The Beginning of Time

Karenleigh A. Overmann

The present analysis focuses on the material component of time, the devices used for measuring and counting it. The biological basis for subjective, experiential time is first reviewed, as are early strategies found cross-culturally for measuring and counting time objectively. These strategies include timekeeping by natural phenomena, using tallies to keep track of small periods of time, harnessing shadows for daily and annual time, and visualizing time with clocks and calendars. The conclusion then examines how such timekeeping devices might influence the conceptualization of time.

Perhaps the most interesting thing about time as a conceptual domain is the fact its material component is so often overlooked. As is true of space and number, time is viewed as a system of ideas created mentally, linguistically, or socially which is later externalized to material forms, rather than as concepts emerging from and through interactions with material forms to occasion explication, naming and sharing. Admittedly, the material component may tend to be somewhat more visible in time than in space and number, for two reasons: first, our concepts of time overtly resemble the natural phenomena which are their basis, and second, time as experienced often differs from time as measured by the clock, perhaps making us aware a material form has a role in the latter. Yet time is no more foreordained to be structured into hours, days, months and years than numbers are to be grouped by the quantity of our fingers or space by the size of our feet; such patternings are instead circumstantial, reflecting the material components of their conceptualization.

Time also differs in the way it emerges. Across cultures, the beginnings of space and number are perceptual and anthropomorphic: space and quantity are visually appreciable in ways which are directly comparable to the human body. Space, the distance across visible surfaces (Gibson 1975), is compared to the lengths and widths of thumbs, hands, forearms, arm spans, feet and paces, while quantity, a property appreciable through the so-called number sense, is represented and expressed with fingers and body parts like toes. Such body-based methods suffice, at least until societies need to measure agricultural fields and monuments or count beyond the hands' capacity and persistence.

In contrast, the body is not the first device for time, since time is neither an extent comparable to the limbs nor a quantity the digits can instantiate. Invisible, intangible and silent, time is experienced as duration (an internal awareness) and change (an external observation). Duration is highly subjective: time can fly, take forever, or briefly vanish, and what one person experiences can have little relevance to what others encounter in the identical context. Change is greatly variable: 'pebbles roll, the leaves fall, the streams flow, and the animals scurry about. … and the sun moves across the heavens' (Gibson 1975, 297). Yet most things change too imperceptibly or unpredictably to be used as a basis for time. To infer time from change, that change must be recurrent and regular.

The planetary cycles have the requisite characteristics. Our planet spins on a tilted axis and revolves around the sun with an encircling moon, creating daily alternations of light and dark, the yearly round of seasons, and a dependable if more variable lunar presence. However ancient timekeeping might be, the planetary cycles which once patterned prehistoric time continue to pattern it today: months and weeks still reflect the moon's periodicity and four-phased appearance, the year is still based on the planet's orbit around the sun, and intercalary

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periods are still needed to keep the two in sync. Before and without cultural constructs to structure time, we experience the planetary cycles through circadian rhythms of wakefulness and sleep, changes and trends in temperature and weather, and ontogenetic trajectories spanning birth, maturation, reproduction, decline and death.

Despite our shared planetary circumstances and species capacities, not all societies structure time. For the Pirahã, an Indigenous people of Amazonian Brazil, the experience of time is summed up 'with a simple formula: "Live here and now." … Living in the now also fits with the fact the Pirahã don't appear to have a creation myth explaining existence. When asked, they simply reply: "Everything is the same, things always are"' (Daniel Everett, quoted in von Bredow 2006). One way to understand this is by distinguishing time as subjectively experienced (internal, lived, phenomenological, or psychological time) from time as objectively measured (external or physical time) (Degni 2022). The Pirahã undoubtedly experience time subjectively, but they do not measure or count it. Significantly, the Pirahã are better known for another unique trait: They lack a system of numbers, not just an inability to count but the absence of numerical expressions (Everett 2005). While the degree to which the Pirahã are truly anumeric is debated (Gordon 2004), a lack of numbers relates logically to the absence of a structured concept of time: societies which do not count anything do not count time, and counting is a primary mechanism for creating and structuring concepts of time.

Assuming all humans experience subjective time, and taking the absence of objective time as our notional starting point, the present analysis examines how human societies count and measure time and the effects the devices used have on its conceptualization. Our ability to develop concepts of objective time is rooted in several biological–psychological mechanisms. From this foundation, we add, first, the ability to associate naturally occurring phenomena with time, and second, the ability to use material devices to count and measure it. We review key technologies like the *gnomon*, the sundial element which casts the shadow used for daily and yearly time. Through the use of such devices, time becomes objective, and its conceptualization inherits aspects of the physical structures used to represent it.

The biological–psychological foundations of subjective time

Subjective time is informed by several biological–psychological mechanisms which humans share with other species. First are the circadian rhythms, internally generated wake–sleep cycles which keep the planet's inhabitants attuned, more or less, to its cycle of days and nights (Panda *et al*. 2002). This system is sloppy because the sense of time it produces is highly variable; it is also sluggish because an hour as experienced is 1.12 times longer than what the clock measures (Campbell 2014). Other mechanisms are interval timing, a sense of duration spanning fractions of seconds to hours (Merchant & de Lafuente 2014), and temporal discrimination, the ability to discern 'before' and 'after' in stimuli separated by at least several milliseconds (Block 2014). In addition, hormonal mechanisms and physiological responses inform seasonal behaviours like mating, nesting, migrating and coat change (Wingfield *et al*. 1997), matters to which humans are not immune (e.g. seasonal affective disorder).

Beyond these mechanisms is the common neural substrate for time, space and number in the primate parietal cortex, particularly the intraparietal sulcus (Dehaene & Brannon 2011). The right posterior parietal cortex has a critical role in the timing of stimuli from different sensory modalities (Bueti *et al*. 2008). Visuospatial perception, the ability to perceive objects in terms of their physical location in relation to us and to each other which is subserved by the parietal cortex, is also important to the experience of time, as temporal judgements enable motor actions in space (Simmons 2003). Neurons of the intraparietal sulcus, which have also been implicated in visual attention, correlate with processes which relate to time (duration), space (distance) and number (quantity) in monkeys (Leon & Shadlen 2003), species used as human proxies because they are evolutionarily close enough to provide neurological insights, while distant enough to be subjected to invasive techniques. Interruptions to visuospatial input from rapid eye movements ('saccades') compress the visual perception of space and interrupt the visual perception of quantity, thereby altering the perception of duration (Morrone *et al*. 2005). The similarities in these stimulus responses and attentional effects support the idea of a common neurological mechanism (Burr *et al*. 2010), as does *synaesthesia*, a neurological condition in which information from one sensory domain activates unrelated senses, causing them to be experienced simultaneously (Cohen Kadosh *et al*. 2012; Hubbard 2007).

Memory is also important. Impairments to short-term and general memory in conditions like amnesia and Alzheimer's disease decrease both accuracy and precision in the ability to estimate time's passage (Nichelli *et al*. 1993). Working

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memory, the mental ability to hold and manipulate multiple pieces of information in conscious attention (Baddeley 1986), has been implicated in both the subjective experience of time and mathematical cognition (LeFevre *et al*. 2005). Timing and time perception rely on an internal biological clock which outputs time interval estimations into working memory (Gibbon *et al*. 1984). In addition, episodic memory, which stores personal experiences, connects our past to our present and enables us to forecast our future (Tulving 2002). The contents of these different forms of memory then inform decision-making processes (Wearden 2003).

