

# The tangle of space and time in human cognition

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**Everyday concepts of duration, of sequence, and of past, present, and future are fundamental to how humans make sense of experience. In culture after culture, converging evidence from language, co-speech gesture, and behavioral tasks suggests that humans handle these elusive yet indispensable notions by construing them spatially. Where do these spatial construals come from and why do they take the particular, sometimes peculiar, spatial forms that they do? As researchers across the cognitive sciences pursue these questions on different levels – cultural, developmental – in diverse populations and with new methodologies, clear answers will depend upon a shared and nuanced set of theoretical distinctions. Time is not a monolith, but rather a mosaic of construals with distinct properties and origins.**

‘If men... did not have the same conception of time, space, cause, number, etc., all contact between their minds would be impossible, and with that, all life together.’ Emile Durkheim ([1], p. 17)

## Investigating everyday time concepts

The human story, as it has unfolded over thousands of years in different parts of the world, has largely centered on everyday activities like food gathering and preparation, tool making, shelter construction, and the anticipation and observation of rites and rituals. These and other basic human endeavors depend for their success on a robust understanding of temporal relations. Yet, time is as elusive as it is fundamental. The familiar ‘past’, ‘present’, and ‘future’, for instance, are not directly observable, but are central to how humans parse experience. How do humans understand such notions and where do these understandings come from? As a starting point, it may be tempting to search for answers directly in human biology and perhaps specifically in the neural underpinnings of time perception. Time perception, however, must be distinguished from time ‘conceptualization’, in the same way that thermoperception must be distinguished from the everyday conceptualization of temperature. Time perception and time tracking are ubiquitous in nature, occurring independently of human conceptualization. Organisms from amoebas to

crocodiles to human beings have all evolved a variety of fundamentally different mechanisms – some biochemical, some emergent from neural networks [2] – for tracking time across scales that span from microseconds to days. Crucially, however, such mechanisms cannot scale up to explain, for instance, the emergence of concepts such as ‘past’ and ‘future’, and the rich inferences they support. These and other time concepts, such as duration and sequence, belong to the realm of high-level cognition: as observed in humans, they are mediated by language and culture, but are also firmly rooted in bodily experience and realized by neural mechanisms that are as yet poorly understood. Everyday time concepts presumably developed as an efficient way of understanding the rich – and yet fundamentally abstract – organization of temporal experience and of coordinating these understandings with others.

But what is the nature of temporal concepts? Over the past four decades scholars have converged on the idea that humans conceptualize time primarily in terms of space – a far more tractable domain. Time is spatialized when, for example, an English speaker points backwards while saying ‘long ago’, when one uses a linguistic metaphor such as ‘Ski season is approaching’, or when a teacher draws a historical timeline running from left to right. The investigation of these ‘spatial construals of time’ (SCTs) has, since the 1970s, advanced in partly overlapping waves using diverse methods that range from linguistic analysis and cross-cultural fieldwork to psychological experiments and more recently neuroimaging. Together, these waves of research have produced a broad and truly multidisciplinary set of findings. The growing diversity of theoretical backgrounds, methods, and populations, however, presents a real challenge, particularly as the field has not yet converged on a set of core theoretical distinctions and methodological standards. In this review, we attempt to provide an overarching analysis of the findings to date, with an eye toward clarifying several outstanding issues.

