Artificial neural networks and complex networks: an integrative study of topological properties and pattern recognition

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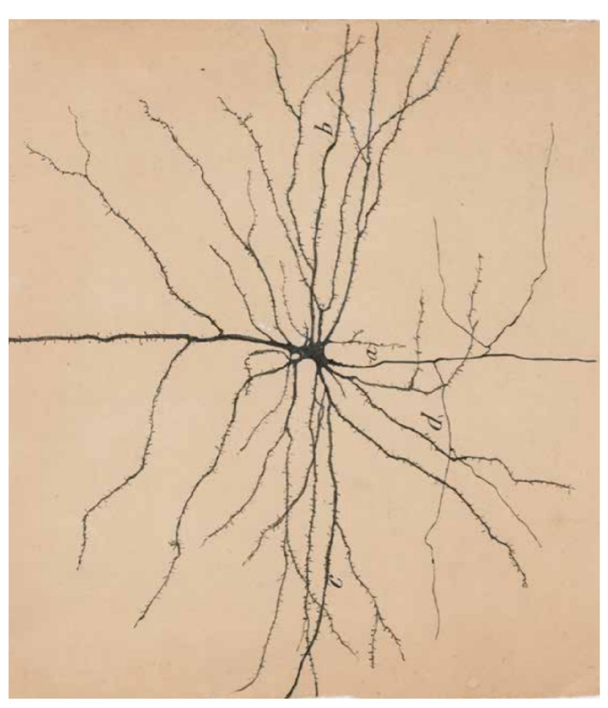
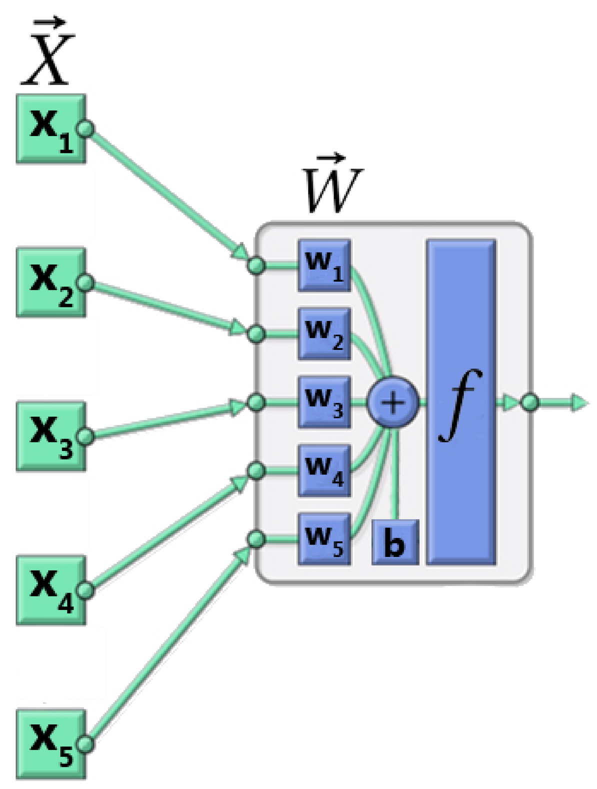
Introduction

Artificial neural networks (ANN) and Complex networks (CN) are gaining attention nowadays due to advances in artificial intelligence, computer hardware, and big data phenomena. Recent deep ANN architectures have been achieving outstanding performance on various problems, which led to the proposal of many models. However, due to the lack of knowledge of its internal functioning, these techniques are used as a black-box approach. For instance, it is possible to produce images that are completely unrecognizable by humans, but which deep convolutional networks strongly believe to be recognizable objects [1]. New studies are then needed regarding the functioning of these networks, contributing to the development of more robust and interpretable models.

