

Simulating bilingual naming in laterally-connected self-organizing maps

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1 Introduction

The BiLex model simulates the bilingual language system: two phonetic self-organizing maps (SOMs) represent English and Spanish words, linked to a shared semantic map via bidirectional associative connections (Fig. 1a) [4]. Traditional SOMs use neighborhood activations; the laterally-connected BiLex uses short-range excitation and long-range inhibition, enabling mechanistic examination of within- and between-map lexical-semantic interactions. Semantic effects — familiarity, typicality, and specificity — can emerge from map interactions. Lateral excitation-inhibition focuses activation over settling steps, providing a novel response time measure. Naming accuracy and response time were examined in English and Spanish.

2 Methods

Phonetic representations used IPA-based feature encodings. Semantic representations, superordinate membership, and typicality were defined using GPT-4o [3] (> 90% MTurk agreement): feature semantics and superordinate-subordinate pairs (e.g., "is *apple* a *fruit*?" via yes/no word-feature queries; typicality as a 0–1 category-membership rating. SOMs were trained by word-frequency sampling (a familiarity proxy), learning boosted or penalized based on expected representation. Learned connections linked maps, superordinates on the phonetic map via subordinates. Naming was simulated by presenting a word to the semantic map, driving lateral interactions within and between maps until activation settled; response time was settling steps to certainty.

3 Results

Overall model accuracy was 73.6% for English naming and 70.5% for Spanish naming, which falls within the range observed for healthy bilingual adults on picture-naming tasks, who name well below ceiling in each language [2]. Most errors were semantically related (49.1%), superordinate responses (28.0%), or phonological (9.2%); only 8.6% were unrelated and 3.0% failed to converge.

Typicality and word frequency had a significant positive correlation, $r_s(664) = .115, p = .003$. Higher frequency was correlated with faster (English $r_s(664) = -.261$, Spanish $r_s = -.180$) and more accurate naming (English $r_s(664) = .157$, Spanish $r_s(664) = .225$; all $p < 0.001$). See Fig. 1*b, c*. Excitation-inhibition dynamics enabled response time measurements via map activation settling steps. The laterally-connected BiLex model successfully simulated naming in both languages.

4 Discussion

A biologically plausible model should produce human-like errors rather than random failures. Errors were consistent with human studies of semantic cognition and naming [5] [1]: within-category coordinate errors, phonological similarity errors, or superordinate responses to subordinate category members. A positive correlation between typicality and word frequency suggested that higher-frequency words tend to be more typical category members, and atypicality in low-frequency words may contribute to naming difficulty. Structured errors validate the model and provided insight into semantic and lexical mechanisms. Future work will examine lexical-semantic impairments and potential treatments.

5 Acknowledgements

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References

- [1] Gary S. Dell et al. “Lexical access in aphasic and nonaphasic speakers”. In: *Psychological Review* 104.4 (1997), pp. 801–838. DOI: 10.1037/0033-295X.104.4.801.
- [2] Kathryn J. Kohnert, Arturo E. Hernandez, and Elizabeth Bates. “Bilingual performance on the Boston Naming Test: Preliminary norms in Spanish and English”. In: *Brain and Language* 65.3 (1998), pp. 422–440. DOI: 10.1006/brln.1998.2001.
- [3] OpenAI. *Hello GPT-4o*. 2024. URL: <https://openai.com/index/hello-gpt-4o/> (visited on 11/04/2025).
- [4] Cristian Peñaloza et al. “BiLex: A computational approach to the effects of age of acquisition and language exposure on bilingual lexical access”. In: *Brain and Language* 195 (2019), p. 104643.
- [5] Timothy T. Rogers et al. “Disorders of representation and control in semantic cognition: Effects of familiarity, typicality, and specificity”. In: *Neuropsychologia* 76 (2015), pp. 220–239.

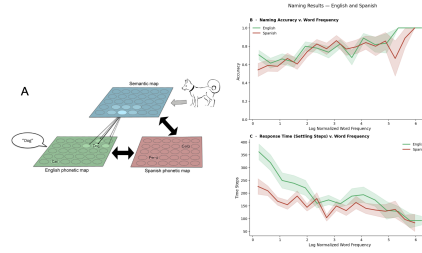


Figure 1: *Left:* BiLex model trained with lateral connections, figure adapted from [4]. Naming is simulated by presenting an input to the semantic map, propagating activation through bidirectional associative connections, and producing a response from the English map. The naming task was repeated in both English and Spanish. *Right:* Naming accuracy and response times for English and Spanish naming; accuracy significantly increased with word frequency ($p < 0.001$) while response times were significantly faster ($p < 0.001$).