Rethinking BICA's R&D challenges:
Grief revelations of an upset revisionist

Emanuel Diamant
VIDIA-mant, Kiriat Ono, Israel
emanl.245@gmail.com

Abstract: Biologically Inspired Cognitive Architectures (BICA) is a subfield of Artificial Intelligence aimed at creating machines that emulate human cognitive abilities. What distinguish BICA from other AI approaches is that it based on principles drawn from biology and neuroscience. There is a widespread conviction that nature has a solution for almost all problems we are faced with today. We have only to pick up the solution and replicate it in our design. However, Nature does not easily give up her secrets. Especially, when it is about human brain deciphering. For that reason, large Brain Research initiatives have been launched around the world. They will provide us with knowledge about brain workflow activity in neuron assemblies and their interconnections. But what is being "flown" (conveyed) via the interconnections the research programme does not disclose. It is implied that what flows in the interconnections is information. But what is information? – that remains undefined. Having in mind BICA's interest in the matters, the paper will try to clarify the issues.

Keywords: Biological inspiration, Brain Research Programs, cognitive modeling, information duality, cognitive information processing

1 Introduction

Biologically Inspired Cognitive Architectures (BICA) is a loosely defined subfield of Artificial Intelligence (AI) aimed at developing thinking machines with human-like or near-human-like intelligence and cognitive capabilities. What distinguish BICA from other similar AI enterprises is that it based on principles explicitly drawn from biology and neuroscience. There is a long lasting and a widespread belief that nature in its evolution has already encountered most of the problems that we experience today and even has a couple of wonderful and unexpected solutions for any of the challenges that we have to cope with. That is the reason why biologically inspired (or, in short, bio-inspired) approaches are so ubiquitous and abundant today when the challenge of creating machines equipped with human-like cognitive capabilities is issued. "Bio-inspired" is the most frequently encountered term applied when it comes to discuss the above-mentioned matters. However, other labels are also around: Naturally-inspired, nature-inspired, neuro-inspired, brain-inspired, brain-like, bio-mimicking, and other similar designates. In [1], a broad overview of 195 cognitive architectures is provided covering 700 practical projects implemented over the past 40 years of BICA research and development endeavor.

Nevertheless, and despite all these impressive numbers and equally important analytic evaluations, BICA's R&D is far from being what most observers would regard as a success story. The plurality of solutions that are being devised (and trustworthily observed in [1]), undeniably indicate a fierce lack of appropriate knowledge and commonly accepted theory that would underpin and justify the intentionality of bio-inspired approaches. If we know nothing about what is going on in our biological prototypes, how could we be inspired by their unknown properties?

Indeed, growing understanding of an urgent need to enhance our competence in brain organization and functioning has led to a world-wide range of government-funded research initiatives like the U.S. BRAIN Initiative, the Human Brain Project in Europe, and brain-focused projects in Japan, China, and Korea.

The central pillar of almost all these projects is the consensus understanding that the neural basis of human cognition is the primary goal of all these enterprises. A quotation from China Brain Project declaration states this point as follows: "We know very little about how neural circuits are assembled from specific types of neurons in different brain regions and how specific neural circuits perform their signal processing functions during cognitive processes and behaviors. This requires detailed information on the architecture of neural circuits at single-cell resolution and on the spatiotemporal pattern of neuronal activity", [2].

The Korea Brain Initiative echoes this objective in very similar words: "The Korea Brain Initiative, which is centered on deciphering the brain functions and mechanisms that mediate the integration and control of brain functions that underlie decision-making. The goal of this initiative is the mapping of a functional connectome with searchable, multi-dimensional, and information-integrated features", [3]. And just a bit later again: "The initiative aims at advancing technologies for a better understanding of the full complexity of the brain, and especially of circuit-function relationship", [3].

It is expected that it would take from 10 to 20 years before the first results and preliminary understanding of how the brain works would be available. That is too long. Meanwhile, BICA's R&D has to continue its march towards its proclaimed objectives, and any critical remarks (like mine) will not slow down its impetuous pace. However, it is worth to be mentioned that such critical faultfinding does exist, and it would be wise sometime and somehow to take it into account.