Given these biological–psychological capacities, humans experience time much like other species do. However, we also engage with material forms in unique ways, and it is this engagement which enables us to conceive of time as a substance with structure and other properties.

Timekeeping by natural associations

Timekeeping, the activity of keeping or marking a steady rhythm, begins as the recognition that two things correspond—perhaps the first appearance of particular stars and a part of the year. For example, the Alaskan Alutiiq begin their year in August, naming it (as translated) 'the Pleiades begin to come' (Clark 1974, 75). In southern Africa, the first appearance of the Pleiades resolves 'any confusion over which month it might be' (Macdonald 1890, 194). Two things are in correspondence: an aspect of the natural world and 'time'. The latter is a concept of something intangible and perhaps ineffable; the former is physical and visible, and it gains tangibility and manipulability when a device is used to represent it (Malafouris 2013).

Shadows are environmental features whose recurrent, reliable change is directly related to the planetary cycles; thus, they frequently serve as a proxy for time, illustrating our ability to infer causal relations. Shadows are longest at dawn and dusk, shortest at noon, and move between these extremes throughout the day. A shadow's length and bearing from the object casting it provide a dependable if approximate time of day. Processing shadow information involves perceptual assumptions—for example, that there is a single, relatively stationary light source somewhere 'above'—which enable contextual inferences about the location, movement, direction, trajectory, shape, depth and background of both the light source and the object casting the shadow (Casati & Cavanagh 2019). The abilities to make perceptual assumptions about shadows and infer causal relations from them are demonstrated by both human infants and non-human primates (Imura *et al*. 2006). It is a small but crucial step from such basic perceptual inferences to the other contextual inferences which are the essence of timekeeping by means of natural associations: the sun's height in the sky, the moon's cycles and phases, the recurrence of seasons and stars, the presence and behaviour of plants and animals.

Human societies are motivated to keep track of time because the planetary cycles are informative about upcoming changes in conditions and resource availability, matters essential to survival. A sense of the stakes involved comes from the names given to the months by the Alaskan Aleuts: March is 'when straps are eaten—starvation'; April is the 'end of eating straps' and the 'time for leaving houses'; and May is the 'month of flowers' (Veniaminov 1840, 256–8). At the opposite end of the resourcing spectrum are the names of the months in siLozi, an African Bantu language: January is the month 'when food is so abundant that children eat too much and defecate anywhere'; February is 'when fish can be seen swimming in small pools'; and March is 'the time of flood waters' (Lukusa 2005, 18–19).

Such names do more than reflect, codify and predict natural conditions: They also imply the use of the sun or stars for timekeeping because one month is usually longer than the others, a typical intercalation for keeping such sequences aligned to the solar year. For the Aleut, the eleventh month was longer (Veniaminov 1840), an intercalary strategy akin to adding a thirteenth month every other year, as was practised by the Romans. The use of the moon is also likely as a plausible basis for dividing the year into 12 months. Since lunations shift across the year in the same way weeks do the modern months, a true lunar calendar soon becomes out of sync with the seasons; this suggests the divisor 12 might reflect an older lunar calendar (Nilsson 1920). Twelve could also be coincidental. Seasonally based calendars can have as few as two months; they may count seasons without combining them to produce calendrical years only half a solar year in length, and they can omit certain periods of time altogether, generally those in which little of societal interest takes place (Nilsson 1920). In any case, this type of timekeeping is inexact, relative to astronomically or mathematically based calendars. As noted for the Yuki, a North American people with a seasonally based calendar, the named month was 'not to be taken literally—it [was] simply the informant's guess of the approximate time of year' (Foster 1944, 202).

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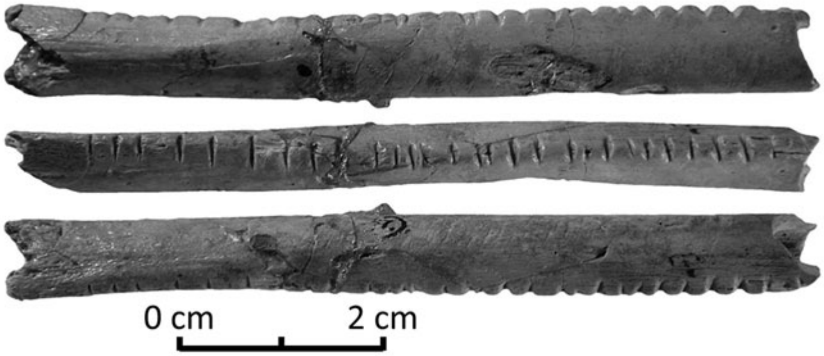


Figure 1. *Engraved baboon fibula from Border Cave, South Africa (three views). (Image from d'Errico* et al. *2012, supporting information, fig. 8, © PNAS and used with permission.)*

Another motivation is the usefulness of time. In the Kalahari, time is used to estimate the distance covered in walking, with speed and distance contextualized by gender and purpose: A woman gathering walks more slowly and covers less distance (1–2 km/hour) than a man does hunting (6–7 km/hour) (Silberbauer 1981). Total distance is 'expressed as the number of nights one would sleep while making the journey, and fractions of a remaining day are indicated by pointing to the position in the sky of the sun' expected on the traveller's arrival (Silberbauer 1981, 98). Here we find both counting and natural associations: completed days are marked by the arrival of night, and the approximate time of a partial day is expressed by the sun's expected location. Such gestural indication is a tropical practice; this is unsurprising, given the variation in daylight and the sun's height from summer to winter in temperate and polar zones (Nilsson 1920).

When timekeeping might have emerged is a question on which the archaeological record is mostly silent, as the kind of natural associations used as early calendars leave few material traces. However, tools like traps and snares, whose yields occur in a future which involves remembering where they were placed in the past, imply the ability to envision past and future (Coolidge & Wynn 2018; Tulving 2002). Archaeological evidence suggests traps and snares were in use by 75,000 years ago (Wadley 2010).

Artefacts which hint at timekeeping begin to appear around 40,000 years ago as pieces of inscribed bone. Lunar timekeeping is suspected whenever the incisions total 28–32 in number, or are organized into groups in this range, as it corresponds to the moon's observed periodicity (Marshack 1985; 1991). An example is the Lebombo bone, a baboon fibula engraved with 29 marks from Border Cave, South Africa, dated to 42,000 years ago (Fig. 1). However, its lunar interpretation is doubtful, for several reasons. First, the bone is broken off at one end, raising the possibility the total number of notches was originally greater than 29 by an unknown amount. Second, the artefact is only 76 mm in length (d'Errico *et al.* 2012) with infinitesimal incisions (1.5–2.5 mm), sizes suggesting it likely served a personal purpose, whereas notations which serve purposes like timekeeping tends to be public (Hayden 2021). Third, while the artefact has a glossy surface indicative of long-term curation (d'Errico *et al.* 2018), there are no physical signs it was used as a calendar. That is, to function for keeping time beyond a single lunar cycle, permanent incisions would need to involve some method of incrementation, but no traces of two likely methods, colouration and fibre wear, have been reported (Overmann 2023). Finally, for contemporary artefacts of similar appearance whose meaning has been interpreted by knowledgeable cultural informants, around 30 marks can mean 'all' of a category of items (Kelly 2020), rather than the number of lunar nights.