## Waves of inquiry in time research

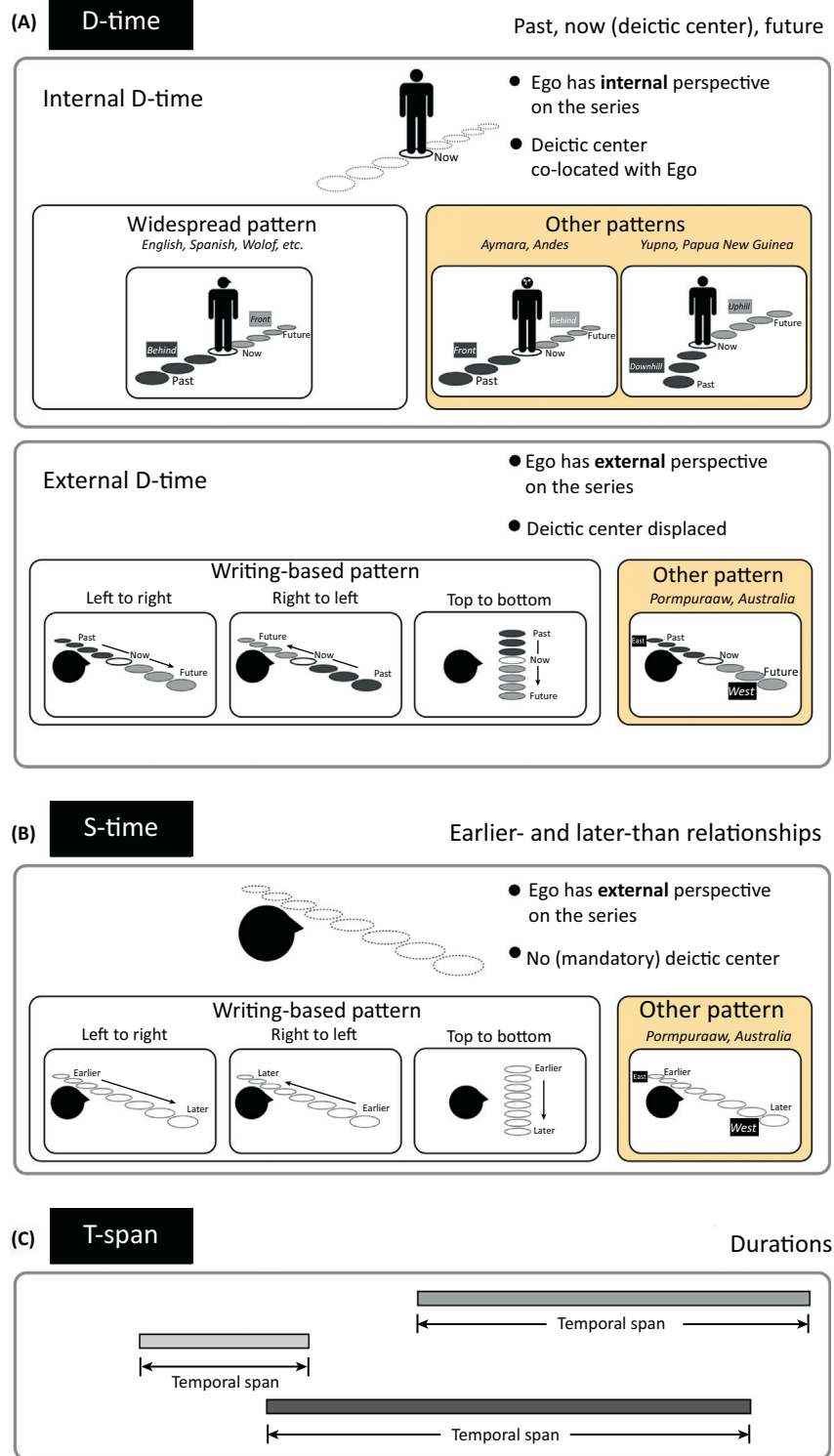
Benjamin Lee Whorf planted early seeds of inquiry (and controversy) in a 1941 paper in which he contrasted the European concept of time as ‘motion on a space’ ([3], p. 151) with a Hopi concept of time that was devoid of spatial metaphor. Part of Whorf’s claim would be largely borne out in the 1970s and 1980s, as linguists [4] investigated in detail how English and other European languages draw on spatial terms to make temporal distinctions in their core

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**Figure 1.** Some core temporal distinctions and their construals. Three qualitatively different time concepts can be distinguished: D-time, S-time, and T-span. **(A)** D-Time assumes a specific temporal landmark – the present moment, now – as the reference point and derives temporal categories – past and future – relative to it. D-time can be construed in two fundamentally different ways: one, with an internal perspective, where the deictic center – the ego – is inherently collocated with ‘now’ in the series (‘internal D-time’), which seems to be universal, and another with an external perspective, where the deictic center is displaced to an external locus (‘external D-time’). A widespread pattern construes internal D-time with the past and future as behind and in front of ego, respectively (left), with two sub-subcases: an ‘ego moving’ case, with static landscape, as in the English expression ‘We are approaching the summer’; and a ‘time moving’ case, with a static ego and moving temporal events, as in ‘The summer is approaching’. Striking variations exist, however (right, colored panel). For the Aymara of the Andes, the future is construed as behind the body and the future as in front [24], and for the Yupno of Papua New Guinea, not only is the past construed as downhill and the future as uphill, irrespective of the orientation of the body, the construal does not follow a straight line, exhibiting a non-linear geometry based on the local topography [49]. **(B)** S-time concerns the relation of one temporal landmark to another, with no mandatory anchoring to the present moment. In the absence of an obligatory ‘now’ – the deictic center – there is simply no future and no past in S-time, just earlier-than and later-than relationships. S-time involves an external perspective and whether it permits and internal form is unknown (but see [46]). Because of the inherently external nature of writing systems, writing direction strongly influences the instantiation of both S-time and external D-time concepts. English speakers (writing

grammar (consider the now-archaic spatial senses of ‘before’ and ‘after’), in their extended lexicon (consider ‘foresight’ and ‘hindsight’), and in their inventory of commonplace phrases (‘She has a bright career ahead of her’ or ‘Back in the age of the dinosaurs’). However, Whorf’s claim about Hopi would be roundly rebutted by an exhaustive linguistic analysis [5], which showed unmistakable parallels between the spatial construal of time in Hopi and in English, including treating the past as something ‘back in time’ ([5], p. 87). Differences across cultures in everyday time concepts are real and striking, as described in much more detail below, but they may not run quite as deep as Whorf claimed.