What I am speaking about is a 2010 paper [4] that provides an improved scientific perception of the operational principles of the brain as a complexly organized system. Relying on this perception the author tries to build an operational, quantitative model of the brain. He claims that "The scientific disciplines involved in cognitive and brain research are committed to a common method to explain the properties and capacities of complex systems. This method is decompositional analysis, i.e. analysis of the system in terms of its components or subsystems… decomposability of complex systems has been accepted as fundamental for the cognitive and computational neuroscience." [4].

Indeed, the decompositional principle allows BICA designers to see the brain as composed of "building blocks" which are dedicated for computing certain principally defined cognitive functions. In [1] these building blocks are outlined as different dissimilar modules performing restricted cognitive functions such as perception, attention, reasoning, learning, planning, decision-making, formation of memory and action shaping.

The author in [4] claims that the decompositional principle is wrong, and that "there is substantial evidence to question this belief. It turns out that this method in fact ignores something fundamental, namely that biological and engineered systems are basically different in nature" and that "…we cannot expect specific functions to be mapped to structurally bounded neuronal structures, and vice versa." [4]. Therefore, the respective author suggests, "that the decomposability assumption of cognitive science must be abandoned" [4].

Of course, as far as I know, nobody has adopted this proposal. BICA designers, as well as other researchers involved in the flagship Brain projects, know perfectly well that in biology, system inputs are of different modalities and processing these inputs is being performed via different paths thus supporting and realizing different cognitive function.

That all does not deny the complexity of cognitive tasks and the resulting complexity of the whole brain organization. Human brain is a complex system of neural elements working at different levels of system organization. It begins with a pair of two neurons interconnected via a synaptic junction and proceeds with tightly coupled and interconnected neuronal groups arranged in clusters, maps and functional arrays. In this manner the complexity of cognitive brain processing is being developed. But what is going on and what happens when two single neurons or even whole neuron groups are actively interacting with each other? For some unknown (to me) reasons this question is never discussed in any brain activity related discourse. Neuronal connectivity is studied in almost every flagship project. What is going on within the interconnections is totally ignored by projects' objectives.

As to my understanding, the most expected and most likely answer to the above raised question should be: the neuronal interconnections convey information. A clear and complete answer. However, this evident and seemingly obvious answer is not so obvious at all. Although the term "information" is the most often and ubiquitously used word today, I am not sure that you will find someone in your surrounding who is skilled enough to explain what the term "information" really means.

Therefore, it will be our duty to find out the proper answer to the question "What actually information is?" – the question so imprudently neglected by flagship Brain research projects (in general) and BICA designers (in particular).

2 What is information?

The notion of "Information" was first introduced by Claude Shannon in his seminal paper "A Mathematical Theory of Communication" in 1948, [5]. Today, Stanford Encyclopedia of Philosophy offers (side by side with Shannon's definition of information) an extended list of other versions of the term: Fisher information, Kolmogorov complexity, Quantum Information, Information as a state of an agent, and Semantic Information (once developed by Bar-Hillel and Carnap), [6]. Again, as it was mentioned earlier, multiplicity of definitions is not a sign of well-being.

Shannon's Information Theory was about the communication of messages as electronic signals via a transmission channel. Only physical properties of the signal and the channel have been taken into account, while the meaning of the message has been ignored totally. Such an approach to information met very well the requirements of a data communication channel. But recent advances in almost all sciences put an urgent demand for meaningful information inclusion into the body of a communicated message.

