Perspectives on Temporal Cognition: From Mechanisms to Cultural Context

André M. Cravo (andre.cravo@ufabc.edu.br)[1]; Dean Buonomano[2]; Anna Christina Nobre[3]; Vera da Silva Sinha[4]

1. Center for Mathematics, Computing and Cognition (CMCC), Federal University of ABC (UFABC)
2. Departments of Neurobiology and Psychology, University of California, Los Angeles
3 . Wu Tsai Institute and Department of Psychology, Yale University
4. Centro de Ciências Humanas, Letras e Artes, Universidade Federal da Paraíba

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Overview

Human cognition is inherently temporal: we draw on memories across time scales to predict and prepare for the future, and the brain accurately generates timed motor behaviors and adaptively focuses our attention in time. To accomplish these temporal tasks, the brain measures time on scales from milliseconds to days. And finally, one of our most salient subjective experiences is that of the passage of time itself.

Timing and temporal processing, however, encompass a diverse range of abilities, including basic computational mechanisms, how time emerges from and modulates other cognitive processes, and the cultural and linguistic factors that shape our experience of time. This symposium explores timing across multiple theoretical perspectives and methodologies, integrating insights from in vivo and ex vivo recordings, human neuroscience, and anthropology. We bring together researchers investigating timing from complementary angles to discuss how temporal cognition emerges, operates, and interacts with other cognitive processes. These speakers will explore questions such as how neural circuits intrinsically generate timing and what distinguishes biological from artificial temporal processing (Dean Buonomano), what neural signatures mark temporal processing in the brain and whether they depend on the task at hand (André Cravo), how the brain dynamically tunes attention in time to anticipate events and optimize behavior (Anna Kia Nobre), and how different cultures conceptualize time through event-based systems that challenge universal models of temporal cognition (Vera Sinha). We will conclude with a moderated panel discussion aimed at exploring the multifaceted nature of temporal cognition.

Timing as a computational primitive of neocortical circuits

Dean Buonomano

The ability to tell time on the scale of tens of milliseconds to a few seconds reflects the most sophisticated example of the brain's ability to perform temporal computations, for it is on this scale that humans process complex temporal patterns—e.g., speech, music, and Morse code. Because of the importance of timing to cognition and sensorimotor processing, we have proposed that timing on this scale is a computational primitive of neocortical circuits. I will present experimental and computational studies that suggest that the ability to tell time relies on the inherent dynamics of neural circuits in the form of "neural population clocks". We have developed computational models that demonstrate that recurrent neural networks in low-gain regimes can decode temporal patterns by relying on short-term synaptic plasticity. In the high-gain regime recurrent neural networks can produce timed responses by generating reproducible neural trajectories (dynamic attractors) such as neural sequences. To experimentally test the hypothesis that neocortical circuits are intrinsically capable of temporal processing we have shown that ex vivo cortical organotypic cultures can learn temporal patterns and generate timed predictions.

It is noteworthy that the notion that temporal processing is a computational primitive of neocortical circuits stands in sharp contrast to how most artificial neural networks used in AI handle time. Indeed, the most significant difference between the brain and current AI architectures–such as transformers– pertains to time. Thus, these studies highlight the inherent temporal nature of neural computations, and the fundamental divergence between the computational principles in the brain and AIs.

Tracking Time in the Brain: Task-Dependent EEG Markers of Interval Estimation

André M. Cravo

Although several theoretical models have been proposed to explain how the brain keeps track of time, there is still no evidence toward a single one. It is often hard to compare models because their behavioral predictions overlap. For this reason, several studies have looked for neural signatures of temporal processing using methods such as electrophysiological recordings (EEG). However, for this strategy to work, it is essential to have consistent EEG markers of temporal processing.

In this talk, I will present results from several studies investigating how temporal information is encoded in the EEG signal. Specifically, across different experiments, we have investigated whether different neural signatures of

In G. Boleda, I. Dautriche, M. Maldonado, C. Saldana and T. Torrent (Eds.), *Proceedings of the 48th Annual Conference of the Cognitive Science Society*

temporal processing: 1. Depend on the task to be executed (whether or not it is a temporal task or different types of temporal tasks); 2. Are encoding the physical duration of an interval or how much longer/shorter an interval is relative to a reference. Lastly, I will discuss how these results align with recent proposals that approximate temporal processing using decision models.

Temporal Dynamics of Anticipation and Selection

Anna C. Nobre

The ability to anticipate events and focus on important signals is fundamental to adaptive behavior, with rich temporal structure at its core. In this talk, I will explore how our understanding of attentional focus has evolved over recent decades, drawing on discoveries from our research on the temporal dynamics of anticipation and selection. Attention functions, from proactive anticipation to action preparation, have emerged as highly dynamic rather than static, flowing in response to the predictable and relevant timing of events. The human brain extracts regularities about temporal associations, probabilities, rhythms, and sequential patterns, ranging from short-term regularities to long-term memories, to tune anticipatory signals in time.

This temporal tuning optimizes both the perception of sensory information and the use of memoranda during retrieval. Beyond modulating perception and action in the present moment, focus has transcended the immediate situation to apply internally to contents available only in the mind. Mental representations are selected, prioritized, and gated dynamically to enhance relevant retrieval and guide future-oriented behavior. By embracing these temporal dynamics and considering attention across past-to-future domains, our treatment of focus is breaking away from simple dichotomies. A much richer field of investigation lies ahead, allowing us to understand the nature and role of attentional focus as a fundamental cornerstone across the gamut of cognition, enabling the brain to anticipate, select, and prioritize information to support adaptive behavior.

Event-Based Time: Rethinking Universal Models of Temporal Cognition

Vera S. Sinha

Understanding how humans conceptualise time is central to research on cognition, language, and culture. While all languages encode deictic relations and the sequential ordering of events, how temporal intervals are conceptualised and expressed varies across cultures. In many societies, time is not organised through abstract, numerically defined units such as calendar or clock time, but through relations among socially and environmentally salient events. Although spatial metaphors for time are widespread, they are not universal.

In this talk, I will present evidence from research on four Amazonian languages and cultures, Amondawa, Huni Kuĩ, Kamaiurá, and Awetý, in which temporal landmarks and intervals are exclusively event-based. Using a multi-method qualitative approach combining ethnographic observation, structured elicitation tasks, and interviews, this research examined lexical and phrasal expressions for time across three domains: seasons, times of day and night, and human life stages. Across these domains, temporal reference is structured through events and activities, supported by cognitive artefacts embedded in everyday practices.

I will discuss how these findings bear on current debates in temporal cognition. Event-based time concepts appear to be widespread in human cultures and likely predate non-universal metric time systems. From this perspective, the historical spread of metric time is associated with particular configurations of language and cognition, including mental timelines and spatialised temporal metaphors. I conclude by suggesting that linguistic and cultural variation offers an important source of insight into the plurality of ways in which time is conceptualised, experienced, and communicated.

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