

THE CALENDARS OF SOUTHEAST ASIA. 2: BURMA, THAILAND, LAOS AND CAMBODIA

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Abstract: In this paper we investigate three Burmese calendars: the Arakanese, Makaranta and Thandeikta calendars. It is shown that the lunar calendar of the two first ones imply a tropical solar year, something that puts the lunar calendar out of phase with the sidereal solar calendar used and possibly indicates a Hellenistic origin. We then examine the calendars of Thailand, Laos and Cambodia, which superficially are similar to the Burmese calendars but have a completely different system of intercalation (Gislén, 2018; Ôhashi, 2006). Because Thailand, Laos and Cambodia have virtually the same luni-solar calendars, the Thai calendar is examined as a typical example.

Keywords: History of astronomy, calendars, Burma, Myanmar

1 BURMA (MYANMAR)

1.1 The Burmese Calendars

The Burmese luni-solar calendars (Htoon-Chan, 1918; Irwin, 1909) have a clear Indian origin but with some very important differences.¹ The calendrical schemes use mean quantities for the Sun and the Moon but for the astronomical calculations use true longitudes are used. The epoch of the original calendars is CE 22 March 638 and they generally count in elapsed years, the first year being year 0. The parameters of the original Burmese solar calendar are the original *Sūryasiddhānta* parameters² but scaled down by a factor of 5400, giving the Sun 292207 days in 800 year and a sidereal year of $29207/800 = 365.25875$ days. The lunar calendar is based on the fact that 703 *tithis* (lunar days or $1/30^{\text{th}}$ of a synodic month) correspond to 692 solar days. This gives a synodic lunar month of $(30 \times 692)/703 = 29.530583$ days, an excellent approximation of the true synodic month.

The original Burmese calendars used a Metonic intercalation scheme for the lunar months, having 7 intercalary months in 19 years, an intercalary year having 13 lunar months instead of 12 months. The years with month intercalation are number 2, 5, 7, 10, 13, 15, and 18 in the 19-year cycle where the number in the cycle is calculated by the year modulus nineteen. This gives $19 \times 12 + 7 = 235$ lunar months in 19 years. Each lunar month contains exactly 30 *tithis*, thus in the 19-year cycle there are $235 \times 30 = 7050$ *tithis*. The number of solar days will then be $(7050 \times 692)/703 = 6939.687055$ days. The mean solar year will have $6939.687055/19 = 365.24667$ days. This is a tropical solar year equal to Hipparchus' tropical year of $365 + \frac{1}{4} - \frac{1}{300}$ days, something that could indicate a Hellenistic influence. As will be seen below, this

year length causes problems when combined with the sidereal year and could be an indication that the lunar and solar calendars were introduced in Burma at different times.

The lunar calendar has a normal year of 12 lunar months with alternating 29 and 30 days, in total 354 days. The names and lengths of the Burmese months (in days) are given in Table 1.

Table 1: Burmese months.

Name	Days
<i>Tagu</i> (တန်ခူး)	29
<i>Kason</i> (ကဆုန်)	30
<i>Nayon</i> (နယုန်)	29/30
<i>Waso</i> (ဝါဆို)	30
<i>Wagaung</i> (ဝါခေါင်)	29
<i>Tawthalin</i> (တော်သလင်း)	30
<i>Thadingyut</i> (သီတင်းကျွတ်)	29
<i>Tazaungmon</i> (တန်ဆောင်မုန်း)	30
<i>Nadaw</i> (နတ်တော်)	29
<i>Pyatho</i> (ပြည့်သို)	30
<i>Tabodwe</i> (တပို့တွဲ)	29
<i>Tabaung</i> (တပေါင်း)	30

There are two variants of the early Burmese calendar: the Arakanese and the Makaranta. Both have an intercalary month with 30 days. The Arakanese calendar inserts this after the first month, *Tagu*, while the Makaranta inserts it after the fourth month, *Waso*. With 7 intercalary years in 19 years there are $(354 \times 19) + (7 \times 30) = 6936$ days. In order to have a calendar that keeps pace with the mean Moon an additional $6939.687055 - 6936 = 3.687055$ days are needed in each 19-year cycle. This is done by the intercalation of extra days. In order to determine

where to insert these days there is a canonical scheme as introduced in the next section.

1.2 Day Intercalation

In the Burmese calendars an intercalary day can only be inserted in a year that also has an intercalary month. The intercalary day is added to the end of the third month, *Nayon*, which will then have 30 days. There will then be three kinds of year, normal years with 354 days, years with an intercalary month and 384 days (*wan-ngè-taŋ*), and years with both an intercalary month and an intercalary day and 385 days (*wan-gyi-taŋ*). To determine which years will have an intercalary day there is a quantity called the *avoman* that essentially is a measure of the excess of *tithis* relative to the solar days. The Makaranta calendar uses the *avoman* of the second *Waso* Full Moon (2WFM) as an indicator of when to intercalate a day. The scheme to compute the 2WFM *avoman* for any year with an intercalary month is as follows:

- 1) Take the number of elapsed years and multiply by 12 in order to get the number of lunar months.
- 2) Add 4, the number of elapsed months up to the second *Waso*, to get the total number of elapsed ordinary months, m .
- 3) Compute the number of intercalary months: $(m \times 7)/(12 \times 19) = (m \times 7)/228$. This implements the condition that there be seven intercalary months in nineteen years.
- 4) Add the number of intercalary months to the number of ordinary months to get the total number of elapsed months.
- 5) Convert the total number of lunar months to *tithis* by multiplying by 30.
- 6) Add the number of *tithis* elapsed up to the Second *Waso* Full Moon, i.e. 14, to get the total number of elapsed *tithis*, t .
- 7) Compute the *avoman* by the formula $(t \times 11 + 650) \bmod 703$.³

If the result is 0 it is replaced by 703. The number 650 is an epoch constant, the *tithi* excess at the epoch being 650/703.

Example: Compute the 2WFM *avoman* for the year 1242 in the Burmese era which had an intercalary month, number 7 in the 19-year cycle:

$$\begin{aligned} 1242 \times 12 + 4 &= 14908 \\ (14908 \times 7)/228 &= 457 \\ \text{Total elapsed months } 14908 + 457 &= 15365 \\ \text{Elapsed } tithis (15365 \times 30) + 14 &= 460964 \\ (460964 \times 11 + 650) \bmod 703 &= 515, \text{ the } \\ &\text{2WFM } avoman. \end{aligned}$$

Once the 2WFM *avoman* has been calculated for one of the intercalary years in the Metonic sequence it is easy to compute the 2WFM *avoman* for any subsequent intercalary year in the sequence by adding one of two numbers: 517 or

259, both modulus 703. The interval between two years in the intercalary sequence can either be two or three years. In a two-year interval there are two normal years with twelve months plus one intercalary month. Thus, $2 \times 12 + 1 = 25$ months and 25×30 *tithis* = 750 *tithis*. The excess $(750 \times 11) \bmod 703 = 517$ is the *avoman* change. As we consider a difference, the epoch constant will cancel.

In a three-year interval there are $3 \times 12 + 1 = 37$ months, where 37×30 *tithis* = 1110 *tithis*, and the excess $(1110 \times 11) \bmod 703 = 259$ is the *avoman* change.

The rule for inserting an intercalary day is this: if the 2WFM *avoman* of the intercalary year is larger than the previous 2WFM *avoman*, there will be an intercalary day. If you take the case of a two-year interval it is easy to see that this statement is equivalent to saying that the previous 2WFM *avoman* lies in the interval [1, 186]. If you add 517 to any number in this interval the result will be less than 703 and thus larger, if it is outside this interval, the sum will be larger than 703 and by the modulus condition will be reduced by 703 and thus then be smaller than the original number. In the same way for a three-year interval, if the previous 2WFM *avoman* lies in the interval [1, 444], addition of 259 will result in a larger *avoman*.

