Working Memory Integrates Geometrical and Temporal Languages of Thought

Elyes Tabbane
(elyes.tabbane@learningplanetinstitute.org)

CEA, NeuroSpin center, Gif/Yvette, France, Université Paris Cité, Paris, France, Learning Planet Institute

Fosca Al Roumi (fosca.al.roumi@googlemail.com)

Cognitive Neuroimaging Unit, Université Paris-Saclay, INSERM, CEA, CNRS, NeuroSpin center, Gif/Yvette, France

Abstract

Human cognitive uniqueness is often attributed to the language faculty (Hauser, Chomsky, Fitch, 2002) that is, a set of abilities supporting speech internally (as thoughts) and externally (in communication). However, natural speech is not the only uniquely human ability, and the properties that support it might not be all there is to human cognitive singularity. In fact, our capacities for music, mathematics and other structured domains have been proposed to rely on a faculty to produce and make use of mental programs that efficiently capture the regularities in our environment to create compressed internal representations (Dehaene et al., 2022). These mental programs rely on a set of internal languages that can combine symbols based on rules and syntactically organize them to create structured expressions, this has been called the Language of Thoughts (LoTs) hypothesis (Fodor, 1975, Dehaene et al., 2022). However, it remains unclear how different LoTs interact to form shared mental representations. We investigate this gap using two behavioral experiments : (1) complexity ratings and (2) delayed sequence reproduction. We show that sequences combining geometrical and temporal regularities, and thus engaging two LoTs, are both judged simpler and remembered more efficiently than those using a single LoT.

Keywords: Language of Thought; Working Memory; Mental Representation; Compression; Sequence Learning; Symbolic Modeling; Temporal Structure.

Introduction

In various domains, humans use internal languages to create compressed expression of objects such as sequences. These internal languages have been called Languages of Thoughts (LoTs), as proposed by Fodor (1975) and produce compressed expression resembling computer-algorithms (Dehaene et al., 2022; Amalric et al., 2017). According to the LoT-theory, distinct internal languages (e.g., LoT-geometry, LoT-temporal, LoT-music) work collaboratively to capture and use different kinds of regularities. Previous work has been building and perfecting a symbolic model that can generate expressions as well as algorithmic complexity for any given sequence (Planton et al., 2021; Amalric et al., 2017; Al Roumi et al., 2021; Tabbane, Al Roumi, Figueira, Dehaene, in press). This model is a computational implementation of the LoT-hypothesis. So far, this line of research has focused on isolating individual LoTs in sequence learning and verifying their predictive power both in behavioral (Planton et al., 2021; Amalric et al., 2017; Tabbane, Al Roumi, Figueira, Dehaene, in press) and brain imaging experiments (Al Roumi et al., 2023, Al Roumi et al., 2021). In very similar experimental paradigm, Amalric et al. (2017), Al Roumi et al. (2021), and Zhang et al. (2022) have shown geometrical regularities have a strong effect on spatial sequence memorization. In fact, participants use geometrical regularities to support their prediction of forthcoming items (Amalric et al., 2017) and their gaze location (Al Roumi et al., 2021). Later work, strongly support that participants also use temporal regularities to compress sequences in working memory (Planton et al., 2021; Al Roumi et al., 2023). But so far, how distinct LoTs interact is unknown.

To study how different internal representations (i.e., LoT-expressions) combine to support sequence representation in working memory, we test sequences with varying level of geometrical and temporal structure. Our underlying theory was that LoTs communicate and a mental expression constructed by one LoT can become an object that can be manipulated by another LoT to build a new expression. (Dehaene et al., 2022).

Methods and Preliminary Results

We chose to explore different geometrical configurations based on Amalric (2018) and Zhang (2022), as well as temporal structures that were taken from previous work (experiment 1) or designed to specifically allign/break the geometrical structure (experiment 2).

Experiment 1. In previous work (in press), we validated that subjective complexity is a good predictor of performance. Applying it to our current work, we started by testing if our predictions would verify based on subjective rating of complexity. In other words, we tested if sequences that have a higher geometrical complexity with a constant temporal structure, would be judged more complex by someone seeing the sequence.

In this computer experiment ran online, participants see 6 dots aranged on the corners of a hexagon. These dots sequentially become bigger drawing a particulary patterns. After seeing the sequence, participants had to judge “How difficult was that sequence to memorize ? 1: Very Simple [...] 7: Very Complex”. There was 23 different temporal structures and each of these 23 base sequences had 3 different geometrical variants. For example, if {1, 2, 3, 4, 5, 6} represent the 6 corners of the hexagon, the *Mirror-*

 Rep sequence ABCDDCBAABCD has three geometrical variants, 123443211234 (rot-1), 136446311364 (zhang-23) and 143663411436 (zhang-30).

We find that subjective complexity correlated most with temporal LoT-complexity. But in certain cases, such as for Play4 (ABACADABACAD), Sub-2 (ABCDABCEABCF) and Mirror-Rep, geometrical structure has a sizable effect on perceived complexity (see Figure 1).

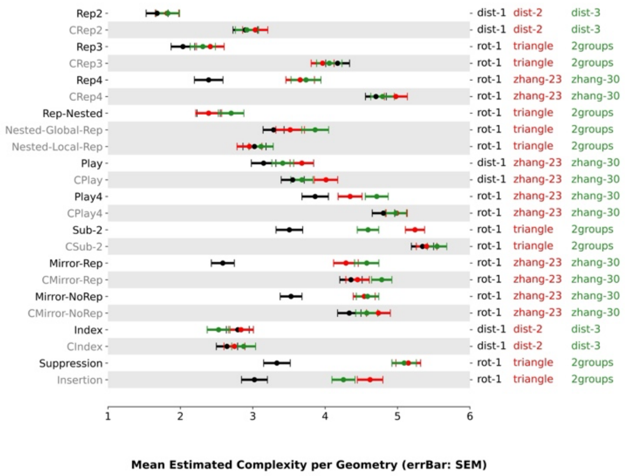

Figure 1 : Subjective complexity experiment.