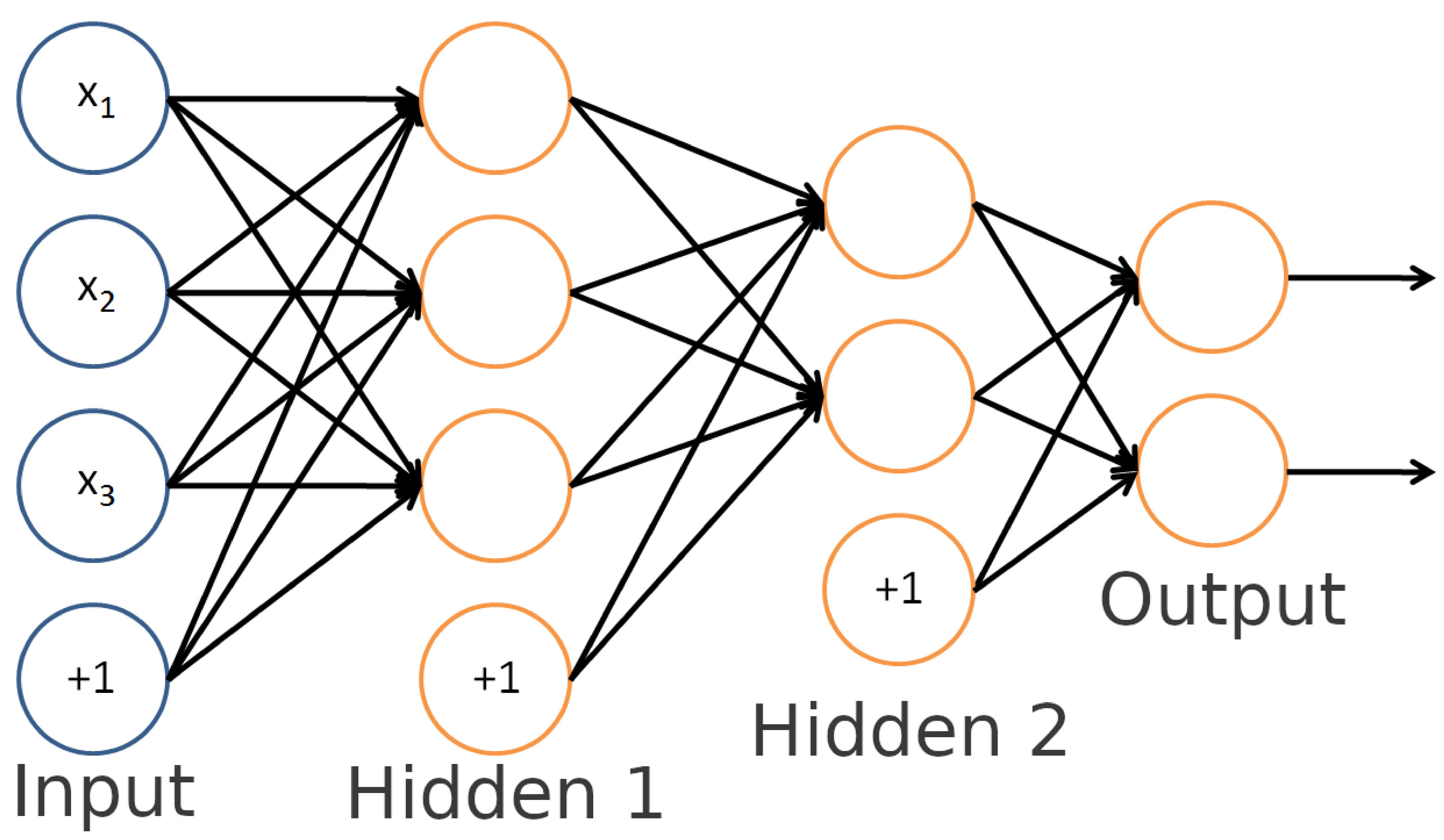
Artificial Neural Networks and Complex Networks



(a) Illustration from Ramón y Cajal, 1904.



(b) Perceptron of Rosenblatt, 1958.



(c) Multilayer artificial neural network.

Figure 1: Natural and artificial neurons (a-b) and an artificial neural network (c).

ANN are naturally represented by CN, i.e. consider a graph $G = \{V, E\}$ where $V = \{v_1, ..., v_n\}$ represent its set of vertices (neurons) and $E\{a(v_i, v_j)\}$ its set of edges (connections between layers). From this graph, several topological measures can be computed such as the vertex degree

$$k(v_i) = \sum_{j=1}^{n} a(v_i, v_j) \quad (1)$$

If G is weighted, the weighted degree is obtained, a measure is commonly known by vertex strength. For directed graphs, changing the order of the sum between $a(v_i, v_j)$ and $a(v_j, v_i)$ allows to compute, respectively, the input and output strength of v_i. There is a wide range of measures that can be explored to quantify and understand the topology and dynamics of networks. Among them, we can consider the betweenness, closeness, average path distances, clustering coefficients, hierarchical degree, and many more [2].