Another artefact with potential relevance to prehistoric timekeeping (Fig. 2) comes from Abri Blanchard, a site near Sergeac, France. The marks on this artefact, a piece of reindeer bone 11 cm long dated to 35,000 years ago, form a serpentine figure which resembles the lunar analemma, the trace of the different heights to which the moon rises over successive nights during a period of several months (Jègues-Wolkiewiez 2005). Their individual shapes also suggest the moon's phases (Marshack 1991). The majority (65 of 69) of marks on the artefact fit the predicted pattern; the remaining four were likely a mistake (Jègues-Wolkiewiez 2005; Rappenglück 2013), a reasonable hypothesis given the overall conformity. Since counting lunar nights does not require characterizing the moon's varied height or its waxing–waning change, the artefact seems not to represent timekeeping *per se*. Nonetheless, if the interpretation is correct, the artefact implies a

Figure 2. *Engraved reindeer bone from Abri Blanchard, France. (Image: CC BY-SA 4.0 with added scale.)*

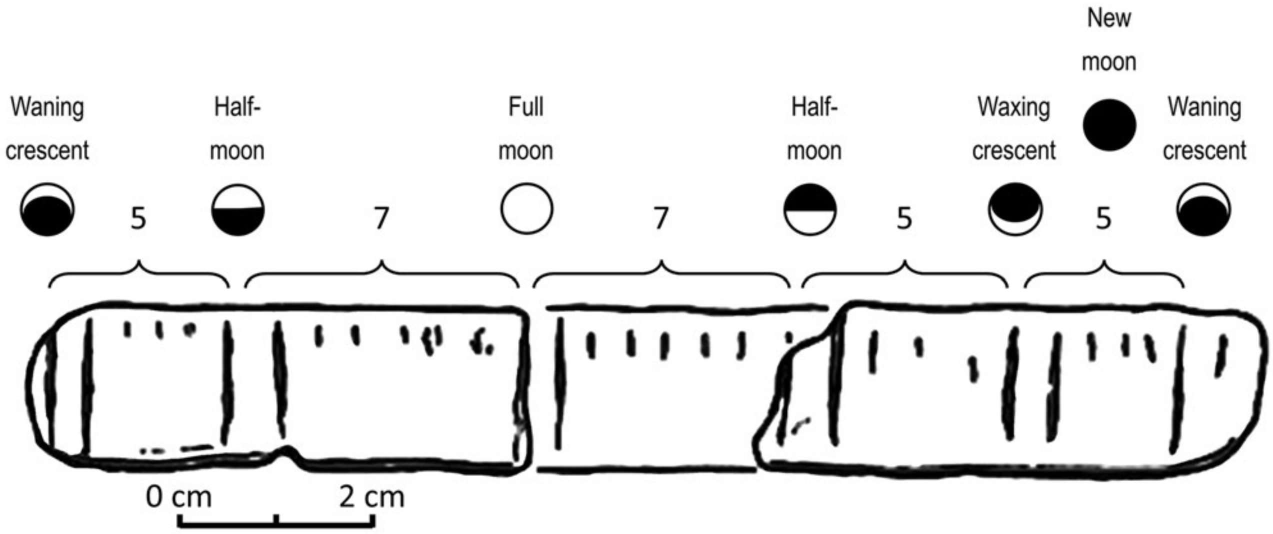


Figure 3. *Engraved marlstone rod from Dolní Věstonice, Czech Republic. (Redrawn and adapted from Emmerling* et al. *1993, 153 fig. 1 & 156 table 1.)*

dedicated skywatcher, suggesting the development of specialization and a degree of sedentism, since the observations were made from a stable location over a period of several months. Certainly, a specialist keeping watch on the moon suggests a society likely to have used the lunar cycles for timekeeping.

A third hint of Palaeolithic moon-watching comes from Dolní Věstonice in the Czech Republic (Fig. 3). Dated to 26,000 years ago, this grey marlstone rod 13.0 × 1.7 × 1.0 cm in size was reconstructed from multiple fragments; 30 long and short marks form groups of 5, 7, 7, 5, 5, possibly indicating the different luminescence conditions created by the new crescent, waxing half-moon, full moon, waning half-moon and disappearing crescent (Emmerling *et al.* 1993). The artefact implies specialization, as the Abri Blanchard bone did, and its notational groupings suggest a concern with the availability of moonlight throughout a lunar month, perhaps in support of forecasting conditions suitable for night-time activities. The groupings also show that interpreting prehistoric markings requires astronomical insight beyond simply knowing the number of lunar nights. Nonetheless, while the interpretation is astronomically plausible, it too remains speculative.

The marks and dots which often accompany paintings in the Upper Palaeolithic caves of France and Spain may have recorded information about the lifecycles of animals used for food, particularly mating and birth (Bacon *et al.* 2023). However, in contemporary cultures, similar marks often represent hunting kills (Nilsson 1920). Further, contemporary cultures are not associated with calendars that are notational in form, seasonally organized and focused on animal lifecycles. Instead, contemporary cultures tend to count time with tallies which accumulate lunations for purposes involving human social matters like pregnancy duration, and by the time calendars are written, they are no longer seasonally based. On the other hand, uniqueness does not completely exclude the possibility prehistoric peoples tracked animal lifecycles using notations. Certainly, the proposed interpretation would be consistent with the specialization, sedentism, notational adeptness and lunar concerns implied by the Abri Blanchard and Dolní Věstonice artefacts. Nonetheless, when artefactual meaning is opaque and there are no cultural informants to provide reliable insight, such interpretations remain speculative. Additional criticisms are offered in Nowell *et al.* 2024.

These devices imply the practice of timekeeping may be quite old, but they do not establish whether or when it had emerged or the form it first took. Nonetheless, they raise the question of why human societies might incorporate such devices into the cognitive system for time. A reasonable answer is this: although the natural and celestial phenomena used for timekeeping are features of the world, they are not yet features which can be touched and manipulated in the way bones and marks can be. It is to unambiguous timekeeping by means of such devices we now turn.

Counting and measuring time

The use of tallies for timekeeping is common among contemporary societies. These devices involve correspondences in the same way natural associations did, except they represent them in a way which depends less on memory and context. A mark generally means a unit of time, often a completed day. Time marked by tallying might be used to estimate distance in travel, typically the amount of ground covered in a day's worth of walking. For example, an Australian Wathaurung messenger painted his arm with 14 stripes of mud, one for each day of his journey across the Outback (Morgan 1852).[1] On his return trip, he would erase a stripe each day. Numbers *per se* were not involved in this quantification of time: some 50 years later, the Wathaurung number system still counted no higher than *three* (Mathews 1904). However, the absence of higher numbers was no challenge, since it is difficult to imagine the stripes themselves or the days they enumerated as being individuated in a way requiring either to be named. That is, each stripe did not mean a particular day had passed or needed to be individually recalled; rather, each stripe meant another day had passed and the return journey would need to include a corresponding day (Overmann 2023).

