Exploration mechanisms intrinsic to semantic networks and the nuanced appraisal of lexical repetition occurrences

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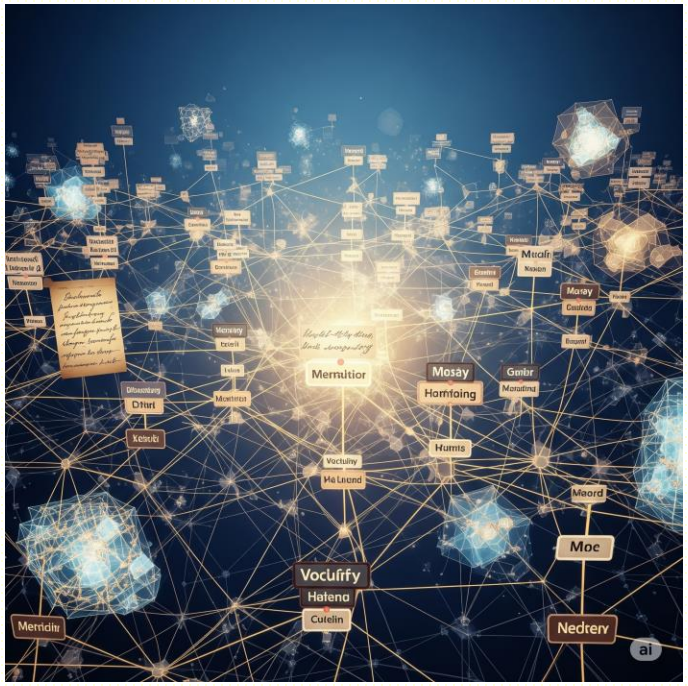
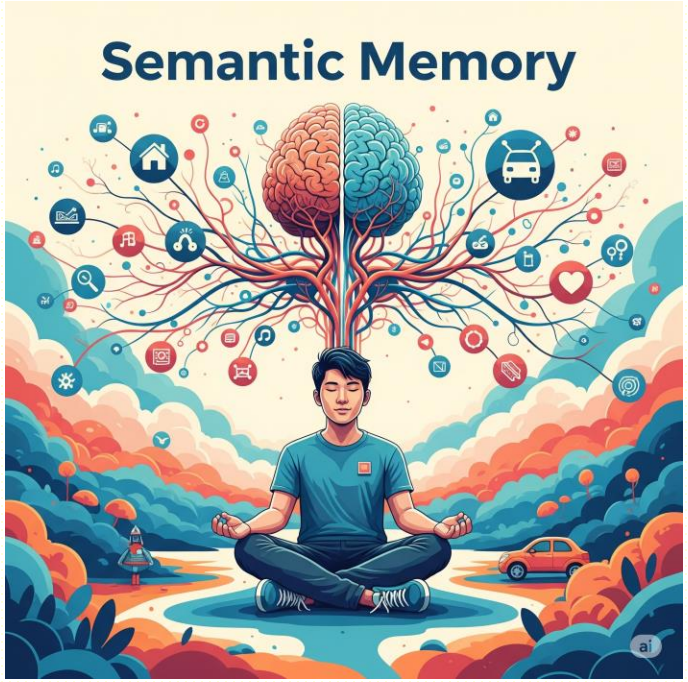
Semantic Memory

It is a type of memory that stores vocabulary and concepts that are not associated with places or times.





We will focus on studying vocabulary retrieval in semantic storage through word production.

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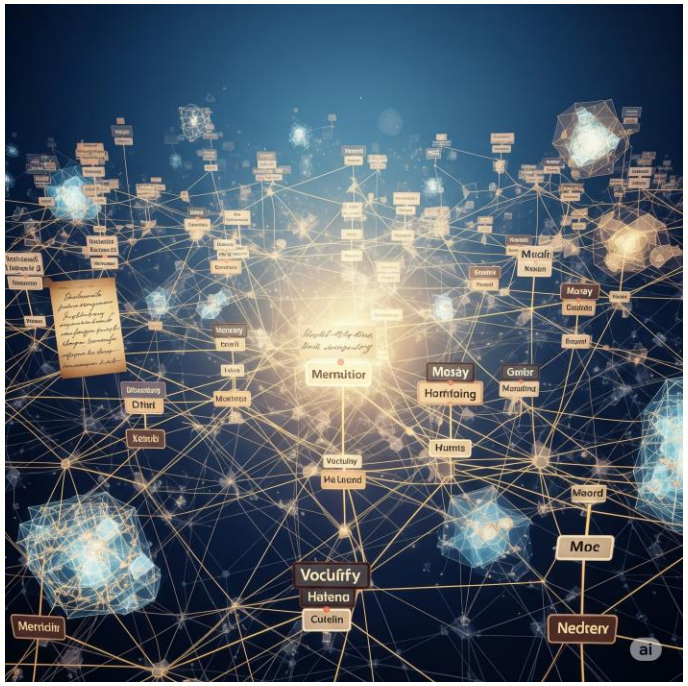