To meet this demand, I have proposed a new definition of information. Contrary to the widespread use of Shannon's Information Theory, my research relies on the Kolmogorov's definition of information, [7]. In the mid-60s of the past century, Kolmogorov has proposed an algorithmic approach to a quantitative information definition [7]. According to Kolmogorov, a not random binary string (called a separate finite object) can be represented by a compressed description of it (produced by a computer program in an algorithmic fashion) "in such a way that from the description, the original message can be completely reconstructed" [8]. "The amount of information in the string is then defined as the size of the shortest computer program that outputs the string and then terminates" [8]. (For a really random string such a condensed description cannot be provided and "the shortest program for generating it is as long as the chain itself" [9]). The compressed description of a binary object has been dubbed as "algorithmic information" and its quantitative measure (the length of the descriptive program) has been dubbed as the description "Complexity".

Taking Kolmogorov's insights as a starting point, I have developed my own definition of information that can be articulated in the following way: **"Information is a linguistic description of structures observable in a given data set".**

To make the scrutiny into this definition more palpable I propose to consider a digital image as a data set. A digital image is a two-dimensional set of data elements called picture elements or pixels. In an image, pixels are distributed not randomly, but, due to the similarity in their physical properties, they are naturally grouped into some clusters or clumps. I propose to call these clusters **primary or physical data structures**.

In the eyes of an external observer, the primary data structures are further arranged into more larger and complex agglomerations, which I propose to call **secondary data structures**. These secondary structures reflect human observer's view on the grouping of primary data structures, and therefore they could be called **meaningful or semantic data structures**. While formation of primary (physical) data structures is guided by objective (natural, physical) properties of the data, the subsequent formation of secondary (semantic) data structures is a subjective process guided by human conventions and habits.

As it was said, **Description of structures observable in a data set should be called "Information".** In this regard, two types of information must be distinguished – **Physical Information and Semantic Information**. They are both language-based descriptions; however, physical information can be described with a variety of languages (recall that mathematics is also a language), while semantic information can be described only by means of natural human language. (More details on the subject could be find in [10]).

Those, who will go and look in [10], would discover that every information description is a top-down-evolving coarse-to-fine hierarchy of descriptions representing various levels of description complexity (various levels of description details). Physical information hierarchy is located at the lowest level of the semantic hierarchy. The process of sensor data interpretation is reified as a process of physical information extraction from the input data, followed by an attempt to associate this physical information (about the input data) with physical information already retained at the lowest level of the semantic hierarchy. If such an association is attained, the input physical information becomes related (via the physical information retained in the system) with a relevant linguistic term, with a word that places the physical information in the context of a phrase, which provides the semantic interpretation of it. In such a way, the input physical information becomes named with an appropriate linguistic label and framed into a suitable linguistic phrase (and further – in a story, a tale, a narrative), which provides the desired meaning for the input physical information. (Again, more details can be found on the website).

3 Rethinking BICA

The segregation between physical and semantic information is the most essential insight about the nature of information gained from the new information definition. It puts BICA design challenges in new light and new circumstances.

The disagreement between modular BICA design approach and integrated fashion of cognitive functional processing is now easily settled by the new understanding about information duality. Indeed, modality of input signals is properly met by physical information processing. While semantic information processing is common to all sensory data inputs. (Essentially, physical information is extracted from input data and then submitted to the semantic information processing part of the system).

Semantic information processing has nothing to do with raw input data (and its features) – raw data features are dissolved in physical information (which is later processed in the semantic information hierarchy). Data features are meaningless in human world perception (and judgment). We understand the meaning of a written word irrelevant to letters' font size or style. We recognize equally well a portrait of a known person on a huge size advertising billboard, on a magazine front page, or on a postage stamp – perceptive information is dimensionless. We grasp the meaning of a scene irrelevant to its illumination. We look on the old black-and-white photos and we do not perceive the lack of colors.

The same is true for voice perception and spoken utterance understanding – we understand what is being said irrelevantly to who is speaking (a man, women, or a child). Irrelevant to the volume levels of the speech (loudly or as a whisper). Blind people read Brail-style writings irrelevant to the size of the touch-code.

And the final bottom line: information is dimensionless, data is dimensional.

Despite all of this, the current wave of AI innovations (Deep Learning, e.g.), including the mainstream of BICA designs, rely completely on data processing (while pretending that they are doing information processing).