Another common form of tally was noted for the Siuai of Papua New Guinea: 'In setting a date for, say, a feast, the host sends to each of his principal guests a palm frond having a number of leaves equal to the number of days before the feast. Thereafter, the host and his guests tear off one leaf each day to mark the passage of time before the feast' (Oliver 1955, 98). Like the Wathaurung example, this form of tally need not involve counting *per se*, since determining 'whether two collections have the same number of terms' does not require 'defin[ing] what that number is' (Russell 1920, 15). Whether or not counting is involved, such material forms keep track of an interval of days with an accuracy and precision which natural associations and human memory cannot match. The information remains public, while becoming dispatchable. The incorporation and use of such devices occasions new relations (e.g. associations between days and device) and social behaviours (setting future dates; daily interaction with the device).

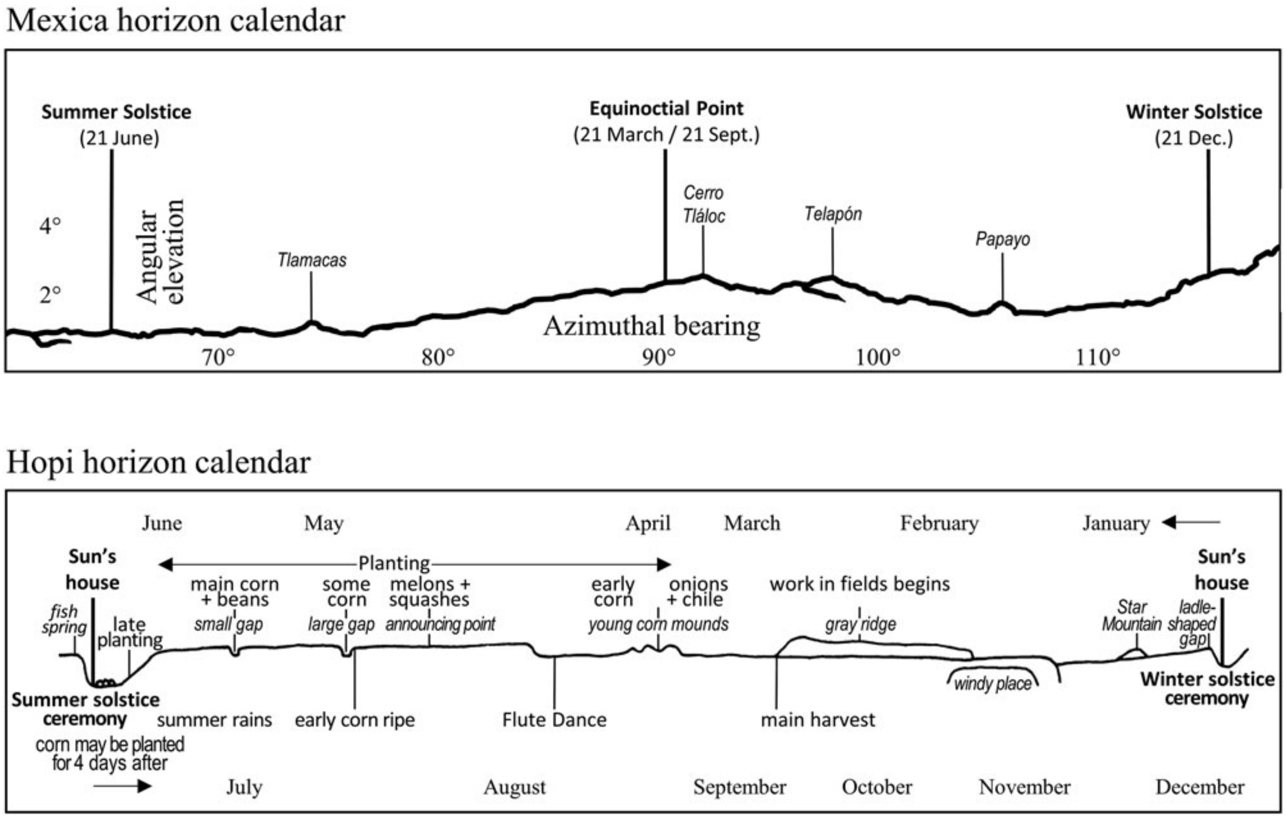
The solar year and intercalation periods

Tallying works well for solar days and lunar months, but the solar year requires different strategies. One is the horizon calendar (Fig. 4), which involves observing where the sun rises (or sets) on the horizon over the course of a year, activity which implies specialization and profound sedentism. In the northern hemisphere, the sun achieves its furthest horizonal positions north and south at the summer and winter solstices (respectively, 21 June and 21 December). Where the sun rises on the eastern horizon is compared to its major landmarks; these alignments inform agricultural activities and time annual rites and celebrations (Ezcurra *et al.* 2022; Forde 1931; Zeilik 1985b).

Close observation of the sun is essential to resolving the mismatch between the lunar and solar cycles. One lunar phase cycle, defined as one new moon to the next, is 29.5 days, a number which does not evenly divide a solar year of 365.2 days. When societies which keep time by the moon notice the mismatch, they tend to repeat or skip a lunar month to bring them back into sync (Nilsson 1920). A formal intercalation period eventually develops to keep the cycles synchronized. For example, the Babylonians and Romans periodically injected a thirteenth month to keep their lunar months aligned to the solar year (Parker & Dubberstein 1956; Warmington 1940). In comparison, the Maya divided the solar year into 18 (non-lunar) months of 20 days; to keep these cycles aligned, a five-day month was appended to the year's end to bring the total to 365 days (Stanzione 2003).

Time changes when it is counted and measured

As numbers elaborate, societies begin using them to count things never counted before, including time (Overmann 2013). For example, the North American Quinault used knotted cords (a form of tally) to count lunations, menstrual cycles and the amount of time between a marriage and the birth


Mexica horizon calendar

Hopi horizon calendar

Figure 4. *Horizon calendars. (Top) Basin of Mexico as viewed from Templo Mayor (19°N). Where the sun rises along the horizon shifts north and south between the solstices, with the equinoxes falling midway between the two. (Redrawn and relabelled from Ezcurra* et al. *2022, 4 fig. 2c; also see Aveni 2001, 242–3.) (Bottom) Eastern horizon from Shungopavi, Second Mesa (36°N), as originally drawn by an Indigenous informant. The annual planting cycle corresponds to the sun's rising position as read right-to-left along the top, then left-to-right along the bottom. (Redrawn and relabelled from Forde 1931, 386 fig. 6b; translations from McCluskey 2021 and pers. comm. 29 December 2023 and 4 January 2024.)*

of a couple's first child in order to establish the heir's legitimacy (Olson 1936). Societies also begin counting human age, either characterizing it in relation to events which identify a specific year or counting it by the number of winters which have passed since birth. In comparison, the Andamans Islanders had 'no means of counting, and no words to express gradations of time … They take no interest in the passing of years, and have no idea of their own age' (Cipriani & Tayler 1966, 151). This does not mean people in societies which do not count time fail to notice change in, for example, their own bodies, for such things are often formalized with public rites transitioning juveniles to adulthood. Rather, it means time is unlikely to be conceived as a structured substance until it is counted.

Counting time gives structure to its conceptualization. The Pirahã, a society which lacks numbers, live in the present 'now' and lack an origin myth (Everett 2005). Once time begins to be counted, a period of the past identified as 'many ago' emerges (Gusinde 1931). As numbers elaborate and the counting of time continues, the long ago and the present eventually yield to a tripartite division: the present time, a mythic past, and an intermediate period which loosely encompasses the last few hundred years (Overmann 2013). However, as time passes, the intermediate period may not become longer or the mythic past more remote from the present (Gell 2020). Nonetheless, counting time not only makes time into a substance which can be counted, it gives it an overall structure. Societies become able not merely to count their days, but also to conceive time as something structured as today, history, and myth.