Example: The year 1242 was number seven ($1242 \bmod 19 = 7$) in the intercalary cycle with the *avoman* equal to 515. The previous intercalary year, 1240, was the fifth in the intercalary cycle and the distance between these years is two years. Thus, the earlier year has a 2WFM of $515 - 517 = -2$. Add 703 to this result and we find the 2WFM *avoman* is 701. The 2WFM *avoman* of the year 1242 is smaller than the previous 2WFM *avoman*, thus there is no day intercalated in the year 1242. The next year with an intercalary month is 1245, number ten in the intercalary cycle. As there are now three years between the previous intercalary year the *avoman* of year 1245 is $515 + 259 = 774$. As it is larger than 703 we subtract 703 and get 71. This is smaller than 515, thus the year 1245 has also no intercalary day. The next year in the intercalary sequence is 1248, number thirteen in the intercalary sequence. Again, the distance in years is three years and the new *avoman* will be $71 + 259 = 330$. As it is larger than the previous *avoman* the year 1248 will have an intercalary day.

We can now calculate the mean number of intercalary days in a 19-year cycle. There are always two two-year intervals in a Metonic intercalation cycle and five three-year intervals. For a two-year interval the probability of an intercalary day is 186/703. The corresponding probability for a three-year interval is 444/703. The

Table 2: Burmese intercalary years with intercalary days.

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34						
2						x	x	x	x	x	x	x	x	x	x	x							x	x	x	x	x	x	x	x	x	x	x								
5	x	x	x	x	x								x	x	x	x	x	x	x	x	x	x																			
7								x	x	x	x													x	x	x	x														
10	x	x	x	x	x	x	x								x	x	x	x	x	x	x	x	x																		
13				x	x	x	x	x	x	x	x	x											x	x	x	x	x	x	x	x											
15	x	x	x														x	x	x	x																					
18						x	x	x	x	x	x	x	x	x	x									x	x	x	x	x	x	x	x	x	x	x	x	x					
2	x	x	x	x																																					
5	x	x	x	x	x	x	x	x	x	x																															
7																																									
10				x	x	x	x	x	x	x	x	x																													
13	x	x																																							
15				x	x	x	x	x																																	
18	x	x	x																																						
2	x	x	x	x	x	x	x	x																																	
5						x	x	x	x	x	x	x	x																												
7				x	x	x	x																																		
10	x																																								
13	x	x	x	x	x	x																																			
15																																									
18	x	x	x	x	x	x	x	x																																	

total mean number of intercalary days in the cycle is then $2 \times 186/703 + 5 \times 444/703 = 2592/703$ solar days = 3.687055 days, exactly equal to the number of required days for synchronising the lunar calendar with the Moon and also the lunar calendar with the tropical year. To this extent there is no need for a solar calendar.

It is often seen stated that the intercalation of days follows a 57-year cycle requiring 11 intercalary days. It is true that very frequently there are 11 intercalary days in 57 years, but the canonical scheme presented above does not result in any recognisable pattern in which years the intercalary days should be inserted and cannot be used as an intercalary rule. Table 2 shows 35 intercalary cycles, each consisting of three 19-year intercalary cycles ($3 \times 19 = 57$) for a total of 1996 years. The far-left column shows the year numbers in the intercalary cycle. Years with an intercalary month that also have an intercalary day are marked with a cross. Every cycle except cycles number 15 and 31 has indeed 11 intercalary days, the exceptions having 12 intercalary days, but there is no simple repeating pattern. Mathematically the intercalation pattern repeats only after 703 cycles. This range is unlikely to have been recognised.

A question is how the Burmese chose the pattern of intercalation years in the Metonic cycle. A possible answer could look like this:

The number of intercalary months is given by $m_1 = (7 \times m)/228$ where we use integer division and m is the number of elapsed normal months. Each time this expression increases by one unit, there will be a new intercalary month. Now, suppose that we place ourselves at the end of *Waso*, month four. We can now calculate for what years in a 19-year sequence there has been a new intercalary month at this moment. Using

$m = \text{cycle year} \times 12 + 4$ in the expression for m , we find the years that the above expression increases by one for cycle years 3, 6, 8, 11, 14, 16, 19, which means that the previous years, 2, 5, 7, 10, 13, 15, 18 must have had an intercalary month. This is exactly the intercalation pattern used in the Makaranta calendar. The Arakanese calendar inserts the intercalary month after *Tagu*, the first month. Using $m = \text{cycle year} \times 12 + 1$, we generate the intercalation pattern 2, 5, 8, 10, 13, 16, 18, which is actually a variant found in the historical record (Chatterjee, 1966; Eade, 1995).

1.3 The Solar Year

The original sidereal solar calendar has 292207 days in 800 solar years with a sidereal solar year of 365.25875 days. The backbone of the solar calendar is the *ahargana*, in Burmese *haragon* or *tawana*, the number of elapsed days since the epoch plus the New Year's Day. The Sanskrit term *ahargana* will be used in what follows. The formula for the *ahargana* at the end of the day of the beginning of a Burmese year is the integer result of $(\text{year} \times 292207 + 373)/800$.

The number 373 is an epoch constant giving the mean age of the Sun in parts of $1/800^{\text{th}}$ of a day at the beginning of the epoch. The final addition of one day brings the *ahargana* up to midnight on New Year's Day, the number of current days from the epoch.

The remainder of the division $(\text{year} \times 292207 + 373)/800$ measures the age of the mean Sun on the beginning of the New Year's Day in units of $1/800^{\text{th}}$ of a day. The 800-complement of this number is the part of the solar day that remains and is called the *kyammat*. The *kyammat* decreases by 207 units from New Year to New Year and when it is 207 or less in value it

Table 3: The changing month intercalation scheme in Thandeikta.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Burmese Year		x			x		x			x			x		x			x	
1201		x		x			x			x			x		x			x	
1217	x			x			x			x			x		x			x	
1228	x			x			x			x		x			x			x	
1263	x			x			x		x			x			x			x	
1317	x			x		x			x			x			x			x	
1328	x			x		x			x			x			x		x		
1344	x			x		x			x			x		x			x		

generates a solar leap year with 366 days. Note that $207/800 = 0.25875$ is the excess over 365 days of the adopted sidereal solar year. The *ahargana* is further used for calculation of the longitudes of the planets.

The problem is that the lunar Metonic calendar is not happily married with this sidereal solar calendar. The sidereal solar year is $365.25875 - 365.24667 = 0.01208$ days longer than the mean lunar tropical year. By the year 1100 in the Burmese Era the two calendars had drifted about 12 days apart and religious celebrations threatened to fall in the wrong season, very much the situation with the Western Julian calendar where Easter moved away from the true vernal equinox because the Julian calendar year is a little too long relative to the true tropical solar year.

The situation in Burma was worsened by a reform of the calendar, the Thandeikta (ထံဒေိက) calendar, that uses the modern *Sūryasiddhānta* parameters for the Sun, 1577917828 days in 432000 years that was introduced in practice around the year 1200 in the Burmese Era (CE 1838). This sidereal year is even longer than the previous sidereal year and the drift accelerated. The remedy was to start changing the intercalation pattern for the lunar months making them occur earlier. This was done in several steps up to the present day. See Table 3, where the crosses mark the years in the 19-year cycle that are intercalary. The left column shows the Burmese years when the change was done. The corresponding Western year is the Burmese year increased by 638.

Secondly, the rule for inserting intercalary days was changed several times and these changes completely destroyed the original beauty and consistency of the original system. Today, there are no canonical rules for setting up future Burmese calendar dates, the intercalation being determined from time to time by a committee of calendarists. A suggestion of a new computer algorithm for a reformed Myanmar calendar can be found on the Internet (Yan Naing Aye, 2013).