Reference knowledge base, where human/system previous life experience is accumulated (to support the system's cognitive tasks processing) has to be also re-evaluated. The critical issue of continuous autonomous learning is closely related to this subject.

As it follows from the preceding discussion, semantics is not a property of the data. Semantics is a property of a human observer that watches and scrutinizes the data. Semantic information is shared among the observer and other members of his community (and that is the common basis of their intelligence). By the way, this community does not have to embrace the whole mankind. This can be even a very small community of several people or so, which, nevertheless, were lucky to establish a common view on a particular subject and a common understanding of its meaning. Therefore, this particular (privet) knowledge cannot be acquired in any other way. (By Machine Learning, for example, by Deep Learning, or other tricks). **Semantic information should be only shared or granted**! There is no other way to incorporate it as the system's reference knowledge base (used for processing/interpreting physical information at the system's input). Therefore, common attempts to formalize semantics and to derive it from input data are definitely wrong.

The form in which semantic information has to be reified is a string of words, a piece of text, a story, a narrative. (That follows from semantic information definition already given above). If we accept this assumption, it will be reasonable to suppose that semantic information processing means some sort of language texts processing. (For humans it is, obviously, human natural language texts, but for plants or bacteria it will be a different kind of language – every living being possess its own intelligence reified as its ability to process semantic information, which is reified in some pra- or proto-language). What implications follow from the statement "semantic information processing means language text processing"? – I do not know (at least at this stage of my research). As to my knowledge, nobody else knows about this not more than I. (Despite there is a well-known research field of computational linguistics, however, the domain of its studies does not overlap with semantic information processing).

4 Conclusions

The list of amendments waiting to be introduced to BICA's design practice is long and inspiring. The paper format does not allow its full exhibition. I hope the conference framework will be a proper place for further exchange of views and in depth discussions.

References

[1] I. Kotseruba, O. Gonzalez, and J. Tsotsos, **"A Review of 40 Years of Cognitive Architecture Research"**, 2016. https://arxiv.org/ftp/arxiv/papers/1610/1610.08602.pdf

[2] Mu-ming Poo, *et al*, **China Brain Project: Basic Neuroscience, Brain Diseases, and Brain-Inspired Computing**, Neuron 92, November 2, 2016, Published by Elsevier Inc., 2016. http://www.cell.com/neuron/pdf/S0896-6273(16)30800-5.pdf

[3] Sung-Jin Jeong, *et al*, **Korea Brain Initiative: Integration and Control of Brain Functions**, Neuron 92, November 2, 2016, Published by Elsevier Inc. 2016. http://www.cell.com/neuron/pdf/S0896-6273(16)30805-4.pdf

[4] Schierwagen, A. **"The Way We Get Bio-Inspired: A Critical Analysis"**, 2010. http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.188.6007&rep=rep1&type=pdf

[5] Shannon, C. **A Mathematical Theory of Communication**, 1948, Published by the Board of Trustees of the University of Illinois. Used with the permission of University of Illinois Press. http://www.mast.queensu.ca/~math474/shannon1948.pdf

[6] **Information.** Stanford Encyclopedia of Philosophy, First published Fri Oct 26, 2012 http://plato.stanford.edu/entries/information/

[7] Kolmogorov, A. **Three approaches to the quantitative definition of information**, Problems of Information and Transmission, Vol. 1, No. 1, pp. 1-7, 1965. http://alexander.shen.free.fr/library/Kolmogorov65_Three-Approaches-to-Information.pdf

[8] Peter Grunwald and Paul Vitanyi, **Algorithmic Information Theory**, 2008. http://arxiv.org/pdf/0809.2754.pdf

[9] Peter Grunwald and Paul Vitanyi, **Shannon Information and Kolmogorov Complexity**, 2004. http://arxiv.org/pdf/cs/0410002.pdf

[10] Diamant, E., **Brain, Vision, Robotics and Artificial Intelligence.** http://www.vidia-mant.info