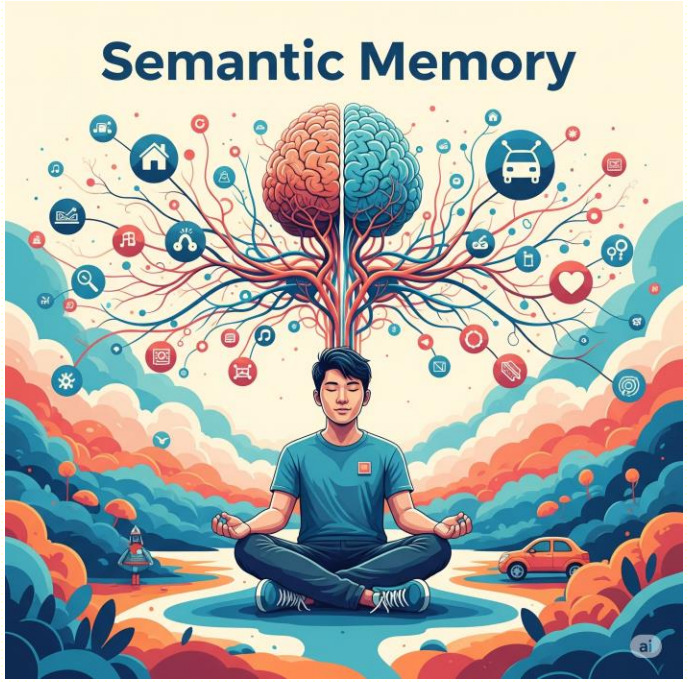

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How do we model word production?

Experiment — Model

Semantic Fluency Test

Category (animals)
Horse
Tiger
Lion
Dog
Parrot
Hen
Hedgehog
Salamander

Verbal fluency tasks are tests of word generation according to specific rules in 60-second intervals.

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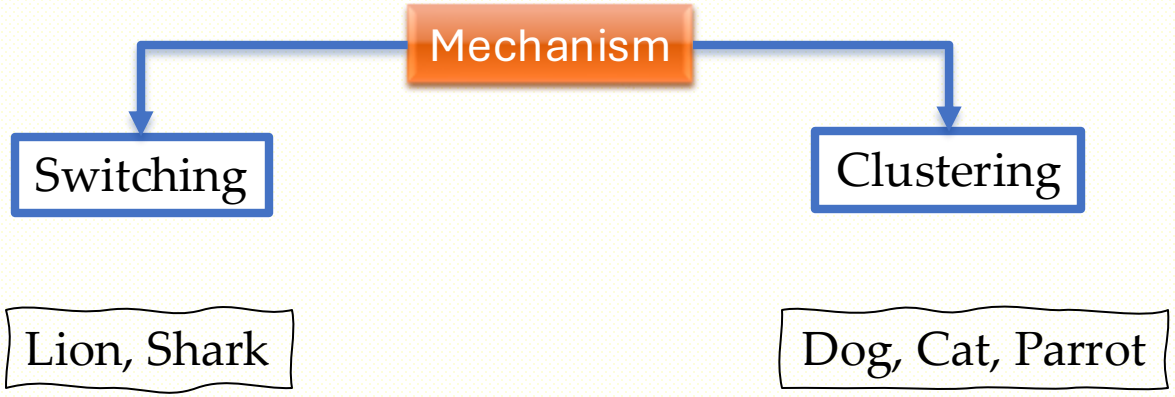