The Arakanese and Makaranta calendars are unique among the Indian-influenced calendars in Southeast Asia in using a Metonic intercalation pattern. There is only one Indian canon that uses this scheme, the *Romakasiddhānta* (Neugebauer and Pingree, 1970–1971; Sastry, 1993;

van der Waerden, 1988). As the name indicates, this canon has Hellenistic origins. Its epoch is CE 21 March 505 or Śaka 427. The scheme for the computation of the excess *tithis* in these original Burmese calendars is exactly paralleled in the *Romakasiddhānta*. It is tempting to assume that the *Romakasiddhānta* was a precursor to the Burmese calendar. However, the presently known facts about the *Romakasiddhānta* are too scanty to draw any safe conclusions.

In the later Thandeikta scheme the New Year *ahargana*, h_0 , is computed by

$$h_0 = [\text{year} - 1100 + (\text{year} - 1100)/193 + 17742]/800 + 1, \quad (1)$$

the New Year *kyammat* by

$$k_0 = 800 - [\text{year} - 1100 + (\text{year} - 1100)/193 + 17742]/\text{mod } 800 \quad (2)$$

and the *avoman* by

$$[11 \times h_0 + (\text{year} - 1100)/25 + 176] \text{mod } 692. \quad (3)$$

In Burma there is sometimes used a 12-year cycle for years where the years are specified by the Sanskrit names for the lunar months.

2 THAILAND, LAOS AND CAMBODIA

2.1 The Sources

The first description of the calendar in the regions of Southeast Asia mainland outside Burma and Vietnam came to Europe with the return of Simone de la Loubère from a visit to Siam in CE 1687. LaLoubère (1642–1729) was a French diplomat and mathematician who led an embassy to Siam (modern Thailand) on a mission instigated by the King Louis XIV of France. On his return, at the request of the King he wrote a description of his travels, which were published in two volumes under the title *Du Royaume de Siam* (Loubère, 1689). An English translation was published in London in 1693 as *A New Historical Relation of the Kingdom of Siam*. In the second volume Loubère gives a detailed description of Siamese astronomical calculations (see Section 6.1), with explanations added by the French chief astronomer Giovanni Cassini (1625–1712). Cassini was both exasperated and impressed by the Siamese methods of calculation:

This method is extraordinary. Tables are not used; but only addition, subtraction, multipli-

cation, & division of certain numbers, for which one at first cannot see the basis, nor how they are related. (Loubère, 1689: 142; our English translation).

Loubère (1689: 202–203) also gives equivalences between four Siamese and Western dates:

- 24 June 1687 = 1 waning, month 8 (Ashada) 2231 (Buddhasakarāt era, inclusive reckoning)
- 20 October 1687 = 15 waxing, month 11 (Asvina)
- 11 December 1687 = 8 waxing, month 1 (Margasirsha)
- 22 December 1687 = 3 waning, month 1 (Margasirsha)

The dates are lunar dates giving the age of the Moon. The first two reveal interesting information: the distance between them is 118 days, precisely equal to four lunar months, but the difference in months is only three (11–8). The conclusion (also made by Cassini, who demonstrated acuity in his analysis) is that there must have been an intercalary month in between. In fact, according to the canonical Thai calendrical rules this year should indeed be intercalary.

The second source of the calendrical schemes of this region came much later with the publication of *Astronomie Cambodgienne* (Faraut, 1910) by the French engineer Felix Gaspar Faraut (1846–1911). Faraut visited Cambodia in 1880–1881 and became Councillor and Chief Engineer of King Norodom I (1834–1904). During his stay he also attended a course on Khmer astronomy by the Royal Astrologer, Daung Okgna Hora Thpdey Chang Vang, on the methods that the latter employed to determine the positions of the planets and to construct the luni-solar calendar. Faraut had a difficult task, being exposed to Khmer technical terminology that had no self-explanatory meaning and to a set of mechanical mathematical operations that had no obvious theoretical basis, just a set of procedures. Also, when he returned to France in 1884 and planned to publish his results, he found that all of his study notes from the course had disappeared. Luckily, two years later he found them, and eventually they were published. Despite its many errors and misunderstandings, Faraut's book is our main source on the workings of the old calendar and astronomy of Thailand, Cambodia and Laos. These workings have been the basis of the computer application SEAC (South-east Asian Calendars) developed by Eade and Gislén that also handles the Burmese calendars.

The third source of information is the monumental astronomical/astrological manual in Thai by Luang Wisandarunkorn (1997). Most of the book deals with astrology, but there are model calculations of planetary longitudes and eclipses that in many cases complement, vindicate and

illuminate Faraut's descriptions.

The calendar in Laos has been dealt with in detail by Prince Phetsarath of Laos (see Phetsarath 1956; 1973), and there is an extensive numerical treatment by Dupertuis (1981).

2.2 The Calendar

The epoch of the Thai Chulasakarāt era (small era) is the same as for the Burmese calendars, namely CE 22 March 638. But there are other eras in use in the region: the Mahasakarāt era (large era), identical with the Śaka Era and with epoch CE 17 March 78; the Buddhasakarāt era with epoch 11 March 544 BCE, the day Buddha attained *parinwāna* or Nirvana; and the Anchan-sakarāt era, with epoch 10 March 691 BCE. This last era, which is not often encountered, appears to have been a device to deal with events before the Buddha era, thus avoiding negative reckoning. These eras will not be much studied here; their calendrical schemes are identical with that of the Chulasakarāt era except for having different epoch constants. The basic machinery for the calendrical and astronomical calculations derive from the Indian *Sūryasiddhānta* albeit in a slightly simplified version.

The Thai lunar months (Table 4), like the Burmese ones, have alternating 29 and 30 days and there is a lunar intercalary month, *adhikamat*. Unlike Indian reckoning in which extra lunar months were observed as they fell due, the *adhikamat* was confined to a second *Ashada* (*Wazo* in Burma), which had 30 days. There is also occasionally an intercalary day, *adhikawan*, inserted at the end of the previous month *Jyestha*. A distinction between the Thai and Burmese systems, one with more dislocating effect than one might have imagined, is that the Burmese mode says that a year with an extra day can occur only in a year that also has an extra month, whereas the Thai system says that a year with an extra month cannot also have an extra day.

The Thai names of the lunar months are almost identical with the Pali names. In what follows, we will refer to the months by their Sanskrit names but without the diacritics.

In most Thai calendrical records, the month is referred to by a number instead of by its name of which there are three styles. Table 5 shows the equivalences used. Intercalary months are referred to by doubling the month number of intercalated month. So, for instance, an intercalated *Ashada* in the Central/Sukhothai system is written 88. The Cambodian names are the less common alternatives for the Sanskrit ones (Eade, 1995).

The calculation of the solar and lunar parameters in La Loubère is somewhat different from that in Faraut (1910) and Wisandarunkorn (1997)

Table 4: Lunar month names.

