Julius Scaliger. However in his *De Emandatione Temporum* (Geneva, 1629) Scaliger says: "Julianam vocauimus, quia ad annum Julianum accommodata ..." (translated by R. L. Reese et al. (3) as "We have termed it Julian because it fits the Julian year ...").

Regarding the Julian period the U.S. Naval Observatory has this to say:

"In the 16th century Joseph Justus Scaliger tried to resolve the patchwork of historical eras by placing everything on a single system. Not being ready to deal with negative year counts, he sought an initial epoch in advance of any historical record. His approach was numerological and utilized three calendrical cycles: the 28-year solar cycle, the 19-year cycle of Golden Numbers, and the 15-year indiction cycle. The solar cycle is the period after which week days and calendar dates repeat in the Julian calendar. The cycle of Golden Numbers is the period after which moon phases repeat (approximately) on the same calendar dates. The indiction cycle was a Roman tax cycle of unknown origin. Therefore, Scaliger could characterize a year by the combination of numbers (S,G,I), where S runs from 1 through 28, G from 1 through 19, and I from 1 through 15. Scaliger first stated that a given combination would recur after 7980 (= 28 x 19 x 15) years. He called this a Julian cycle because it was based on the Julian calendar. Scaliger knew that the year of Christ's birth (as determined by Dionysius Exiguus) was characterized by the number 9 of the solar cycle, by Golden Number 1, and by number 3 of the indiction cycle, or (9,1,3). Then Scaliger chose as this initial epoch the year characterized by (1,1,1) and determined that (9,1,3) was year 4713 of his chronological era [and thus that year (1,1,1) was 4713 B.C]. Scaliger's initial epoch was later to be adopted as the initial epoch for the Julian day numbers." – The 21st Century and the 3rd Millennium

It turns out, however, that the Julian period was discovered by others before Scaliger. Roger, Bishop of Hereford, discusses the three cycles used by Scaliger in his *Compotus* (written in 1176 CE) and states that "these three ... do not come together at one point for 7980 years" (see (5)), although he does not identify the year (4713 B.C.) of their coincidence. Furthermore, according to R. L. Reese et al. (6):

"A 12th-century manuscript indicates that the 7980-year period was used explicitly for calendrical purposes by an earlier Bishop of Hereford, Robert de Losinga, in the year A.D. 1086, almost a century before the Bishop of Hereford named Roger. ... Robert de Losinga combines the solar, lunar and indiction cycles into a "great cycle [magnum ciclum]" of 7980 years ... Thus the manuscript by Robert de Losinga places the earliest known use of the Julian period in the year A.D. 1086."

The first Julian period began with Year 1 on -4712-01-01 JC (Julian Calendar) and will end after 7980 years on 3267-12-31 JC, which is 3268-01-22 GC (Gregorian Calendar). 3268-01-01 JC is the first day of Year 1 of the next Julian period.

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3. Julian Day Number

Although Joseph Justus Scaliger was, as noted above, one of the founders of the science of chronology, he did not invent the Julian day number system. Its inventor was the astronomer John W. F. Herschel. In *The Standard C Date/Time Library* (p.42) Lance Latham writes:

"It remained, however, for the astronomer John F. Herschel to turn this idea [of Scaliger's] into a complete time system, rather than a method of relating years. In 1849, Herschel published *Outlines of Astronomy* and explained the idea of extending Scaliger's concept to days."

Following Herschel's lead astronomers adopted this system and took noon GMT -4712-01-01 JC (January 1st, 4713 B.C.) as their zero point. (Note that 4713 B.C. is the year -4712 according to the astronomical year numbering.) For astronomers a "day" begins at noon (GMT) and runs until the next noon (so that the nighttime falls conveniently within one "day", unless they are making their observations in a place such as Australia). Thus they defined the Julian day number of a day as the number of days elapsed since January 1st, 4713 B.C. in the proleptic Julian Calendar.

Thus the Julian day number of -4712-01-01 JC is 0. The Julian day number of 1996-03-31 CE (Common Era) is 2,450,174 — meaning that on 1996-03-31 CE 2,450,174 days had elapsed since -4712-01-01 JC.

Actually "day" here means a day and a night. Calendricists have a word for a day and a night, namely, "nychthemeron". Generally when calendricists use the term "days" they are talking of nychthemerons.

In most calendars the calendar date changes at midnight. In these calendars a nychthemeron is the period from one midnight to the next. For astronomers, however, a nychthemeron runs, not from midnight to midnight, but from noon to noon. And in some calendars, e.g., the Jewish Calendar, a nychthemeron runs from sunset to sunset. Thus a nychthemeron simply means a day and a night, and cannot be more precisely defined except with respect to some particular calendar or class of calendars.

The Julian day number is a count of nychthemerons elapsed since some particular nychthemeron. Thus there are slight variations on the Julian day number system depending on which kind of nychthemeron is being counted, as we shall see below.

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4. Astronomical Julian Day Number and Astronomical Julian Date

An *astronomical Julian day number* is a count of astronomical nychthemerons (i.e., nychthemerons which begin at noon GMT) from the astronomical nychthemeron which began at noon GMT on -4712-01-01 JC.