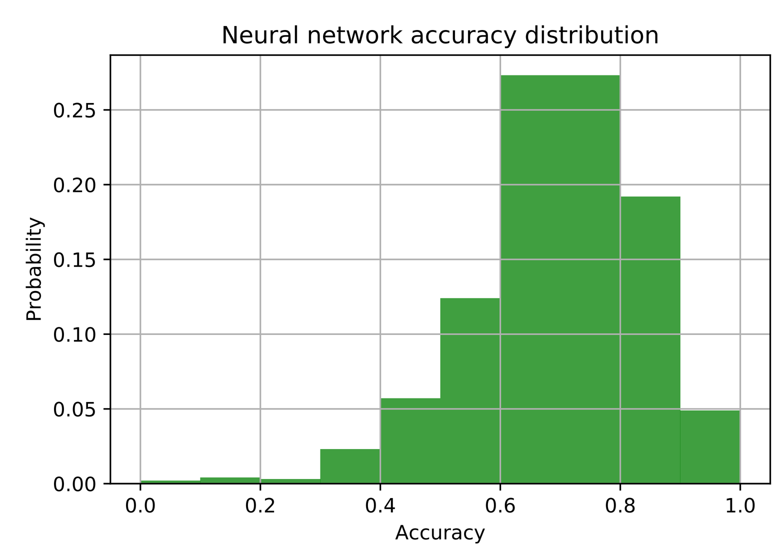
Proposal

We hypothesize that the topology of ANNs plays a crucial role in its overall functioning. To analyze that, the ANN elements (neurons and weights) are considered as a complex network whose dynamics evolve from a random initial state to a final trained model in a given task. Then the topological properties of the network are quantified to establish correlations with its performance.

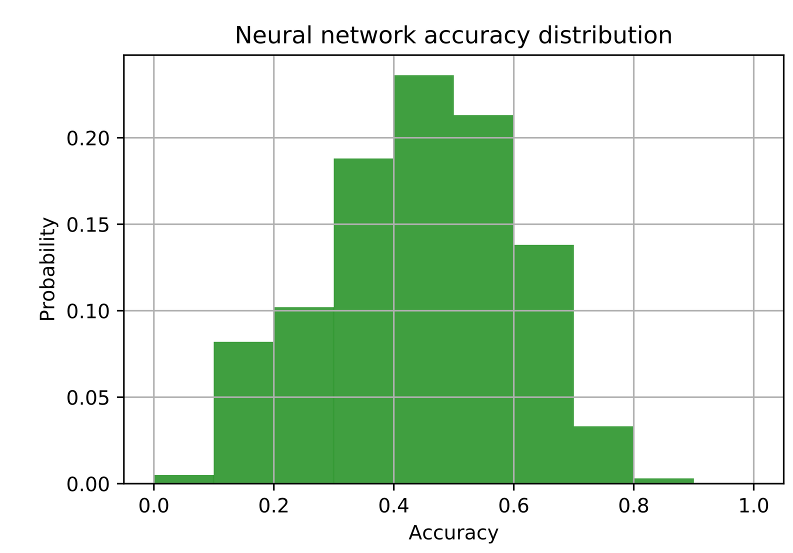
Our first analysis considers deep feedforward ANN as directed graphs, where connections point towards the propagation of information from the input to the output layer (forward). We then analyze the correlation between two topological measures (input and output strength) of the hidden layers with the network performance (test accuracy rate).

Experiments and Results

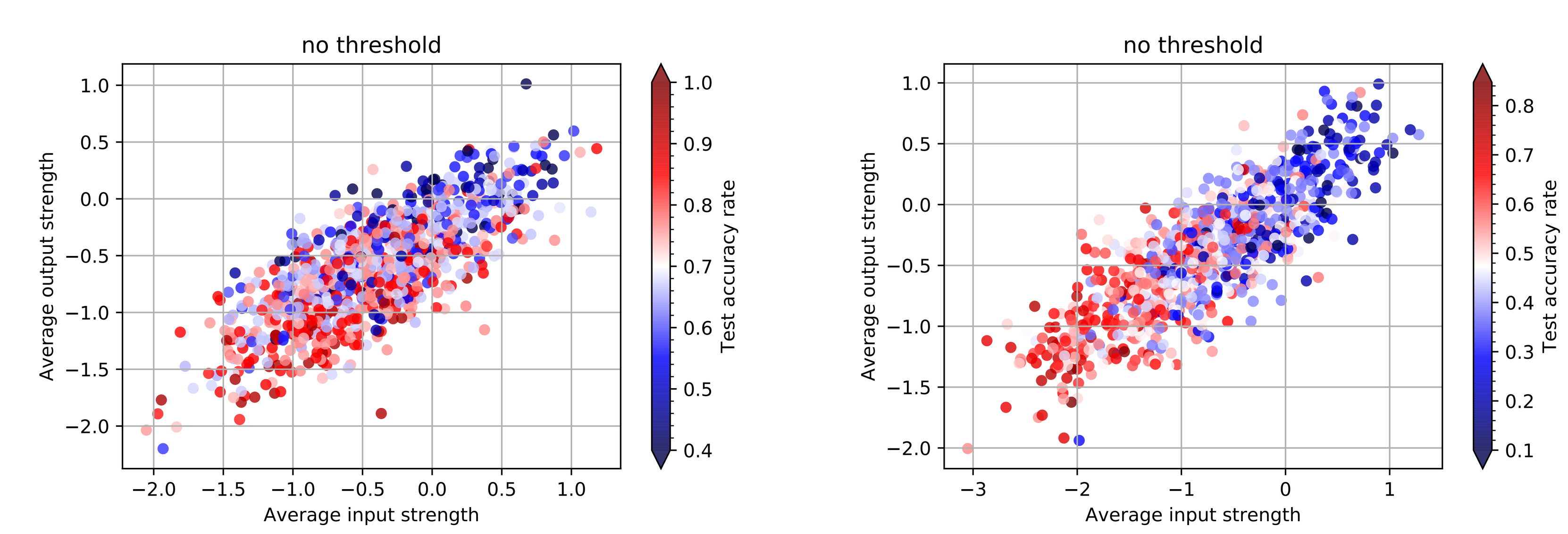
The experiment considers 1000 ANN with different random initial weights trained in two datasets (MNIST and Fashion MNIST). Results indicate a strong correlation between the network accuracy and the average strength of hidden neurons. This indicates the existence of topological elements directly related to network performance. Here, networks with higher accuracy have hidden neurons with negative average input and output strength, while networks with low accuracy show the opposite.