In the 1980s and 1990s, conceptual metaphor theorists, marshaling abundant evidence of the systematic spatial construal of time in language, argued that the mapping between time and space is about underlying thought, and not just surface linguistic expression [6]. In the late 1990s, cognitive psychologists started to investigate this proposal, examining observable behavior for evidence of the psychological reality of SCTs [7,8]. It was found, for instance, that spatial experiences such as riding on a train influenced people’s responses on an ostensibly unrelated temporal reasoning task (deciding whether ‘moving Wednesday’s meeting forward’ put it on Monday or Friday) [9]. It was also found that, although spatial reasoning influenced temporal reasoning, temporal reasoning did not influence spatial reasoning in the same way – not only was the spatial construal of time cognitively real, it was unidirectional [10]. These laboratory-based investigations continue to this day [11–15], targeting ever more specific interactions between temporal reasoning and spatial reasoning, chiefly in post-industrial populations.

Beginning also around the late 1990s, and expanding considerably in the past five years, is a wave of work on cross-cultural variation in SCTs. These investigations have studied time in radically different cultural niches, such as in populations with and without literacy, in languages replete with spatial metaphors for time or largely lacking them, in urban environments and in remote areas of the Andes and Amazon. Even though still in its early stages, this research has already uncovered universal patterns, striking cultural particulars, and no shortage of puzzles [16,17]. The latest wave of time research, also poised for rapid expansion in the years ahead, is cognitive neuroscientific work on the neural bases of time conceptualization. An initial focus of this work has been on the nature and degree of overlap between the neural bases of spatial and temporal conceptualization [18–20].

### Core temporal concepts and their construals

More than a century ago, the philosopher John McTaggart [21] proposed the fundamental distinction between what he called ‘A-series’ and ‘B-series’. The A-series, also called ‘tensed’ or ‘deictic time’ – here referred to as ‘D-time’ – assumes a specific temporal entity – the present moment,

‘now’ – as the reference point and derives temporal categories – ‘past’ and ‘future’ – relative to it. For example, the expression ‘Tomorrow will be a nice day’ refers to a day in the future that is only specified by the moment in which the sentence is uttered – the ‘now’, or deictic center. As the deictic center changes, so does the referent of ‘tomorrow’. The B-series, also called ‘tenseless’ or ‘sequence time’ – here ‘S-time’ – concerns the relation of one temporal landmark to another, with no mandatory anchoring to the present moment. For example, the expression ‘After the storm it will be a nice day’ characterizes the temporal relation between two events, the storm and the nice day that follows it, but this relation does not depend on when the sentence is uttered. There is simply no future and no past in S-time, just earlier-than and later-than relationships (Figure 1).

The distinction between D-time and S-time – analyzed in the cognitive linguistics literature under different names [22–26] – has been paramount not only in philosophy, but also in modern physics [27,28], psychology [29,30], and linguistics [31]. In cognitive neuroscience, D-time implicitly lies at the core of models of temporal integration [32] and figures in discussions of ‘mental time travel’ [33] and whether this capacity is shared by great apes [34,35].

As different as they are, D-time and S-time share a central feature: they both refer to ‘series’ of ordered temporal events. In that, they are radically different from the concept of duration or temporal span – here ‘T-span’ – which refers to a perceivable or measurable temporal magnitude, such as ‘five minutes’, ‘the whole morning’, or ‘several months’. The spatial construal of T-span in language is evident in expressions such as ‘A tiny fraction of a second’. The conceptual nature of T-span can be more easily grasped when considering durations that transcend known biological mechanisms for time tracking, such as millennia. Linguists have long examined more fine-grained features of event structure, under the labels of ‘aspect’ and ‘aktionsart’. It remains an interesting possibility that these micro-features of events are construed spatially as well, but cognitive scientists to date have primarily focused on the spatial construal of event series (D-time and S-time) and of duration (T-span).

Based on extensive theoretical linguistic analysis a number of scholars have recently proposed more nuanced taxonomies of time concepts and their construal [36,37], with one aim being to bring them into alignment with taxonomies of spatial frames of reference [38–41]. Despite intuitive appeal and the promise of parsimony, a definitive taxonomy of ‘temporal frames of reference’ remains elusive. One challenge is that distinctions within the spatial frames of reference literature are still being proposed and debated [42]. Another is that space is three-dimensional, with complexities and possibilities for multiple perspectives that have no clear counterparts in the domain of time. And, indeed, time has peculiarities all its own, such as the

left-to-right) construe earlier (and past) times to the left, whereas Hebrew speakers (right-to-left) construe them to the right and Mandarin speakers (writing top-to-bottom) construe them as above (left). Variations not based on writing have been found, such as in the Aboriginal Australian Pormpuraaw, where earlier (and past) is construed as eastward (right, colored panel) [56]. (C) T-span refers to durations, perceivable or quantifiable temporal magnitudes – temporal spans – than can be compared to each other. It is radically different from D-time and S-time, because these refer to ordered series of events or landmarks that are themselves temporal entities.

notorious problem of ‘directionality’ as debated by philosophers and physicists for centuries [28] – peculiarities which are not inherited from the domain of space. The critical point is that humans do not map space and time onto each other in an exhaustive fashion, but rather recruit a limited subset of possible spatial experiences (e.g., forward motion along a path) for construing the full complement of temporal experiences [26]. Thus, although these proposals have yielded insights, we adopt a conservative approach here, only positing those taxonomic distinctions required to make sense of the available behavioral evidence.

