

Neural networks and physical systems with emergent collective computational abilities

Abstract

“Computational properties of use to biological organisms or to the construction of computers can emerge as collective properties of systems having a large number of simple equivalent components (or neurons). The physical meaning of content-addressable memory is described by an appropriate phase space flow of the state of a system. A model of such a system is given, based on aspects of neurobiology but readily adapted to integrated circuits. The collective properties of this model produce a content-addressable memory which correctly yields an entire memory from any subpart of sufficient size. The algorithm for the time evolution of the state of the system is based on asynchronous parallel processing. Additional emergent collective properties include some capacity for generalization, familiarity recognition, categorization, error correction, and time sequence retention. The collective properties are only weakly sensitive to details of the modeling or the failure of individual devices.”

Introduction

- The process of how a part of neurobiology is implemented to integrated circuits to accomplish large and complex tasks are discussed in the paper.
- The analogous of electric and brain circuits are dealt theoretically and beautifully. It is one of the initial stage papers that proved the stability and ability of neural networks, which later emerged into the machine learning.
- The increasing efficiency of general content-addressable memory towards ideal memory with the help of neurons and mathematical formulae are described elaborately.
- The paper started with the explanation of transformation of biological neurons and their synapses to the electrical circuits and their processions. He also elaborates the computer memory differences and requirements in the real world by taking the general content-addressable memory and the ideal memory as the cases.
- The corresponding relations between the physical systems like magnetic and vortex flows are also taken as instances to discuss the elementary components and their interactions.

Previous Works

- The use of Perceptrons until that period is well stated in the paper and also other applications of them and their limitations. So, this paper has not stated any implementation of Perceptrons as the author found that has to be overcome by the application of neurons.
- The advantages of neurons and their implementations in memory stabilization are well stated.
- This paper also showed the time sequential memory, stability of memories, categories of generalization be also emergent properties and collective in origin and how the computational properties arise from them.
- Even the model changes dynamically, the previous works are not as robust for the change. So, the author concentrated on the collective properties to be the solution for the problem.

Content

- Initially a few coordinates of a physical system is considered from X_1, X_2, \dots, X_n . These coordinates are comprised into a vector X , called as state vector of the physical system.
- Then the points which are stable locally are considered as X_a, X_b, \dots . It is stated that if the system starts at some point $X_a + \Delta$, and moves to X_a in the time being, then the point $X_a + \Delta$ has partial knowledge of the system and the point X_a gives the total knowledge of the system at X_a .
- So, for any system if the dynamics is dominated by the stable points, then the system state space can be defined as the general content-addressable memory.
- He denoted the processing devices as neurons. The neurons will be given the values of '0' or '1' based on their firing rate. And the connections with other neurons were also denoted by '0' and '1'. ('0' if not connected, '1' if connected).
- Certain cases are assumed to get the solutions based on the probability of the errors occurred in the location of stable states. The table states are also described exactly in the paper with certain examples and formulae, which makes the reader life easy.
- The noise is calculated by the Gaussian's distribution with the probability error,

$$P = \frac{1}{\sqrt{2\pi\sigma^2}} \int_{N/2}^{\infty} e^{-x^2/2\sigma^2} dx .$$

Normal distribution probability function.^[1]

where N = number of errors in state.

- In addition to that the author also presented a good command in combining the theory and the mathematics in a pattern that the explanation goes in a flow.
- Finally, author has shown his confidence in making the sensitive chips for decrease of error propagation through his method implementing through elementary integrated chips.

Results

- The algorithm has given the statistics of five out of five being stable in the given matrices of a stated. When the number is increased to 15, half of the states had been stable.
- By the algorithm, the evaluation of the neurons did also take place and the memories were also maintained to be stable states.
- In addition, the algorithm also made the model very analogous to the natural physical systems which resolved the ambiguity and the very precise modelling in the prior methods.

Discussion and thoughts

- A good theory is given to explain the physical terms of the hardware of the computer systems, their backdrops and drawbacks.
- Different memory properties are also discussed in the perspective of author. The mathematical proofs are also derived for the memory storages of the neurons in dynamic state, which consumes the major part of the paper.

- The drawbacks of Perceptrons in Distributed systems and the memory errors in hardware are well addressed.
- The structure of the paper is very symmetric and simple to find the topics.
- To be precise, no other figures are given to represent any type of process that author explained.

Conclusion

- Being an old paper, it generates a good overview in the neurons and neural networks. The drawbacks of the previous procedures are also finely marked.
- The assumptions are also very limited with respect to the practical applications and the terminology used in the formulae are also briefly explained.
- Despite of these all, the author assumed that the reader has a good knowledge in formulating because he did not give any references to the formulations.
- It, in spite takes the reader to a bit confused state in understanding the formulae.
- It would be even more interesting if the basis for the formulations are given or referenced by the author.