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Conceptual Networks

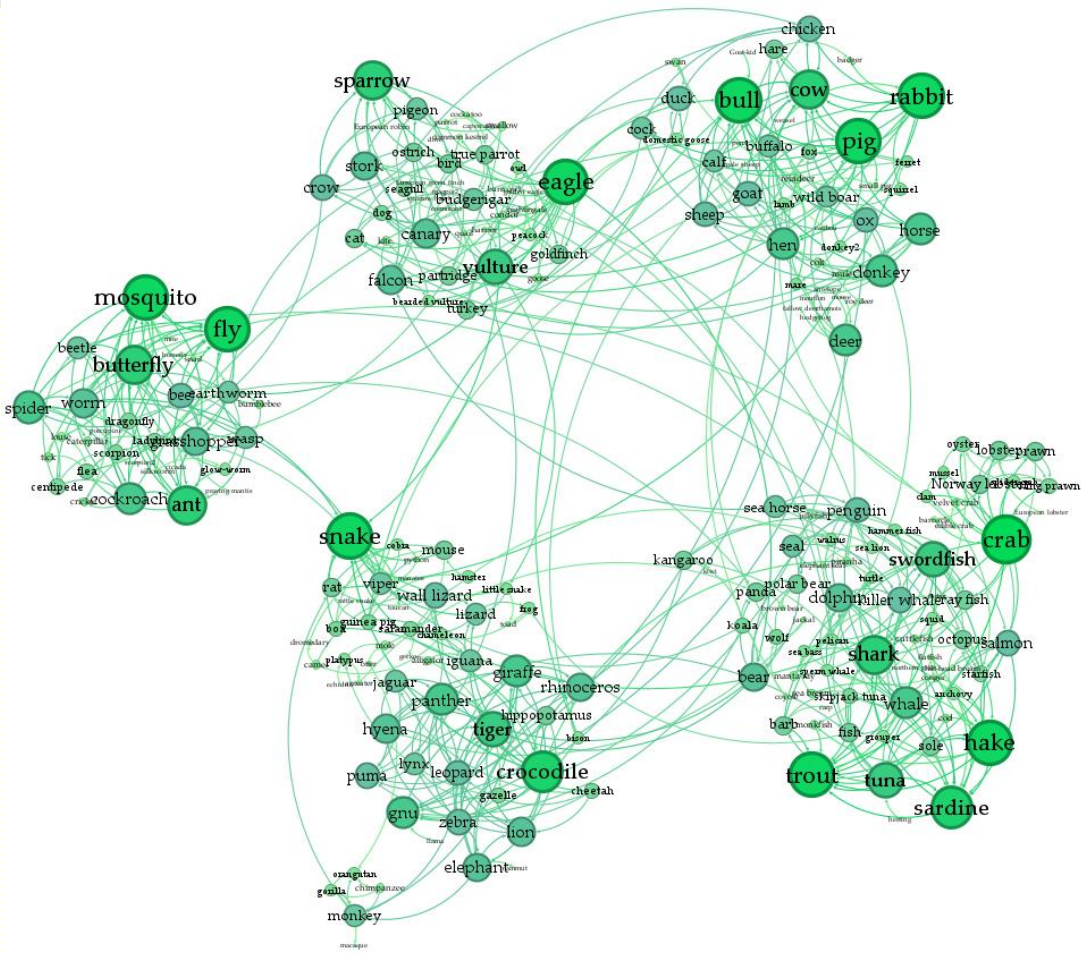

Figure 1: CN: Conceptual network.

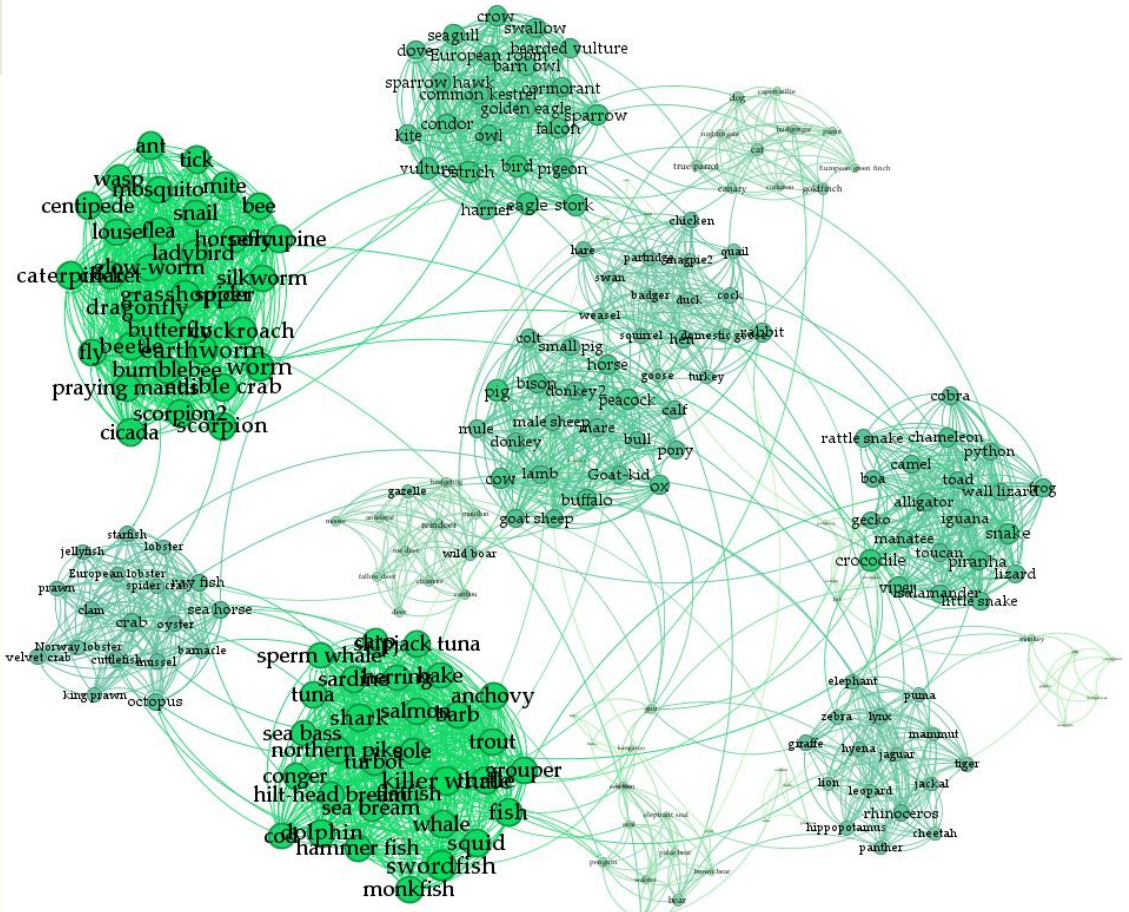

Figure 2: ECN: Enriched Conceptual Network

Short-Term memory

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Just as switching and clustering mechanism are affected by trauma to the frontal and temporal lobe, the short-term memory is affected by disorders such as aphasia.

Decrease the number of element that can be stored.

