

Cognition and Computational Paradigms of Brain Processing: Capacities and Limitations

Cognição e paradigmas do processamento cerebral: capacidades e limitações

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RESUMO

O estudo da Neurocomputação permitiu à Ciência Cognitiva novos desafios e paradigmas, determinando os limites de processamento de informações do cérebro humano e realizando um paralelo sobre as possibilidades de inclusão das tecnologias de inteligência artificial nas investigações empíricas. Há uma comparação a ser realizada, sendo os processamentos mentais simulados por processos artificiais gerados por analogias computacionais. Assim como a computação, a mente humana processa suas informações de modo hierárquico e com capacidade previamente estabelecida. O presente trabalho realiza uma revisão sobre o tema, considerando que para ser obtida uma expansão da capacidade mental, deva se respeitar os limites cerebrais, anatômico e dependente de uma evolução biológica, mas utilizar recursos extracerebrais para sua expansão quantitativa e qualitativa.

Palavras-Chave: Paradigmas computacional, redes mensais, cognição, capacidade cerebral.

ABSTRACT

The study of the Neurocomputation allowed to Cognitive Science new challenges and paradigms, determining the processing limits of information on the human brain and carrying through a parallel on the possibilities of inclusion of the technologies of Artificial Intelligence in the empirical inquiries. It has a comparison to be carried through, being the mental processings simulated by artificial processes generated based on computational analogies. As well as the computation, the mind human being processes its information in hierarchic way and with capacity previously established. The present work carries through a revision on the subject, considering that to be gotten an expansion of the mental capacity, must respect the cerebral limits, anatomical and dependent of a biological evolution, but use extra-brain resources for its quantitative and qualitative expansion.

Key Words: computational paradigms; neural networks; cognition; brain capacity.

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INTRODUCTION

The Cognitive Science and its consequent investigation always motivated the search for new paradigms. For being a field of studies where the phenomena we observe are always susceptible to modelling, the proposal of including the human cognition as representable by means of mathematical simulation is considered useful. As well as the cognition, the psychopathological phenomena are also analyzed by this same method.

The growing interest in using accessory mechanisms to understand the psychopathologies and the cognition derives from the relative incapacity of the human mind to understand and to validate the emotional and behavioral processes. There is a standardization to be sought for and without the aid of tools this task becomes more complex and fruitless. For this end, the appearance of digital technologies supplies this need initially and it proposes a vast number of investigative possibilities to certify. The Artificial Neural Networks (ANNs) are the logical and mathematical instruments for this investigation and validation to be accomplished.

However, one of the first questions to be asked is about the processing capacity of the human mind. The cognitive limits and the storage of information should be considered when one intends to perform an analysis of this processing. Once those limits are established, one can anticipate which are the possibilities and targets to be reached when searching for an optimization for such limits. That is why the interest to develop testable methods to reach that objective appears.

Therefore, the present work initiates a narrative revision on the computational paradigms and a historical synthesis on the origins of Neurocomputation. After that it revises, in general terms, the literature on the computational models that simulate the operation of the normal and pathological human mind. In that intention, we permeate the capacity and limits of the mental processes. Verifying computational and ANNs models, besides analyzing their applications, we will comment on their peculiarities and borders between the computational analogy and the human mind. Starting from this knowledge, such methods can be applied to the investigation of psychopathological phenomena and the processing of emotional information using the modelling of natural systems¹.

COGNITIVE PROCESSING AND COMPUTATIONAL PARADIGMS

1. Processing of information and Computational Analogy

Starting from the analysis of the literature, there is a justification that supports the possibilities of comparison between the natural cognitive processing, accomplished by the human mind, and the intrinsic mechanisms of the neurocomputational models. Following this argument, the epistemological need to determine an artificial cognitive model that simulates or represents the mental functions, and that recognizes its limits and ambitions, appears. Empiric modellings, applicable or not, have appeared to foment a decisive paradigm of an equivalent model for the Human Cognition and its cybernetic homolog.

The Cognitive Science, a field delimited by the observation of phenomena and experiences based on case-studies, allows analogies and probable simulations, typical of computational logic. Therefore, it would come from the human model the presupposition for theoretical characterization of these studies, and the need for one to outline and to understand the cognitive processing in man.

According to Cognitive Psychology, the processing of information demands a perspective of a deeper analysis, derived from a diversified and complex net of theories, methods and concepts. Kail and Bisanz⁵ revised such concepts, organized and proposed four sub-classifications of the cognitive operation: the cognitive phenomena would be described and explained as processes and mental representations that intervene between stimuli and responses susceptible to observation; individual processings act in a unified way, respecting an hierarchal organization; Subjacent to all cognitive activity, there is a small number of elementary processes; the cognitive development happens through self-modification or adjustment, and this can be measured by changes in internal, innate structures. However, one cannot deny the decisive impact of external, environmental factors.