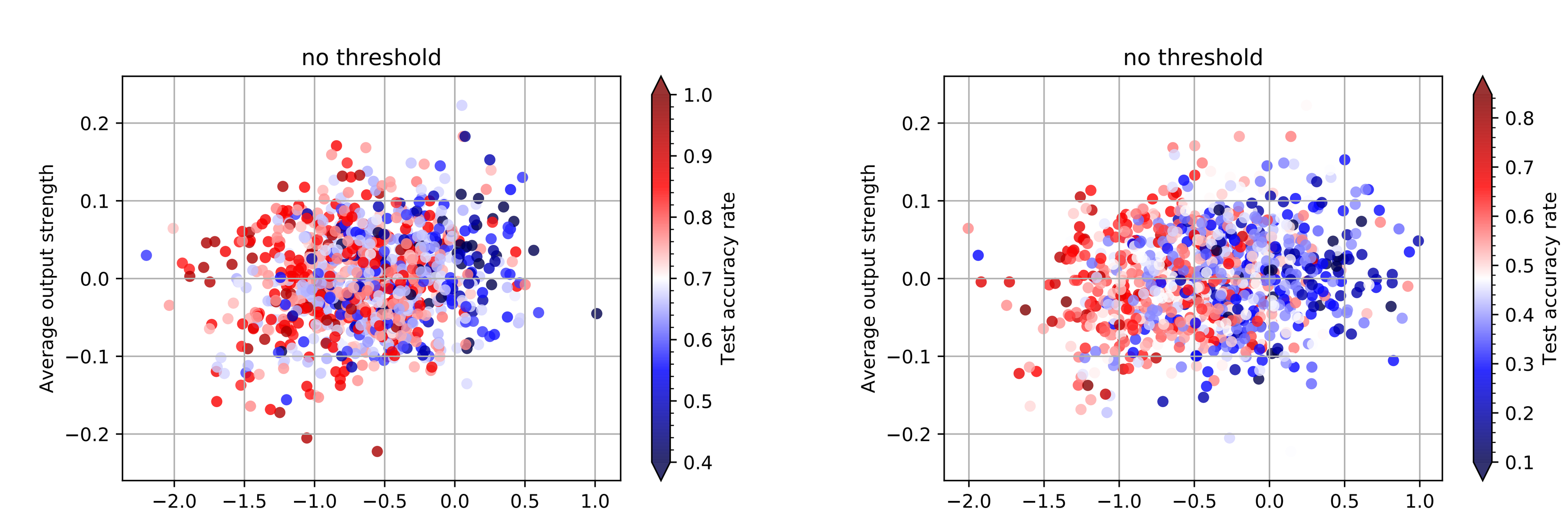
(a) MNIST.



(b) Fashion MNIST.



(c) Hidden layer 1 results.



(d) Hidden layer 2 results.

Figure 2: The distribution of performance of 1000 ANN (a-b). Results based on the average neuron strength (input and output) of individual hidden layers (c-d).

References

[1] A. Nguyen, J. Yosinski, and J. Clune. *Deep neural networks are easily fooled: High confidence predictions for unrecognizable images.* In Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition, pages 427-436, 2015.

[2] L. da F. Costa, F. A. Rodrigues, G. Travieso, and P. R. Villas Boas *Characterization of complex networks: A survey of measurements.* Advances in Physics, 56(1):167-242, 2007.