For recording the time of an astronomical event the Julian day number of the nychthemeron in which the event occurs is, of course, usually not sufficiently precise. In order to specify the time of an event astronomers add a fractional component to the Julian day number, e.g., 0.25 = 6 hours (1/4 of 24 hours) after the start of the nychthemeron. An astronomical Julian day number plus a fractional component specifying the time elapsed since the start of the nychthemeron denoted by that Julian day number is called an *astronomical Julian date*. (The term "Julian date" has several meanings, as explained in Section 8 below.)

Thus the astronomical Julian date 0.5 is the midnight point separating -4712-01-01 JC and -4712-01-02 JC, the astronomical Julian date 1.25 is 6 p.m. on -4712-01-02 JC, and so on.

An astronomical Julian day number can also be seen as an astronomical Julian date which is an integer, and which denotes the period running from the start of an astronomical nychthemeron (noon GMT) to the start of the next.

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5. Chronological Julian Day Number and Chronological Julian Date

At some point students of calendrical science decided that the Julian day number system would be very useful in their field, provided the notion of a "day", i.e., "nychthemeron", were changed to accord with that notion as commonly used in connection with calendars. The Gregorian Calendar begins days at midnight, but not all calendars do (for example, the Jewish Calendar has nychthemerons which begin at sunset). Thus arose a variation of the Julian day number and Julian date called "chronological" to distinguish them from the "astronomical" versions.

A *chronological Julian day number* is a count of nychthemerons, assumed to begin at midnight GMT, from the nychthemeron which began at midnight GMT on -4712-01-01 JC. Chronological Julian day number 0 is thus the period from midnight GMT on -4712-01-01 JC to the next midnight GMT. Chronological Julian day number 2,452,952 is the period from midnight GMT on 2003-11-08 CE

(Common Era) to the next midnight GMT.

Again a fractional component may be added to the chronological Julian day number to form a chronological Julian date. For example, the chronological Julian date 0.5 is noon GMT on -4712-01-01 JC, the chronological Julian date 1.25 is 6 a.m. GMT on -4712-01-02 JC, and the chronological Julian date 2,452,952.75 is 6 p.m. GMT on 2003-11-08 CE.

So defined, a chronological Julian date is tied to zero degrees longitude because the fractional component denotes time elapsed since midnight GMT. We may, however, wish to use the concept in connection with calendars intended to be used at other places on Earth, where midnight is midnight local time and not midnight GMT. For example, nychthemerons denoted by dates in the Chinese Calendar run from midnight Beijing standard time to the next midnight BST, and midnight in Beijing occurs eight hours earlier than midnight at Greenwich.

So in order to use the concept of a chronological Julian date when studying calendars whose dates denote nychthemerons which begin at midnight local time, but not midnight GMT, we can define a local chronological Julian date whose value is the GMT-based chronological Julian date with a value between 0 and 0.5 added or subtracted to account for the timezone difference (added for locations East of Greenwich, subtracted for locations West of Greenwich). For example, chronological Julian date 2,452,952.75 with respect to Beijing, which denotes 6 p.m. on the Beijing-nychthemeron numbered 2,452,952, equals the chronological Julian date 2,452,952.75 - 1/3 = 2,452,952.417 with respect to Greenwich (which is 10 a.m. on 2003-11-08 CE).

Thus, although there is only one variety of astronomical Julian date (the one tied to the meridian of zero degrees longitude) there are as many varieties of chronological Julian date as there are longitudes which we might wish to use in the study of various calendars.

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6. Modified Julian Day Number

Since most days within about 150 years of the present have Julian day numbers beginning with "24", Julian day numbers within this 300-odd-year period can be abbreviated. In 1957 the convention of the *modified Julian day number* was adopted by the Smithsonian Astrophysical Observatory:

Given a Julian day number JD, the *modified Julian day number* MJD is defined as MJD = JD - 2,400,000.5. This has two purposes:

i. Days begin at midnight rather than noon.
ii. For dates in the period from 1859 to about 2130 only five digits need to be used to specify the date rather than seven.

MJD 0 thus corresponds to JD 2,400,000.5, which is twelve hours after noon GMT on JD 2,400,000 = 1858-11-16 (Gregorian or Common Era). Thus MJD 0 designates the midnight of November 16th/17th, 1858, so day 0 in the system of modified Julian day numbers is the day 1858-11-17 CE.

The main virtue of the MJD is that such dates require fewer bytes of memory for storage. For calendrical studies the chronological Julian day number is preferable.

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7. Lilian Day Number

This concept is similar to that of the Julian day number. It is named after Aloysius Lilius (an advisor to Pope Gregory XIII) who was one of the principal inventors of the Gregorian Calendar reform. The Lilian day number is defined as "the number of days since 14 October 1582 in the proleptic Gregorian Calendar". This was the time of the introduction of the Gregorian Calendar, when it was decreed by Pope Gregory XIII that the day following 4 October 1582 (which is 5 October 1582, in the Julian Calendar) would thenceforth be known as 15 October 1582. Strictly speaking there is no "14 October 1582" in the Gregorian Calendar, since the Gregorian Calendar did not begin until 15 October 1582, thus the need (in the definition to refer to the "proleptic" Gregorian Calendar). Thus 15 October 1582 GC is Lilian day 1 (the first day of the Gregorian Calendar), 16 October 1582 is Lilian day 2, and so on.