Based on the basic organization of those premises, this conceptual approach contemplates the idea that a comprehensive scientific model of the cognitive performance in a certain mental task incorporates underlying

mechanisms, in other words, perceptive processes for codifying information. Besides, other processes would be necessary for the manipulation and storage of information, processes to select and make the stored information available and to decide among the alternative possibilities of behaving.

We can also consider the existence of specifications related to the way the information is organized, chained and represented internally in the mental atmosphere. Such concepts motivate the research and the understanding of the learning and developing processes; changes in the acquisition of information that happen along the time and in the identification of characteristics of surrounding areas. The environmental interference contributes not only to qualify, but also to restrict such changes, as pointed out by Cleeremans³.

An important contribution was given by Chalmers², who developed a study in the Department of Philosophy of the University of California seeking to establish the ambitions of Artificial Intelligence and the role of computers in Cognitive Science. When he analyzed the viability and the connection among computational systems, based on abstract logic and concrete physical systems, Chalmers elaborated his observation starting from the idea that a system establishes a computation if its causal structure reflects the formal structure of that computation. The author made use of formal logic and of an approach of systems to demonstrate that the thesis of computational sufficiency and the thesis of computational explanation are both perfectly justifiable. Such theses are justifiable, continues Chalmers, "for being the consequence of observation that the computation can specify general patterns of organization and that the fruit of mental processing is an intrinsic organizational invariable to such patterns".

Opposing to the ideological challenges represented by theoreticians like Searle, Harnard and Putman, who disagree with cognitive computation, Chalmers presents his considerations in an incisive way. Such theoretical fundamentals can be understood after considering that any and all physical systems accomplishes some kind of computation representing "finite-state automata" with a single internal state; that not all the instances and processes of a system perform computation; that not all systems can perform all the computations and that any given system

can accomplish more than a computation. He enumerates, therefore, a representative logic, a paradigm, with the purpose of explaining or repeating cognitive processes, but by this same logic one cannot state that the brain would be a Turing Machine and that the surroundings would be the ribbon. By the same argument, the brain would be a machine just like the one conceived according to Von Neumann's principles. Theories that elaborate a more detailed and consecutive concept of the cognitive processing at real level are connectionists, and analogically a "real state".

When we respect the theses of the computational sufficiency and explanation, the detailed description of the cognition phenomena can reveal complex causal dynamics or even architectures that vary from subject to subject. At this point one must point out that the computational paradigm should not be confused with the presupposition that the human cognition is reduced to the strict execution of action rules. Therefore, computational models include rules in simple, low hierarchy processings, such as the neuronal operation; without possessing, however, rules at cognitive level, that demands a larger complexity. From this analysis there is a supposition that we can understand the argument that the brain can behave as a computer, understanding the computations and not the computer (the machine) as the central point of those approaches described.

2.The Computational Brain

The brain, be it human or from some animals, has as one of its main attributes the capacity to generate complex cognitive processes. Man depends, for his survival, on his capacity to notice the world, to abstract and to ratiocinate, to create and to elaborate, and to judge. He also relies on mnemonic resources to enable and to improve the use of his limited corporal capacity, when compared with several animals, and to interact in an effective way with the environment. From an evolutionist perspective, humanity's main advantage in the natural selection of the species is its ability to produce, manage and apply its knowledge in its own benefit and in society's as well.

That developed brain capacity would derive from the neuronal quality and architecture, that would offer better patterns for data processing in humans; a decisive factor for its bigger competitive advantage in relation to knowledge.

However, there are limitations related to the expansion of the human cognitive processes, revealed by studies that evaluated the measurable capacity of this performance.

From that supposition, some investigations were proposed. This possibility can be verified when we consider the discrepancy between an indefinitely complex world and a brain limited to 1500 grams of cellular substance. Using combinatorial analysis, Ward¹⁸ identified the brain as an organ with approximately 10^{10} to 10^{11} neurons, forming a net with about 10^{14} synapses. In a simple comparison with the number of particles of the Universe (as seen) that possesses approximately 10^{80} particles and 10^{120} known interactions, this rate is very low. The rate is $1:10^{106}$.