Harnessing the shadow to visualize time in spatial terms

A common strategy for making the passage of time visible and measurable, as distinct from counting

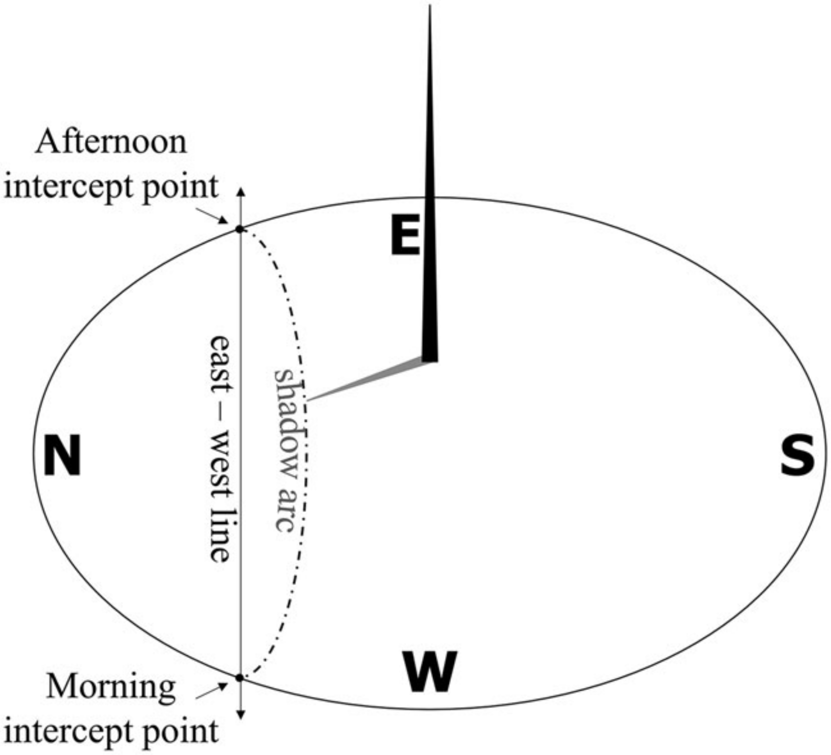


Figure 5. *Gnomon used for cardinal alignments. (Image: author.)*

the recurrence of cycles, involves the shadow. Typically, visualization and measurement involve a *gnomon*, the shadow-casting piece in a sundial. A gnomon can be as simple as a stick set into the ground, so it easily falls within the technological repertoire of even very early societies (Tyson 2003). Beyond indicating the daylight hours, shadow lengths, when closely measured, enable detection of *solstices*, the year's longest and shortest shadows; *equinoxes*, equivalent midpoint shadows between the solstice extremes; and *latitude*, a variable informing shadow length. Solstices and equinoxes delimit the solar year, which is generally calculated from solstice to solstice or from equinox to equinox. Latitudinal variability enabled the Greek mathematician Eratosthenes to deduce the planet's circumference in the late first millennium BCE (Orzel 2022). A gnomon can also be used to determine the four cardinal directions (Fig. 5). A circle is drawn around the gnomon, as guided by a string attached to its base, and the points where its shadow crosses the circle in the morning and afternoon are marked; a line through these points runs east–west, while a line placed perpendicular to it runs north–south (Kelley & Milone 2005).

Evidence of ancient shadow use is found across the globe in the form of gnomons and sundials, textual records of shadow recordings, and cardinal alignments in monumental constructions. One of the oldest artefacts was discovered in Egypt's Valley of the Kings about a decade ago (Fig. 6). Dated to the second millennium BCE, this limestone slab measures 17.8×15.2×3.3 cm and contains a hole for a gnomon surrounded by an ink semicircle divided to convert the shadow into hours (Bickel & Gautschy 2014). It was found on the floor of a workman's hut surrounded by limestone chips with sketches and short inscriptions, a context suggesting it regulated the workdays of the artisans who decorated the Valley's tombs (Bickel & Gautschy 2014). The semicircle is marked to make the hours fairly equal in duration, with the exception of a longer sixth hour (12.5 on the figure), which perhaps encompassed a midday break (Vodolazhskaya 2014). The method of marking the hours, along with context of the sundial's findspot, suggest such artefacts were used to regulate daytime activities in the manner of the analogue clock, its technological descendent.

Tables of shadow lengths for solstices and equinoxes, measurements used in astronomy and divination, are attested in Mesopotamia towards the end of the second millennium BCE (Rochberg 2010). Other Babylonian texts describe how to construct a sundial: a gnomon was to be set up on a stone slab; its lines were drawn according to its morning

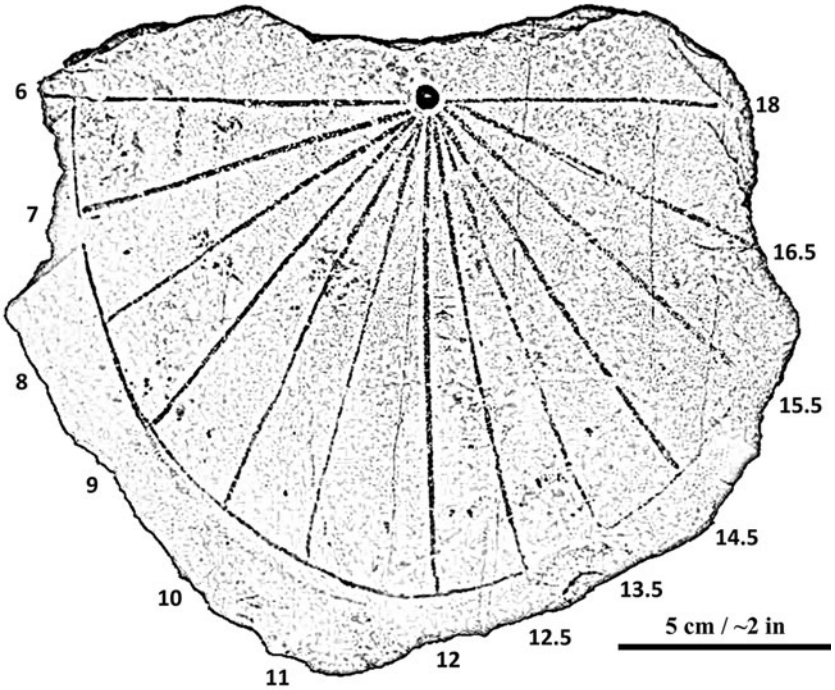


Figure 6. *Vertical sundial from the Valley of the Kings. (Redrawn and relabelled from Vodolazhskaya 2014, 3 fig. 2 & 6 fig. 5.)*

and noon shadows as the longest and shortest of the day, with the solstice shadows giving the longest (winter) and shortest (summer) shadows of the year (Rochberg 2010). As reconstructed, the Babylonian sundial corresponds to something recorded by the Greek historian Herodotus: 'the sun-clock and the sundial, and the 12 divisions of the day, came to Hellas from Babylonia and not from Egypt' (Herodotus II:109; as translated in Godley 1922). The 12 divisions of the Babylonian day applied to the period between sunrise and sunset, with two successive sunrises comprising a 24-hour cycle—a conceptualization still in use today, albeit starting at midnight (or sundown) and with hours of equal duration. These records and their complex mathematical applications suggest Babylonian shadow use was much older than the second millennium BCE.