One important distinction inspired by such recent theoretical analysis concerns the ‘perspective’ taken by the speaker or cognizer (here ‘ego’) [36,37]. In construing a temporal series it is possible to adopt an ‘internal’ or ‘external perspective’ on the series. The internal perspective can be likened to the perspective of a passenger inside a moving train, whereas the external perspective can be likened to the perspective of one observing the moving train from a distance. The distinction aligns with that between character- and observer-viewpoint in gesture analysis [43,44] or between route- and survey-perspective in the study of navigation [45]. Positing these two possibilities of perspective clarifies, for instance, the apparently puzzling case of multiple SCTs existing in many languages (see Box 1, for an analysis in English). D-time thus exhibits two construals: one, with an internal perspective, where the deictic center – the ego – is inherently collocated with

‘now’ in the series (‘internal D-time’), and one with an external perspective, where the deictic center is displaced to an external locus (‘external D-time’). S-time, on the other hand, inherently involves an external perspective and whether it permits an internal form is unknown (although recent experimental evidence suggests that this form can be enacted under specific circumstances, for example, when acoustic stimuli and non-spatial (verbal) responses are involved [46]). Note that the external perspective common to external D-time and S-time is familiar from cultural technologies and, in the case of the former, may have originated from them (Box 2).

These temporal distinctions and their construals do not exhaust the concepts of time humans rely on, but they constitute a core set for understanding SCTs and their variation (see Box 3, for further elaborations). Importantly, they likely have different developmental and historical origins and often involve the recruitment of different spatial contrasts. Keeping their differences and interrelations will prove critical as researchers begin to take their investigations outside the laboratory, as well as into the brain.

### Patterns and particulars in time concepts

Much as genetic and phenotypic variation is essential for understanding the basic mechanisms of evolutionary biology [47], the investigation of cross-cultural variation in SCTs is essential for understanding the mechanisms that underlie their emergence, stabilization, and change.

To date there are no systematic empirical reports describing a culture that lacks SCTs altogether, although cultures appear to vary considerably in the ‘degree’ to which SCTs surface in both linguistic expressions and in cultural representations. On one end of the spectrum, languages such as Aymara of the Andes [24] and English [6] are replete with spatial metaphors for time in their basic lexicon and in their store of common expressions. Note these are not just a willy-nilly sprinkling of spatial words, but the systematic recruitment of spatial contrasts to construe temporal contrasts. On the opposite end, Kuuk Thaayorre of Australia has none [48]. And yet all three of these groups have been documented to operate with culturally shared SCTs, as evidenced by gesture and other behaviors.

A few more fine-grained features of the basic construal of time as space appear particularly widespread. For example, internal D-time is broadly attested and thus appears to be more basic than external D-time. The robust association between the present moment (‘now’) and the spatial deictic center (‘here’) is still seen in cultures that recruit allocentric spatial contrasts for time, such as the Yupno of Papua New Guinea [49] (that is, contrasts not deriving from the asymmetries of the body, such as front/back, but from asymmetries in the environment, in this case uphill/downhill). The association is even seen in the Amondawa of the Amazon, a culture claimed to largely lack SCTs, but which exhibits a basic polysemy between the words for ‘here’ and ‘now’ [50]. Another widespread feature is that T-span concepts are construed in terms of spatial magnitude, be it linear extent or amount (Table 1). In English, vacations can be ‘long’ or ‘short’, whereas in languages such as Greek, they are more often ‘big’ or ‘small’

#### Box 1. The case of multiple SCTs in English

Across more than a decade of psychological studies, a complicated picture of SCTs in English has emerged. Studies examining postural sway [81], motor actions along the front-back axis [82,83], and gesture [84] have all found evidence of the cognitive reality of front-back mappings of D-time originally noted by linguists. However, other SCTs, not expressed in the English language, also appear robust. Studies that involve arranging cards that represent events [56–58] or gestures during story recollection [84,85] have reported a strong preference for ‘left-to-right’ spatializations of S-time, with earlier events on the left and later events on the right. Further support for this horizontal mapping comes from reaction time studies that involve left-right oriented stimuli or left-right arranged response locations [46,66]. What is initially puzzling is that several studies have also reported unanimous recruitment of the left-to-right direction for construing D-time, for example, in tasks in which participants are asked to point to ‘yesterday’ when first provided with the location of ‘today’ [55,56]. A crucial feature of this type of task is that it displaces the deictic center to an external locus, encouraging a viewing of the series from the outside as one would view any other sequence. The fact that the sequence happens to involve deictic terms (‘now’, ‘today’, etc.) appears to be less important than the fact that the sequence is viewed from an external perspective. But where does this external variant of deictic time come from? For modern Westerners, it is familiar from, for instance, budget graphs that span past, present, and future years, as well as from the practice of reading a calendar, on which it is always possible to locate ‘today’, as well as ‘yesterday’ and ‘tomorrow’. One consequence of this familiarity with a graphically mediated, external perspective on D-time is that, in cases in which someone is free to adopt either an internal or external perspective, as in gesture, they may show both left-right and front-back SCTs of D-time [84]. Future work will be needed to test predictions generated by this account, such as that subpopulations with less exposure to graphical representations of time will be less likely to adopt the external viewpoint on D-time.



