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New Directions in Information Processing †

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Abstract: Our understanding of genomics, neuroscience, cognitive behaviors of biological systems, and theoretical understanding of information from the general theory of information (GTI) is throwing new light on information processing structures both in nature and the digital information systems. The session on "New Directions in Information Processing" in the "Theoretical and Foundational Problems in Information Studies" conference at the 2021 IS4SI Summit was devoted to bringing different views from experts in multiple disciplines. We present here an overview of the session and highlight some of the observations discussed in various presentations. These include the nature of computation, the relationship between data, information and knowledge, nature of information processing structures in biology, classical and quantum computations, and their relationship with the Church-Turing Thesis, etc. in addition to the individual presentations of their papers, a plenary talk discussed not only how information processing structures operate in biological systems, but also pointed to a novel approach to design and build a new class of digital machines that enhance the sentience, resilience, and intelligence of current generation information technologies.

Keywords: information; knowledge; structures; autopoiesis; cognition; Turing Machine; structural machine; triadic automata; data structures; knowledge structures

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1. Introduction

According to Larry Masinter, Internet pioneer, formerly with Adobe, AT&T Labs, and Xerox PARC, who helped create Internet and web standards with IETF and W3C, "Technology and social innovation intended to overcome the negatives of the digital age will likely cause additional negative consequences. Examples include the decentralized web, end-to-end encryption, AI and machine learning, social media." [1].

Current information technology (IT) in the digital world is based on an observation made by Alan Turing over 70 years ago on how humans compute using numbers. The Church–Turing Thesis (CTT) translates this observation to current-day general-purpose computers and brings us all the benefits of global connectivity with real-time communication, collaboration, and commerce at scale. IT has radically changed the way, we humans, interact with each other in daily lives, conduct business globally with instantaneous access to information, and improve efficiency with automation using machines. Artificial intelligence (AI) which uses IT, enables people to rethink how we integrate information, analyze data, and use the resulting insights to improve decision making, and has already proved transformative in multiple aspects of modern life.

On the other hand, cybersecurity continues to be a major concern both for businesses and individuals. Trust, data privacy, the abuse of social media, and exploitation using misinformation continue to be major issues. A major AI problem that is yet to be tackled is ethics. The way how AI bots are used and the lack of transparency of how the algorithms in machine learning and deep learning, increase the opportunity for abuse and exploitation. Artificial intelligence algorithms predict based on the training given to them. An algorithm will label things as per the assumption of data it is trained on. Hence, it will simply ignore the correctness of data and the results obtained would not be reliable.

While we keep making incremental improvements, there are reasons to believe that there is a need to reexamine the current computing models derived from CTT and search for new directions in information processing. The session on "New Directions in Information Processing" in the "Theoretical and Foundational Problems in Information Studies Conference" at the 2021 IS4SI Summit was devoted to bringing different views from experts in multiple disciplines on new approaches to address both theoretical and practical aspects of information, its processing, and use by both biological and digital computing systems.

2. Overview of the Presentations in the Session

There were 12 presentations in the session including one plenary talk that was accessible to all participants in the summit. In this overview, we present the highlights from this session. The plenary talk was presented by Mikkilineni [2]. It was a synthesis of four related papers presented in this session [3–6]. These papers bring forward some of the limitations of current algorithm-based and neural-network-based computing architectures and suggest a new understanding of genomics, neuroscience, the science of complex adaptive systems, and the general theory of information GTI point to new directions in information processing. They show that it is possible to apply GTI and derive a new approach to not only model how living organisms exploit autopoietic and cognitive behaviors but also infuse these behaviors into digital automata to advance our information processing systems. The talk is also accessible in video form [6,7].

Abrahão et al. [8] discussed expected emergent open-endedness from partial structures extensions under algorithmic perturbations. According to the authors, "Enactivism claims that the interaction in the environment brings forth a world, where the changes in the organisms that are emergent concerning the environmental surroundings occur at the same time that the organisms are capable of bringing forth an environment that is emergent concerning the respective embedded organism." Their results connect the unbounded increase of emergent algorithmic information in complex systems with endless irreducible extensions of formal knowledge.

In his talk [9], Adamatzky analyzed the structure of the fungi family, problems solved on the particular classes of the family, and complexity issues. "Fungi are iniquitous creatures capable of adaptation in hush environments. Recently there is a growing intelligence of the fungi comparable with that of slime mold and plants and that fungi sense and process information in a highly efficient way. To formalize information processing in fungi, we developed several classes of fungal automata which constitute the family."