Thai	Days	Lao	Khmer	Pali	Sanskrit
Chitra (จัตรา)	29	Chit	Chaet	Citta	Caitra
Wisakha (วิสาข)	30	Wisakha	Vesak	Visakha	Vaiśākha
Chettha (เชษฐ)	29/30	Set	Jais	Jeṭṭha	Jyeṣṭha
Asalha (อาสาฬห)	30	Asalaha	Ashad	Āsālha	Āṣāḍha
Sawana (สวาน)	29	Sawana	Srap	Sāvana	Śravaṇa
Phatrabot (ภัทรบพ)	30	Phatthrabot	Phutrobot	Poṭṭhapāda	Bhādrapada
Atsawayut (อัศวายุช)	29	Atsawayut	Asuj	Assuayuja	Aśvina
Kattika (กัตติกา)	30	Karttika	Kadhek	Kattikā	Kārttika
Mikasira (มิคสิริ)	29	Mikhasina	Mekasay	Māgasira	Mrgasīrṣa
Putsa (ปุตส)	30	Putsa	Bos	Phussa	Pauṣa
Makha (มาฆ)	29	Mat	Meak	Māgha	Māgha
Phakkhun (ผัคคณ)	30	Phakkhun	Phagaun	Phagguṇa	Phālguna

and is based on the lunar calendar. It seems to be related to an earlier calendrical epoch in Siam and is in many ways similar to the corresponding Burmese calculation. The era used in La Loubère's calculation is the Chulasakarat era with elapsed years. Given the year y , the elapsed lunar months m of the year, and the elapsed lunar days of the month or *tithis*, t , the procedure is as follows:

- 1) Compute the number of elapsed normal lunar months from $m_0 = 12 \times y + m$.
- 2) Compute the number of intercalary months $m_1 = (m_0 \times 7)/228$. This assumes a Metonic calculation that is not, as will be seen, the case for Siam. The information in La Loubère shows that the Siamese year 1049, corresponding to CE 1687, was a year with an intercalary month which it was not in the Burmese calendar with Metonic intercalation.
- 3) Compute the total number of elapsed *tithis* $T = 30 \times (m_0 + m_1) + t$.
- 4) Compute the *avoman*: $a = (t \times 11 + 650) \bmod 703$.
- 5) Compute the *ahargana*: $h = T - (T \times 11 + 650)/703$. The *ahargana* (lit. 'collection of days') is the number of elapsed solar days since the epoch. The relation uses the fact that a *tithi* corresponds to 692/703 of a solar day.

Once the *avoman* and *ahargana* are calculated they are used in the same way as in Faraut (for Cambodia) and Wisandarunkorn (for Thailand) to calculate the longitudes of the Sun and the Moon and the planets.

Table 5: Month equivalences.

Sanskrit	Cambodia	Central/ Sukhothai	Keng Tung	Chiang Mai
Caitra	Magha	5	6	7
Vaisakha	Madhava	6	7	8
Jyestha	Sukra	7	8	9
Ashadha	Suci	8	9	10
Sravana	Nabhas	9	10	11
Bhadrapada	Nabas	10	11	12
Asvina	Isha	11	12	1
Karttika	Urja	12	1	2
Margasirsha	Sahas	1	2	3
Pausha	Sahasya	2	3	4

The calculations for the solar calendar in Faraut (1910) and Wisandarunkorn (1997) are identical to the early Burmese calendars, as is evident by their arriving at identical results (Eade, 1995). There is the same rule for a solar leap year—that if the *kyammat* (or in Thai the *kam-macabala*, see below) is less than or equal to 207, the solar year is a leap year with 366 days. However, the rules for intercalating the lunar months are different, more complex, and not Metonic. We will use the *suryayatra* rules that seem to be more reliable (Eade, 2000). The solar new year occurs on the day when the mean solar sidereal longitude is zero, i.e. when the mean Sun enters the first zodiacal sign. This is in Thai *thalœngsok*. The true Sun has zero longitude about two days earlier, the *songkran*, and the interval between the two is used for celebration. The solar new year occurs in the lunar month of *Caitra* or sometimes in the following month *Vaisakha*. The basic rule is that the solar year can never start earlier than 6 *Caitra* or later than 5 *Vaisakha*, the following lunar month, although this latter date may, by a subsidiary rule, be pushed to 6 *Vaisakha*. As the normal lunar year is 11 or 12 days shorter than the solar year (depending on whether the previous solar year is a leap year or not) the solar new year will start the corresponding number of days later in the lunar calendar if there is no intercalary month. This means that if the start of the lunar year occurs in the interval later than 24 *Caitra* and before or on 6 *Vaisakha* there is a need for an intercalary lunar month. If a lunar year starts on 24 *Caitra* and the next year would start on 6 *Vaisakha* there is also an intercalary year.

There is an exception to these rules—that if a lunar year starts on 25 *Caitra* and the next year would start on 5 *Vaisakha* there is no intercalation, as it would sometimes generate two years in sequence with intercalary months. These rules effectively lock the lunar calendar to the sidereal solar one and in this way avoid the problems that the Burmese calendar has.

It is possible to compute the average frequency of the intercalation of months using the

fact that the intercalation rules keep the solar and lunar calendars in step.

Nineteen sidereal solar years have $19 \times 365.25875 = 6939.91625$ days. This corresponds to $6939.91625/29.53058321 = 235.0077613$ synodic months. Nineteen years each with twelve synodic months contain $19 \times 12 = 228$ months. Thus, we have on average $235.0077613 - 228 = 7.0077613$ intercalary lunar months in a 19-year period in order to keep the solar and lunar calendars aligned. This is very close to the Metonic intercalation frequency, though the intercalation pattern will not be fixed but will recede slowly within a 19-year cycle in a way similar to the recession of intercalary cyclic years in the Burmese Thandeikta calendar.

The rule for the intercalation of a day in the lunar calendar uses the New Year *avoman*. This is computed using the New Year *ahargana*, h_0 , computed as in the Makaranta calendar by

$$h_0 = (\text{year} \times 292207 + 373)/800 + 1 \quad (4)$$

where integer arithmetic is used. The New Year *avoman*, a_0 , is then computed by

$$a_0 = (h_0 \times 11 + 650) \bmod 692 \quad (5)$$

If the *avoman* is equal to zero it is changed to 692. The remainder of the division

$$(\text{year} \times 292207 + 373)/800 \quad (6)$$

is the excess time, expressed in $1/800^{\text{th}}$ of a day or the 'age' of the Sun at the end of the New Year day. The quantity 800 minus the remainder is the *kammacabala* corresponding to the Burmese *kyammat*. If the *kammacabala* is less than or equal to 207 the solar year is a leap year with 366 days.

Example: Compute the *ahargana* and the New Year *kammacabala* of the Chulasakarāt year 1238:

$(1238 \times 292207 + 373)/800 = 452190$ and remainder 639. The *ahargana* is $452190 + 1 = 452191$ and the *kammacabala* = $800 - 639 = 161$. As this is less than or equal to 207, the year is a solar leap year.

Example: Compute the New Year *avoman* for Chulasakarāt 1238:

$(452191 \times 11 + 650)/\bmod 692 = 655$. The *avoman* is 655.

The *avoman* increases by 11 units each day. During a normal solar year, the New Year *avoman* increases by $(365 \times 11) \bmod 692 = 555$, during a solar leap year by $555 + 11 = 566$. The distance of these numbers from 692 is 137 and 126 respectively. An increase of 555 is, in modular language, the same as a decrease of 137. If the New Year *avoman* of a normal year is equal to 137 or less, it means that the lunar calendar needs an intercalary day; for a leap year there will be an intercalary day if the New Year

avoman is equal to 126 or less. However, this rule can mean that an intercalary day falls in a lunar year with an intercalary month. This has to be avoided and there are quite complicated rules on how to move the intercalary day to one of the adjacent years.⁴ This is a step where it is quite probable that in practice other rules were used, for instance by always moving the day to the following or always to the preceding year. This expedient would in the long run have no lasting effect but would make the calendar sometimes deviate a day from the canonical calendar.

We can also calculate the frequency of day intercalation, irrespective of the precise insertion rules. The probability of having a leap year is $207/800$, the probability of a normal year $(800 - 207)/800 = 593/800$. The probability of an intercalary day is $126/692$ and $137/692$ respectively. Thus, the joint probability is:

$$[(126/692 \times 207)/800] + [137/(692 \times 593)/800] = 0.1938638$$

or on average $19 \times 0.1938638 = 3.6834122$ days in 19 years. We have the relation

19 sidereal solar years = $19 \times 365.25875 = 6939.91625$ days

19 normal lunar years with 354 days plus on average 7.0077613 intercalary years with 30 days give

$(19 \times 354) + (7.0077613 \times 30) = 6936.232839$ days.