In China, gnomonic observations ensured the imperial calendar was accurate and precise. These attributes were critical to governance, as the divine mandate of the emperor, the 'Son of Heaven', was considerably weakened if the moon and sun failed to obey the calendar; after all, why should peasants 'pay taxes and serve in the army if the emperor didn't know the secrets of the heavens?' (Aslaksen 2003, 34). The oldest Chinese gnomon found to date, a painted stick dated to 2300 BCE, comes from Taosi, northern China (Li 2015). There is textual evidence of early gnomon use: shadow lengths were recorded in the *Zhoubi suanjing* (*Gnomon of the Zhou Dynasty*), representing observations made around 2000 BCE (Li 2015). Errors suggest its intermediate shadow lengths were derived rather than measured, as adjusted by the *cun qian li*, a heuristic for correlating shadow length with latitude which was vital to synchronizing imperial timekeeping across a vast empire (Li & Sun 2009). The heuristic said the shadow of a gnomon 8 *chi* tall (~1.96 m) increases by 1 *cun* (1⁄10 *chi*) for every 1000 *li* (about 400 km) of movement north; it decreases by the same amount when moved south (Li & Sun 2009). In comparison, changes in longitude affect time, with each degree of movement adding (west) or subtracting (east) about four minutes, relative to the original longitude (Sobel 2007). As was true of Mesopotamia, these records and complex mathematical applications suggest Chinese shadow use significantly predates its appearance in artefactual and textual forms.

Among the most famous architectural alignments with the sun are the pyramids at Giza, built during the third millennium BCE; the four corners of their bases point precisely east–west and north–south. Pyramidal alignments honoured the sun god Ra, ancient Egypt's most important deity, with the east–west direction marking the trajectory from birth to death which terrestrial life shared with Ra's daily transit across the sky (Wilkinson 2017). In Babylon, the four corners of the Ziggurat of Ur, an elevated brick platform used as temple and celestial observatory during the third millennium BCE, were oriented towards the cardinal directions (Woolley 1924), as were the so-called Chinese pyramids used as royal tombs in the first millennium BCE (Magli 2018). In Europe, Stonehenge (2000–3000 BCE) and Newgrange (3200 BCE) were built with solar alignments: Stonehenge looks to the place on the horizon where the sun rises on the summer solstice and sets on the winter solstice, while Newgrange contains a special 'roof-box' which admits the sun on the winter solstice, the only sunlight to reach inside the chamber during a year (Orzel 2022). In the New World, architectural alignments are found at Chichén Itzá, Yucatán Peninsula, where the Pyramid of Kukulcán (1000 CE), 'the feathered serpent god of rebirth and creativity', produces striking equinoctial interplays of sunlight, shadows, stairs and carvings which suggest an enormous serpent descends its northern stairway (Aveni *et al*. 2004, 123). In Machu Picchu (1450 CE) and Cusco (1100 CE), Peru and Chaco Canyon, New Mexico (900–1150 CE), buildings and streets align with solstices and equinoxes, publicly marking the timing of annual celebrations and notable events (Aveni 2001; Dearborn & Schreiber 1986; Sofaer 2007; Zeilik 1985a).

The ancient astronomical traditions share the incorporation of celestial phenomena into *cosmologies*, culturally constructed ways of understanding how society, nature and the divine are interconnected (Iwaniszewski 2009). They also differ, first, by the effect of latitude on the sun's geometry, and second, by the presence or absence of writing. In the temperate zones, stars circle the celestial pole, so 'either the celestial equator or the ecliptic [becomes used] ... as the fundamental reference plane' (Aveni 1981, 163). In the tropics, the sun passes directly overhead at certain times of year, so the astronomical frame of reference is based on zenith (the point directly overhead), nadir (its subsurface point), and the horizon (Aveni 1981). Novel technologies exploit the zenith: a hollow vertical tube will admit sunlight into a chamber on zenith dates; these alignments permitted a more precise estimation of the equinox, relative to shadow measurements (Aveni 2001). As for writing, Mesopotamia, Egypt, China and Mesoamerica were the epicentres of original writing systems where literacy and mathematics developed, enabling the recording of astronomical data and the calculation and prediction of celestial movements and events. In comparison, European and North American astronomy was performed by oral societies which preserved their celestial observations as directional alignments in monuments, architecture and roads.

The visualization of time

Clocks and calendars represent time in spatial terms to help us visualize, codify and organize it (de Smedt & de Cruz 2011). Where clocks make visible the time of day, calendars visualize longer cycles—months and years. Cross-culturally, calendars are differentiated by the specific celestial features used as their basis, the strategies employed to keep the cycles in sync, and whether the cycles are astronomically observed or mathematically calculated. Calendars come in three basic types: solar, lunar and lunisolar. A solar calendar is based on the planet's orbit around the sun, as assessed by its effects on the solar geometry: the mechanical properties and alignments which produce the solstices and equinoxes, seasons, and annual recurrence of stars. Sub-divisions need not be lunar (e.g. the 20-day months of the Maya solar calendar). A lunar calendar is based on the moon, as marked (for example) by the first appearance of the new moon; this yields a period of 29.5 days. Since 'a half day cannot be observed, and since weather may obscure observation', the lunar month, as observed and recorded, can range from 28 to 32 days (Marshack 1985, 31). As lunations do not evenly divide the solar year, a lunar calendar is not aligned to it. A lunisolar calendar uses both solar and lunar cycles and must find a way to keep the two in sync, since there are more than 12 but fewer than 13 lunations per solar year.

Calendars can take different physical forms. A calendar can be a sequence of conditions and activities, as for example, the Aleut and Bantu months whose names describe, codify and predict recurrent aspects of the natural and social worlds. The names form an *ordinal sequence*, a progression of invariant elements (e.g. months of the year; days of the week; the counting numbers) subserved by a dedicated neural network (Cohen Kadosh & Gertner 2011). A dedicated neural network is the kind of evolutionary change which typically occurs over a long period of time, and this suggests human societies began forming such sequences at a fairly remote time in prehistory. Ordinal sequences are also *overlearned*, which means they become fixed in memory in a way which makes them resist the normal processes which change memorized information and word forms (an examination of these effects in the counting numbers *one* through *five* is provided by Pagel & Meade 2017). These attributes not only ensure the continuity of such sequences, they also connect their present forms to their past forms and explain their persistence.

Sequences of marks like the Wathaurung mud stripes and Siuai palm fronds form calendars, with each mark (stripe or frond) meaning one day's worth of time. Made of perishable materials, these ad hoc devices synchronize activity within short, specific temporal contexts, typically days or weeks separating related social events: embarking upon and then returning from a journey; scheduling and later celebrating a ritual. Such devices could potentially be made of durable materials. As mentioned earlier, a durable calendar accumulating lunar nights implies the ability to display and predict the completion of subsequent cycles. Such employment would reasonably involve a method of incrementation similar to those used with the Wathaurung stripes and Siuai fronds.