A classic essay, published by Miller¹³, gathered a group of biophysical studies that evidenced the existence of neurological limits quantified in the human capacity to process information. Among the discoveries, the discovery of specific maximum limits for the identification, differentiation and/or evaluation of sound tones, position of points in space (in terms of bi-dimensionality) and concentrations of saline solutions are worth mentioning. He also verified clear limits for memories of random sequences of several unrelated contents and for the capacity of re-codifying binary numbers in decimal formats.

As a delimiter of the capacity of cognitive performance, Merkle¹¹ mentioned studies of this performance and did a revision concerning the mental physiology and compared this hypothesis with Claude Shannon's theory of information, coming to the conclusion that the human memory has a maximum storage capacity of approximately two bits per second, being equivalent to 7KB per hour, 133KB per day (approximately 16 hours awake) and 41MB per year. Therefore, an individual that lived to be 80 years old, with all his/her mental intact, would accumulate up to 3,3 GB of information during his/her existence. Just using an example for simple comparison, the average data storing capacity of a personal computer in 2005 was, at least, 20 times superior. In another study, Merkle¹² used several measures from the operation of the brain physiology to estimate the maxim processing capacity between 10^{13} and 10^{16} operations per second, with an average consumption of 10 Watts for such an objective.

White¹⁹ mentions several studies dealing with the brain's mnemonic capacity and with the way the human

brain processes information, concluding that most of the people have already physiologically reached a maximum level of cognitive function. The author stresses that the use of stimulating substances such as caffeine, nicotine and sucrose are used in strategies to increase the cognitive performance, they produce benefits considered only as transitory. These considerations are subject to criticism, as we will see when we analyze the limits of the cognitive processing and the cybernetic interrelation.

There is a well accepted argument related to the current incapacity of a machine to completely simulate the complex cognitive processing. In a study, Kurtzweil⁶ presents this argument based on the point of view of the computational hardware, pointing out that the brain presents well defined physiologic limits. Such limits, however, have already been fully overcome by the present digital technology. Kurtzweil believes that a skilled digital mechanism will succeed in the Turing Test, including the capacity of self-awareness and emotivity.

According to Minsky¹⁴ the Turing Machine is an abstract construct able to perform computations, or to perform a sequence of logical operations. It consists of a "reading and writing head" that scans a one-dimension (or two-dimension) ribbon divided in squares, each one of them written with a "0" or a "1". Computation begins with the machine in a certain "state" scanning a square. It erases what it finds there, prints a "0" or "1" in the same place, moves on to an adjacent square and enters in new "state". This behavior is completely determined by three parameters: (a) The "state" in which the Machine is; (b) the number in the square that it is scanning; (c) A Table of Instructions.

The Table of Instructions specifies for each "state" and for each binary entry what the machine must write, in which direction it must move and in which "state" it must enter. It is exemplified with the following command: If you are in "State 1", scanning a 0; Print 1, move to the left and go to "State 3". It can only list a finite number of "states", and each of them becomes implicitly defined by the role it performs in the Table of Instructions. Such "states" are frequently known as the Machine's "Functional States".

The aforementioned mechanism only depends on the development of specific algorithms, capable to learn through a self-organization based on experience, something that he believes to happen before the year 2029. The Artificial

Neural Nets would be the main executor of a level of ideal organization, able to simulate this reality and to undertake a quite complex Artificial Intelligence and collaborate to the underlying and explicit mental processes.

Even though they exist, the human cognitive limitations have enough capacity for the individual to work with the immediate challenges of survival and well being. An audacious analogy can be made from the presupposition that the Universe we see can contain an immense amount of possible interactions among its components⁷, very superior to the quantitative capacity that the brain empirically could support⁵. However, Man's surrounding environment (our planet its known vicinities) means only a fraction of that universe, because it represents a unit possibly small and simple enough for the Central nervous system to hold it.

The Theory of Information, if observed separately, offers answers to two essential subjects: how much information can be compressed into a given medium and how much information can possibly be transmitted through a channel that is subject to interferences¹⁶. This Theory establishes mathematical limits for the compression and data transmission capacity of any device, the human brain included. In this same investigation line, it is worth mentioning the works of Merkle¹¹⁻¹², which analyze the human brain capacity and were developed considering the principles and theorems of this Theory, created by Shannon 40 years before.

An important paradox to be considered appears from the analysis of the arguments and facts above described. We suppose the existence of a physically limited human brain, whose capacity is finite. On the other hand, there are arguments of the existence of a level of cognitive performance that seems to overcome such limits and, therefore, it cannot be justified just by physiologic processes.

Following the complexity paradigm, Pinker¹⁵ demonstrates that even the simplest tasks, like the identification of objects and the detection of space relationships may demand a powerful integrated system of specialist processing modules. He states that as the activities become more and more complex, the degree of sophistication presented requires an exponential increment of those specialist modules.