Add to this the 3.6834122 days from the day intercalation and we get 6939.91625—exactly matching the mean number of days in a 19-year year period. By this means the Thai intercalation scheme achieves a perfect synchronisation of the sidereal solar and lunar calendars and with the Moon.

There are a few other quantities that are used in calendrical calculations and are often specified in the records. The *uccabala* relates to the position of the Moon's apogee. It is calculated using the formula

$$\text{uccabala} = (\text{ahargana} + 2611) \bmod 3232 \quad (7)$$

where 2611 is an epoch constant. The number 3232 is the period of rotation in days for the apogee.

The *masaken* counts the number of elapsed lunar months. First the number of *tithis* is computed: a solar day is equal to $703/692$ of a *tithi* and the *tithi* was $650/692$ at the epoch. As each lunar month is equal to 30 *tithis*, the number of lunar months is simply the *tithis* divided by 30.

$$\text{masaken} = [(\text{ahargana} \times 703 + 650)/692]/30 \quad (8)$$

The *tithis* within the lunar month is computed by

$$[(\text{ahargana} \times 703 + 650)/692] \bmod 30 \quad (9)$$

Example: Compute the *uccabala*, *masaken*,

and *tithi* for New Year 1238, *ahargana* 452191.
 $(452191 + 2611) \bmod 3232 = 2322$, the *uccabala*.
 $(452191 \times 703 + 650) / 692 = 459379$
 $459379 / 30 = 15312$, the number of elapsed
 lunar months since the epoch.
 $459379 \bmod 30 = 19$, the *tithi*.

Since the system was implemented locally over a wide area for centuries, as is evidenced by monastic inscriptions, it may be concluded that the numbers that caused the system to function from year to year were easily memorised and reliably passed from generation to generation.

2.3 The Sexagesimal Calendar

Another calendar component used in Northern Thailand, Laos, and also in Burma is the cyclic sexagesimal calendar. In Northern Thailand it is used for both days and years, in Burma only with a duodecimal cycle for years. It is built from the combination of a decimal with a duodecimal cycle but such that only odd or even elements

Table 6: Names of the Watches.

Time	Thai	Lao
06:00–07:30	<i>tut chao</i>	<i>tuttgart</i>
07:30–09:00	<i>klong ngai</i>	<i>ngay</i>
09:00–10:30	<i>træ thiang</i>	<i>te kaeu thieng</i>
10:30–12:00	<i>thiang</i>	<i>thieng</i>
12:00–13:30	<i>tut chai</i>	<i>tutsay</i>
13:30–15:00	<i>klong kham</i>	<i>leng</i>
15:00–16:30	<i>træ kham</i>	<i>thè kaeu kham</i>
16:30–18:00	<i>[phat] kham</i>	<i>phat lam</i>
18:00–19:30	<i>tut dük</i>	<i>tuttgart</i>
19:30–21:00	<i>klong dük</i>	<i>deuk</i>
21:00–22:30	<i>træ dük</i>	<i>thè kaeu thieng</i>
22:30–00:00	<i>dük</i>	<i>thieng khun</i>
00:00–01:30	<i>tut rung</i>	<i>tutsay</i>
01:30–03:00	<i>klong rung</i>	<i>khua</i>
03:00–04:30	<i>træ rung</i>	<i>thè kaeu hung</i>
04:30–06:00	<i>rung</i>	<i>phat lan</i>

are paired. This will give precisely sixty different combinations. The Thai names of the decimal cycle items are: *kap, dap, raway, moeng, poek, kat, kot, ruang, tao* and *ka*.

The duodecimal series is: *cai, pao, yi, mao, si, sai, sanga, met, san, rao, set* and *kai*.

Sometimes also the Thai animal names are given: *Chuat, Chalu, Khan, Tho, Marong, Maseng, Mamia, Mamae, Wok, Rakaa, Cho, Kun*.

These names are the same as in the Chinese duodecimal series: rat, ox, tiger, rabbit, dragon, snake, horse, goat, donkey, rooster, dog and pig.

The sexagesimal day cycle is often combined with the seven-day cycle of weekdays to generate a larger 420-day cycle.

2.4 Time Measure

Time of the day is sometimes measured in watches where the period from one dawn to the

next is divided into eight day- and eight night-watches, giving 90 minutes for each (see Table 6). By South-east Asia reckoning the subunits of time are the *pada/bat* of six minutes, the *nadi*, or sixtieth of a day (24 hours), 24 minutes, and the *nalika* of 60 minutes.

2.5 King Rama IV's Lunar Calendar

A special Thai lunar calendar is the Pakkhakhanana (ปักษ์คณนา, fortnight calculation) calendar (Chunpongtong, 2008) invented by the Thai King Rama IV or Mongkut (CE 1804–1868; Saibejra, 2006). He noted that the phases of the Moon in the Thai lunisolar calendar were sometimes displaced by up to two days relative to the true Moon and was concerned that the Buddhist sabbath days would not be celebrated at the stipulated times. The Pakkhakhanana calendar, although using the mean Moon, gives phases of the Moon that are much closer to the real Moon than the standard Thai calendar.

The calendar uses a board with five sets of rows of Khmer letters, 𑄆 (M, for *Maha* or big) and 𑄇 (C, for *Chula*, small) and with pegs to mark the settings (see Figure 1a). Figure 1b shows the schematic layout for 11 February 2019, Magha 7 waxing 1380, Julian Day 2458526. The setting in the second figure is not the same as in the first one. The scheme is based on fortnights, i.e. the waxing and waning parts of a lunar month that each one can have either 14 or 15 days (whereas the standard calendar always has 15 days, expressed as 14 waxing days and full Moon day).

The letter in a specific set of rows determines which row, M or C, to use in the next set of two rows below it. The bottom rows determine whether the fortnight has 15 (M) or 14 (C) days. These rows are not shown on the Pakkhakhanana board. For each day, the number in the bottom row is stepped up one step. As the number reaches 14 or 15, the counting starts again from 1 and the position in the set of rows above is stepped up by one to the right. As the steps reach the end of the row, the position in the set of two rows above is stepped one step to the right and so on. All the time the choice of the row where to begin within the two set of rows is determined by the letter in the set above. Full Moons and New Moons occur when the number in the lowest rows is fourteen or fifteen, quarter Moons when it is eight. The scheme is based on a mean lunar half-month of 14.765297 days. The first day of the calendar is Saturday 28 January 1736, Julian Day 2355148 when the Moon was 1 waning.

The procedure to compute the setting pattern of the board is as follows:

- 1) Subtract 2355147 from the Julian Day.
- 2) Divide the result by 16168, increase the quotient by 1, keep the remainder.
- 3) Divide the remainder by 1447, increase the quotient by 1, keep the new remainder.
- 4) Divide the remainder by 251, increase the quotient by 1, keep the new remainder.
- 5) Divide the remainder by 59, increase the quotient by 1, keep the new remainder.
- 6) Divide the remainder by 15, increase the quotient by 1, keep the new remainder.
- 7) The remainder is the day number in the half-month.

The reason for the numbers 15, 59, 251, 1447, and 16168 is that they are chosen to be successively more close approximations of days of an integer number of half-months. They correspond respectively to 1, 4, 17, 98, and 1095 half-months.

Example: 11 February 2019, Julian Day 2458526.

- 1) $2458526 - 2355147 = 103379$
- 2) $103379/16168 = 6:6371, 6 + 1 = 7$
- 3) $6371/1447 = 4:583, 4 + 1 = 5$
- 4) $583/251 = 2:81, 2 + 1 = 3$
- 5) $81/59 = 1:22, 1 + 1 = 2$
- 6) $22/15 = 1:7, 1 + 1 = 2$

The board setting pattern is 7:5:3:2:2:7 as shown in Figure 1b. The rule will sometimes give a setting that needs to be adjusted.⁵ The number of elapsed half-months is computed from this setting by $(7-1) \times 1095 + (5-1) \times 98 + (3-1) \times 17 + (2-1) \times 4 + 2 = 7002$. As the number of elapsed half-months is even, the Moon will be waxing 7.