## Box 2. Cultural technologies for understanding time

Technologies for reckoning, recording, and representing temporal structure have taken many forms across different cultures and time periods [86] (see Figure 1, for a Native American example). For members of modern post-industrial societies the experience of time has come to be inescapably mediated by cultural technologies and graphical conventions [87]. Clocks, calendars, and timelines are by now omnipresent, in both material and digital forms. Graphs and comic strips follow entrenched conventions for depicting temporal sequence, and browsers prominently feature ‘back’ and ‘forward’ buttons (which, notably, point left and right, respectively). No less important than these explicit representations of time is the implicit representation of time that comes with literacy, as the act of reading or writing fuses dynamic visuo-manual action with temporal sequence. One thing all these practices have in common is that they clearly ‘spatialize’ time. But do they merely reflect pre-existing SCTs or do they feed back to shape the construal of time in important ways?

An uncontroversial consequence of such technologies and conventions is that they influence the particular spatial form SCTs take across cultures. SCTs of S-time among English speakers (left-to-right) [57] and among Hebrew speakers (right-to-left) [68], for instance, correlate with differences in representational practices of these cultures, but

not with any linguistic differences. Temporal technologies may well have other, more subtle cognitive consequences, as well. First, we hypothesize that they may give rise to external D-time, a peculiar blend of deictic and sequence time concepts. Second, the ubiquity of such technologies probably contributes to the stability of the very SCTs they give rise to, too. Third, these technologies enshrine and may thus reinforce the basic concept of time *per se* – that is, the notion of time as an independent property of the world that can be quantified much like length or brightness. Fourth, and finally, because graphical conventions for time often parallel conventions for representing number, order, and other continua, it is possible that experience with representations such as these promotes an alignment across conceptual domains that might not otherwise exist.

In considering the possible cognitive consequences of familiar contemporary temporal technologies, it is important to emphasize that, as ubiquitous as they now are, they emerged and spread only very recently in human history. The first timelines in the West seem to date only to the 1700s [88], and widespread literacy is largely a 20<sup>th</sup> century historical development. Present day small-scale societies that rely on oral traditions, whose temporal technologies are either qualitatively different from Western post-industrial ones or in some cases altogether non-existent, may throw critical light on these issues.



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**Figure 1.** The Lakota Long Soldier winter count. ‘Waniyetu wowapi’ or the Lakota ‘winter counts’ are examples of a cultural practice for representing temporal sequence. Each year (‘waniyetu’), measured from first snowfall to first snowfall, was depicted by one picture. ‘Wowapi’ – ‘anything that is marked on a flat surface and can be read or counted, such as a book, letter, or drawing’ (Smithsonian Institution (2013). Lakota winter counts: online exhibit, Smithsonian Institution, [http://wintercounts.si.edu/html\\_version/html/index.html](http://wintercounts.si.edu/html_version/html/index.html)) – indicates that the viewer had an external perspective on the drawing. The resulting temporal sequence of pictures, which depicts humans and animals in a canonical position with their front facing earlier times, is a material realization of S-time. This version – called ‘Long Soldier’ – covers the period 1798–1902. (National Museum of the American Indian, Smithsonian Institution, Catalog number NMAI 11/6720. Photo by NMAI Photo Services. Muslin cloth, 176 × 88 cm. Reproduced with permission).

[51]. These features are best treated as candidate universals whose status may change as more cross-cultural work is conducted.

Within the over-arching frame provided by these broad patterns, considerable cross-cultural variation has been attested. Construals of D-time and S-time vary widely in terms of the spatial contrasts on which they draw (Figure 1). Early linguistic work noted the widespread recruitment of the front–back axis to express D-time concepts – with the past mapping to the back (as in ‘Leave your childhood behind’), the present mapping to the space co-located with the ego (as in ‘Election day is here’), and the future mapping to the front (as in ‘The years ahead will be

difficult’) [52] – as well as to express S-time concepts, with the later events conceived of as behind earlier events (as in ‘The keynote presentation is followed by a reception’) [53] (see also the Lakota Winter Count in Figure 1, Box 2). Some influential commentators explained these patterns by reference to the salience of the front–back axis in human anatomy and specifically its pronounced asymmetry [54]. However, cross-cultural work has since revealed unexpected diversity. In the case of internal D-time, in the Aymara of the Andes, the future is construed as behind the body and the future as in front [24]. Among the Yupno, not only is the past construed allocentrically as downhill and the future as uphill, but also the construal does not follow a