SWITCHING RANDOM WALK

The Switching Random Walk is a mechanism defined by matrix elements of the form:

$$P_{ij}^{srw} = qP_{ij}^{sw} + (1-q)P_{ij}^{cl} \quad (1)$$

where

$$P_{ij}^{cl} = \frac{a_{ij}}{k(V_i)} \quad (2)$$

and we defined

$$P_{ij}^{sw} = \lambda_j$$

With λ_j as

$$\lambda_j = \begin{cases} \dfrac{1}{|V|}, \\ \dfrac{k(v_j)}{\sum_{i\leq|V|} k(v_i)}, \\ \dfrac{K - k(v_j) + 1}{\sum_{i\leq|V|} K - k(v_j) + 1}, \\ \dfrac{P_{v_f}}{\sum_{i\leq|V|} f_{v_i}} \end{cases} \quad (3)$$

Mean-first Passage Time and Entropy Rate

Mean-first Passage Time

The Mean-first Passage Time (⟨MFPT⟩) defines the mean time for the first occurrence of a stochastic event. It is a time of the steps in the process $\langle T \rangle = [\langle t_{ij} \rangle]$

Defining a fundamental matrix

$$z = (I - \Pi^{srw} + \Pi^{\infty}_{srw})^{-1}$$

With I is the identity matrix, and Π^{∞}_{SRW} the stationary state of the Markov chain.

The analytic derivation of $\langle T \rangle = [\langle t_{ij} \rangle]$

$$\langle t_{ij} \rangle = \frac{z_{jj} - z_{ij}}{\omega_j}$$

Then, the $\langle MFPT \rangle$ is the mean over each pair of elements in $\langle T \rangle$

$$\langle MFPT \rangle = \frac{1}{2\binom{V}{2}} \sum_i \sum_{i \neq j} \langle t_{ij} \rangle \qquad (4)$$

$\langle MFPT \rangle$ is a measure of performance for a Markov chain.

Mean-first Passage Time and Entropy Rate

Entropy

Entropy H for a stochastic process with a probability distribution $P_{i1}, P_{i2}, \ldots, P_{in}$, considering the transition from $v_i \rightarrow v_j$ as a random variable v is defined as

$$H(V) = -\sum_{j=1}^{n} P_{i,j}^{srw} \log P_{i,j}^{srw} \qquad (5)$$

Entropy Rate

Then, we define the average over initial states of this quantity respect to the stationary measure (Π_i) and transition matrix (P_{ij}^{srw}).

$$h(V) = \sum_{i=1}^{n} \Pi_i H_i = -\sum_{i=1}^{n} \sum_{k=1}^{n} \Pi_i P_{i,j}^{srw} log P_{i,j}^{srw} \qquad (6)$$

The entropy rate is a measure of efficiency and indicates how the entropy of the system changes at each step.

MFPT and Entropy rate

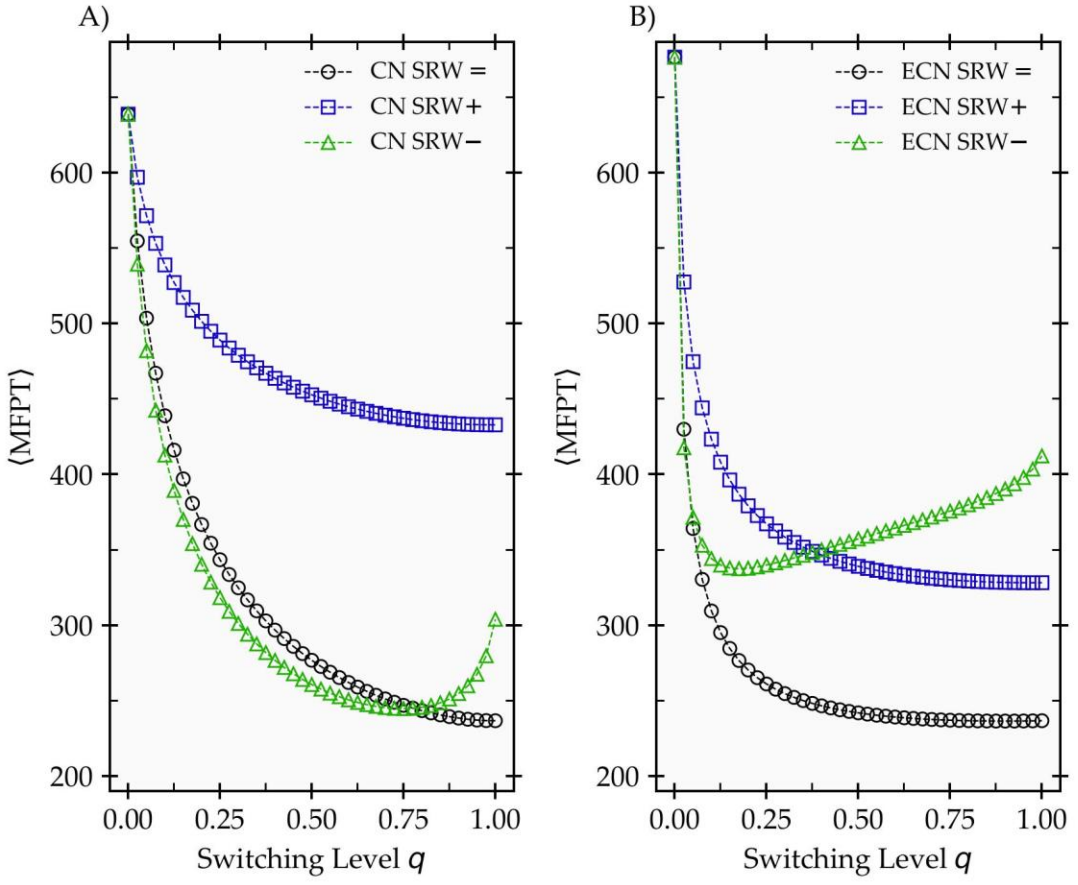

Figure 3: $\langle MFPT \rangle$ as function of switching level q. Each bias of random walker acting on *(A)* Conceptual Network *(CN)* and *(B)* Enriched conceptual network *(ECN)*