The scheme generates a lunar calendar with a more even distributions of half-months of 14 days than the standard Thai luni-solar calendar and is closer to the real Moon phases. The calendar pattern repeats after 289577 days. A test run with a computer implementation of the calendar from CE 1850 to 2000 shows that the maximum deviation from the mean astronomical Moon only is ± 0.5 days. At present the calendar is only used by Dhammayuttika Nikaya, an order of the Theravada Buddhism in Thailand.

3 CONCLUDING REMARKS

The original Burmese calendars are unique in Southeast Asia in using a Metonic intercalation. Also, the lack of connection between the lunar and solar calendars is specific. It would be highly interesting to investigate the origins of these calendars once more information becomes available. One possibility is a connection with the Indian *Romakasiddhānta* with which they share many similarities (Gislén, 2019). The later Thandeikta calendar tries to remedy the discrepancy between the lunar and solar calendars by modifying the intercalation scheme.

The Thai calendar achieves a perfect synchronization between the lunar and solar calendars. However, the use of a sidereal solar calendar means that it will drift slowly in relation to the real seasons. The solar New Year, originally chosen to start at the vernal equinox at the epoch in CE 638, now starts about a month later.



Figure 1a: A Pakkhakhanana board.

11 February 2019 CE (7 Magha1380 CS)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	C
M	C	C	C	C	C	C	C	C	C	C	M							
C	C	C	C	C	C	C	C	C	C	M								
M	M	M	M	M	M	M	C											
C	M	M	M	M	M	C												
M	C	C	C	M														
C	M	M	M	M	C													
M	C	M	M	M	C													
C	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15			
M	1	2	3	4	5	6	7	8	9	10	11	12	13	14				
C	1	2	3	4	5	6	7	8	9	10	11	12	13	14				

Figure 1b: The Pakkhakhanana board, schematic layout.

It is very important to realise that there are canonical calendar schemes that are based on sound astronomical facts and constructed by highly educated and skilled experts in the field.

The canonical rules for computing the calendar were codified in a set of inherited rules, much like a computer program, which if followed, generated the desired result. This procedure did not require that the person doing the calculation had any understanding of the underlying astronomical model. This way of working has some obvious advantages: the many horoscope calculations recorded in the temples could be done by unskilled monks. The drawback is that once a rule was misunderstood or distorted, the error could propagate without possible correction for all future time.

Such distortions, however, are quite rare considering that this system has worked for the order of a millennium. Another more frequent issue could be that there were sometimes in the practical application of the rules shortcuts or simplifications made, of which there is some evidence, or intercalation changes made at the whim of some ruler. When a satisfactory procedure has been established that accurately and consistently replicates the data to be found in the Thai inscriptions, it is something of an aggravation that there is nonetheless some tendency for the data to represent a one-day difference from one's expectation. One takes into account here that there are three kinds of lunar year: a normal one of 354 days, and two others in which either an extra day (355 days) or an extra month (384 days) is added as a means of causing the lunar years to keep pace with the solar years. In the case where an extra day is required there were some complicated theoretical rules set up to determine which years should receive the extra day—a matter on which even today there is a discussion. One consequently suspects that the one-day differences to be met with are the result not of minor computation errors, but of a settled difference in procedure.

The very complicated calculations of the true longitudes of the planets for the horoscopes were sometimes done at some fixed time intervals and not always on the day as they should have been. Corrections for calculating true longitude from mean longitude were sometimes added instead of subtracted or vice versa. Also, in some cases there have been errors in the procedure of transferring the computed calendrical data to the actual written record. The digits for one (๑), eight (๘), and zero (๐) are very similar in Burmese as are four (၄) and five (၅) in Thai. Any small defect could easily change one digit to the other. This means that when comparing the actual calendrical field records, the fact that some numerical information deviates from what is expected from a canonical calculation does not necessarily mean that the record or the calendar is wrong. It is better to characterise it as different. Luckily many of the

records contain redundant calendrical data making it possible to spot such deviations.

Another source of apparent error is that the astronomical day starts at midnight but the civil day at sunrise or for villagers, 'when they could see lines in the palm of their hand' (Diller, 2000). This means that depending on the convention an event could be assigned to one of two different days and weekdays if the time of the event occurred in the interval between midnight and sunrise.

4 NOTES

1. This is the second paper in a series that reviews the traditional calendars of Southeast Asia. The first paper (Gislén and Eade, 2019) provided an introduction to the series.
2. For specialist astronomical terms used in this paper see the Glossary in Section 6.3.
3. The Burmese and Thai astronomical and calendrical calculations are based on integer arithmetic. Thus, the division of two numbers, for instance $10/3$ gives the result 3 with a remainder of 1. In this paper we use the mathematical modulus function where $10 \bmod 3$ means the remainder of 10 divided by 3. Actually, we use a slightly different definition: if the remainder is 0 it is replaced by the divisor, $20 \bmod 5$ is then 5, not 0.
4. For Thai rules for intercalary days see Section 6.2 below.
5. For example, starting with 98956, the rule gives the setting 7:2:2:5:1:14. However, there are only four columns for the fourth item and the number 5 must be adjusted to 4. This will add 59 to the remainder and give the correct setting 7:2:2:4:5:13.

5 REFERENCES

- Chatterjee, G.K., 1996. Traditional calendar of Myanmar (Burma). *Indian Journal of History of Science*, 33, 143–160.
- Chunpongtong, L., 2008. *Thai Calendar: Astronomy and Mathematics*. Bangkok, National Astronomical Research Institute of Thailand (in Thai).
- Diller, A., 2000. *Thai Time*. See https://openresearch-repository.anu.edu.au/bitstream/1885/41890/3/thai_time.html
- Dupertius, S., 1981. Le calcul du calendrier *laotien*. *Péninsule*, 2(3), 17–79 (in French).
- Eade, J.C., 1995. *The Calendrical Systems of Mainland South-East Asia*. Brill, Leiden.
- Eade, J.C., 2000. Rules for interpolation in the Thai calendar: *suryayatra* versus the *sasana*. *Journal of the Siam Society*, 88, 195–203.
- Faraut, F.G., 1910. *Astronomie Cambodgienne*. Saigon, F.H. Schneider (in French).
- Gislén, L., 2018. On lunisolar calendars and intercalation schemes in Southeast Asia. *Journal of Astronomical History and Heritage*, 21, 2–6.
- Gislén, L., 2019. A hypothetical *Romakasiddhānta*

- Calendar. Journal of Astronomical History and Heritage*, 22, 339–341.
- Gislén, L., and Eade, C.J., 2019. The calendars of Southeast Asia. 1: Introduction. *Journal of Astronomical History and Heritage*, 22, 407–416.
- Htoon-Chan, 1918. *The Arakanese Calendar. Third Edition*. Rangoon, Rangoon Times Press.
- Irwin, A.M.B., 1909. *The Burmese and Arakanese Calendars*. Rangoon, Hanthawaddy Printing Works.
- Loubère, S. le, 1691. *Du Royaume de Siam, Tome 2*. Paris, Jean Baptiste Coignard (in French).
- Neugebauer, O., and Pingree, D., 1970–1971. *The Pañcasiddhantika by Varahamihira*. København, Historisk-filosofiske Skrifter udgivet af det Kongelige Danske Videnskabernes Selskab, 6(1).
- Ôhashi, Y., 2006. The riddle of the cycle of intercalation and the sidereal year: an aspect of the mainland South-East Asian calendars. In Chen, K.Y., Orchiston, W., Soonthornthum, B., and Strom, R. (eds.). *Proceedings of the Fifth International Conference on Oriental Astronomy*. Chiang Mai, Chiang Mai University. Pp.149–154
- Phetsarath, S.A., 1956. Le calendrier Lao. *France-Asie*, 118–120, 787–812 (in French).
- Phetsarath, S.A., 1973. *Astrologie Laotienne* (first part by Maha Vivalong). Vientiane, Lycée Fangoum (in French).
- Saibejra, N., 2006. King Mongkut: the Father of Thai Science. In Chen, K.-Y., Orchiston, W., Soonthornthum, B., and Strom, R. (eds.). *Proceedings of the Fifth International Conference on Oriental Astronomy*. Chiang Mai, Chiang Mai University. Pp. 15–18.
- Sastry, T.K., 1993. *Pañcasiddhāntika by Varahamihira*. Madras, Adyar (P.S.S.T. Science Series No. 1).
- van der Waerden, B.L., 1988. On the Romakasiddhānta. *Archive for History of Exact Sciences*, 38, 1–11.
- Wisandarunkorn, L., 1997. *Khamphi Horasasat Thai (Standard Thai Astrological Scripture)*. Bangkok, Inter-print (in Thai).
- Yan Naing Aye, 2013. *Algorithm, Program and Calculation of Myanmar Calendar*. See <http://cool-emerald.blogspot.com/2013/06/algorithm-program-and-calculation-of.html> (in Burmese with English translation).