**Box 3. Further elaborations of SCTs: cyclic and helix time**

D-time, S-time, and T-Span constitute core concepts, but they do not necessarily exhaust all the desired properties involved in everyday notions of time. For instance, the familiar iteration of day and night, lunar shape patterns, and yearly seasons is not captured by the basic structure of these concepts. Cultures around the world have developed – presumably to capture the missing iterative properties – what anthropologists and commentators have labeled as ‘cyclic’ time models, which are observed in groups as diverse as Aymara [89,90], Toba [91], Malagasy [92], and Yucatec Maya [66], among others (this is not to be confused with the ‘Lakota winter counts’ (Figure 1, Box 2), which typically depict an inward-curling sequence of temporal events that is not iterative). From the perspective we offer here, these are characterizations that constitute elaborated versions of S-Time. There is a topological correspondence between locations on any given segment of S-time in linear space with locations on a corresponding segment of the circle representing cyclic time, which preserve order and the fundamental inference that earlier times always precede later times within that segment. The same argument applies to helix (or spiral) time observed, for example, in certain domains in physics and in science fiction writing [93], which captures even further inferential structure – the iterative, but never identical, repetition of temporal events. This helix characterization is likewise external to the ego and holds a topological correspondence between locations on any given segment of S-time linear space with locations on a corresponding segment of the helix, such that earlier times always precede later times. So-called cyclic and helix time are thus further elaborated variations of S-Time and, as in the case of simple S-time, T-span concepts can combine with them to characterize duration.

It is important to note, however, that, although such concepts are often described as ‘cyclic’ – a term that clearly evokes a particular spatial form – this need not imply that the described construals are themselves intrinsically spatial. Indeed, temporal repetition may in principle be construed in non-spatial ways, as in the English expression ‘Her ankle throbbed with pain’, where the pain is felt in a series of regular beats that do not invoke a dynamic trajectory in space. Care is thus required to ensure that any spatial dimension to the construal is not in fact a projection from the observer.

straight line, exhibiting a non-linear geometry rooted in the surrounding topography [49]. With respect to S-time and external D-time, Mandarin speakers recruit the vertical axis (in addition to the horizontal one) for SCTs [55], whereas a population of speakers of aboriginal Australian languages recruits the east-west axis [56] (see Table 1, for an overview of cross-cultural findings). Such examples are not merely boggling exotica; they prompt reconsideration of the fundamental mechanisms that give rise to all SCTs, no matter how familiar or how peculiar.

Given widespread patterns, on the one hand, and striking cultural particulars, on the other, a focal issue in this area has been the various factors that shape SCTs. In addressing this issue, at least three levels of analysis must be distinguished: moment-to-moment, individual, and cultural. In cases where multiple SCTs are available to express a given time concept, such as D-time in English (Box 1), a mix of situational and pragmatic factors may determine which one an individual uses in a given moment. As seen in gesture, for example, the choice could be modulated by the temporal granularity required – front-back for coarse-grained material and left-right for fine-grained.

At the next level of analysis, why individuals in a certain culture come to habitually construe time in one way or another has been attributed to linguistic metaphors [17], practices for representing time [57–59], and group-level

spatial reasoning styles [48]. At the highest level of analysis, why a culture ‘selects’ certain linguistic metaphors, conventions of temporal representation, or spatial reasoning styles in the first place may depend on environmental factors (e.g., a mountainous landscape) [49], collective worldviews (e.g., cultural conceptions of the cosmos) [60], and, speculatively, in how certain temporal concepts do or do not mesh with certain spatial contrasts [54]. All of these factors may play a role in shaping SCTs, but their relative weighting remains to be investigated.

Our understanding of the extent of cross-cultural variation in SCTs and its sources will be furthered by work on small-scale communities that rely on oral traditions. For one, languages from such communities present natural experiments in how linguistic structure shapes the construal of time. In terms of how they handle temporal reference, the variation across such groups is considerable, with some languages altogether lacking tense or temporal connectives such ‘before’ and ‘after’ [61], whereas others assiduously mark several degrees of deictic remoteness, in verbal tense [31] and temporal lexicon [62], as well as in evidential systems [63]. Differences across such communities in the handling of spatial reference, an important factor in shaping SCTs, are no less striking [64].

A major obstacle to research on time in small-scale communities, however, is methodological. A flurry of recent studies [50,62,65–67] has investigated SCTs in indigenous communities using arrangement tasks, a classic method used successfully in post-industrial groups to investigate S-time and external D-time [57,68]. In such tasks, participants sort cards that represent different stages of an event (e.g., the life-cycle of a chicken) or place tokens that represent temporal words (‘tomorrow’, ‘yesterday’) after being given an external deictic center (‘today’). These efforts have met with mixed results, often with many attested spatial arrangements within a given community. One possible interpretation of these results [62] is that SCTs in these cultures are not as stable or not as systematic as they are in post-industrial groups. It is possible, indeed likely, that cultures vary in this way, but such a conclusion would be premature in these cases. After all, another interpretation is that arrangement tasks are not well-suited for use in such populations, because they presuppose familiarity with materials and practices that, in fact, require considerable cultural scaffolding. Analysis of spontaneous co-speech gesture, which is ubiquitous in humans and occurs naturally without elicitation, offers an especially fruitful complement to careful linguistic analysis in small-scale groups. Gesture can convey fine-grained properties of construals (such as their particular three-dimensional geometry), which would not be possible to investigate within the confines of an arrangement task.

