Proceeding Paper

Symbiotic Information Processing and Technological Progress †

Mark Burgin [1,*] **and Rao Mikkilineni** [2]

1   Department of Computer Science, University of California, Los Angeles (UCLA), Los Angeles, CA 90095, USA
2   School of Business, Golden Gate University, San Francisco, CA 94105, USA; rmikkilineni@ggu.edu
*   Correspondence: markburg@cs.ucla.edu
†   Presented at Philosophy and Computing Conference, IS4SI Summit 2021, online, 12–19 September 2021.

Abstract: The goal of the paper is the introduction and exploration of new types of information processing. Starting with the typology developed in such an important class of information processing as computation, we extend this typology by analyzing information representations used in computational processes and delineating novel forms of information representations. While the traditional approach deals only with two dimensions of information processing—symbolic and sub-symbolic, our analysis explicated one more dimension—super-symbolic information processing. Information processing in biological systems is both symbolic and sub-symbolic, having the form of genes and neural networks. Nevertheless, in their evolution, biological systems have advanced their abilities one step further by developing super-symbolic information processing and evolving symbiotic information processing that performs information processing on the combined knowledge in the brain from both symbolic, subsymbolic, and super-symbolic information processing to derive higher order autopoietic and cognitive behaviors. Performing all forms of information processing, biological systems achieve much higher cognitive and intelligence level. That is why here we also consider a new type of computing automata called structural machines with the goal of transferring these advantageous features of biological systems to the existing information processing technology.

Keywords: information; computing; process; symbolic; subsymbolic; super-symbolic; structure; superstructure; structural machine

1. Introduction

Information processing has many forms, types and categories, which are differentiated according to specific characteristics of information processing. Infware, that is, objects that are carriers and representations of the processed information, form an imperative constituent of information processing in general and computation in particular. Based on the computational infware, traditionally two pure forms of conventional computations are taken into consideration—symbolic computations and sub-symbolic computations [1]. With respect to infware, both are pure types of computations, while existing and new combined or amalgamated types and forms of computations are studied later.

Here we study these and more advanced types in the scope of the general information processing, assuming that computation does not encompass all types and forms of information processing.

Symbolic information processing is performed with data having the form of explicit symbolic systems, such as systems of numbers, icons, or letters, and the information processing system operates with individual symbols. Here, symbols are defined as linguistic objects, such as digits 0 and 1 or letters *a* and *b*, understanding that these linguistic symbols are only names of symbols in a more general philosophical sense [2].

Sub-symbolic information processing is performed as transformations of data described by non-linguistic objects such as specific signs, signals, or geometric relationships. Note that sub-symbolic information processing can be modeled by symbolic information processing.

In both cases, the transformed entities are represented by the states of the information processing system and by the states of its elements. Thus, to portray and study information processing systems and their functioning, researchers use various mathematical models of information processing, such as recursive functions or Turing machines, which work with separate symbols.

Sub-symbolic (intuitive) information processing means that the information processing system uses elementary operations with concealed semantics. This kind of information processing is performed by such theoretical models as artificial neural networks and cellular automata. Sub-symbolic (intuitive) information processing allows the elimination of explicit algorithms/programs and using instead optimization processes, which improve functioning of the system by upgrading its implicit algorithms and programs.

Sub-symbolic (intuitive) information processing is realized by the neural ensembles in the brain. Researchers of cognition conjecture that the object formation can function as the transition from a stream of massively parallel sub-symbolic micro-functional events to symbol-type serial processing through sub-symbolic integration [3]. Sub-symbolic (intuitive) information processing is a model of functioning of the emotional and effective systems of the human brain [4].

Symbolic (rational) information processing means that the information processing system uses elementary operations with elementary objects having individual semantics. This kind of information processing is performed by such theoretical models as Turing machines, inductive Turing machines, and vector machines [5]. Symbolic (rational) information processing is a model of functioning of the left hemisphere of the human brain. The advantage of the symbolic (rational) information processing is the explicit form of the algorithms and programs that control and direct the functioning of the system.

2. A New Dimension of Information Processing

Symbolic and sub-symbolic information processing form two dimensions in the space of information processes. At the same time, the general theory of structures and brain neurophysiology point to one more pure type of information processing. Indeed, if there is sub-symbolic information processing, then it must be *super-symbolic information processing*, in which superstructures are transformed.

In information technology, supercomputers are computers that have essentially better characteristics of information processing, and usually it is the higher speed of computing. In a similar way, superstructures are structures that have essentially higher complexity.

Researchers try to model functioning of the brain using artificial neural networks. It is possible to compare this to a situation when, using only functioning of biological cells, biologists would try to explain the multifaceted functioning of the human organism with its higher functions.