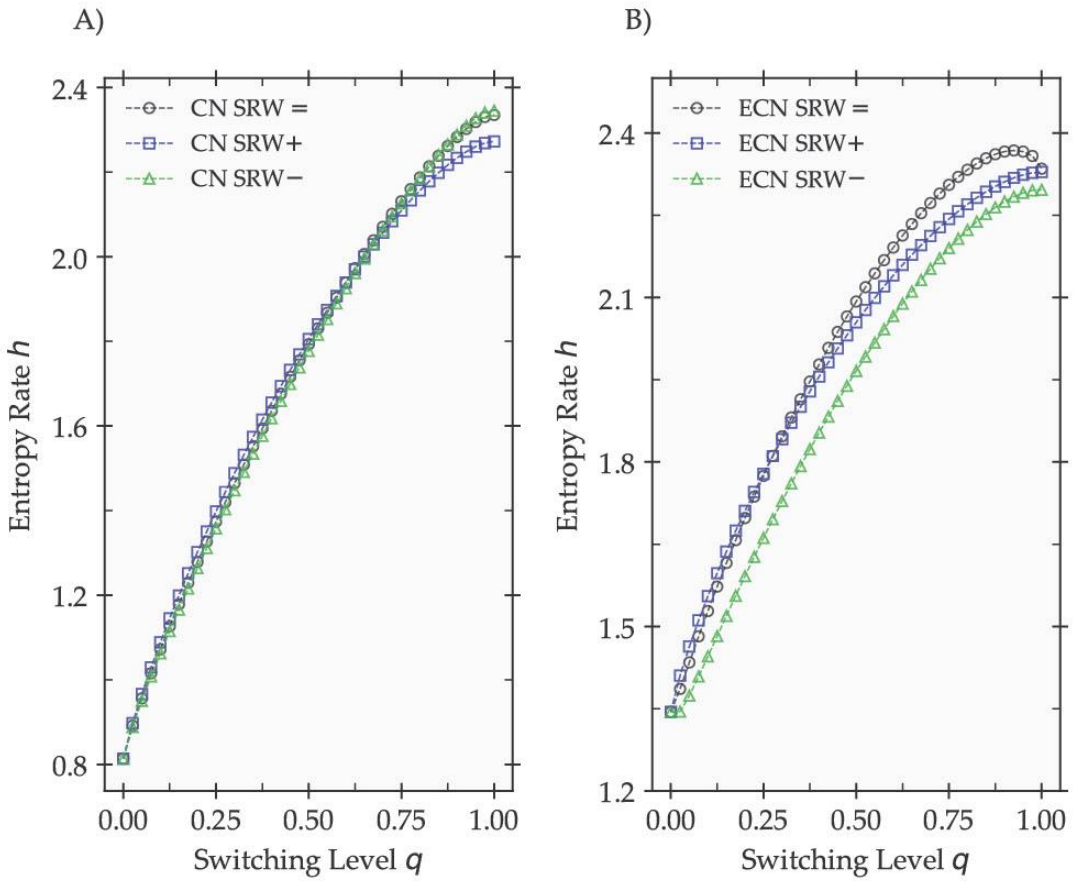

Figure 4: Entropy rate h as function of switching level q. Its calculated the entropy rate for each bias on *(A)* Conceptual Network *(CN)* and *(B)* Enriched conceptual network *(ECN)*.

