Investigating Hebbian Alternatives to Dense Associative Memory

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Abstract

Dense Associative Memories generalize traditional Hopfield networks while providing a substantially increased capacity. To do this, they show that by increasing the separation of similarity scores between query patterns and stored patterns. The cost of increased capacity is simplicity and biological plausibility. We propose to investigate the capacity characteristics of all Hebbian associative memories, to see if there exists any alternative to Dense Associative Memories which maintains the simplicity and appeal of Hopfield networks.

Humans are able to recognize and retrieve patterns of data using distorted, noisy, and partial patterns (Rumelhart et al., 1986). This capacity of human memory is known as *content-addressability*: patterns which are stored in memory are able to be "looked up" by themselves or their parts. Modeling this property is a classical task in computational cognitive and neuroscience (see Amari (1972), Little (1974), Marr (1971), Nakano (1972), and Stanley (1976)). The family of models which implement content-addressability are known as *associative memory models* (AMs). A recent revival of interest AMs in machine learning research, driven by their equivalence with "attention" layers in the transformer architecture (Ramsauer et al., 2021; Vaswani et al., 2023), has led to drastic advances in the storage capacity of AMs (Demircigil et al., 2017; Hu et al., 2024; Krotov & Hopfield, 2016).

References

Amari, S.-I. (1972). Learning patterns and pattern sequences by self-organizing nets of threshold elements. *IEEE Transactions on Computers*, *C-21*(11), 1197–1206. https://doi.org/10.1109/T-C.1972.223477

Demircigil, M., Heusel, J., Löwe, M., Upgang, S., & Vermet, F. (2017). On a model of associative memory with huge storage capacity. *Journal of Statistical Physics*, *168*(2), 288–299. https://doi.org/10.1007/s10955-017-1806-y

Hu, J. Y.-C., Wu, D., & Liu, H. (2024, October 31). Provably optimal memory capacity for modern hopfield models: Transformer-compatible dense associative memories as spherical codes. https://doi.org/10.48550/arXiv.2410.23126

Krotov, D., & Hopfield, J. J. (2016, September 27). Dense associative memory for pattern recognition. https://doi.org/10.48550/arXiv.1606.01164

Little, W. (1974). The existence of persistent states in the brain. *Mathematical Biosciences*, *19*(1), 101–120. https://doi.org/https://doi.org/10.1016/0025-5564(74)90031-5.

Marr, D. (1971). Simple memory: A theory for archicortex. *Philosophical Transactions of the Royal Society of London*, *262*(841), 23–81.

Nakano, K. (1972). Associatron-a model of associative memory. *IEEE Transactions on Systems, Man, and Cybernetics*, *SMC-2*(3), 380–388. https://doi.org/10.1109/TSMC.1972.4309133

Ramsauer, H., Schäfl, B., Lehner, J., Seidl, P., Widrich, M., Adler, T., Gruber, L., Holzleitner, M., Pavlović, M., Sandve, G. K., Greiff, V., Kreil, D., Kopp, M., Klambauer, G., Brandstetter, J., & Hochreiter, S. (2021, April 28). Hopfield networks is all you need. https://doi.org/10.48550/arXiv.2008.02217

Rumelhart, D. E., Hinton, G. E., & McClelland, J. L. (1986, July 17). A general framework for parallel distributed processing. In *Parallel distributed processing: Explorations in the microstructure of cognition: Foundations* (pp. 45–76, Vols. 2, Vol. 1). The MIT Press. Retrieved August 28, 2025, from https://doi.org/10.7551/mitpress/5236.001.0001

Stanley, J. C. (1976). Simulation studies of a temporal sequence memory model. *Biological Cybernetics*, *24*(3), 121–137. https://doi.org/10.1007/BF00364115

Vaswani, A., Shazeer, N., Parmar, N., Uszkoreit, J., Jones, L., Gomez, A. N., Kaiser, L., & Polosukhin, I. (2023, August 2). Attention is all you need. https://doi.org/10.48550/arXiv.1706.03762