Experiment 2. Expanding on experiment 1, we thought that if sizable effects are still found in a task mostly built around temporal structure, we should observe massive interactions if both geometrical structure and temporal structure were given the same weight in each sequence. We thus designed longer sequences (16 elements) that can accommodate for combinations of geometrical and temporal patterns. We had a total of 4 distinct temporal structures with 7 geometrical variants, which sum to 28 tested sequences.

We found that when geometrical structure is very complex (*irregular*, 84715236) or if temporal structure is complex (*Rep-2b2*, ABCDABEFCDGHEFGH), encoding of the whole sequence fails (See Figure 2, we used Damerau-Levenshtein Distance). Our preliminary results strongly suggest interactions between temporal structure (Figure 2, y-axis) and geometrical structure (Figure 2, x-axis).

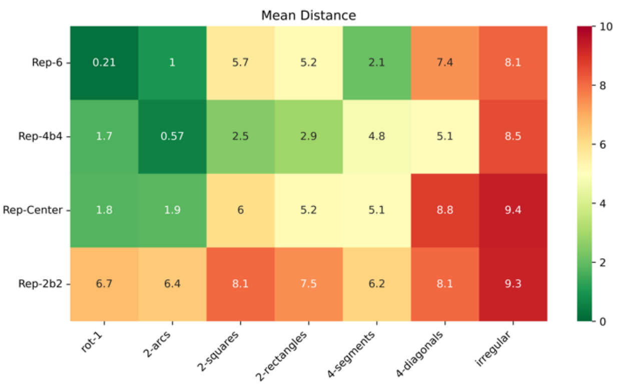

Figure 2 : LoTs interactions experiment.

Discussion

These preliminary results point to several next steps. (1) We aim to develop a computationally efficient model of interactions between temporal and geometrical LoTs. (2) We will test how complexity measures from each LoT independently explain performance variance using ANOVA. (3) We plan to expand the second experiment by refining stimuli and increasing the sample size. This will allow for qualitative analyses—such as variations in response time—to probe chunking and representational structure. (4) We also aim to investigate how sleep influences structure learning and generalization.

We expect qualitative analyses to reveal the underlying structure of internal representations. In the competing condition (temporal and geometrical structures interfere), we expect to observe a dynamic chunking pattern: initial encoding of lower-level groups, followed by integration of a second, higher-order structure once the first stabilizes. For example, the Rep-Center > 2-squares configuration should facilitate chunking into four-element groups (1357-8246-8246-1357). However, current performance suggests that such chunking fails to emerge without learning (single presentation per sequence), implying that the LoT-geometry initially dominates parsing but struggles when the temporal structure does not offer clear support.

In contrast, when the temporal pattern is salient—such as in Rep-4b4 > 2-squares (1357-1357-8246-8246)—compression occurs more readily, indicating successful interaction or reinforcement between LoTs. We hypothesize that the LoT-temporal struggles to identify higher-order repetitions when chunking is inhibited at the lower level, due to the lack of parseable units.

Finally, we expect that repeated exposure to a smaller set of sequences, combined with sleep, will facilitate gist extraction and improve cross-LoT integration. Sleep is likely to enhance representational collaboration by reducing interference across modalities, as previously suggested in work on abstraction and consolidation (Lewis & Durrant, 2011).

Acknowledgments

Elyès Tabbane is a student from the FIRE PhD program, funded by the Bettencourt Schueller Foundation and the EURIP Graduate Program (ANR-17-EURE-0012). This work also acknowledges institutional support from Université Paris Cité.

References

Hauser, M. D., Chomsky, N., & Fitch, W. T. (2002). The faculty of language: what is it, who has it, and how did it evolve?. science, 298(5598), 1569-1579.

Dehaene, S., Al Roumi, F., Lakretz, Y., Planton, S., & Sablé-Meyer, M. (2022). Symbols and mental programs:

a hypothesis about human singularity. Trends In Cognitive Sciences, 26(9), 751-766.

Fodor, J. A. (1975). The language of thought. Harvard University Press.

Amalric, M., Wang, L., Pica, P., Figueira, S., Sigman, M., & Dehaene, S. (2017). The language of geometry: Fast comprehension of geometrical primitives and rules in human adults and preschoolers. PLoS computational biology, 13(1), e1005273.

Planton, S., van Kerkoerle, T., Abbih, L., Maheu, M., Meyniel, F., Sigman, M., Wang, L., Figueira, S., Romano, S., & Dehaene, S. (2021). A theory of memory for binary sequences: Evidence for a mental compression algorithm in humans. PLoS computational biology, 17(1), e1008598.

Al Roumi, F., Planton, S., Wang, L., & Dehaene, S. (2023). Brain-imaging evidence for compression of binary sound sequences in human memory. Elife, 12, e84376.

Al Roumi, F., Marti, S., Wang, L., Amalric, M., & Dehaene, S. (2021). Mental compression of spatial sequences in human working memory using numerical and geometrical primitives. Neuron, 109(16), 2627-2639.

Lewis, P. A., & Durrant, S. J. (2011). Overlapping memory replay during sleep builds cognitive schemata. Trends in cognitive sciences, 15(8), 343-351.

Zhang, H., Zhen, Y., Yu, S., Long, T., Zhang, B., Jiang, X., Li, J., Fang, W., Sigman, M., Dehaene, S., & Wang, L. (2022). Working memory for spatial sequences: developmental and evolutionary factors in encoding ordinal and relational structures. Journal of Neuroscience, 42(5), 850-864.