It is not known whether Lilius himself employed this concept. The calendricist Joe Kress has traced the earliest use of the Lilian day number to its inventor, Bruce G. Ohms of IBM in 1986 (7).

The relation between Julian day numbers and Lilian day numbers is: LDN = JDN - 2,299,160

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8. Different Meanings of "Julian Date"

The term "Julian date" has three different meanings, two of them entirely respectable and the third used only by those who don't know any better.

(i) As noted above, a Julian date is a date in the Julian Calendar, the predecessor of the Gregorian Calendar.

(ii) Astronomers and calendricists use the term in this sense, but (as explained in Section 4 and Section 5 above) also in another sense, according to which a Julian date is a number, denoting a point in time, which consists of an integer part and a fractional part (e.g., 2439291.301), where the integer part is a Julian day number (see Section 3) and the fractional part specifies the time elapsed since the start of the day denoted by that Julian day number.

(iii) In the commercial world the term "Julian date" has unfortunately been used for a quite different concept, that of the number of a day in a particular year, so that January 1st = day 1, February 28th = day 59, and so on. To use the term "Julian date" to mean day-of-year when the term also means a date in the Julian Calendar (not to mention its use in the third sense by astronomers and calendricists) is simply to invite confusion. Those who study calendars unanimously recommend that the use of the term "Julian date" to mean "number of a day in a year" be dropped. The proper term for this concept is "ordinal date", as per definition 3.4 in ISO8601:2000(E), Data elements and interchange formats — Information interchange — Representation of dates and times, Second edition 2000-12-15 (downloadable as a PDF file here).

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9. Conversion Algorithms

Mathematicians and programmers have naturally interested themselves in mathematical and computational algorithms to convert between Julian day numbers and Gregorian dates. The following conversion algorithm is due to Henry F. Fliegel and Thomas C. Van Flandern:

The Julian day (jd) is computed from Gregorian day, month and year (d, m, y) as follows:

```
jd = ( 1461 * ( y + 4800 + ( m - 14 ) / 12 ) ) / 4 +
     ( 367 * ( m - 2 - 12 * ( ( m - 14 ) / 12 ) ) ) / 12 -
     ( 3 * ( ( y + 4900 + ( m - 14 ) / 12 ) / 100 ) ) / 4 +
     d - 32075
```

Converting from the Julian day number to the Gregorian date is performed thus:

```
l = jd + 68569
n = ( 4 * l ) / 146097
l = l - ( 146097 * n + 3 ) / 4
i = ( 4000 * ( l + 1 ) ) / 1461001
l = l - ( 1461 * i ) / 4 + 31
j = ( 80 * l ) / 2447
d = l - ( 2447 * j ) / 80
l = j / 11
m = j + 2 - ( 12 * l )
y = 100 * ( n - 49 ) + i + l
```

Days are integer values in the range 1-31, months are integers in the range 1-12, and years are positive or negative integers. Division is to be understood as in integer arithmetic, with remainders discarded, and `(m-14)/12` is -1 for `m <= 2` and is 0 otherwise.

In these algorithms Julian day number 0 corresponds to -4713-11-24 GC, which is -4712-01-01 JC.

These algorithms are valid only in the Gregorian Calendar and the proleptic Gregorian Calendar. They do not correctly convert dates in the Julian Calendar.

It seems that the designers of these algorithms intended them to be used only with non-negative Julian day numbers (corresponding to Gregorian dates on and after -4713-11-24 GC). In fact they are valid (only) for dates from -4900-03-01 GC onward when converting from a Julian day number to a date, and (only) from -4800-03-01 GC onward when converting from a date to a Julian day number.

Some articles, mainly concerning the origin of the Julian period:

1. Grafton, A. T.: History and Theory, XIV, 156 (1975)
2. Moyer, G.: Sky and Telescope, 61, 311 (1981)
3. Reese, R.L., Everett, S.M. & Craun, E.D.: "The origin of the Julian Period: An application of congruences and the Chinese Remainder Theorem", American Journal of Physics, vol. 49 (1981), 658-661.
4. van Gent, R. H.: Sky and Telescope, 62, 16 (1981)
5. Reese, R.L., Craun, E.D. & Mason, C.W.: "Twelfth-century origins of the 7980-year Julian Period", American Journal of Physics, vol. 51 (1983), 73.
6. Reese, R.L., Craun, E.D. & Herrin, M.: "New evidence concerning the origin of the Julian period", American Journal of Physics, vol. 59 (1991), 1043.
7. Ohms, Bruce G.: "Computer processing of dates outside the twentieth century", IBM Systems Journal, 15 (1986), 244-51, pp. 244-6.

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