Considering that the human survival and well-being

require much more than just the basic capacities of perception and psychometricity, it becomes evident that the human beings need an immense apprehension, manipulation and use of knowledge capacity to be successful as a species. With this statement in mind, it is worth questioning if the human brain would offer, by itself and unaided, capacity for that task.

Comparing the average of 800MB of information produced a year by each individual, noted by Lyman and Hal⁹, with the annual capacity of the human beings of only 41MB annual physiologic storage¹¹, we come to a proportion of approximately 20:1 between the amount of accumulated data and the physiologic capacity of storage of the human brain.

When mentioning several authors and recognizing the existence of specific limits for the capacity of the brain in deciphering, accurately, data and clinical information in due time and without significant mistakes, Hannan⁴ supplied important argumentation to justify the computational aid in this activity. The author uses such considerations as a means to justify the need and usefulness of the use of tools of processing of information to support clinical decisions in hospital systems. These mechanisms are nothing more than receivers of information codified by the individual cognitive effort, respecting algorithms and databases, usually simple, to build reasoning based on information¹⁰.

In a more realistic context, it is safe to state that, considering the discoveries demonstrated in the works above mentioned, the group of the neurophysiologic variables explains less than 50% of the variance of the cognitive performance. In other words, more than half of the variance needs an explanation other than the biological variations among the individuals¹⁷.

Again we can contemplate the idea that the human brain is unable to supply the processing needs associated to survival and people's well-being separately. Add the fact that humanity has been successful not only in terms of survival, but also in multiplying itself intensely in the last thousands of years. We come to the conclusion that some form of amplification of the cognitive capacity has developed, perfected and consecrated. This expansion has happened through extra-brain processing, especially in the last decades and there is no denying in the role of computers in this process.

3. Evolutionary limitation of the Brain and Accessory Resources

Knowing that biological limits determine the competence of the human brain and that the possibility that that structure be, by itself, unable in endowing the computational power necessary for its survival demands, it is plausible to imagine that the evolution of the homo sapiens sapiens moves toward the increase of this capacity through a gradual manifestation of a "plastic" Central Nervous System. However, studies exist based on biophysical and algebraic data that disagree with this probable evolution.

British scientists from British Telecom, mentioned by Ward¹⁸, point out the inexistence of a clear evolutionary path that can lead to an increase in the capacity of brain processing. One of the outstanding evidences was that possible increases in the diameter of the axons or increase of the neuronal density, decisive factors speed up the transmission of pulses, would inversely be useful in the final balance. This observation started from the analysis that there would be more need of thermal isolation (myelin hem) and of a larger cranial cavity, resulting in a reduction of the efficiency of the synapses.

We conclude that such evolutionary processes empirically do not produce an appropriate and satisfactory answer to the dilemma, the computational incapacity of the human brain. One may argue on the use of processes and extra brain mechanisms as an alternative. Similar mechanism occurs with electronic processors, that with greater processing capacity needs had their sizes reduced, with a risk of overheating.

In the same line of thought, Lock⁸ points out that the animal evolution is fundamentally autoplasic, based on adaptations that depend on its genetic expression, while the human evolution is alloplastic, associated to the manipulation of objects physically disconnected the body's limits (through instruments, tools).

When mentioning Vigotsky, Ward¹⁸ recollects the concept of Proximal Development Zone (PDZ), this concept being used to justify the existence of a medium through which objects, instruments and social practices collaborate for the cognitive development. The concept of PDZ allows

the understanding of the process of cultural transmission of knowledge and of patterns of logical thoughts from an "originator" to a "receiver", through interactions where the first structures the environment to highlight a logic predetermined for the second. It is possible to extend that notion to understand the way new knowledge and logics develop, starting from acquisitions and past experiences, with several elements of the environment, as studies with human beings and primates demonstrate¹⁷.

In this discussion, the premise is that the environment and the organism act synergistically and that they are determined, this idea being an indispensable starting point to understand the adaptation that happens throughout the course of the evolutionary processes. With the use of this hypothesis one can obtain a means to fundament and to limit the changes that happen due to the relationship between a certain life structure and its environment, or, at least, to accept this evolutionary position. One may ask a question: to what extent does the environment stimulate or influence genetics? No conclusion can be obtained so far, but there are inferences that one can investigate, either biological or adaptive, based on the implications of this process along the time.