Shadows used to indicate time of year form calendars. The apparent motion of the sun slows down at the solstices, the points where it stands still (*solstitium*) and then turns in the direction of its movement (e.g. Fig. 4). On a sundial, if the distance between the solstice shadows is evenly divided, the months around the solstices will be longer in their number of days, those at the equinoxes shorter. The Javanese solar calendar illustrates the effect: of the 12 months in the calendar, those centred around the solstices are 41–43 days long, those centred on the equinoxes just 23–27 days (Aveni 1981, 167). The same solar geometry affects daily timekeeping, as equidistant marks produce unequal hours. To make the hours equal in duration, marks must be unevenly spaced, with those centred on noon placed closer together, those towards sunrise and sunset spaced more widely apart (e.g. Fig. 6).

Landscape can be a calendar, implying a society which is sedentary. Calendars formed from the natural landscape are shown in Figure 3. Calendars formed by cultural landscapes include megaliths (Newgrange, Stonehenge), pyramids (Egypt, Mesopotamia, China), and architecture and roads (Chichén Itzá, Cusco, Machu Picchu, Chaco Canyon). The large earthen mounds raised in Cahokia, North America (*c.* 1100 CE) bridge the natural and cultural landscapes (Aveni 2001). All these structures were aligned to represent and highlight various solar, lunar and celestial phenomena in ways which were public and impressive (Aveni 2001).

A calendar can be a circle, a form evoking the movement of a gnomon's shadow, the curve of the natural horizon, the sun's arc through the sky, and the rotation of stars around the celestial pole. Megaliths like Stonehenge are typically circular in their layout, reflecting and perhaps representing the horizon (Aveni 2001). The stones at Wurdi Youang, an Australian site possibly more than 11,000 years old, are also roughly arranged in a circle (Fitzsimmons 2016; Hamacher & Norris 2011). The Aztec calendar stone, an impressively carved piece of basalt some 3.6 m in diameter housed in Mexico City's Museo Nacional de Antropologia, reiterates the circular shape. The centre of the circle depicts a deity, perhaps the sun god Tonatiuh, the earth god Tlaltecuhtli, or a hybrid of the two (Villela *et al.* 2010). The deity is encircled by glyphs representing the 20 days of the Aztec month, and then by rings representing eclipse markers, solar rays, full moons and the cardinal directions. These cosmological themes suggest the calendar functioned to visualize time, rather than indicate it observationally in the way the circles at Stonehenge and Wurdi Youang did.

Finally, a calendar can be written, a development necessarily following the invention of writing. A written calendar is typically a table, a form permitting specialists to organize, compare and analyse data on shadow lengths and celestial movements. Tables are found in the calendrical traditions of the Near East, China and Mesoamerica. Tables are also the direct precursor of the modern calendar. An early example is the Fasti Antiates Maiores (Fig. 7), a table 1.16×2.50 m in size painted on a wall of the ancient Roman city of Antium and dated to 84–55 BCE (Hannah 2013). It consisted of 12 months of 28, 29, or 31 days organized into eight-day weeks; a thirteenth intercalary month of 27 days was inserted every other year, producing alternating years of 355 or 377 days long (Warmington 1940). This table was accompanied by a list of consul names, juxtaposing the calendar's cyclical time with a linear sequence of historical events (Feeney 2007; Laurence & Smith 1996). The list reflects a developing trend towards numbering years consecutively instead of restarting their count with each new ruler's reign. Consecutive numbering would eventually become anchored by a specific event (e.g. Gregorian, Islamic and Hebrew) or cycle (e.g. Chinese and Maya).

The material component of time and its conceptual influence

Human thinking reflects the material circumstances of its evolution. Our thoughts are not merely 'about' the world and its various parts and properties; our cognition is specifically adapted to the planet we live on and the kind of species we are—for example, our sensory and perceptual systems are

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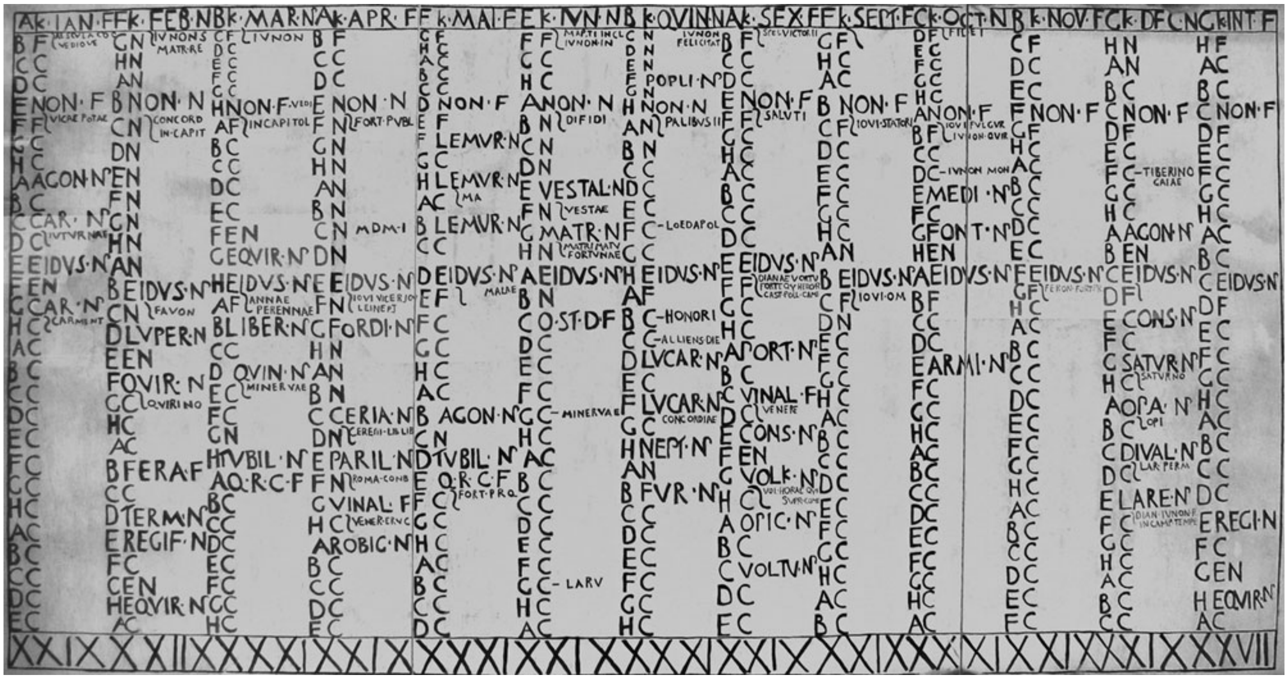

Figure 7. *Fasti Antiates Maiores (as reconstructed). The top row lists the first day of each month and the month names (January–December plus an intercalary month). Days are marked A–H (eight-day weeks); also marked are the* Kalends *(first day of a month),* Nones *(new moons), and* Ides *(full moons) (Warmington 1940, 453–65). The bottom row lists the number of days in each month. (Image: CC BY-SA 4.0.)*

adapted to detect and extract information from our natural and social environments. Thus far, these are not contentious positions. It is more radical to see material forms not as merely the object, context or stimulus of our thinking, but as a constitutive component of it (Malafouris 2013). One way to approach this is to see our use of material forms as rearranging the world in ways which let us make different sense of it. In this approach, rather than being the passive recipients of our mental content, material devices are a domain which co-creates our thinking as it interacts with our brains, bodies and behaviours.