**The mosaic of time**

An important source of difficulties for interpreting the ensemble of existing data is a tendency to approach ‘time’ as a monolith, a view with deep roots in the Western philosophical tradition [50]. This view remains prominent today [69] but, if unchecked, may lead to unwarranted leaps of generalization. Investigations into the origins of any given time concept – for example, T-span [70–73] – provide a

**Table 1. The cognitive reality of SCTs – a classification of studies that provide behavioral evidence of SCTs in some of the world's cultures**

Spatial construal				Methods	Spatial reference	Linguistic metaphors	Notes
Group 1 <sup>a</sup>	English	DT <sup>INT c,d</sup> :	<i>past: back; future: front</i>	GES-S [84], PSY-L [81–83]	egocentric [96]	past behind ego, future in front; later events behind earlier events; duration can be long/ short [6]	<i>writing</i> : L-to-R; <i>other tech</i> : L-to-R timelines and calendars; for similar patterns, see also: German [83], Italian [12]
		DT <sup>EXT</sup> :	<i>past: left; future: right</i>	ARRG [56], GES-E [55], GES-S [84]; PSY-L [46]			
		ST:	<i>earlier: left; later: right</i>	ARRG [56,57], GES-E [55], GES-S [84], PSY-L [46, 94], PSY-N [68,95]			
		TS:	<i>duration: extent</i>	PSY-N [70]			
	Greek	TS:	<i>duration: amount</i>	PSY-N [51]	egocentric*	duration can be large/ small [51]	see also: Indonesian [51]
	Hebrew	DT <sup>EXT</sup> :	<i>past: right; future: left</i>	ARRG [68]	egocentric*	*	<i>writing</i> : R-to-L; <i>other tech</i> : *
		ST:	<i>earlier: left; later: right</i>	ARRG [57,68], PSY-N [68]			
	Mandarin	DT <sup>EXT</sup> :	<i>past: up; future: down</i>	GES-E [55], PSY-N [55]	egocentric*	past up, future down (only on some time scales) [55]	<i>writing</i> : T-to-B; L-to-R; <i>other tech</i> : * for comparison, see: Taiwanese [58], Cantonese [59]
			<i>past: left; future: right</i>	GES-E [55], PSY [55]			
		ST:	<i>earlier: up; later: down</i>	ARRG [58], GES-E [55], PSY-N [55,95,97]			
			<i>earlier: left; later: right</i>	ARRG [58], GES-E [55], PSY-N [55,95,97]			
	Spanish	DT <sup>INT</sup> :	<i>past: back; future: front</i>	GES-S [24]	egocentric*	past behind ego, future in front; later events behind earlier events [24]	<i>writing</i> : L-to-R; <i>other tech</i> : L-to-R timelines and calendars
		DT <sup>EXT</sup> :	<i>past: left; future: right</i>	PSY-L [74,75]			
		ST	<i>earlier: left; later: right</i>	PSY-N [76]			
Group 2 <sup>b</sup>	Aymara	DT <sup>INT</sup> :	<i>past: front; future: back</i>	GES-S [24]	mixed [60]	past in front of ego, future behind	<i>writing</i> : none attested; <i>other tech</i> : none attested
	Pormpurraw	DT <sup>EXT</sup> :	<i>past: east; future: west</i>	ARRG [56]	geocentric [48]	none attested	<i>writing</i> : none attested; <i>other tech</i> : none attested
		ST:	<i>earlier: east; later: west</i>	ARRG [56]			
	Yupno	DT <sup>INT</sup> :	<i>past: downhill; future: uphill</i>	GES-S [24]	geocentric [98]	limited expressions attesting past downhill, future uphill [49]	<i>writing</i> : none attested; <i>other tech</i> : none attested

<sup>a</sup>Group 1 includes globally dispersed populations characterized by high levels of literacy and a predominantly modern, post-industrial lifestyle.

<sup>b</sup>Group 2 includes geographically restricted populations characterized by low levels of literacy and a predominantly traditional lifestyle. Note that several recent studies among Group 2 populations are not included in the table because they fail to provide clear evidence of a systematic, widely shared SCT [50,65–67]. In these cases, it remains unclear whether this negative evidence is due to a genuine lack of shared SCTs in the population or due to limitations in the methods used to investigate them.

<sup>c</sup>Abbreviations: DT<sup>INT</sup>, internal D-time; DT<sup>EXT</sup>, external D-time; ST, S-time; TS, T-span; PSY-L, psychological task involving linguistic stimuli; PSY-N, psychological task involving non-linguistic stimuli; GES-S, spontaneous gesture; GES-E, elicited gesture; ARRG, an arrangement task involving cards, tokens, or stickers.

<sup>d</sup>We consider a task to provide evidence about the SCT of internal D-time only if it allows a participant to freely determine the location of the deictic center, as in spontaneous gesture and postural sway tasks, or only makes available an internal perspective, as in tasks that require motor responses along the sagittal axis. If, by contrast, a task requires that a participant displace the deictic center to an external location, as in arrangement tasks or tasks that involve screen presentation, we consider this as providing evidence of external D-time.