MFPT and Entropy rate

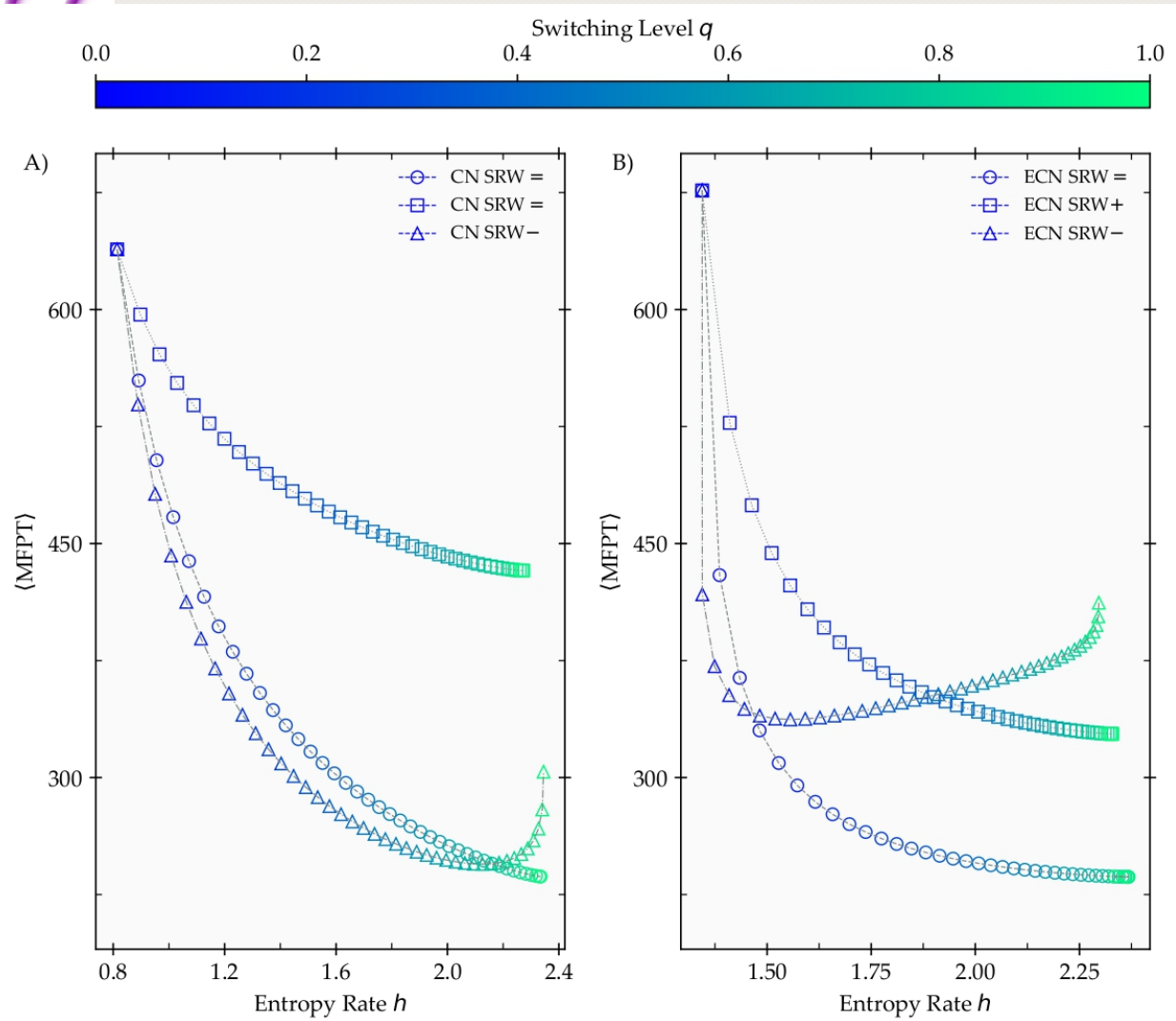

Figure 5: $\langle MFPT \rangle$ as function of switching entropy rate h for $SRW =, SRW+, SRW-$ for *(A)* Conceptual Network *(CN)* and *(B)* Enriched conceptual network *(ECN)*

Repetitions

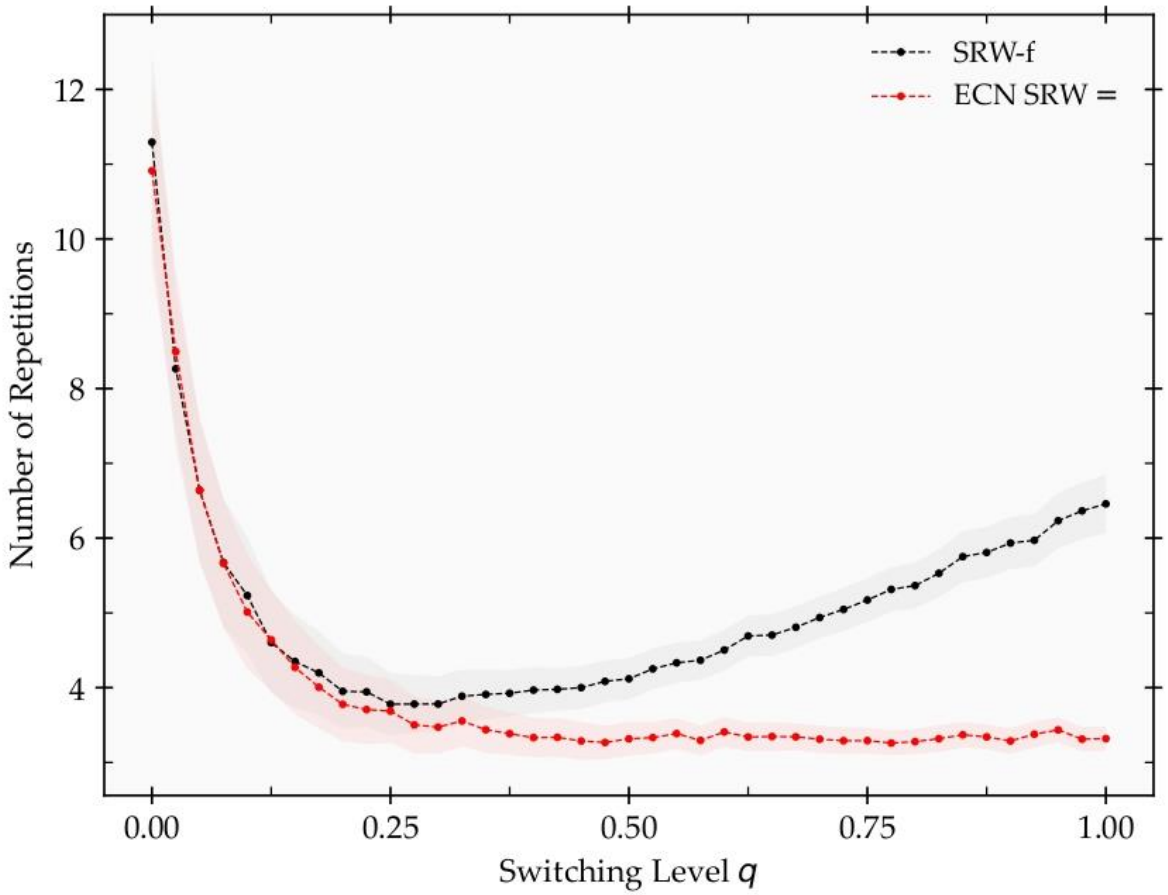

Figure 6: Variations of the number of repetitions as a function of switching level q, for frequency-based bias and equiprobable bias for enriched conceptual network.