Super-symbolic (transcendent) computing is a model of functioning of the right hemisphere of the brain. The processing of images by operation with holistic shapes is an example of super-symbolic computing. The advantage of the super-symbolic (transcendent) computing is its ability to operate big formal and informal systems of data and knowledge. Implementation of super-symbolic computing is the solution to the problem of big data and information overflow.

Symbolic structures are composed from symbols in a simple way, that is, these structures have low structural complexity. Symbols, words, texts as linear composition of words, and sets are symbolic structures.

According to the general theory of structures, there is a hierarchy of structures composed of different orders of structures [2].

Symbolic superstructures are composed from symbols and symbolic structures. Intricate hypertexts, multicomponent images, and structures of higher order are symbolic superstructures.

3. The Three-Dimensional Picture of Information Processing

The combination of pure types produces mixed types of information processing. The first step in this direction gives us *hybrid information processing*, which comprises both symbolic and sub-symbolic information processing being a two-fold type of information processing and encompassing hybrid computations [1]. Hybrid information processing allows combining advantages of both symbolic and sub-symbolic information processing.

Conventional models of computation perform either symbolic information processing, e.g., finite automata, Turing machines, inductive Turing machines or random-access machines (RAM), or sub-symbolic information processing, e.g., neural networks or cellular automata [5]. New models, such as neural Turing machines [6] or structural machines with symbolic and sub-symbolic processors [7], carry out hybrid information processing. A *neural Turing machine* is a recurrent neural network with a network controller connected to external memory resources. As a result, it combines the sub-symbolic computation of neural networks with symbolic computation of Turing machines.

Super-symbolic (intuitive) information processing adds one more dimension to the general schema. Synthesizing it with symbolic (rational) information processing and sub-symbolic (intuitive) information processing in one model, we come to *symbiotic information processing*. Structural machines with flexible types of processors can accomplish symbiotic information processing. Symbiotic information processing allows combining advantages of all three pure types of information processing representing the entire type of information processing.

As a result, we have:

Three pure types:

- Sub-symbolic information processing;
- Symbolic information processing;
- Super-symbolic information processing.

Three twofold types:

- *Hybrid information processing* combines symbolic and sub-symbolic information processing.
- *Blended information processing* combines sub-symbolic and super-symbolic information processing.
- *Fused information processing* combines symbolic and super-symbolic information processing.

One entire type of information processing:

- *Symbiotic information* processing combines all three pure types of information processing.

4. Structural Machines as a Tool for Symbiotic Information Processing

Structural machines provide means for symbiotic information processing when they possess processors of different types [7].

A structural machine M works with structures of a given type and has three components:

The *control device* C_M regulates the state of the machine *M*

The *processor* P_M performs transformation of the processed structures and its actions (operations) depend on the state of the machine *M* and the state of the processed structures.

The *functional space* Sp_M consists of three components:

- The *input space* In_M, which contains the input structure.
- The *output space* Out_M, which contains the output structure.
- The *processing space* PS_M, in which the input structure(s) is transformed into the output structure(s).

We assume that all structures—the input structure, the output structure, and the processed structures—are of the same type.

Computation of a structural machine *M* determines the *trajectory of computation*, which is a tree in a general case and a sequence when the computation is deterministic, and is performed by a single processor unit.

5. Modeling and Implementing Autopoietic and Cognitive Behaviors with Structural Machines

All living organisms are autopoietic and cognitive. Autopoiesis refers to a system with well-defined identity, which is capable of reproducing and maintaining itself. Cognition, on the other hand, is the process of information acquisition. A living organism is a unique autonomous system made up of components and relationships changing over time without changing the unity of the system. The genome contains the knowledge that is required to build the components using physical and chemical processes and physical resources. Information processing structures in the form of genes and neurons provide the means for building, operating, and managing the stability of the system while interacting with the external world where the interactions are often, non-deterministic in nature and are subject to large fluctuations. Our understanding of how theses information processing structures operate comes from the analysis of the genome, experiments in neuroscience, and the studies of cognitive behaviors in living organisms.

In the language of the General Theory of Information (GTI) [4], a genome encapsulates "knowledge structures" [7] coded in the form of DNA and executed using the biological "structural machines" [8–10] in the mode of genes and neurons, which utilize physical and chemical processes (dealing with conversion of matter and energy). The information accumulated through biological evolution is encoded into knowledge to create the genome, which contains the knowledge network defining the function, structure, and the autopoietic and cognitive processes to build and evolve the system while managing both deterministic and non-deterministic fluctuations in the interactions among the internal components or their interactions with the environment.