<sup>e</sup>The asterisk indicates that, to our knowledge, the phenomenon has not been documented systematically. [94–98].



critical piece of the broader puzzle, but do not necessarily shed light on the origins of other SCTs. Srinivasan and Carey [71], for instance, investigated the functional overlap between length and duration in nine-month-old infants and adults and, in drawing conclusions about ‘the nature and origin of functional overlap between representations of space and time’ (as the title of their article reads), suggested that such overlap is the result of an innate evolutionary recycling of spatial representations for the purpose of representing time, a recycling that is independent of language and other cultural practices. Although to a certain degree this may be the case for T-span, specifically, it remains unclear how the functional overlap between length and duration could scale up to yield the rich complexities of D-time and S-time. Relatedly, claims about how a given culture construes time as a whole are often based on paradigms that only investigate S-time and external D-time, which are significantly more amenable to controlled experimental investigation than is internal D-time. Reaction time [74–76] and arrangement tasks [56,57], for instance, have solidly confirmed left-to-right construals of S-time and external D-time with speakers of several European languages, but remain blind to internal D-time concepts. In such cases, rather than being treated as different time concepts that require independent investigation, these core concepts have been taken merely as different operational definitions of time on the whole. Crucially, however, the factors that give rise to different time concepts and shape their particular spatial properties are likely qualitatively different in each case (Box 4). This suggests, in turn, that they may be

supported by different neural substrates, an important point as cognitive scientists begin to investigate SCTs in the brain [77].

Just as it is dangerous to assume a specific time concept, such as T-span or S-time, generalizes to time as a whole, it may be dangerous to assume that they are exclusively and inherently ‘temporal’ in the first place. A plausible alternative is that time concepts share representational resources with what are often thought of as non-temporal concepts, such as ‘order’, which is also construed spatially [78]. S-time concepts may in fact just be incidentally temporal – that is, manifestations of a more generic ordinal concept recruited (and spatialized) *ad hoc*. Similarly, the relationship between T-span and general magnitude concepts requires further investigation. Evidence suggests that the mapping between temporal and spatial magnitude may be both asymmetric ([70,79]; but consider [72]) and possibly privileged [71]. However, exactly when this mapping comes about (evolutionarily, developmentally) and by what mechanisms (maturational, cultural) it is driven remains unclear. Concepts of time – and their construals – are not uniform and they may partly overlap with and draw on concepts of other domains. Time, as conceptualized everyday by humans, is not a monolith so much as a mosaic.

### Concluding remarks

Together, the concepts of D-time, S-time, and T-span allow for sophisticated recording, planning, and coordination that would otherwise be impossible. In construing such concepts in terms of spatial contrasts, we leverage our considerable evolved capacities for spatial reasoning [80]. Although biological evolution may have laid the groundwork for the basic spatial construal of temporal experience in the broadest sense, it is cultural evolution that has determined its complexities and specificities. As the variation described above suggests, SCTs develop in particular niches, in interplay with linguistic resources and cultural practices.

Philosophers, physicists, and cognitive scientists have long theorized about time – along with domains such as cause and number – as a monumental and monolithic abstraction. In fact, however, the way humans make sense of time for everyday purposes is, as in the case of biological time tracking, more patchwork. Despite the recent cross-disciplinary surge of research in this area, questions remain about the different pieces that make up the mosaic of time and the origins of these pieces. Further work examining SCTs in radically different cultural and linguistic contexts, studying the developmental trajectory of time concepts from early short-duration-magnitude associations to fully-fledged construals of S- and D-time, and investigating relations between temporal concepts and neighboring concepts, such as order, all stand to illuminate how space and time are tangled in human cognition and, ultimately, why.

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### Box 4. Questions for future research

- How did the historical advent of writing and other temporal technologies change time conceptualization? How does prolonged immersion in writing and other graphical practices shape time concepts over the course of the lifespan?
- The mapping between temporal magnitude and spatial magnitude seems to be both privileged and asymmetric, but when exactly does this mapping come about (evolutionarily, developmentally), driven by what mechanisms (maturational, cultural), and supported by what neural mechanisms?
- How exactly do children transition from basic concepts of T-span to the richer notions of the S-time and D-time? Through what processes are these concepts – and their construals – learned and how, if at all, do they depend on each other?
- Formally, S-time and external D-time share many properties and they seem to co-exist in cultures whenever they have been attested. Are there any cultures that exhibit one, but not the other? Is the presence of S-time a necessary condition for the emergence of external D-time?
- How do spatial construals of time relate to spatial construals of other abstract concepts, such as number and order? Is the common spatial construal of these domains observed in European groups (e.g., left–right in English) driven primarily from the bottom up by shared neural substrates or from the top down by common graphical practices?
- Several reports point to co-variation between a culture’s habits of thinking and talking about space and its habits of construing time. Are there exceptions to this pattern and, if so, what causes them?
- Across a large sample of the world’s cultures, would multiple co-existing SCTs – with different spatial contrasts recruited for different concepts as we find in English – prove to be the norm? If so, what factors might explain the ‘selection’ of one spatial contrast or another for a given temporal concept?



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