We are looking for signs of material influence on our concepts of time, similar to those found in numbers and space. In numbers, our concepts are fundamentally and pervasively structured by the use of the hands as the first contiguous device used for representation and expression; the structural properties which emerge from using the fingers in counting include discreteness, stable order, linearity and productive grouping (Overmann 2023). Complex concepts of numbers which lack these properties are almost inconceivable, not just because these properties are the reason the concepts are complex, but also because it is difficult to imagine what complex numbers would be like without such properties—if they were even possible. It is similarly difficult to imagine what sort of thing space would be if it were not measured and parsed in units like feet and metres. For time, a parallel hypothetical case would need to be independent of the planet we live on and our biological–psychological capacities for subjective time. Whatever this hypothetical construct might be, it would surely be far removed from time as we currently conceive it. The best we seem able to do is envision counterfactuals—time travel, enchanted sleep, heavenly eternity—which imagine an escape from time's parameters but do not challenge its nature as conceptualized.

We conceive of time as structured into days, months and years. These divisions are unambiguously related to the planetary cycles whose recurrent, regular change provides their foundation. Clocks and calendars enable us to visualize these cycles as past, present and future. Further, incorporating and using material devices for this purpose harnesses their power to accumulate the cognitive effort of past individuals and generations and distribute it to new individuals and future generations (Hutchins 1995; Overmann 2023). In this way, the prehistoric gnomon directly supports the later invention of the sundial and analogue clock, just as its reliable indication of the sun's movement underpins the subsequent emergence of explicit notions of time of day and year.

Cultural conceptualizations of time endow it with further attributes: First is *motion*, which characterizes whether it is time itself or the perceiver which moves. This motion has *direction*, typically a circular or linear flow. This flow has an associated *pace*, which is either fast or slow; it also has an associated *duration*, the length of its elapse between successive events. Finally, time has a *frame of reference*, in which event sequencing or temporal ordering is ego-centric or absolute. These attributes are reasonably traced to the material means by which time is visualized, counted and measured. For example, when represented by a gnomon, attributes like pace and duration become objective and public, where they were once subjective and personal. Many of the phenomena used for time are circles or partial circles: the sun's disk and its daily arc across the sky, the face of the moon and its rise and set, the celestial rotation of stars, the circular sweep of shadows. Circular or cyclical conceptualization of time are common, found in ancient societies like the Babylonians and Maya and contemporary societies like the Nuer, Gawa and Hopi (Closs 1977; Evans-Pritchard 1939; King 1912; Munn 1992b; Whorf 1950). In this regard, the linear conceptualization of time more prevalent in Western societies stands out as unusual, although—since calendars and clocks are cyclical in nature, genealogies and king lists linear—the two constructs often coexist (Munn 1992a).

The material forms used as proxies for time influence these conceptualizations in other ways. Counting and measuring create and delimit periods of time. Periods excluded from this process are essentially timeless: they are literally outside of time, like the (uncounted) months which separate the (counted) monsoon seasons in the Bismarck Archipelago or the (uncounted) dark nights before the new moon reappears (Nilsson 1920). Other attributes are dichotomous: time is concrete or abstract, immanent or transcendent, process-linked or homogeneous (Gell 2020). Years identified by memorable events (e.g. catastrophes, battles, political matters) are 'concrete', individuated and specific to cultural groups in ways years labelled numerically are not. The sunrise on an ancestral horizon, shadow of a megalith, and city calendar painted on the forum wall tether time to place in a way quite distinct from time as represented by a wristwatch or other portable or interchangeable device. And time linked to specific agricultural and ritual events (Fig. 4) involves cultural knowledge and governs societal behaviours in ways the time used to synchronize today's global networks does not.

In these dichotomous qualities, we find another similarity between time and numbers, especially in the notion conceptualizations are either concrete or abstract. In numbers, the distinction distinguishes numbers which are attached to an object being counted ('concrete') from numbers which are not so attached ('abstract'). In making this distinction, the material forms used to represent the concepts are often overlooked. As the mental representation of numbers is highly perishable and their mental manipulation is relatively limited, the necessity of using material forms for representing and manipulating keeps numbers bound to them, no matter how elaborated numbers become (Overmann 2023). What does change are the number and type of material forms involved in representing and manipulating; for example, numbers represented by only the fingers, as in a digit-tally system, are tied to that material form in a way numbers represented by fingers, tallies, tokens like coins, and written notations are not. As various material forms are recruited into the cognitive system, concepts become distributed over multiple forms, becoming functionally independent of any particular form (Overmann 2019). Elaboration of the material component of time—for example, adding sundials, obelisks, water clocks, candles, hourglasses, calendars, chronometers, grandfather clocks, pocket watches, wristwatches, stopwatches, atomic clocks and the apps on our phones—surely realizes a similar effect: time as conceptualized becomes seemingly independent of any particular technology, while depending on them as the means of its visualization and manipulation.

Since time first began to be time, we have thought of it as fixed. However, improved measurement technologies and techniques show the planetary cycles are not quite as stable as assumed. The planet's rotation changes daily by a fraction of a millisecond; that change is not invariably slower but has recently sped up, so intercalary adjustments will now require subtracting time and not just adding it, a possibility 'never . . . foreseen or tested' (CGPM 2022). The solar geometry is also changing. The moon is shrinking in size; the planet both expands and contracts (Tsuchiya *et al*. 2013; Watters *et al*. 2019). Every year, the moon moves 4 cm farther from the planet, which in turn moves 15 cm farther from the sun (Krasinsky & Brumberg 2004; Williams & Boggs 2016). Every moment the planet occupies a different position in space, relative to the solar system, galaxy and universe, so the background of stars changes over time (Aderin-Pocock 2022). All this takes place in a universe which has been expanding from the moment of its birth some 14 billion years ago (Hawking 1995). While each of these changes is infinitesimal, they are cumulatively relevant. Time which depends on where the planet is and what it happens to be doing is a different concept of time, relative to what our ancestors thought it was.

On the other hand, this kind of materially influenced conceptual change is exactly what we should predict, if the material forms used to count and measure time indeed influence how we conceive it. The question we have asked here is whether our cultural conceptualizations of time are structured by the material forms used for its visualization and manipulation in ways similar to those found in space and numbers. We have argued the answer is 'yes', with the incorporation and use of material devices providing both opportunities and a mechanism for them to influence the concepts they represent and help to explicate.

Note

1. The account comes from John Morgan's 1852 biography of William Buckley (1780–1856), a transported convict who escaped and lived with the Wathaurung for over 30 years. While some elements of Buckley's story were fantastical and were probably intended to provoke interest, his account is held to describe Indigenous Australian life accurately (Curr 1886; Flannery 2017; Tipping 1966).

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Karenleigh A. Overmann
University of Colorado
Colorado Springs
1420 Austin Bluffs Pkwy
Colorado Springs, CO 80918
USA
Email: karenleigh.overmann@keble.oxon.org

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Author biography

Karenleigh A. Overmann directs the Center for Cognitive Archaeology at the University of Colorado, Colorado Springs. She earned her doctorate in archaeology at the University of Oxford as a Clarendon scholar in 2016. Her most recent book is *The Materiality of Numbers* (Cambridge University Press, 2023).