Trying to understand the implications of this co-determination, we considered an implication relationship, unlike a relationship of simple causality. The difference between both is determined by the fact that the first refers to events logically dependent, whereas the second refers to events logically independent, and this last one needs an empiric investigation of the related events involved, or, to be observed. Lock⁸ distinguishes the two possible basic types of events according to time:

- a. Diachronic Implications: Also known as meta-applications, they are those where the events happen along the time;
- b. Synchronous Implications: Also mentioned as synergetic applications, they are those where the events happen at the same time.

Lock's suggestion is that one can also apply such relationships for the mental processes, instead of referring just to physical changes in time. These implications relate to the investigation of merely symbolic systems, available to elucidate the way through which they can contain other

symbols. Such symbolism will result in an inspiration for a computational analogy, already existing since the 1950's, and for the Artificial Intelligence representing those models, starting from connexionist logic.

CONCLUSION.

The understanding of the cognitive phenomena and of the mental representation of the brain processes is an interesting field for cognitive neural-science because it represents an interesting method to investigate the psychopathologies. It is fundamental to understand the capacity of the brain to process its qualitative and quantitative functions if the argument of neural-computation is to be set to work with the new techniques of cognitive investigation.

Based on these computational theories dedicated to brain processing, it is natural to indicate that these possibilities open an interesting analysis field for the search of behavioral patterns and of the possibilities of expansion of the cognitive limits, through accessory resources. It becomes, therefore, a possible argument for the fundament of Neural- computation as an assistant for Cognitive Neural- science.

BIBLIOGRAPHICAL REFERENCES

1. Brasil-Ribeiro, A. Paradigmas Computacionais, Modelagem de Sistemas Naturais Conexionistas e Psicopatologia: Uma Revisão. Dissertação de Mestrado. 2006. UFPE. Recife-PE
2. Chalmers, D.J. (1999) – A Computational Foundation for The Study of Cognition. In: www.paradox.ucsc.edu em 26 de junho de 2005.
3. Cleeremans, A. (1997). Principles for Implicit Learning. In D. Berry (Ed.), *How implicit is implicit learning?* (pp. 196-234), Oxford: Oxford University Press.
4. Hannan, T.J. (2003) – Eletronic Medical Records. Health Informatics. In: Overview. Editado por E. Hovenga, M. Kidd, B. Cesnik. Churchill Livingstone, Austrália.
5. Kail, R. e Bisanz, J. (1992) The information-processing perspective on cognitive development in childhood and adolescence. In: Stemberg, R.J. & Berg, C.A. – *Intellectual Development*. Cambridge University Press. Cambridge, UK.
6. Kurtzweil, R. (2002) – A Wager on the Turing Test: Why I Think I Will Win. In: www.kurzweilai.net/articles/art0374.html?printable=1 acessado em 03 de agosto de 2005.
7. Lloyd, S (2002) – Computational Capacity of The Universe. *Psychical Review Letters*, 88, 237901.
8. Lock, A.J. (2000) – Phylogenetic Time and Symbol Creation : Where Do Zopeds Come From? *Culture & Psychology*, Vol. 6, No.2, 105-130.
9. Lyman, P e Hal, R.V. (2003) – How Much Information , 2003. In: www.sims.berkeley.edu/how-much-info-2003, acessado em 21 de julho de 2005
10. McClelland, J., Rumelhart, D. et al., (1986) *Parallel Distributed Processing*, Vol II. Cambridge, MA: MIT Press.
11. Merkle, R.C. (1988) – How Many Bytes in Human Memory. *Foresight Update*, 04, Outubro 1988.
12. Merkle, R.C. (1989) - Energy Limits to the Computational Power of the Human Brain. *Foresight Update*, 6, agosto 1989.
13. Miller, G.A. (1956) – The Magical Number Seven, Plus or Minus Two: Some Limits on Our Capacity for Processing Informations. *The Psychological Review*, 1956, vol.63, pp.81-97.
14. Minsky, M. (1967) – *Computation: Finite and Infinite Machines*. Prentice-Hall, Englewood Cliffs, New Jersey, USA.
15. Pinker, S. (1998) – *Como a mente funciona*. Editora Schwarcz Ltda. São Paulo, SP
16. Shannon, C.E (1949) *The Mathematical Theory of Communication*. University of Illinois, Illinois, EUA.
17. Souza, B.C. (2005) *A Teoria da Mediação Cognitiva: Os Impactos Cognitivos da Hiper cultura e da Mediação Digital*. Tese de Doutorado. Universidade Federal de Pernambuco. Recife, PE.
18. Ward, M. (1997) – End of the road for brain evolution. *New Scientist*, vol. 153, pp.14.
19. White, N. (2003) – Cognitive Enhancement : An Everyday Event? – *International Journal of Psychology*, vol.33, n. 2, pp-95-105.