6 APPENDICES

6.1 Extract from La Loubère's *Du Royaume de Siam*

Règles pour trouver le lieu du Soleil & de la Lune au temps de la naissance de quelqu'un.

- I.
 1. Posez l'Ere.
 2. Soustrayez l'âge de la personne de l'Ere, vous aurez l'âge de la naissance.
 3. Multipliez-la par 12.
 4. Ajoûtez-y le nombre des mois de l'année courante: & pour cela, si l'année courante est *Attikamaat*, c'est-à-dire, si elle a 13 mois de la Lune, vous commencerez à compter par le 5 mois; que si elle n'est point *Attikamaat*, vous commencerez à compter par le 6 mois.

5. Multipliez par 7 le nombre trouvé art. 4.
6. Divisez la somme par 228.
7. Joignez le quotient de la division au nombre trouvé art. 4; cela vous donnera le *Maasaken* (c'est-à-dire, le nombre des mois) que vous garderez.

II.

1. Posez la *Maasaken*.
2. Multipliez par 30.
3. Joignez-y les jours du mois courant.
4. Multipliez par 11.
5. Ajoûtez-y encore le nombre de 650.
6. Divisez par 703.
7. Gardez le numérateur que vous appellerez *Anamaan*.
8. Prenez le quotient de la fraction trouvé art 6, & le soustrayez du nombre art. 3: le reste sera l'*horoconne* (c'est-à-dire, le nombre des jours de l'Ere) que vous garderez.

III.

1. Posez l'*horoconne*.
2. Divisez par 7.
3. Le numérateur de la fraction est le jour de la semaine. *Nota*, Que le premier jour de la semaine est le Dimanche.

IV.

1. Posez l'*horoconne*.
2. Multipliez-le par 800.
3. Soustrayez-en 373.
4. Divisez-le par 292207.
- 5 Le quotient sera l'Ere, & le numérateur de la fraction sera le *Krommethiaponne*, que vous garderez.

V.

1. Posez le *Krommethiaponne*.
2. Soustrayez-en l'Ere.
3. Divisez le reste par 2.
4. Négligeant la fraction, soustrayez 2 du quotient.
5. Divisez le reste par 7: la fraction vous donnera le jour de la semaine. *Nota*, Que quand je diray la fraction, je n'entends parler que du Numérateur.

VI.

1. *Horoconne*.
2. Soustrayez-en 621 [or add 3232 – 621 = 2611]
3. Divisez le reste par 3232.
4. La fraction s'appelle *Outhiaponne*, que vous garderez.

Si vous voulez avoir le jour de la semaine par, l' *Outhiaponne*, prenez le quotient de la division susfaite; multipliez-le par 5; puis joignez-le à l' *Outhiaponne*; puis soustrayez-en 2 jours; divisez par 7, la fraction marquera le jour.

Tout ce que dessus s'appelle *Poulasouriat*, comme qui diroit la force du Soleil.

VII.

1. Posez le *Krommethiapponne*.
2. Divisez-le par 24350.
3. Gardez le quoirient, qui sera le *Raasi*, c'est à dire, le Signe où sera le Soleil.
4. Posez la fraction de la division susdite, & la divisez par 811.
5. Le quotient de la division sera le *Ongsaa*, c'est à-dire, le degré où sera le Soleil.
6. Posez la fraction de cette division, & la divisez par 14.
7. Le quotient sera le *Libedaa*, c'est-à-dire, la minute.
8. Soustrayer 3 du *Libedaa*.
9. Mettez ce qui est au *Libedaa* au dessus de l'*Ongsaa*, & l'*Ongsaa* au dessus du *Raasi*: cela fre une figure qui s'appellera le *Matteniomme* du Solei que vous garderez: Je croy que c'est *locus medius Solis*.

Sections VIII and IX treat the calculations of the true longitude of the Sun.

X. Pour la Lune pour trouver le matteiomme la Lune.

1. Posez l'*anamaan*.
2. Divisez-le par 25.
3. Mépriez la fraction, & joignez le quotient avec l'*anamaan*.
4. Divisez le tout par 60 le quotient sera *ongsaa* la fraction sera *libedaa*, & vous mettrez un 0 au rasi.
5. Posez autant de jours que vous en avez mis cy-dessus au mois courant sect. 2. II.3.
6. Multipliez ce nombre par 12.
7. Divisez le tout par 30, le quotient, mettez-le au *rasi* de la figure précédente qui a un 0 au rasi, & la fraction joignez-le à l'*ongsaa* de la figure.
8. Joignez toute cette figure au *mateiomme* du Soleil.
9. Soustrayez 40 du *libedaa*. Que si cela ne ce peut, vous tirez 1 du *ongsaa* qui vaudra 60 *ibedaa*.
10. Ce qui restera dans la figure est le *matteiomme* de la Lune cherché.

6.2 Thai Rules for Intercalary Days

The rules for the insertion of intercalary days ensure that the flow of weekdays is uninterrupted. The rules as given in Faraut (1910) are very difficult to understand and to apply in practice. Below is a simpler equivalent scheme in which three basic pieces of information are needed:

1) The type of year: normal, year with intercalary day, year with intercalary month and year with both intercalary day and month, below

denoted A, B, C, and BC respectively. Years BC have a collision between intercalary day and month must be adjusted in the Thai scheme, moving the intercalary day to one of the adjacent normal years. The type of year can be calculated by using the rules outlined in this paper.

2) The solar New Year weekday. This is easily computed from the solar New Year *ahargana* (h_0) by $h_0 \bmod 7$ where 0 = Saturday, 1 = Sunday, and so on.

3) The (preliminary) lunar date of the solar new year. Using the New year *ahargana*, h_0 , the number of elapsed *tithis*, t_0 , is computed by the following formula:

$$t_0 = (h_0 \times 703 + 650) / 693 \quad (10)$$

Then the *tithi* of the solar New Year is given by $t_1 = t_0 \bmod 30$. If $t_1 < 6$ the date will be in *Vaisakha*, the second lunar month; otherwise in *Caitra*, the first lunar month. $t_1 = 0$ is replaced by $t_1 = 1$ (*Vaisakha*). (A very rare exception is that if the *avoman* is equal to 692, t_1 should be diminished by one.)

Counting backwards from the solar New Year weekday it is now easy to find the weekday, W , of 1 *Caitra*, the beginning of the lunar year. Depending on the type of year the weekday of the start of the next lunar year, W_{next} can be calculated:

- 1) For a normal year by $(W + 4) \bmod 7$, ($354 \bmod 7 = 4$).
- 2) For a year with an intercalary day by $(W + 5) \bmod 7$, ($355 \bmod 7 = 5$).
- 3) For a year with an intercalary month (by $(W + 6) \bmod 7$, ($384 \bmod 7 = 6$). A year with both an intercalary day and month is treated as one with only an intercalary month, the intercalary day not being inserted but kept in waiting.