This knowledge about the genome and the GTI leads us to the Burgin–Mikkilineni [11] thesis that allows designing a new class of digital automata by infusing autopoietic and cognitive behaviors. Being a form and component of autopoietic and cognitive information processing systems, the digital genome is a collection of "knowledge structures" [8] coded in the executable form to be processed with technical "structural machines" [9] implemented using digital genes (in the form of symbolic computing algorithms) and digital neurons (in the form of sub-symbolic neural network algorithms), both of which use stored program control implementation of Turing machines and more advanced automata. Figure 1 shows super-symbolic computing in the shape of both biological and digital computing machines. DNA uses together symbolic computing with the sequences of nucleotides A, T, C, G, and subsymbolic computing with neural networks. The digital genome uses symbolic computing with algorithms operating on sequences of symbols 0 and 1, and sub-symbolic computing using neural network algorithms. The super-symbolic computing in biology is performed by the neocortex managing both the networks of genes and neurons. The autopoietic behavior is controlled by the genes and cognitive behaviors are controlled by the nervous system with 4E cognition. The digital genome proposed here uses the structural machine as shown in Figure 1 to create a super-symbolic overlay with knowledge structures managing both symbolic and sub-symbolic computations using current state of the art.
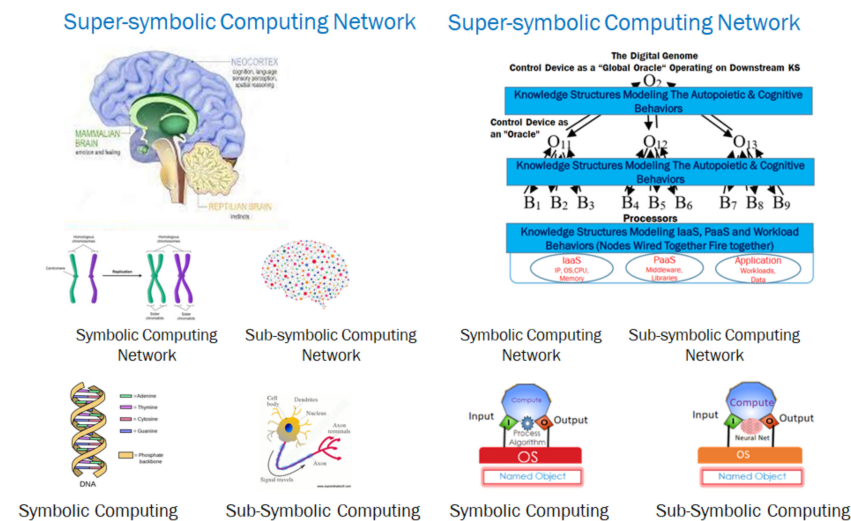
Figure 1. Super-symbolic computing in biological and digital computing.

6. Conclusions

We have introduced and discussed a new pure type of information processing called super-symbolic information processing; three twofold types of information processing called hybrid, blended, and fused information processing; and one entire type of computations called symbiotic information processing. Symbiotic information processing combines advantages of subsymbolic, symbolic, and super-symbolic information processing aimed at the advancement of the current state of the art in information technology with higher order autopoietic and cognitive behaviors, as well as at the modeling of information processing in the mind. The structural and functional analysis of these forms of information processing is the further goal of this research.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Burgin, M.; Dodig-Crnkovic, G. A Taxonomy of Computation and Information Architecture. In Proceedings of the 2015 European Conference on Software Architecture Workshops, Dubrovnik, Croatia, 7–11 September 2015; pp. 1–8.
2. Burgin, M. *Structural Reality*; Nova Science Publishers: New York, NY, USA, 2012.
3. Clark, A. *Microcognition: Philosophy, Cognitive Science, and Parallel Distributed Processing*; MIT Press: Cambridge, MA, USA, 1989.
4. Burgin, M. *Theory of Information*; World Scientific: New York, NY, USA; London, UK; Singapore, 2010.
5. Burgin, M. *Super-Recursive Algorithms*; Springer: New York, NY, USA; Heidelberg/Berlin, Germany, 2005.
6. Graves, A.; Wayne, G.; Danihelka, I. Neural Turing Machines. *arXiv* **2014**, arXiv:1410.5401.
7. Burgin, M.; Adamatzky, A. Structural machines and slime mold computation. *Int. J. Gen. Syst.* **2017**, *45*, 201–224. [CrossRef]
8. Burgin, M. Triadic Automata and Machines as Information Transformers. *Information* **2020**, *11*, 102. [CrossRef]
9. Burgin, M.; Mikkilineni, R.; Phalke, V. Autopoietic Computing Systems and Triadic Automata: The Theory and Practice. *Adv. Comput. Commun.* **2020**, *1*, 16–35. [CrossRef]
10. Burgin, M.; Mikkilineni, R. From Data Processing to Knowledge Processing: Working with Operational Schemas by Autopoietic Machines. *Big Data Cogn. Comput.* **2021**, *5*, 13. [CrossRef]
11. Burgin, M.; Mikkilineni, R. On the Autopoietic and Cognitive Behavior, EasyChair Preprint no. 6261, Version 2. 2021. Available online: https://easychair.org/publications/preprint/tkjk (accessed on 17 February 2022).