The properties of the physical level chosen to embody information in a computational model ultimately determine its computational capabilities and power. Therefore, the limitations of the classical Turing Machine are purely physical. So, is a machine that computes following the principles of quantum mechanics more powerful than a computing device designed in accord with classical physics? The paper by Akl [10] "endeavors to prove that the answer is definitely affirmative. Furthermore, the difference is made by those problems, defined in purely quantum mechanical terms, whose quantum solutions are impossible to simulate classically."

In a very interesting presentation and the corresponding paper, Basti and Vitiello [11] present a quantum field theory (QFT) approach to data streaming in natural and artificial neural networks.

The presentation and the corresponding paper by Burgin and Zellweger [12] describe a way to model data relationships with named sets. Data are representations and containers (carriers) of information while data with their relationships form data structures. Therefore, modeling data relationships is important for the organization and optimization of information processes. Manipulation with data demands various operations and in the case of using named sets for data representation, a variety of operations, such as mappings of different kinds, union, intersection, difference, renaming, naming, interpreting, and reinterpreting, is provided by the theory of named sets. I believe that application of the named

sets in information processing will transform how we design next-generation information processing systems [2].

Cezar Câmpeanu [13] tackled the relative randomness and descriptional complexity in algorithmic information theory. Namely, he used the concept of minimal description length to define the complexity. The unified complexity theory uses the dual measure for defining the complexity of an object relative to a class of algorithms, so the length is just one possible measure for objects. To further define randomness, we need additional properties of the encoding, such that together with the measure, it will form an Encoded Blum Static Complexity Space. This presentation discussed aspects of his approach in the case of the classes of algorithms without the universality property, analyzed ways, and gave examples to address the possible issues.

In his presentation and the corresponding paper, Eugene Eberbach [14] discusses undecidability and complexity for Super-Turing models of computation. It would be interesting to see a similar analysis of the triadic automata derived from the general theory of information.

An interesting presentation and the corresponding paper from Pier Luigi Gentily [15] suggest a new direction in the form of chemical artificial intelligence where fuzzy logic is processed "not only through electronic circuits and software but also through chemical reactions in wetware."As the author says, if we want to approach the information processing power of the human nervous system, we need to design hierarchical structures similar to those we find in humans. Such hierarchical structures should also be autopoietic and cognitive to approach the performances of living beings. Implementing autopoietic and cognitive structures, processing fuzzy logic at the molecular level will boost the development of Chemical Artificial Intelligence.

Endre Pap's presentation and the corresponding paper [16] discuss pseudo-analysis as a tool of information processing. The theory of the pseudo-analysis is based on the idea to replace the field of real numbers endowed the usual addition and product, with new operations so-called pseudo-addition and pseudo-multiplication in the framework of the semiring. These operations are related to the process of combining several numerical values into a single representative, which is called aggregation, and the corresponding numerical function is called aggregation function. Information fusion in an intelligent system is a fundamental problem, and its use is rapidly increasing as more complex systems are being developed. The paper discusses pseudo-analysis in the context of information fusion.

In their talk, Nancy Salay and Selim G. Akl, attempted to tackle the very controversial topic of consciousness [17] arguing that reductive information-processing metaphor was unsalvageable and should be discarded. Instead, they suggested that we should be adopting a non-reductive, information-processing account that explained how the inputs and outputs of consciousness were contentful by examining the external factors that had given rise to them.

In Tilmann Wurtz's presentation and the corresponding paper [16], logic gates were mapped to a gene induction event in early embryogenesis. This suggests that logic gates are involved in the signal flow in cells between signal reception and gene usage. Logic gates in biological systems may constitute a new path to model cell behavior in the context of gene regulation. This approach may allow for simulations of biological processes. In the future, biological processes might be studied using the general theory of information alluded to in other papers in this session.

3. Conclusions

The special session on new directions in information processing brought together experts from different disciplines to look at information processing from different viewpoints to pave the path for the future. Three observations are worth highlighting in the conclusion. First, the general theory of information provides new insights into how we model autopoietic and cognitive behaviors in living organisms and design a new class of digital automata that would mimic these behaviors. Second, our understanding of consciousness

is evolving, and perhaps the new insights of information processing structures will play a role in the future to develop a consensus. Third, information in physical and quantum realms requires a reexamination of our current computing models based on CTT.

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