Short-Term Memory

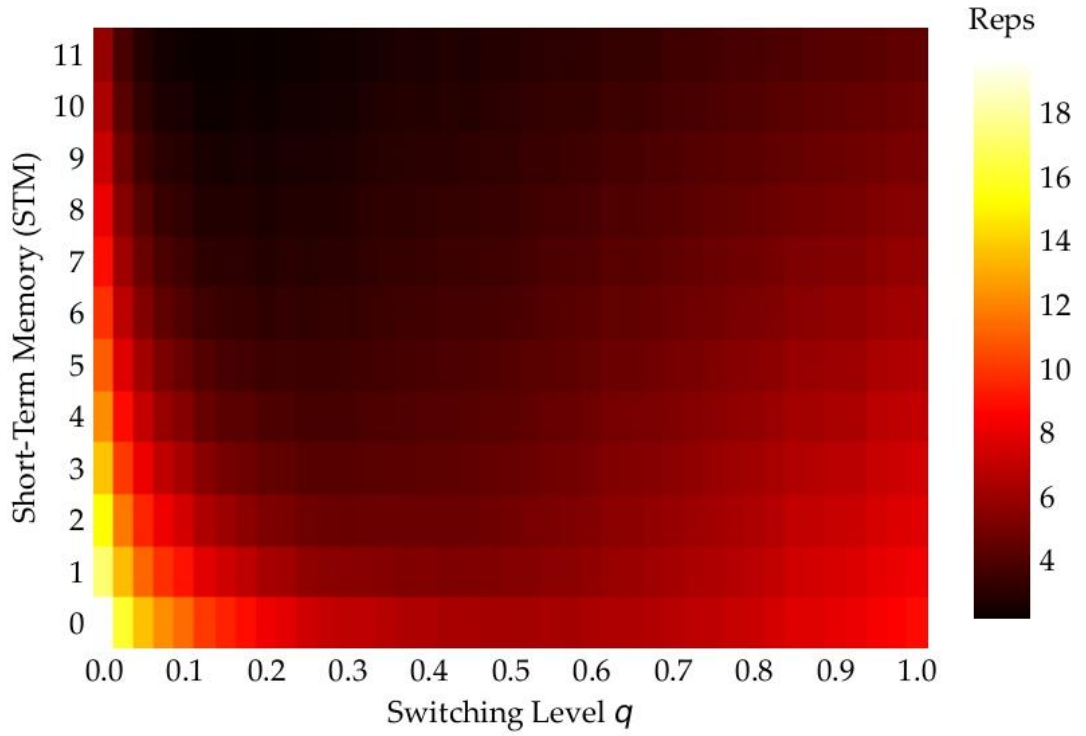

Figure 7: Short-term memory as a function of q for $SRWf$.