As an example, we look at a sequence of the years 20–39 in the Chulasakarat era and get Table 6.

The requirement for an uninterrupted flow of weekdays is that W_{next} of any year should be equal to W of the following year. In year 22 and 38 we need to move the whole lunar year back one day in order to achieve this. This will also cause the solar new year date to move one day forward in the lunar calendar. It is called "*l'exception One*" by Faraut (1910: 121). For year 22 this shows a case when the solar year will start on 6 *Vaisakha*, the date being pushed from 5 *Vaisakha*.

There are two instances of intercalary years, 30 and 35, where it is necessary to move the extra day to one of the adjacent years. For year 30 it is seen that by increasing W_{next} in the previous year by one unit and thus making the year one day longer and moving the part of the lunar year from 1 *Waso* to the end of the year on step

Table 6: Intercalary day allocation.

Year	Type	W	W_{next}	t_1
20	B	0	5	13
21	A	5	2	23
22	C	3→2	2→1	5→6
23	A	1	5	16
24	C	5	4	27
25	B	4	2	8
26	A	2	6	19
27	C	6	5	1
28	A	5	2	11
29	A	2	6→0	22B
30	BC	0	6	4
31	A	6	3	14
32	C	3	2	25
33	A	2	6	7
34	A	6	3	18
35	BC	3	2	29
36	A	3→2	0	9→10B
37	A	0	4	21
38	C	5→4	4→3	2→3
39	A	3	0	13

forward, the extra day can fit into that year as an intercalary day 30 in the month of *Nayon* and the flow of weekdays will be restored.

For year 35 the following year could start one day earlier making room for the extra day and again restore the flow of weekdays. This will move the part of the lunar year from the start to the end of the third month, *Nayon*, where the extra day will be inserted and thus also move the lunar date of the solar new year one day forward in the lunar calendar.

Note, however, that the extra day could also have been accommodated in the year following year 30 by changing W of year 31 from 6 to 5 and moving the W and W_{next} of year 30 one step down and the solar new year lunar date of that year one step up (Table 7). This could implement an alternative rule of always inserting the intercalary day in the following year. In a similar way the extra day in year 35 can be inserted in the previous year. These are possible solutions of the intercalation problem but require more shifts.

6.3 Glossary

adhikamasa An indication as to whether or not a given year has an intercalary lunar month in it. Intercalary months are used to ensure that the lunar calendar keeps in step with the solar one. In Thai it is *adhikamat* (อธิกมาส).

adhikavara An indication as to whether or not a given year has an intercalary day in it. Intercalary days are used to ensure that the lunar calendar keeps in step with the (mean) Moon. In

Table 7: Intercalary vatriant allocation.

Year	Type	W	W_{next}	t_1
20	B	0	5	13
21	A	5	2	23
22	C	3→2	2→1	5→6
23	A	1	5	16
24	C	5	4	27
25	B	4	2	8
26	A	2	6	19
27	C	6	5	1
28	A	5	2	11
29	A	2	6	22
30	BC	0→6	6→5	4→5
31	A	6→5	3	14→15B
32	C	3	2	25
33	A	2	6	7
34	A	6	3	18
35	BC	3	2	29
36	A	3→2	0	9→10B
37	A	0	4	21
38	C	5→4	4→3	2→3
39	A	3	0	13

Thai it is *adhikawan* (อธิกวาร).

ahargana The number of elapsed days since the epoch.

Anchansakarat era One of the eras used in Thailand with epoch 10 March 691 BCE.

Arakanese Calendar A calendar used in Arakan. It is similar to the *Makarata* Calendar and having the same epoch 22 March 638 CE. Instead of doubling Waso in an intercalary year, the *Arakanese* calendar doubles the first month Tagu.

avoman Thai อวมาน, Burmese အဝမာန်. The excess of lunar days over solar days in units of $1/692$ of a lunar day modulus 692. It increases by 11 units each solar day. It is used to determine when to add intercalary days in the calendar. Sometimes in Burmese astronomy the avoman is expressed in units of $1/703$ of a solar day.

bath Thai (บาท). A Thai time unit equal to $\frac{1}{4}$ *nadi* or 15 *vinadi*.

bizana Burmese ဝိဇနာ. See *vinadi*.

Buddhasakarat era One of the eras used in Thailand. The epoch is 11 March 544 BCE.

Burmese Era The epoch of the Burmese Era is identical with the Thai *ahargana*, the number of elapsed days since the epoch CE 22 March 638.

haragon Burmese term for *ahargana*. The term *tawana* is used more often.

horakhun Thai หอศุณ. See *ahargana*.

kammacabala Thai (กัมมัชผล). A quantity that gives the excess of solar days over whole solar days.

kromatopol Khmer term for Thai *kammacabala*.

kyammat Burmese ကြွယ်. See *kammacabala*.

Mahasakarāt era An era used in Thailand. Its epoch is the same as the *Saka era*, CE 17 March 78.

masaken Thai มาสแคะ. In Burma the term *sandyamat* (စန္ဒြေမာတ) is used. The number of elapsed lunar months since the epoch.

modulus A mathematical operation on an integer where an integer is divided by another integer and the modulus is the remainder.

nadi An Indian time measure with 60 *nadi* in a day and night. In Thai it is *nathi* and in Burmese *nayi*. It corresponds to 24 minutes.

nakṣatra A measure of the Moon's longitude where the zodiac is divided into 27 parts, each covering 13° 20'. In Thai it is called *roek* and in Burmese *nekkhat*.

Pagan Kingdom The first kingdom to unify the regions that would later be the present-day Burma. From around the ninth century it expanded from settlements at Pagan. At the end of CE 1200 it was subject to several Mongol invasions.

nalika Thai time unit corresponding to 60 minutes.

nathi Thai นาฬิกา. See *nadi*.

nayi Burmese နှာရီ. See *nadi*.

nekkhat Burmese နက္ခတ်. See *nakṣatra*.

nyepi The Balinese New Year day, the first day of month 10, Kadasa.

pada Thai time unit corresponding to 6 minutes.

roek Thai ฤกษ์. See *nakṣatra*.

Romakasiddhānta An Indian astronomical canon characterised by being the only Indian canon using Metonic intercalation.

Śaka era An Indian era with epoch CE 17 March 78. See *Mahasakarāt era*.

Songkran Thai สงกรานต์ from Sanskrit *sankranti*. Strictly, *Songkran* is the time when the Sun passes from any one sign to another, but the word is used more particularly in connection with its passage from Pisces to Aries (*maha-songkran*). The precise time of *Songkran* is when the True Sun has a longitude of 0. See further under *thalcengsok*.

suryayatri A set of computational rules for the Thai calendar based on the rules of the original *Sūryasiddhānta* albeit in a slightly simplified ver-

sion.

thalcengsok Thai เถลิงศก. More generally a word defining the start of an era; but used by astrologers to refer to the time when the Sun's mean longitude reaches 0°. This moment defines the end of the New Year festival period.

uccabala A measure of the position of the Moon's apogee. It increases by one unit a day to a maximum of 3232.

vinadi An Indian time measure being 1/60th of a *nadi*.

wan-gyi-tat Burmese ဝါငယ်ထပ်. A Burmese lunar year with an intercalated month and an intercalated day.

wan-ngè-tat Burmese ဝါကြီးထပ်. A Burmese lunar year with an intercalated month.

yoga An artificial quantity being the sum of the longitudes of the Sun and the Moon. It is expressed as the possible 360° divided into 27 parts, each spanning 13° 20'. There are dozens of other kinds of *yoga*, but very little assistance is given by the handbooks as to how they are determined.



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