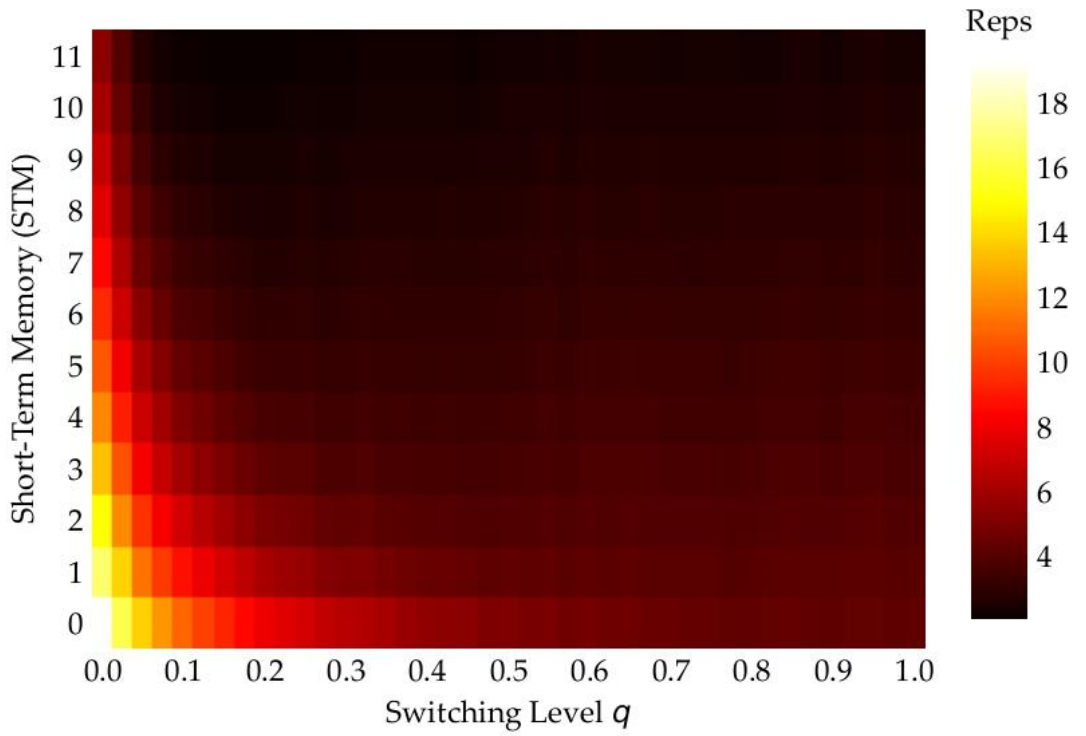

Figure 8: Short-term memory as a function of q for $SRW =$ for an enriched semantic network.

Short-Term Memory

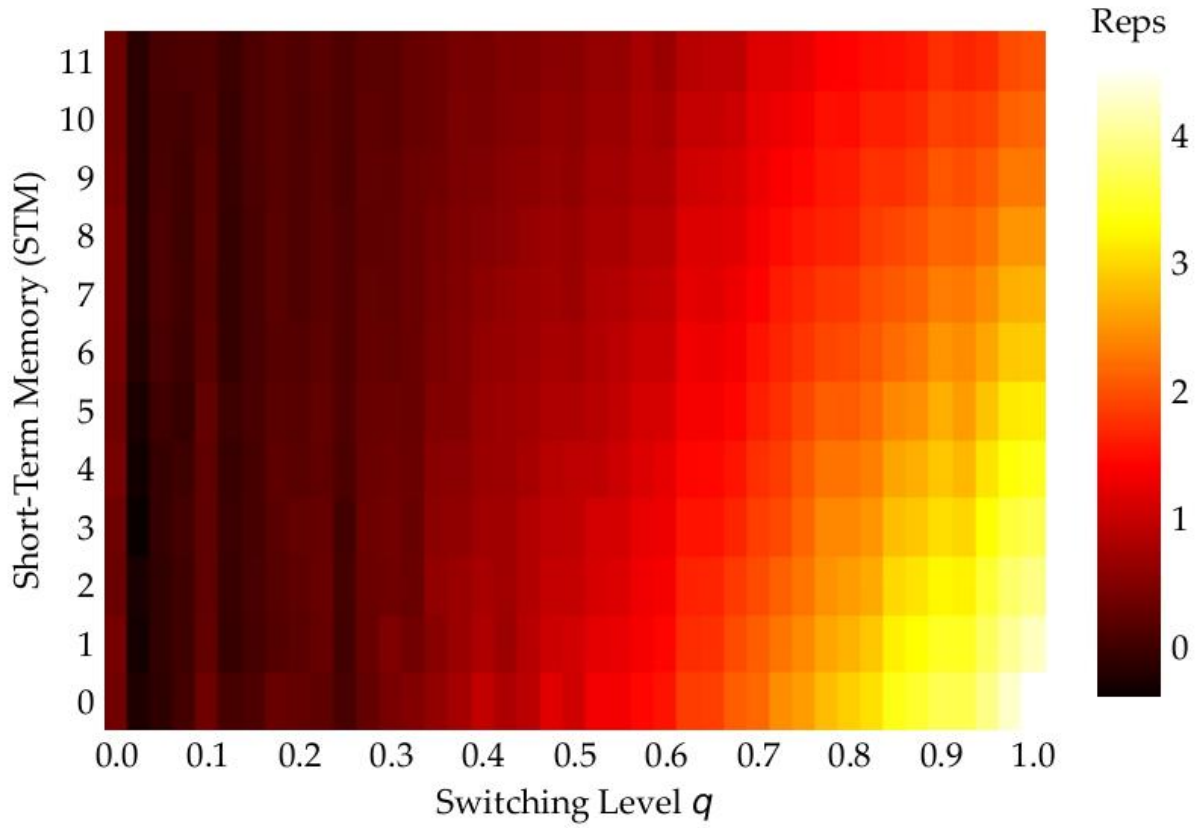

Figure 9: Differences between uniform frequency distribution ($SRWf$) and equiprobable distribution ($SRW =$) on an enriched conceptual network.

Conclusions

- In comparison between $\langle MFPT \rangle$ and h values, we observe that the behavior in both the positive bias and the equiprobable case is inversely proportional. An increase in efficiency leads to a decrease in performance.
- The performance of the fluency test is associated with how rich the lexical vocabulary is (a greater number of links between words from different subcategories), this richness determines the topology of the semantic network.
- Our results suggest that the optimal range for word retrieval (characterized by a low number of repetitions) lies where subcategory shifts are not frequent. This range coincides with the typical capacity of short-term memory (STM).

Considerations

We considered the number of repetitions and switching levels as indicators of performance in a fluency test, however, there exist other variables that were not considered, the number of clusters or the number of conceptual shifts in each test

González, K. N., Espinosa-Otalora, G., Goñi, J., & Naranjo-M, F. (2025). Exploration mechanisms intrinsic to semantic networks and the nuanced appraisal of lexical repetition occurrences. *Physica A: Statistical Mechanics and its Applications*, *660*, 130363.

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